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Research Article

Diallel analysis for yield and its contributing characters in Indian mustard" [*Brassica juncea* (L.)Czern&Coss]

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Abstract
A set of 8×8 diallel crosses (excluding reciprocals) of Indian mustard along with their parents were evaluated to identify heterotic crosses and estimate general and specific combining ability of parents and crosses, respectively. Observations were recorded on 13 economically important characters. Best hybrids were selected on the basis of estimates of mid parent heterosis, better parent heterosis and standard heterosis. Among the 28 hybrids, three hybrids *viz.*, HYOLA 401 × GM-1, PM 67 × ZEM-1 and GM-2 × GM-3 exhibited superior performance for yield and its component traits as they registered significant and positive estimates for midparent, better parent and standard heterosis. Genetic variance components indicated the involvement of non-additive gene action for the inheritance of all the characters under study. Parents viz., GM-3, ZEM-1, Varuna and PM-67 were good general combiner for yield per plant, while HYOLA 401 and HNS 0004 were good general combiner for earliness and dwarfness and oil and protein content respectively. Based on sca effects, the high ranking crosses for yield and its component traits were HYOLA 401 × GM-1, PM 67 × ZEM-1 and GM-2 × GM-3. For oil content, the superior crosses were HYOLA 401 × HNS 0004 and HNS 0004 × ZEM-1.

Key words: Mustard, combining ability, diallel, gene action, heterosis

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 with an area of 6.51 million hectares with 7.67 million metric tonnes and 1179 kg/ha as production and productivity respectively. This crop ranks second in area and third in production. Improving yield and oil content are the major breeding objectives in case of mustard. Heterosis breeding approach is one of the most successful breeding options being employed for the improvement of crop varieties. Heterosis study provides information about probable gene action and helps in sorting out desirable gene action. Comprehensive analysis of the combining ability involved in the inheritance of quantitative characters and in the phenomenon of heterosis is necessary for the evaluation of various possible breeding procedures (Allard, 1960). The information garnered from combining ability helps in partitioning the total genetic variation into general combining ability of parents and specific combining ability of crosses, which is useful to assess the nature of gene action controlling different characters. With this point of view, the investigation was envisaged with the following objectives: (i) to estimate the magnitude of heterosis, heterobeltiosis and standard heterosis (ii) to unravel the gene effects and gene action involved in the expression of various characters and (iii) to study the general combining ability effects of parents and specific combining ability effects of crosses.

Material and Methods

The experimental material comprised of eight parents viz., PM 67, HYOLA 401, HNS 0004, ZEM-1, GM-1, GM-2, GM-3 and Varuna and their 28 half diallel crosses. The seeds of 28 F_1 hybrids and eight parents were produced by hand emasculation-hand pollination and selfing, respectively during *Rabi* 2010-11. These 28 F_1 hybrids along with 8 parents were evaluated in randomized block design with three replications during *rabi* 2011-12 at Anand Agricultural University, Anand. This site located at 22^0 35' North Latitude and 72^0 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.

Observations were recorded for various characters on five randomly selected competitive plants in each genotype in each replication. The phenological characters *viz.*, days to flowering and days to maturity were recorded on plot basis. Data on days to 50 % flowering, days to maturity, plant height (cm), number of primary branches, number of secondary branches, length of main branch (cm), number of siliquae per plant, siliqua length (cm), number of seeds per siliqua, thousand seed weight (g), yield per plant (g), oil content (%) and protein content (%) were subjected to diallel analysis according to Model-I, Method-II proposed by Griffing (1956). Analysis of variance suggested by Panse and Sukhatme (1967) was followed to test the significant differences between the genotypes for all the characters. Heterosis expressed as per cent increase or decrease in hybrid (F1) over its mid parent value, better parent value as well as check variety/hybrid (GM-3) in the desirable direction was estimated for various traits.

Results and Discussion

Per se performance**:** Among parents, GM-3, ZEM-1 and Varuna showed their superiority for yield and its important component characters like number of siliquae per plant, length of main branch, number of primary and secondary branches per plant. Parents *viz.* PM 67, GM-2 and GM-1 exhibited high oil content. Parents desirable for earliness were HYOLA 401 and Varuna. Among hybrids, PM 67 × ZEM-1, GM-2 × GM-3 and HYOLA 401 × GM-1 were identified as superior for yield and its component characters. For oil content, the superior hybrids were HYOLA 401 × HNS0004, HNS 0004 × ZEM-1 and HNS 0004 × GM-1.

Estimation of heterosis**:** Considerable amount of heterosis, heterobeltiosis and standard heterosis were observed for yield and most of other related traits studied, however the degree of heterosis varied from cross to cross. Standard heterosis is the most effective parameter amongst the three parameters of heterosis. In the present study, GM-3 was used as the standard check. On overall basis, hybrids HYOLA 401 ×GM-1, PM 67 × ZEM-1 and GM-2 × GM-3 exhibited high estimates of relative heterosis, heterobeltiosis and standard heterosis for yield per plant (Table:1). Positive heterosis estimates were pronounced in all characters barring days to 50 % flowering, days to maturity, plant height, siliqua length and number of seeds per siliqua. HYOLA 401 × HNS 0004 showed high estimates of three parameters of heterosis for characters like days to 50 % flowering, days to maturity, plant height, siliqua length, oil and protein content. Earlier studies by Khulbe et al. (1998), Agrawal and Badwal (1998), Kumbhalkar et al. (2000), Sheikh and Singh (2001), Ghosh et al. (2002), Singh et al. (2003), Rai and Verma (2005) and Gupta et al. (2011) also revealed heterosis in desirable direction for variouscharacters in Indian mustard.

Combining Ability Analysis**:** The analysis of variance for combining ability revealed the significance of mean squares due to gca and sca for all the traits, except gca mean square for days to maturity. This indicated that both additive and non-additive gene actions played important role for the inheritance of these traits; whereas for days to maturity, only sca mean square was observed significant, indicating the importance of non-additive gene action for the expression of this trait. The sca variance component was observed to be higher than the respective gca variance component (σ^2 gca/ σ^2 sca ratio < 1) for all the traits, indicating the preponderance of non-additive gene action for the inheritance of all the traits (Table 2). Similar results were also reported by Sheikh and Singh (1998), Mahto and Haider (2001), Singh *et al.* (2003) and Gupta *et al.* (2011).

The general combining ability effect (Table 3) enables the identification of desirable parents for hybridization program. An overall appraisal revealed that GM-3 was good general combiner for maximum number of characters *viz.*, number of secondary branches, length of main branch, number of siliqua per plant, thousand seed weight, yield per plant, protein content. HYOLA 401 was good general combiner for earliness and dwarfness as it expressed significant negative gca estimates for days to 50 % flowering, days to maturity and plant height. For oil and protein content, HNS 0004 was considered as the good general combiner. It was also good combiner for plant height, siliqua length and number of seeds per siliqua. Varuna was good general combiner for days to 50 % flowering, number of secondary branches, length of main branch, thousand seed weight and yield per plant; while GM-2 was good combiner for number of primary branches, number of secondary branches, length of main branch, thousand seed weight, protein content. Another parent ZEM-1 was good general combiner for number of primary branches, number of secondary branches, number of siliqua per plant, yield per plant. The parents PM 67 and GM-1 were average combiners for most of the characters, even though their *per se* performance was good. On the whole, GM-3, ZEM-1, Varuna and PM 67 were good general combiners for yield and its component traits.

Based on the perusal of sca effects, the cross combinations *viz.*, HYOLA 401 × GM-1, PM 67 × ZEM-1 and GM-2 × GM-3 were the high ranking combinations for yield per plant (Table 4). Generally the crosses showing high sca effect for yield per plant also exhibited high or average sca effect for yield components like number of primary branches, number of secondary branches, length of main branch, number of siliquae per plant and test weight. For oil content, only two hybrids *viz.*, HYOLA 401 × HNS 0004 and HNS 0004 × ZEM-1 manifested significant and positive sca estimates, which were poor as far as yield is concerned.

From the foregoing discussion, it may be concluded that three hybrids *viz.*, HYOLA 401 ×

GM-1, PM 67 × ZEM-1 and GM-2 × GM-3 exhibited superior performance for yield and its component traits as they registered significant and positive estimates for midparent, better parent and standard heterosis. Genetic variance components indicated the involvement of non-additive gene action for the inheritance of all the characters under study. Parents viz., GM-3, ZEM-1, Varuna and PM-67 were good general combiner for yield per plant, while HYOLA 401 and HNS 0004 were good general combiner for earliness and dwarfness and oil and protein content respectively. Based on sca effects, hybrids viz., HYOLA 401 × GM-1, PM 67 × ZEM-1 and GM-2 × GM-3 were considered as superior for yield and its component traits. If proper seed production technology is in place, heterotic hybrids can be explored for commercial cultivation.

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Table 1. Mean performance and Heterosis (%) of most promising hybrids for yield and its contributing traits

Hybrids	Particulars	DF	DM	PH	PP	SP	LB	NS	SL	SS	TW	YP	OC	PC
PM 67 × ZEM-1	*Per se* performance	53.3	112.67	233.80	8.80	26.20	137.53	970.53	4.80	15.93	4.53	56.12	30.73	24.02
	Relative heterosis	-2.14*	-2.17**	5.53**	20.00**	14.08**	16.03**	84.10**	2.38	-0.62	2.41	75.51**	-6.08**	-4.65**
	Heterobeltiosis	-1.84	-0.88	12.04**	11.86**	10.39**	13.10**	63.20**	-4.38**	-7.00**	1.64	65.33**	-10.59**	-7.63**
	Standard heterosis	-3.61	-1.74	5.66	25.71**	10.08	-0.20	83.81**	-0.21	13.22**	-9.22*	59.11**	-3.79	-12.43**
	sca effects	0.69*	-1.57	9.04	0.99**	2.01	13.21**	285.51**	0.13	0.49	0.14	15.84**	-1.00	-0.63
HYOLA 401 × GM-1	*Per se* performance	54.33	118.67	219.73	8.83	24.60	152.60	798.87	4.80	15.13	4.44	47.62	32.22	26.38
	Relative heterosis	19.85**	4.86**	19.44**	42.86**	54.23**	37.77	100.54**	-15.62**	-13.03**	2.86*	100.52**	0.83	1.64*
	Heterobeltiosis	26.36**	7.55**	26.96**	19.91**	4.24	21.37**	80.47**	-24.33**	-26.54**	-10.30**	84.67**	0.32	-1.03
	Standard heterosis	-1.81	3.49	-0.70	26.14**	3.36	10.74**	51.30**	-0.21	7.53	-11.02**	35.01**	0.88	-3.83
	sca effects	7.72**	5.36**	24.28**	2.00**	5.31**	31.49**	316.58**	-0.77**	-0.99**	0.04	19.00**	0.23	0.74
GM-2 × GM-3	*Per se* performance	49.67	119.00	213.93	7.93	27.22	148.07	824.13	4.70	15.73	5.64	51.44	31.96	28.03
	Relative heterosis	-11.83**	0.42	-5.10**	7.21**	9.33**	8.77**	61.52**	3.91**	16.83**	7.02**	60.64**	-0.87	1.60*
	Heterobeltiosis	-10.24**	3.78**	-3.31	1.71	4.71**	7.45**	56.09**	-2.42	11.85**	1.56	45.85**	-1.79	1.00
	Standard heterosis	-10.23**	3.78	-3.32	13.29	14.37	7.45*	56.09**	-2.29	11.80**	13.03**	45.85**	0.06	2.19
	sca effects	-4.38**	2.06	-5.21	0.39	1.22	10.45**	250.16**	-0.04	1.26**	0.25*	13.18**	0.25	0.82

DF- Days to 50 % flowering, DM-Days to maturity, PH-Plant height (cm), PP-Primary branches/pl., SP-Secondary branches/pl., LB- Length of main branch, NS- No. of siliquae/pl., SL- Siliqua length (cm), SS- No. of seeds/siliqua, TW- Thousand seed weight (g), YP-Yield/pl.(g), OC- Oil content (%), PC-Protein content (%).

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

Table 2. Mean square due to general and specific combining ability for different characters in Indian mustard

Sources	d.f.	DF	DM	PH	PP	SP	LB	NS	SL	SS	TW	YP	OC	PC
Gca	7	29.72**	7.66	850.17**	1.14**	75.90**	600.66**	34459.04**	0.85**	7.53**	1.13**	185.37**	2.18**	6.79**
Sca	28	21.01**	18.28**	210.18**	0.47**	8.56**	123.56**	15747.45**	0.33**	2.56**	0.08**	63.89**	0.91**	1.49**
Error	70	1.22	3.87	48.16	0.12	1.40	8.75	381.49	0.03	0.13	0.02	2.28	0.70	0.30
σ^2 g		0.107	0.339	4.214	0.011	0.122	0.765	33.381	0.002	0.012	0.002	0.199	0.061	0.026
σ^2 s		1.003	3.183	39.600	0.101	1.150	7.191	313.671	0.023	0.109	0.014	1.873	0.575	0.244
σ^2 g/ σ^2 s		0.107	0.107	0.106	0.109	0.106	0.106	0.106	0.087	0.110	0.143	0.106	0.106	0.107

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

Table 3. General combining ability effects for different characters in Indian mustard

Parents	DF	DM	PH	PP	SP	LB	NS	SL	SS	TW	YP	OC	PC
PM 67	0.12	-0.57	0.10	-0.08	0.29	0.06	21.68**	-0.07	0.78**	-0.09**	2.44**	0.15	-0.80**
HYOLA 401	-2.98**	-1.53**	-10.66**	-0.59**	-3.90**	-8.99**	-47.53**	0.48**	1.48**	-0.26**	-2.42**	0.11	0.23
HNS 0004	-0.28	0.13	-12.67**	-0.06	-4.77**	-12.73**	-87.14**	0.32**	0.74**	-0.50**	-8.13**	1.04**	1.47**
ZEM-1	1.88**	0.07	16.02**	0.58**	1.59**	-2.54**	110.87**	-0.39**	-0.73**	-0.22**	3.87**	-0.49*	-0.81**
GM-1	-1.05**	0.10	-2.52	0.11	0.88*	3.30**	-22.65**	-0.04	-0.75**	-0.05	-2.93**	-0.20	-0.85**
GM-2	1.38**	0.93	6.25**	0.24*	1.87**	5.55**	-8.62	-0.30**	-0.60**	0.33**	-0.17	-0.14	0.35*
GM-3	2.02**	1.27*	4.26*	-0.02	1.82**	5.27**	30.12**	-0.09	-0.31**	0.37**	4.46**	-0.22	0.61**
Varuna	-1.08**	-0.40	-0.78	-0.17	2.22**	10.08**	3.27	0.09	-0.61**	0.42**	2.89**	-0.27	-0.20
S.E.(gi)	**0.327**	**0.582**	**2.053**	**0.103**	**0.350**	**0.875**	**5.778**	**0.050**	**0.108**	**0.039**	**0.446**	**0.247**	**0.161**

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

Table 4. Specific Combining ability effects for different characters in Indian mustard

Crosses	DF	DM	PH	PP	SP	LB	NS	SL	SS	TW	YP	OC	PC
PM 67 x HYOLA 401	-6.11**	-1.97	0.06	-0.64*	-0.83	-14.33**	1.71	0.28	0.88**	-0.41**	-0.28	-1.08	-1.87**
PM 67 x HNS 0004	-6.15**	-0.64	-6.67	-0.64*	-1.96	-3.31	56.72**	-0.20	0.09	0.01	4.87**	0.04	-1.14*
PM 67 x ZEM1	0.69*	-1.57	9.04	0.99**	2.01	13.21**	285.51**	0.13	0.49	0.14	15.84**	-1.00	-0.63
PM 67 x GM 1	4.95**	1.73	26.73**	-0.22	-0.21	12.17**	-8.50	-0.12	-0.22	-0.13	-1.91	-0.29	0.57
PM 67 x GM2	-0.81**	-3.44	-7.85	-0.01	-1.53	-3.61	-74.27**	0.50**	0.76*	-0.08	-2.28	-1.13	-0.98*
PM 67 x GM3	-2.78**	-0.11	-6.66	0.18	0.11	14.01**	5.72	-0.44**	-1.73**	0.68**	2.90*	-0.30	-0.47
PM 67 x Varuna	2.65**	-0.11	-14.29*	1.07**	0.72	-7.67**	5.44	-0.23	-0.63	-0.11	-1.43	-0.23	1.84**
HYOLA 401 x HNS 0004	-9.05**	-9.67**	-22.50**	-0.26	0.36	-5.81*	-153.27**	1.94**	0.85**	0.30**	-7.64**	1.83*	1.83**
HYOLA 401 x ZEM1	5.79**	-0.61	16.94**	0.44	-0.34	3.27	56.79**	-0.49**	-0.75*	0.32**	5.74**	-0.33	-0.83
HYOLA 401 x GM 1	7.72**	5.36**	24.28**	2.00**	5.31**	31.49**	316.58**	-0.77**	-0.99**	0.04	19.00**	0.23	0.74
HYOLA 401 x GM2	3.62**	4.19*	20.31**	0.04	1.25	4.71	15.81	-0.67**	-0.87**	0.07	1.87	-0.15	0.60
HYOLA 401 x GM3	4.65**	5.19**	1.59	0.56	3.10**	-2.21	-45.66*	-0.33*	-2.49**	0.37**	-5.23**	1.06	1.51**
HYOLA 401 x Varuna	-3.25**	0.19	-12.19	0.12	3.57**	8.91**	14.72	-0.46**	-1.13**	0.31**	1.38	-0.54	-1.83**
HNS 0004 x ZEM1	2.75**	4.39*	15.35*	0.51	6.00**	15.47**	26.53	-0.21	-3.07**	0.13	-3.19*	1.50*	2.09**
HNS 0004 x GM 1	0.35	2.69	-8.11	0.64*	-1.28	-5.03	-67.46**	-0.37*	-2.58**	-0.01	-5.99**	1.02	0.51
HNS 0004 x GM2	3.59**	-1.47	15.85*	0.17	-1.47	6.25*	41.15*	-0.54**	-0.86**	-0.39**	-0.48	0.40	-0.19
HNS 0004 x GM3	-0.71*	2.19	-4.15	-0.03	1.57	6.13*	35.79*	0.61**	0.45	0.01	4.22**	-1.17	-1.66**
HNS 0004 x Varuna	-0.61	5.86**	-6.52	-0.95**	-1.56	-2.55	-96.67**	-0.44**	-1.79**	-0.01	-10.23**	0.46	0.51
ZEM1 x GM 1	-7.15**	-6.57**	-17.14**	-0.87**	-3.52**	-4.29	18.90	0.75**	-1.52**	-0.11	-4.60	0.01	-0.14
ZEM1 x GM2	-3.25**	-0.41	-11.77	0.33	-3.31**	-15.94**	-111.19**	0.34*	1.27**	-0.14	-3.77**	-0.21	-0.26
ZEM1 x GM3	-0.55	3.26	10.02	0.06	2.87**	-4.26	34.60	-0.05	0.91**	-0.33**	2.60	-0.35	0.31
ZEM1 x Varuna	1.89**	3.93*	-9.94	-0.25	2.88**	5.06	47.91**	-0.05	0.68*	-0.28*	2.91*	0.44	-0.01
GM 1 x GM2	-7.31**	-6.77**	-14.50*	-0.60	2.07	1.15	-107.47**	0.32*	1.00**	-0.26*	-6.49**	-0.82	-1.04*
GM 1 x GM3	-0.28	-2.44	-6.84	-0.48	-2.88**	-18.17**	-116.35**	0.40**	2.14**	-0.12	-4.69**	-0.82	-2.00**
GM 1 x Varuna	3.49**	3.89*	13.06*	-0.12	1.46	-1.98	93.30**	-0.17	1.57**	-0.10	9.33**	-0.21	-0.02
GM 2 x GM3	-4.38**	2.06	-5.21	0.39	1.22	10.45**	250.16**	-0.04	1.26**	0.25*	13.18**	0.25	0.82
GM 2 x Varuna	0.72*	-5.61**	-13.77*	-0.32	1.87	3.84	71.34**	0.69**	0.09	0.15	7.69**	0.16	-0.53
GM 3 x Varuna	2.75**	-4.94**	3.02	-0.13	-1.69	-6.88*	5.20	0.09	0.87**	0.04	2.27	0.73	1.60**
S.E. (sij)	0.317	1.784	6.293	0.317	1.072	2.682	17.711	0.153	0.331	0.119	1.369	0.758	0.494

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