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Research Note

Assessment of combining ability for seed yield and component traits in Indian mustard (*Brassica juncea* L.)

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Abstract
A study involving hybrids developed by crossing eight Indian mustard (*Brassica juncea* L.) lines in diallel fashion, excluding reciprocals, was taken up during *Rabi* 2022-23, to investigate their combining ability for yield and contributing traits. It was observed that the mean squares attributed to genotypes, encompassing parents, crosses and parents *vs*. crosses, were statistically significant for all examined attributes. Furthermore, both GCA and SCA components of variance were identified as statistically significant across all the examined attributes. Notably, the genotypes BPR-540-6, BRIJRAJ and DRMR-1165-40 were observed to be good general combiners for seed yield and other yield-attributing traits, indicating their potential utility in breeding programs. The estimates of SCA revealed that specific combining ability effects were both significant and positive for seed yield/plant in the cross combinations of DRMR-150-35 × KRANTI, BRIJRAJ × RH-725 and DRMR-2059 × KRANTI. Based on the *per se* performance and the noteworthy specific combining ability effect for seed yield/plant, it is recommended that the hybrids DRMR-150-35 × KRANTI and BRIJRAJ × RH-725 be leveraged in heterosis breeding or recombination breeding endeavors to attain higher seed yields.

Keywords: - Mustard, diallel mating, GCA,SCA

Mustard (*Brassica juncea* L.) is a crucial oil-seed crop cultivated during *Rabi* season. It belongs to the Cruciferae family, which includes six cultivars. The *Brassicaceae* family, also known as Cruciferae, currently comprises 3709 species and 338 genus (Warwick *et al.*, 2006). At the cytological level, *Brassica juncea* L. is an amphidiploid (2n=36). *Brassica juncea* emerged through a natural chromosomal duplication after hybridization between *Brassica rapa* (2n=20) and *Brassica nigra* (2n=16) and reproduces through self-pollination. Many authors have used different strategies to improve seed yield and quality in Brassica (Singh *et al.*, 2003; Gami *et al.*, 2012) and have reported different types of gene action and combining abilities in different sets of genotypes. Assessing combining ability in the inheritance of quantitative traits and heterosis is essential for evolving breeding strategies (Allard, 1960). Understanding combining ability helps in selecting suitable parents and determining gene action to enhance economic yields by integrating favorable traits. For effective recombination breeding and selection, the working germplasm must exhibit variability in economically important traits.

To develop superior hybrids and recombinant strains, evaluating the combining ability of parent genotypes is essential. Since mustard is predominantly self-pollinating, the diallel design proposed by Griffing (1956) is an efficient tool for screening genotypes. Previous research (Wos *et al.*, 1999) underscores the role of additive gene action in determining yield-related traits. With this foundation, this study was taken up to investigate the combining ability of Indian mustard parents.

Eight mustard lines namely DRMR-150-35, DRMR-1165-40, DRMR-2059, BRIJRAJ, RH-406, RH-725, KRANTI and BPR-540-6, selected based on their morphology, maturity time, and yield-enhancing traits, were crossed in half diallel fashion during *Rabi*, 2022-23, to generate 28 hybrid combinations. The resulting 28 F_{1s}, along with their parental lines, were evaluated at the Agronomy Field, SKN College of Agriculture, Jobner (Jaipur, Rajasthan) during *Rabi* 2022-23 in a randomized block design with three replicates. To ensure a healthy crop, the spacing was configured at 30 cm between rows and 10 cm between plants. Fourteen traits, including plant height (PH), primary branches/plant (PB), secondary branches/ plant (SB), siliquae/plant (SP), siliqua length (SL), seeds/ siliqua (SS), seed yield/plant (SY), biological yield/plant (BY) and harvest index (HI), were observed from ten randomly selected plants. In addition, data on days to 50% flowering (DF), days to maturity (DM), 1000-seed weight (TW), protein content (PC) and oil content (OC) were assessed on a whole-plot basis. An analysis of variance was performed for 14 traits according to Panse and Sukhatme (1985). The analysis of combining ability was carried out using Griffing's Method 2, Model I (1956). Oil and protein estimation was done using Near Infrared Reflectance Spectroscopy (NIRS) as per Velasco and Becker, 1998, Biskupeck-Korell and Moschner, 2007.

The analysis of variance demonstrated significant genetic variation between parents and hybrids (**Table 1**). The hybrids exhibited significant differences in performance as compared to the parents. It also indicated significant variability in the respective traits among the parents. Notably, significant differences between treatments for each trait were observed, aligning with identical outcome noted by Maurya *et al.* (2012), Saini and Patel (2015) and Kumar *et al.* (2022). Furthermore, the combining ability variances based on GCA and SCA for all the traits exhibited high significance for studied traits (**Table 2**). Both gene effects were found to be crucial in governing the inheritance of all characters. Notably, the GCA: SCA ratio indicated the prevalence of non-additive gene effects influencing these traits. These observations concur with the reports of Gupta *et al.* (2010), Saeed *et al.* (2013), Synrem *et al.* (2013) and Saini and Patel (2015).

A considerable variation in the GCA effects was noted across the parents (**Table 3**). Specifically, BRIJRAJ and BPR-540-6 for siliqua/plant and seed yield/plant; BPR-540-6, RH-406 and DRMR-1165-40 for days to maturity; BRIJRAJ and RH-725 for days to maturity; BRIJRAJ for primary branches/plant; BRIJRAJ and DRMR-150-35 for seeds/siliqua; BPR-540-6 and DRMR-1165-40 for test weight; BPR-540-6 for harvest index; DRMR-1165-40 for oil content; BPR-540-6 and DRMR-150-35 for protein content were found to be the most desirable combiners. The parents BRIJRAJ, DRMR-1165-40 and BPR-540-6 were identified as effective combiners for most of the traits. This indicated the predominance of additive gene action and hence could be effectively utilized to create homozygous lines that may be used to improve the desired characters. To obtain desired recombinants in Indian mustard, these parental lines may be used to produce the inter-matting population. Similar observations have been recorded by Binodh *et al.* (2008), Patel *et al*. (2013), Tele *et al.* (2014) Kumar *et al.* (2017) and Adhikari *et al.* (2018).

The specific combining ability estimates for the 28 combinations are furnished in **Table 4**, which indicated that there was no common combiner found among any of the cross combinations. Notably, the cross combination DRMR-2059 × RH-406 demonstrated a highly significant and desirable negative specific combining ability effect for days to 50% flowering and for days to maturity, offering an opportunity for leveraging early maturing genotypes in successive generations. Additionally, other hybrid combinations exhibiting good specific combining abilities for various important traits were RH-406 × BPR-540-6 for plant height, DRMR-1165-40 × BRIJRAJ for primary branches/plant, BRIJRAJ × RH-725 for secondary branches/plant, DRMR-1165-40 × BPR-540-6 for siliquae per plant, RH-406 × BPR-540-6 for siliqua length, DRMR-2059 × KRANTI for seeds/siliqua, RH-725 × KRANTI for 1000-seed weight, DRMR-150-35 × KRANTI for seed yield, DRMR-150-35 × DRMR-2059 for biological yield per plant, DRMR-150-35 × KRANTI for harvest index, DRMR-2059 × BPR-540-6 for oil content and DRMR-1165-40 × RH-406 for protein content. Similar outcomes also noted by Singh *et al.* (2007), Ahsan *et al.* (2013) and Patel *et al.* (2016).

In **Table 5**, data regarding six top-performing parent lines, their best-performing hybrid combinations and the effects of specific combining ability on seed yield/plant are detailed. The analysis of specific combining ability (SCA) effects showed that four cross combinations, namely DRMR-150-35 × KRANTI, BRIJRAJ × RH-725, DRMR-2059 × KRANTI and DRMR-1165-40 × BRIJRAJ, exhibited positive effects for seed yield/plant. It was noted that the inclusion of a proficient general combiner parent resulted in heterotic hybrids with desirable SCA effects. Evaluation of hybrid performance in relation to heterosis, considering both mid-parent and better-parent for seed yield/plant, indicated significant and positive heterosis in the aforementioned four crosses. This suggested the importance of considering general combining ability effects of the parents in conjunction with specific combining ability effects and the performance of crosses individually to accurately gauge the value of any hybrid. Such findings align with previous analyses done by Niranjana *et al.* (2014), Adhikari *et al.* (2018), and Chaurasiya *et al.* (2018).

Based on the foregoing discourse, it can be inferred that hybrids DRMR-150-35 × KRANTI, BRIJRAJ × RH-725, DRMR-2059 × KRANTI, and DRMR-1165-40 × BRIJRAJ, which demonstrated heightened mean values, significant heterosis when compared to both mid-parent and better-parent values and desirable SCA effects for seed yield/plant, hold promise for applied plant breeding applications. These notably significant heterotic crosses

Table-1. Analysis of variance of parents and hybrids for yield contributing traits in *Brassica juncea* L.

Source of variation	Df.	Traits													
		DF	DM	PH	PB	SB	SP	SL	SS	TW	SY	BY	HI	OC	PC
Replication	2	1.37	12.70	26.77	0.24	1.24	293.25	0.03	0.15	0.06	0.22	1.50	1.84	0.08	0.10
Treatments	35	18.68**	99.81**	410.90**	1.59**	13.52**	4953.04**	0.42**	1.75**	0.23**	14.06**	196.40**	7.64**	4.40**	7.59**
Parent	7	19.90**	29.87**	228.89*	0.76**	7.10**	2805.91**	0.19*	2.29**	0.22**	3.35*	102.73**	2.78*	2.83**	3.18**
Hybrid	27	17.47**	116.74**	230.88**	1.35**	8.05**	5101.87**	0.45**	1.42**	0.13**	11.11**	112.26**	8.57**	2.68**	8.60**
Parent Vs F_1's	1	42.67**	134.52**	6545.43**	13.81**	205.84**	15964.65**	1.13**	6.81**	2.92**	168.92**	3123.75**	16.68**	61.87**	11.10**
Error	70	2.07	9.84	96.63	0.20	2.20	337.77	0.07	0.58	0.03	1.20	20.50	1.19	0.70	0.31

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

Table-2. Analysis of variance of general and specific combining ability for yield contributing traits in *Brassica juncea* L.

Source of variation	Df.	Traits													
		DF	DM	PH	PB	SB	SP	SL	SS	TW	SY	BY	HI	OC	PC
GCA	7	2.11**	17.97**	116.32**	0.74**	4.80**	699.40**	0.07**	0.67**	0.05**	3.18**	37.95**	1.68**	2.48**	1.10**
SCA	28	7.25**	37.10**	142.13**	0.48**	4.43**	1888.92**	0.16**	0.56**	0.08**	5.07**	72.35**	2.76**	1.21**	2.89**
Error	70	0.69	3.28	32.21	0.07	0.73	128.16	0.02	0.19	0.01	0.40	6.84	0.40	0.23	0.10

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

Table-3. Estimates of general combining ability for parents for 14 traits in *Brassica juncea* L.

Parents	DF	DM	PH	PB	SB	SP	SL	SS	TW	SY	BY	HI	OC	PC
DRMR-150-35	-0.28	-0.39	-1.91	-0.31**	0.78**	-2.62	-0.09*	0.26*	-0.10**	-0.85**	-1.55*	-0.73**	0.06	0.31**
DRMR-1165-40	-0.41*	-0.23	-5.31**	0.14	0.00	-5.63	0.03	0.02	0.06*	0.38*	0.65	0.30	0.98**	0.14
DRMR-2059	0.26	1.01	5.91**	0.10	0.06	-8.25*	0.06	0.17	-0.05	-0.10	0.40	-0.20	-0.02	-0.35**
BRIJRAJ	0.36	-1.73**	-2.10	0.52**	0.98**	12.14**	-0.06	0.31*	-0.04	0.56**	3.36**	-0.07	-0.61**	-0.01
RH-406	-0.59*	2.51**	0.56	-0.34**	- -1.19**	-9.00**	0.04	-0.12	-0.02	-0.85**	-3.45**	-0.25	-0.29*	-0.61**
RH-725	-0.31	-1.43**	-1.21	-0.10	-0.46	-3.19	0.13**	-0.50**	0.05	0.25	0.54	0.20	-0.50**	0.20*
KRANTI	0.43	0.01	1.73	0.00	-0.35	6.32	-0.10*	-0.09	-0.03	0.15	0.22	0.11	0.23	-0.02
BPR-540-6	-0.64*	0.24	2.34	0.00	0.18	10.22**	-0.01	-0.05	0.12**	0.46*	-0.17	0.63**	0.16	0.35**
SE (gi)±	0.25	0.54	1.68	0.08	0.25	3.35	0.05	0.13	0.03	0.19	0.77	0.19	0.14	0.10
SE (gi-gj)±	0.37	0.81	2.54	0.12	0.38	5.06	0.07	0.20	0.04	0.28	1.17	0.28	0.22	0.14

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

Table 4. Estimates of specific combining ability effects for 14 traits in *Brassica juncea* L.

Cross	DF	DM	PH	PB	SB	SP	SL	SS	TW	SY	BY	HI	OC	PC
DRMR-150-35 × DRMR-1165-40	-0.47	-2.67	-9.01	-0.58*	0.20	-20.45*	-0.27	0.32	-0.08	-0.57	6.62**	-2.04**	-0.02	-1.60**
DRMR-150-35 × DRMR-2059	2.53**	4.43**	-14.47**	0.69**	0.41	38.91**	0.61**	-0.70	0.17	0.23	12.20**	-2.03**	-0.31	1.79**
DRMR-150-35 × BRIJRAJ	-1.57*	-9.17**	-7.63	0.57*	0.28	-21.92*	-0.13	-0.04	0.01	0.24	-2.10	0.81	0.66	-0.21
DRMR-150-35 × RH-406	1.19	5.93**	2.34	0.79**	2.32**	45.19**	0.31*	0.16	0.03	1.43*	7.24**	0.16	1.18**	1.80**
DRMR-150-35 × RH-725	3.09**	7.20**	-5.25	-0.45	0.46	-9.19	-0.23	0.94*	0.40**	-1.27*	-1.88	-1.25*	-0.06	0.22
DRMR-150-35 × KRANTI	-2.64**	-8.90**	-6.82	0.19	3.04**	20.87*	-0.06	-0.87*	-0.04	3.79**	4.96*	3.60**	0.41	1.71**
DRMR-150-35 × BPR-540-6	1.09	4.20*	-3.66	0.48*	-0.95	-36.03**	0.11	0.69	-0.11	-1.87**	-7.17**	-1.12	0.87	-0.50
DRMR-1165-40 × DRMR-2059	3.66**	5.26**	-11.27*	0.24	1.39	25.59**	-0.15	-0.30	0.15	2.19**	0.94	2.58**	0.83	2.35**
DRMR-1165-40 × BRIJRAJ	-2.11**	-3.34*	2.64	1.36**	1.43	41.73**	-0.14	0.03	-0.01	2.41**	7.47**	1.28*	1.52**	0.85**
DRMR-1165-40 × RH-406	1.99**	5.10**	8.78	0.48*	2.37**	12.57	0.69**	1.13**	-0.04	2.40**	11.88**	0.44	1.22**	2.40**
DRMR-1165-40 × RH-725	-1.77*	-1.64	-8.45	0.58*	0.88	67.72**	0.26	0.27	-0.36**	1.83**	-0.30	2.44**	-0.39	0.59*
DRMR-1165-40 × KRANTI	-1.84*	-1.40	-11.89*	-0.42	-1.44	-77.12**	-0.09	-0.14	-0.05	-2.15**	-7.24**	-1.00	0.45	-2.46**
DRMR-1165-40 × BPR-540-6	-3.44**	-4.97**	9.37	0.34	2.44**	70.32**	0.36*	0.46	-0.02	1.97**	7.25**	0.90	-0.19	0.87**
DRMR-2059 × BRIJRAJ	-0.44	5.76**	-8.48	-0.04	1.47	36.35**	0.62**	-0.38	0.04	1.74**	8.97**	0.21	1.35**	2.19**
DRMR-2059 × RH-406	-5.67**	-10.80**	7.92	0.15	0.48	-26.17*	-0.21	-0.15	-0.18	-2.44**	-6.48**	-1.96**	0.24	-2.65**
DRMR-2059 × RH-725	-0.11	3.13	-8.93	0.11	-0.89	-47.89**	-0.24	-0.37	0.27**	-0.57	-3.91	0.46	0.93*	-2.50**
DRMR-2059 × KRANTI	1.16	-8.64**	6.33	0.85**	2.40**	54.17**	-0.33*	1.58**	0.17	2.78**	4.29	2.47**	-0.45	0.65*
DRMR-2059 × BPR-540-6	2.89**	2.80	-8.18	-0.76**	-0.12	-26.72*	0.01	0.88*	0.16	1.13	1.73	1.01	1.64**	-1.10**
BRIJRAJ × RH-406	2.56**	-1.07	-10.34*	-0.53*	-0.55	33.77**	-0.08	0.78	0.18	0.82	7.00**	-0.48	-0.84	-2.42**
BRIJRAJ × RH-725	-2.21**	-4.47**	-1.89	0.96**	3.76**	47.62**	0.72**	-0.08	0.03	3.37**	9.18**	2.01**	0.57	2.07**
BRIJRAJ × KRANTI	-2.61**	-3.90*	-7.10	-0.10	-0.44	-24.56*	-0.48**	-0.43	-0.03	-1.20*	-1.45	-1.08	0.03	-1.73**
BRIJRAJ × BPR-540-6	-1.21	1.86	-4.51	-0.11	-1.58*	-63.92**	-0.12	0.24	0.41**	-2.06**	-5.06*	-1.45*	-0.04	-1.24**
RH-406 × RH-725	-4.77**	-9.04**	-9.09	-0.25	-0.25	-45.77**	-0.29*	-0.65	0.21*	0.04	2.68	-0.59	0.29	0.85**
RH-406 × KRANTI	1.49	7.53**	-10.10	0.29	-0.42	27.25**	0.00	-0.61	0.09	0.11	3.53	-0.62	0.79	1.97**
RH-406 × BPR-540-6	0.56	6.30**	-20.04**	-0.38	-0.08	5.13	0.74**	-0.63	0.21*	1.43*	4.91*	0.66	-0.70	-0.50
RH-725 × KRANTI	-1.27	2.46	7.98	0.48*	0.85	20.24	0.33*	0.25	0.48**	1.18*	10.40**	-0.77	0.94*	0.17
RH-725 × BPR-540-6	1.46	10.23**	-18.26**	-0.62**	-0.81	-0.69	0.66**	-0.25	0.14	0.32	0.92	0.21	-0.49	-1.31**
KRANTI × BPR-540-6	0.39	-4.54**	2.80	0.75**	2.18**	46.03**	-0.05	0.07	0.05	1.09	4.24	0.41	0.57	1.68**
SE (Sij)±	0.75	1.64	5.15	0.23	0.78	10.27	0.14	0.40	0.09	0.57	2.37	0.57	0.44	0.29

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

Table 5. Top rank crosses for seed yield per plant in *Brassica juncea* L.

S. No.	Cross combination	Per se performance	SCA effects	Magnitude of GCA P_1	P_2	Other traits with significant specific combining ability effect
1	DRMR-150-35 × KRANTI	17.07	3.79**	-0.85**	0.15	Days to 50% flowering Days to maturity Secondary branches/plant Siliquae per plant
2	BRIJRAJ × RH-725	18.17	3.37**	0.56**	0.25	Days to 50% flowering Days to maturity Primary branches /plant Secondary branches/plant Siliquae per plant
3	DRMR-2059 × KRANTI	16.81	2.78**	-0.10	0.16	Days to maturity Primary branches /plant Secondary branches/plant Siliquae per plant
4	DRMR-1165-40 × BRIJRAJ	16.19	2.41**	0.38*	0.56**	Days to 50% flowering Days to maturity Primary branches /plant Siliquae per plant

*, ** Significant at 5 % and 1% levels, respectively. Where, P_1= parent 1 and P_2= parent 2.

could effectively harness non-additive gene actions through heterosis breeding strategies.

Drawing on the above-mentioned discussion and in alignment with supporting findings from other studies, it is concluded that hybrids DRMR-150-35 × KRANTI, BRIJRAJ × RH-725, DRMR-2059 × KRANTI and DRMR-1165-40 × BRIJRAJ possess considerable potential for practical plant breeding applications. These hybrids, marked by significant heterosis and desirable specific combining ability effects for seed yield/plant, could be effectively exploited and non-additive gene action could be harnessed.

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