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Combining ability (SCA & GCA) and heterotic response analysis in Indian mustard (*Brassica juncea* L. Czern & Coss)

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Abstract
The analysis of variance for combining ability were found significant for all the characters. The variance among males, females and due to interaction between males and females were found highly significant for all the characters. The line namely; Varuna, Maya, Ashirwad, NDR-8501, Pusa Bold and Pusa Bahar were found good general combiners for all the characters. The cross combinations namely; Varuna x RK-9808, Pusa Bahar x Mathura Rai, NDR-8501 x RK-9807, B-85 x Mathura Rai, Urvashi x RK-9808 and Pusa Bold x Mathura Rai were found good specific combiners and showed positive heterotic response for all the characters.

Keywords: *Brassica juncea*, Combining ability, heterosis and Indian mustard

1. Introduction
India is a leading oilseed producing county of the world with around 7 per cent contribution in the global production. Indian mustard [*Brassica juncea* (L.) Czern & Coss.] is the second largest oilseed crop in India after soybean. It is cultivated in *Rabi* (Post-rainy) season mainly in North-West India and contributes nearly 27 per cent edible oil pool in the country. Rapeseed-mustard plays a major role in the catering edible oil demand of the country. Population of India is increasing rapidly and consequently edible oil demand is also going up day-by-day, hence, it has become necessary to enhance the present production by developing superior varieties of Indian mustard. Rapeseed- mustard oil is used primarily for edible purposes and is the principal cooking oil in the mustard growing areas of the country. Besides, seeds are used as condiments and in preparations of salad, juices, curries and pickels. The meal cake left after oil extraction forms an important cattle feed and may also be as organic manure**.** Rapeseed mustard group of crops play a vital role in human nutrition and oilseed economy of the country. Mustard oil contains vitamins, minerals, proteins and carbohydrate. It has been reported that 100g of mustard oil produce a sizeable amount of erucic acid (52.2%) and linolinic acid (12.4%). The protein content in mustard ranges between 24-30% on the whole seed basis and between 34-40% on meal basis (Anonymous, 2016).

2. Materials and Methods
The present investigation comprised 20 lines as female and 4 testers as male of Indian mustard [*Brassica juncea* (L.) *Czern* and *Coss.*]. These materials were selected on the basis of variability for different characters and maintained by selfing for several generations. 20 lines were crossed with 4 testers in line x tester mating design (O. Kempthorne, 1957) [5]. Twenty females and four males were sown during *Rabi* 2009-10 at Oilseed Research Farm, Kalyanpur, Kanpur and all the females were crossed with each of four males to produce sufficient amount of F_0 seeds of 80 crosses. All the twenty four parents and eighty F_1s were sown on November 4, 2009 in a Randomized Block Design (RBD) with three replications at Oilseed Research Farm, Kalyanpur of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. Each treatment was planted in one row, of 3m length and 45 cm apart, Plant to plant distance was maintained at 15 cm by thinning. All the recommended agronomic practices were adopted for raising a good crop. Data were recorded on five randomly taken plants of each treatment in each replication for all the characters namely; days to 50% flowering, days to maturity, plant height (cm), number of primary branches per plant, number of secondary branches per plant and biological yield per plant (g)

3. Results and Discussion

The results of analysis of variance (ANOVA) for combining ability for all the characters are given in Table-1. The variance among males, females and due to interaction between males and females were found highly significant for all the characters. These results were also similar to Khulbe *et al.* (2002) [7]. Ghose and Gulati (2001) [3]. Singh and Sachan (2003) [15]. and Sachan *et al.* (2004b) [14]. The results of gca effects are given in Table-2. The parents namely, Vaibhav, RH-30, Maya, Pusa bahar, RLM-198, Kranti and Varuna for days to 50% flowering, Varuna and Maya for days to maturity, Varuna, RH-30, Urvashi, Rohini, Pusa bold and Varuna for number of primary branches per plant, Maya, Urvashi and Pusa Jaikisan and Pusa Agrani for number of secondary branches per plant, Ashirvad, Vaibhav, Varuna, Maya, Pusa bahar and KR-5610 for plant height and Varuna, Rohini, Vaibhav, KR-5610 and RLM-198 for biological yield per plant were found good general combiners. Similar finding were also reported by Thakur *et al.* (1989) [26]. Singh and Lallu (2004) [19]. Singh *et al.* (2008b) [20]. and Singh *et al.* (2010) [23, 24].

Table 1: Analysis of variance (ANOVA) for combining ability effects for six characters in Indian mustard (*Brassica juncea* L. Czern & Coss).

Sources of variation	d.f.	Days to 50% flowering	Days to maturity	No. of primary branches /plant	No. of secondary branches /plant	Plant height (cm)	Biological yield /plant (g)
Line	19	58.18**	68.71**	2.20**	114.69**	126.89**	29.52**
Tester	3	14.52**	79.55**	0.30	6.77**	343.99**	3.22**
Line x Tester	57	1703.02**	2402.50**	0.27	75.62**	3010.34**	420.33**
Error	158	2.76	2.87	0.78	1.55	16.18	8.27

*significant at p= 0.05, **significant at p= 0.01.

Table 2: General combining ability (gca) analysis for six characters in Indian mustard.

Parents /Lines	Days to 50% flowering	Days to maturity	No. of primary branches /plant	No. of secondary branches /plant	Plant height (cm)	Biological yield /plant (g)
Varuna	-1.54**	4.22**	-0.43*	0.38**	0.57	0.92**
Maya	1.96**	7.22**	-0.10	-0.04**	-2.26**	-0.25
Urvashi	1.29**	5.72**	-0.10	-0.09**	-1.93**	-0.92**
Basanti	1.21**	-1.87**	0.65**	0.34**	2.32**	-1.33**
Rohini	-0.04	5.38**	0.07	0.29**	0.07	1.58**
Pusa bold	-0.12	-10.87	-0.02	-0.18**	1.66**	-1.75**
Kranti	1.62**	1.22**	-0.18	0.51**	4.41**	-0.75**
NDR-8501	-1.12**	0.63**	0.07	-0.07**	-0.01	-0.42
Pusa bahar	1.79**	-0.62**	-0.10	0.28**	0.16	-1.92**
Pusa barani	-1.21**	-4.03**	0.82**	0.57**	-2.43**	0.42
Pusa jai kisan	-0.96**	2.55**	-0.43**	0.26**	-0.51	0.17
Vaibhav	2.21**	-2.78**	-0.18	-0.07**	0.74*	1.33**
Durgamani	-0.79	-3.20**	-0.60**	-0.10**	3.66**	-1.00**
Ashirvadh	-1.21**	-3.28**	-0.85**	-0.51**	-2.51**	-1.00**
KR-5610	0.88*	-2.87**	-0.60**	-0.68**	-0.43	1.50**
B-85	-0.12	-9.87**	0.07	-0.02*	-1.43**	1.33**
Vardan	0.62	-2.78**	-0.27	0.18**	0.49	0.58*
Nav-gold	-0.46	6.38**	-0.10	-0.61**	0.91*	-0.83**
RH-30	-2.38**	5.97**	0.73**	-0.32**	-3.18**	1.67**
RLM-198	-1.62**	2.88**	1.57**	-0.12**	-0.34	0.75**
S.E.(gi) (±)	0.44	0.44	0.08	0.03	0.37	0.72
Testers						
Pusa agrani	0.18	0.18	-0.27**	0.14**	0.84**	-0.13
RK-9807	0.07	0.07	0.28**	0.14**	-0.79**	0.10
RK-9808	0.21	0.21	-0.17*	0.10**	0.17	-0.37
Mathura rai	-0.46**	-0.46**	0.15	-0.37**	-0.23	0.40
S.E.(gi)(±)	0.17	0.17	0.21	0.01	0.15	0.29

***significant at 5 and 1%, respectively.

The results of specific combining ability (sca) effects are presented in Table-3. The cross combinations namely; Varuna x RK-9808 and Urvashi x Pusa Agrani for days to 50% flowering, Varuna x Mathura Rai, Maya x Mathura Rai, NDR-8501 x RK-9807, B-85 x Mathura Rai for days to maturity, Maya x Pusa Agrani, Kranti x Mathura Rai, NDR-8501 x Pusa Agarni and Pusa barani x RK-9808 for number of primary branches per plant, Maya x RK-9808, Pusa Bahar x Mathura Rai, Durgamani x Pusa Agrani, Durgamani x RK-9807 for number of secondary branches per plant, NDR-8501 x RK-9807, Ashirvadh x Mathura Rai, KR-5610 x RK-9807, B-85 x RK-9808, RH-30 x Pusa Agrani for dwarf plant height and NDR-8501 x Mathura Rai, B-85 x Pusa Agrani, Maya x Pusa Agrani, Rohini x Mathura Rai and Pusa bold x Mathura Rai for biological yield per plant were found good specific combiners. These results were also similar to Khulbe *et al.* (1998a) [6]. Ghosh *et al.*(2002) [4]. Singh *et al.* (2006) [18, 22]. Singh and Dixit (2007) [25]. Lohia *et al.* (2008) [8]. Nigam *et al.* (2009) [10]. and Maurya *et al.* (2012) [9].

Table 3: Specific combining ability analysis for six characters in Indian mustard.

Cross combinations	Days to 50% flowering	Days to maturity	No. of primary branches /plant	No. of secondary branches/plant	Plant height (cm)	Biological yield /plant (g)
Varuna x Pusa Agrani	-1.01	-2.52**	0.35	1.24*	2.42	-3.20*
Varuna x RK-9807	1.43	1.28*	-0.87*	-0.05	-3.01	1.57
Varuna x RK-9808	-2.04**	-4.00**	-0.08	1.60**	-0.61	0.03
Varuna x Mathura Rai	1.62*	5.23**	0.60	-2.80**	1.20	1.60
Maya x Pusa Agrani	-0.51	-3.18**	-1.32**	-3.18**	0.84	4.97*
Maya x RK-9807	-1.74*	-1.72**	0.47	-2.13**	-0.60	0.73
Maya x RK-9808	4.12**	-1.00	-0.08	2.85**	1.47	-3.13*
Maya x Mathura Rai	-1.88*	5.90**	0.93*	2.45**	-1.71	-2.57*
Urvashi x Pusa Agrani	5.49*	-2.68**	-0.65	-1.35**	1.42	-0.37
Urvashi x RK-9807	-1.41	-2.55**	-0.20	1.37**	1.65	-0.60
Urvashi x RK-9808	-3.21**	-0.17	0.58	0.02	-4.95**	0.87
Urvashi x Mathura Rai	-0.87	5.40**	0.27	-0.05	1.87	0.10
Basanti x Pusa Agrani	-0.09	0.57	-1.07**	1.57**	-5.75**	-1.62
Basanti x RK-9807	-1.99**	1.03	0.05	0.29	1.15	-0.85
Basanti x RK-9808	0.54	0.08	0.83*	-0.60	1.89	2.28
Basanti x Mathura Rai	1.54*	-1.68**	0.18	-1.80**	2.75	0.18
Rohini x Pusa Agrani	-0.51	-7.35**	0.18	-0.43	-1.25	-2.20
Rohini x RK-9807	2.26**	-1.22*	-1.03**	-0.71	-0.01	-1.43
Rohini x RK-9808	-0.54	1.17*	0.75*	1.27*	-0.95	1.03
Rohini x Mathura Rai	-1.21	7.40**	0.10	-0.13	2.20	2.60*
Pusa Bold x Pusa Agrani	0.57	0.90	0.93*	-1.51**	1.84	-1.53
Pusa Bold x RK-9807	1.68*	3.03**	0.72	0.54	-2.93	0.23
Pusa Bold x RK-9808	-2.79**	-0.92	-0.83*	1.19*	1.14	-1.30
Pusa Bold x Mathura Rai	0.54	-3.02**	-0.82*	-0.21	-0.05	2.60*
Kranti x Pusa Agrani	-1.51*	4.48**	-1.23**	-1.60**	3.67*	1.13
Kranti x RK-9807	0.26	2.95**	-0.78*	0.79	-0.43	-0.77
Kranti x RK-9808	0.12	1.00	0.00	-0.56	-0.03	-0.30
Kranti x Mathura Rai	0.12	-8.43**	2.02**	1.37**	-3.21*	-0.07
NDR-8501 x Pusa Agrani	1.91*	4.07**	2.52**	-0.10	-8.00**	1.80
NDR-8501 x RK-9807	1.01	6.20**	-0.37	1.29*	1.90	0.90
NDR-8501 x RK-9808	-2.12**	2.25**	-0.25	-0.73	4.84**	0.70
NDR-8501 x Mathura Rai	-0.79	-12.52**	-1.96**	-0.46	1.45	-3.40**
Pusa Bahar x Pusa Agrani	-3.01**	2.98**	0.02	-1.18*	-2.08	-0.70
Pusa Bahar x RK-9807	-1.57*	0.45	-0.20	-0.20	1.82	-0.60
Pusa Bahar x RK-9808	0.29	-0.50	-0.75*	-0.81	0.89	1.53
Pusa Bahar x Mathura Rai	4.29**	-2.93**	0.93*	1.79**	-0.63	-0.23
Pusa Barani x Pusa Agrani	-1.34	0.07	0.77*	-1.07*	3.17*	-1.03
Pusa Barani x RK-9807	0.76	-1.13	0.55	-0.88	3.07*	-0.93
Pusa Barani x RK-9808	-2.04**	0.92	1.33**	0.10	0.47	0.87
Pusa Barani x Mathura Rai	2.63**	0.05	-2.65**	-0.30	-6.71**	1.10
Pusa Jai kisan x Pusa Agrani	1.74*	3.48**	0.35	-0.60	-3.50*	-1.78
Pusa Jai kisan x RK-9807	-2.16**	-0.05	-0.20	-0.21	-0.90	-1.02
Pusa Jai kisan x RK-9808	1.38	1.67**	-1.08*	1.10*	1.80	0.12
Pusa Jai kisan x Mathura Rai	-0.96	-5.10**	0.93*	-0.30	2.62	2.68*
Vaibhav x PusaAgrani	-3.76**	1.48*	1.10**	-0.60	0.09	1.38
Vaibhav x RK-9807	1.01	-1.05	0.22	-0.21	-6.01**	0.15
Vaibhav x RK-9808	1.87*	0.67	-0.33	0.77	3.39*	0.28
Vaibhav x Mathura Rai	0.88	-1.10	-0.98**	0.04	2.54	-1.82
Durgamani x Pusa Agrani	1.24	0.57	0.85*	4.32**	1.75	0.47
Durgamani x RK-9807	-0.99	1.63**	-0.03	2.04**	2.32	0.57
Durgamani x RK-9808	-1.13	1.75**	-0.25	-2.98**	-7.95**	0.37
Durgamani x Mathura Rai	0.88	-0.68	-0.57	-3.38**	3.87*	-1.40

Ashirwadh x Pusa Agrani	-0.01	-0.68	0.57	-0.68	3.75*	0.38
Ashirwadh x RK-9807	2.09**	-0.55	-0.45	-2.30**	-3.68*	0.15
Ashirwadh x RK-9808	3.29**	1.17*	0.00	-0.65	-5.61**	-2.38
Ashirwadh x Mathura Rai	-5.37**	0.07	1.02**	3.62**	5.54**	1.85
KR-5610 x Pusa Agrani	0.57	0.90	-1.15**	1.15*	-3.16*	-0.78
KR-5610 x RK-9807	-0.32	-0.97	0.63	-1.80**	6.07**	0.65
KR-5610 x RK-9808	1.21	1.08	-0.92*	0.19	0.47	0.45
KR-5610 x Mathura Ra	-1.46	-1.02	1.43**	0.45	-3.38*	-0.32
B-85 x Pusa Agrani	-0.43	-1.77**	-0.48	0.99	-7.16**	4.38**
B-85 x RK-9807	-3.66**	-1.30*	0.97**	0.70	1.74	-0.18
B-85 x RK-9808	0.21	-1.92**	-0.58	-0.98	5.47**	-1.05
B-85 x Mathura Rai	3.88**	4.98**	0.10	-0.71	-0.05	-3.15*
Vardan x Pusa Agrani	0.49	0.82	-1.15**	-1.26**	-1.91	0.47
Vardan x RK-9807	-0.74	-0.72	0.97**	0.79	-0.35	0.57
Vardan x RK-9808	0.46	-1.00	1.08*	-0.56	2.05	-0.30
Vardan x Mathura Rai	-0.21	0.90	-0.90*	1.04*	0.20	-0.73
Nav-gold x Pusa Agrani	2.57**	-1.35*	0.20	-0.01	4.25**	0.22
Nav-gold x RK-9807	-0.66	-0.55	-0.20	0.37	1.15	0.32
Nav-gold x RK-9808	-0.46	-3.50**	0.25	-0.65	2.55	-1.55
Nav-gold x Mathura Rai	-1.46	5.40**	-0.07	0.29	-7.96**	1.02
RH-30 x Pusa Agrani	-1.84*	-2.60**	0.52	-0.76	4.00*	-1.95
RH-30 x RK-9807	0.93	-1.80**	-0.03	1.29*	3.24*	1.15
RH-30 x RK-9808	1.79*	-0.42	-0.25	0.60	-1.03	0.95
RH-30 x Mathura Rai	-0.88	4.82**	-0.23	-1.13*	-6.21**	-0.15
RLM-198 x Pusa Agrani	-0.59	1.82**	0.02	2.90**	5.59**	-0.03
RLM-198 x RK-9807	3.84**	0.28	-0.20	-1.38**	-6.18**	-0.60
RLM-198 x RK-9808	-0.96	1.67**	0.58	-1.73*	-5.11**	0.53
RLM-198 x Mathura Rai	-2.29**	-3.77**	-0.40	0.20	5.70**	0.10
S.E (s_{ij}) (±)	0.53	0.46	0.37	0.48	1.83	1.00

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

Heterosis was calculated in per cent over economic parent for six characters and the results of heterosis are presented in Table-4. The cross combinations namely, Basanti × Pusa-Agrani, Maya × RK-9808, Pusa Bahar × RK-9807 and Urvash × Pusa Agrani were showed significant economic heterotic response for early flowering. The cross combinations namely; Varuna × RK-9808, Maya × RK-9808, RH-30 × RK-9808 and RLM-198 × RK-9807 were showed significant and desirable economic heterotic response for early maturity. The cross combinations namely; Pusa bold × RK-9807, Kranti × RK-9807, Pusa Bahar × RK-9807 and Pusa barani × RK-9808 were showed significant and desirable economic heterotic response for more number of primary branches per plant. The cross combination namely; RH-30 × RK-9807, Durgamani × RK-9808, Vaibav × Pusa Agrani, Pusa bahar × RK-9808 and Kranti × RK-9808 showed significant and desirable economic heterotic response for more number of secondary branches per plant. The cross combinations namely; Durgamani × Pusa Agrani, B-85 × Pusa Agrani, Nav gold × Pusa Agrani and RH-30 × RK-9807 were showed significant and desirable economic heterotic response for dwarf plant height and the cross combination namely; Varuna × Pusa Agrani was showed significant and desirable economic heterotic response for less biological yield per plant. These results were also similar **Singh *et al*. (2009) [21].** Priti *et al*. (2010) [12]. Vaghela *et al*. (2011) [27]. Verma *et al*. (2011) [28]. Patel *et al*. (2013) [11]. and Singh *et al*. (2013) [16].

Table 4: Top best five economic cross combinations for six characters in Indian mustard (*Brassica juncea* (L.) Czern & Coss)

Characters	Economic crosses	Heterosis over economic-parent	SCA effects	GCA effects
Days to 50% flowering	Varuna x RK-9808	-1.38**	-2.04**	H x H
	Maya x RK-9807	-3.70**	-1.74**	L x H
	Urvashi x RK-9808	-3.23**	-3.21**	H x H
	Kranti x Pusa Agrani	-3.70**	-1.51**	H x H
	Pusa Jai Kisan x RK-9807	-2.77**	-2.16**	H x H
Days to maturity	Maya x Pusa Agrani	-10.95**	-3.18**	H x L
	Urvashi x RK-9808	-0.84**	-0.17**	L x H
	Rohini x RK-9807	-6.20**	-1.22**	H x H
	Kranti x Mathura Rai	-5.40**	-8.43**	H x H
	Varuna x RK-9808	-3.05**	-4.00**	L x H
Number of primary branches per plant	Kranti x Mathura Rai	21.90**	2.02**	H x H
	NDR-8501 x Pusa Agrani	20.00**	2.52**	H x H
	Pusa Barani x RK-9808	22.85**	1.33**	H x H
	Vaibhav x Pusa Agrani	7.42**	1.10**	H x L
	Ashirwad x Mathura Rai	3.36**	1.02**	L x H

Number of secondary branches per plant	Varuna x RK-9808	5.29**	1.60**	H x H
	Maya x RK-9808	15.08**	2.85**	H x H
	Basanti x Pusa Agrani	1.89**	1.57**	L x H
	Kranti x Mathura Rai	2.05**	1.37**	H x H
	Pusa Bahar x Mathura Rai	7.39**	1.79**	H x H
Plant height (cm)	Urvashi x RK-9808	-8.67**	-4.95**	H x H
	Basanti x Pusa Agrani	-8.57**	-5.75**	H x L
	NDR-8501 x RK-9807	-7.98**	-8.00**	L x H
	Pusa Barani x Mathura Rai	-15.57**	-6.71**	H x H
	Vaibhav x RK-9807	-11.08**	-6.10**	H x H
Biological yield per plant (g)	Varuna x Pusa Agrani	0.89**	3.20**	L x H
	Maya x RK-9808	2.19**	3.15**	H x H
	Maya x Mathura Rai	5.35**	2.57**	H x H
	NDR-8501 x Mathura Rai	3.06**	3.40**	H x H
	B-85 x Mathura Rai	2.35**	3.15**	H x L

***significant at 5 and 1% levels, respectively

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