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Heterosis and combining ability for important quantitative traits in *Brassica juncea* L. under late sown conditions

Awnish Kumar, Ravi Shankar Singh, Chandan Kishore, Mankesh Kumar, Tushar Ranjan, Jyoti Kumari, Digvijay Singh and Shubham Chakraborty

Awnish Kumar
Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Ravi Shankar Singh
Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Chandan Kishore
Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Mankesh Kumar
Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Tushar Ranjan
Department of Molecular Biology and Genetic Engineering, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Jyoti Kumari
Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Digvijay Singh
Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Shubham Chakraborty
Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Corresponding Author:
Chandan Kishore
Department of Plant Breeding and Genetics, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Abstract
An experiment was conducted for the study of heterosis and combining ability in Indian mustard, (*Brassica juncea* L.) using 7×7 half diallel mating design along with their parents. Data were recorded for eleven quantitative characters. Analysis of variance (ANOVA) of design of experiment showed significant differences between all the treatments for all the characters, indicating that sufficient variability were present among the treatments for all the characters studied. The results of ANOVA for combining ability showed that, the variances due to general combining ability (GCA) and specific combining ability (SCA) were significant for all the character except days to maturity (for SCA variance only). Results revealed operation of both additive and non-additive gene action with preponderance of non-additive gene action for most of the traits except days to fifty per cent flowering, days to maturity and plant height. Among the seven parents, two parents namely Varuna and RAURD 14-18 showed significant positive GCA effects for seed yield per plant. On the basis of SCA effects the best cross combinations selected for seed yield per plant were RAURD 14-18 × RAURD-214, RAURD14-18 × JD-6 and VARUNA × RGN-73. Whereas, cross combinations RGN-73 × RAURD-214 (-2.54), VARUNA × JD-6 (-2.13) and KRANTI × RAURD-214 (-2.06) were identified superior for earliness and days to maturity. For seed yield per plant, the only cross combination RAURD 14-18 × RAURD-214 was identified as the best heterotic cross for all three types of heterosis, estimated over best check NRCHB-101. Hence, the result may suggested that the female parent of best heterotic cross combination, may be converted into CMS line and male as restorer line for its commercial exploitation after re-examining the CMS effect on the identified performance.

Keywords: diallel, combining ability, heterosis, ANOVA, Indian mustard

1. Introduction

Indian mustard (*Brassica juncea* L. Czern and Coss) is one of the important and widely accepted *Rabi* oilseed crop in India; occupies a premier position with acreage of more than 80% among the oilseed crops. It is popularly known as *Rai, Raya* or *Laha.* It is a dicot crop, belonging to family *Brassicaceae* with chromosome number 2n= 4x=36. It is a self-pollinated crop; but an average of 7.5 to 30 per cent cross pollination has been reported under natural field conditions (Abraham, 1994; Rakow and Woods, 1987) [1, 18]. It is an amphidiploid crop having AABB genome, originated naturally from interspecific cross of *Brassica rapa* (2n=2x=20, AA) and *Brassica nigra* (2n=2x=16, BB). In general, Middle East is considered as place of origin of *Brassica juncea* where it's both diploid ancestral parents; *Brassica rapa* (2n = 20, AA) and *Brassica nigra* (2n = 16, BB) were hybridized naturally that gave rise to the current species of *Brassica juncea* that first appeared in the region of Eastern India and Caucasus, and China is well considered as one of the major centre of origin for mustard crops (Prakash and Hinata, 1980) [17].

The interpretation of the whole scenario concludes there is huge scope of rapeseed-mustard diversification in India. Traditionally, farmers mostly prefer long duration varieties of *Kharif* crops specially rice coupled delayed sowing due to delay in rainfall and also flood conditions prevailing in the northern plains, forces farmers for late sowing of mustard crop. However, there are only limited number of Indian mustard variety recommended for late sown condition. Hence, there is need to develop Indian mustard variety suitable for late sown condition. Heterosis breeding in any crop plant has been the most rewarding technique among various breeding methods accessible to the plant breeders and geneticists for the improvement of yield in crop plants. Heterosis is considered as a means of improving the yield and other vital traits in mustard. Around 13 to 204.6% of heterosis for seed yield in *B. juncea* L. has been reported in many scientific studies (Tyagi *et al*. 2001, Yadav *et al.* 2012 and Meena *et al.* 2015) [24]. It is generally observed that genetically diverse groups showed more heterosis than within the group combinations. Study of heterosis provides information about probable gene action and helps in sorting out desirable gene action. As it is well known that by only phenotypic performance, breeders cannot confidently judge the combining ability of parents because it depends upon large number of complex genetic interaction as well as on environment. So for efficient and productive breeding programme, it is necessary to evaluate the nature of gene action associated with expression of traits, check the capability of the parents, and identification of superior F_1 hybrids for further exploitation in breeding programmes. In this situation combining ability analysis is a very useful tools available to the plant breeder, which provides values of combining ability effects and helps in in identification of the desirable parents and hybrids for further breeding programme. Taking in to account all the aforesaid information, the present investigation was taken up with a half-diallel set of 7x7 crosses and evaluated them along with their parents and four checks for eleven quantitative characters to know the heterotic combinations of crosses and identification of best parents for breeding program by considering the gene actions and per-se performances.

2. Material and Methods

The present investigation was carried out to obtain information on heterosis and combining ability for yield and its contributing characters in Indian mustard. The experiment was conducted at Bihar Agricultural College farm, Bihar Agricultural University, Sabour, Bhagalpur, during *Rabi* 2019-20 and 2020-21. Bhagalpur is located at an elevation of 52.73 meters above mean sea level, between 25º 50' N latitude and 87º 19' E longitudes. The experiment was carried out in a favorable ecosystem of heavy textured alluvial soil with no field heterogeneity. Seven parents, their 21 half diallel crosses, and four checks made up the experimental materials. During Rabi 2019-20, hand emasculation-hand pollination and selfing were done to generate seeds for 21 F_1 hybrids and 7 parents, respectively.

The 21 F_1 hybrids, 7 parents along with the 4 checks were evaluated in randomized block design with three replications during *Rabi* 2020-21. Two rows of each entries were grown having row length of 3 meter. The inter-row and intra-row spacing was kept 30 and 10 cm, respectively. All the recommended package of practices was adopted to raise a good crop. Data were recorded for various characteristics viz; Days to fifty per cent flowering, Days to maturity, Plant height (cm), Number of primary branches per plant, Number of secondary branches per plant, Siliqua length (cm), Number of siliquae per plant, Number of seeds per siliqua, Test weight (g), Seed yield per plant (g), Seed yield per plot (g). The observations were made on five randomly selected competitive plants for each genotype per replication. On a plot-by-plot basis, phenological characteristics such as days to flowering and days to maturity were recorded. For statistical analysis, the replication-wise mean values were used. Combining ability analysis was performed following the method given by Griffing (1956) [9]. The Method II and Model I of Griffing (1956 a) [9] were used for estimating GCA and SCA effects. Heterosis (Relative, heterobeltiosis and standard) for each character was computed using standard formula.

Table 1: Description of the parents used for generation of 7 x7 half diallel set in present study

Sr. no.	Parents no.	Name of the parent	Source of procurement	Characteristics
1.	P_1	RAURD-14-18	RAU, PUSA	Long bearing length, high siliqua density.
2.	P_2	VARUNA (NC)	BHU, Varanasi	Long duration & high yield.
3.	P_3	JD-6 (ZC)	IARI, New Delhi	Early maturing, for rainfed areas
4.	P_4	KRANTI (NC)	GBPUAT	Powdery mildew and white rust resistant, oil 40%
5.	P_5	RGN-73	RAU,ARS, Sriganganagar	Suitable for Irrigated, frost conditions
6.	P_6	PM-25 (NC)	IARI, New Delhi	Suitable for early sown irrigated conditions, high temp. tolerance at juvenile stage
7.	P_7	RAURD-214	RAU, PUSA	Earliness, heavy basal branching.

Table 2: Description of the checks used in present study.

S. No.	Check	Source of procurement
1.	Rajendra suflam (LC)	RAU, Pusa
2.	Kranti (NC)	GBPUAT
3.	NRCHB-101 (ZC)	DRMR, Bharatpur
4.	CS-56 (LR)	CSSRI, Karnal

3. Results and Discussion

3.1 Combining ability

3.1.1 General combining ability effects

None of the parents were found as good general combiner for all the traits under study (table 5). The number of traits for which a parents is identified as good general combiner varied. For example, RAURD -214 was found good general combiner for seven traits, RAURD 14-18 and JD-6 for four, Varuna for three, Kranti and RGN-73 for two, and PM 25 for one character only. The positive significant GCA effects of Varuna for seed yield/plant was found to be associated with the positive significant GCA effects of days to fifty per cent flowering, days to maturity, plant height and test weight. Moderate GCA effects for seed yield case of JD-6 was found to be associated with the positive significant GCA effects of primary branches, secondary branches, and high GCA effects for number of siliqua per plant, moderate GCA effects of Kranti for seed yield/plant was found to be associated with the positive significant GCA effects for siliqua length, test weight, moderate GCA effect for number of siliqua per plant and seed per siliqua. PM-25 showed moderate GCA effects for seed yield/plant was found to be associated with the positive significant GCA effects of days to fifty per cent flowering, days to maturity, plant height and number of siliqua per plant. High GCA effect for RAURD 14-18 was associated with the positive GCA effect of days to maturity and test weight. Similarly, poor GCA effect of RGN-73 for seed yield was found to be associated with the negative GCA effect of primary branches, number of siliqua per plant and test weight. While, poor GCA effects for seed yield/plant of RAURD-214 was found to be the cause of negative GCA effect for days to fifty per cent flowering, days to maturity, plant height, number of siliqua per plant and test weight. The parent RAURD-214 and RGN-73 was poor performer for seed yield but they were used in the study because of their respective desirable GCA effects showing characters. These findings were similar with results reported by Lal *et al*. (2012), Nasrin *et al*. (2011) [15], Maurya *et al*. (2012) [14], Singh *et al*. (2013), Dholu *et al*. (2014) [7], Adhikari *et al* (2018) [2] and Choudhary *et al*. (2019) [5].

3.1.2 Specific combining ability

Among all 21 F1's evaluated, large number of hybrids showed significant SCA effects in desirable direction like eight for days to 50% flowering, three for days to maturity, five for plant height, eight for number of primary branches per plant, nine for number of secondary branches per plant, eight for siliqua length, twelve for number of siliqua per palnt, ten for number of seed per siliqua, twelve for test weight, twelve for seed yield per plant and eleven for seed yield per plot. Crosses with favorable SCA effects for seed yield and two or more component characters may be chosen as suitable crosses for use in future breeding programmes targeted at directional improvement of these contributing traits. In 12 crossings, acceptable SCA effects for seed yield were linked to desirable SCA effects for one or more component traits. Significant positive SCA effects for seed yield of RAURD 14-18 × RAURD-214 was associated with significant and desirable SCA effects for days to 50% flowering, primary branches per plant, secondary branches per plant, siliqua length, number of siliqua per plant, number of seed per siliqua and test weight. The desirable SCA effects for seed yield in RAURD 14-18×JD-6 was accompanied by significant desirable SCA effects for primary branches per palnt, secondary branches per plant, siliqua length, number of siliqua per plant, number of seed per siliqua and test weight. In VARUNA×RGN-73, KRANTI×RAURD-214, and RGN-73× RAURD-214, favorable SCA effects for seed yield were supported by significant SCA effects in the intended direction for six, five, and seven component characters, respectively. As a result, these three crossings could be considered remarkable crosses for improving seed production and one or more component traits at the same time.

The ranking of high SCA crossings for seed yield revealed that parents with high GCA estimates did not always have high SCA estimations. As a result, this cross can be improved through selection. The eleven crosses with significant favorable SCA effects for seed yield combined both or at least one average/good general combiner. Therefore, the result suggest that dominant ×dominant and possibly additive × dominant gene interactions are in action for the genetic control of yield expression in these crosses. Based on this, heterosis breeding looks to be the best method for exploiting accessible genetic variability. Similar results were reported by Ghosh *et al* (2002) [8], Singh *et al* (2008) [22], Arifulla *et al* (2012) [4], Dholu *et al* (2014) [7], Chaurasiya *et al* (2018) [6] and Kaur (2019) [12].

Based on SCA effects the crosses VARUNA ×JD-6 (-2.76) followed by PM-25 ×RAURD-214 (-2.35), RAURD 14-18 ×VARUNA and RAURD 14-18 ×RAURD-214 (-1.87) appeared promising crosses for earliness of flowering. Similarly RGN-73 ×RAURD-214 (-2.54), VARUNA ×JD-6 (-2.13) and KRANTI× RAURD-214 (-2.06) could be identified as superior crosses for earliness of maturity. The estimates of SCA effect indicated that cross RAURD 14-18 ×RAURD-214 (-20.54) was the best specific combiner followed by RAURD 14-18 ×VARUNA (-9.06) and RGN-73 ×RAURD-214 (-7.83) for reducing the plant height. The top two crosses for number of primary branches per plant were RAURD 14-18 ×RAURD-214 (0.89) and RGN-73 ×RAURD-214(0.84). VARUNA ×RGN-73(1.68) and RAURD 14-18 ×RAURD-214 (1.64) were the best crosses for number of secondary branches per plant. The best crosses for siliqua length were VARUNA ×RGN-73(0.63) and RAURD 14-18 ×VARUNA (0.51). The promising crosses for number of siliqua per plant were RAURD 14-18 ×RAURD-214 (52.52) and RGN-73 ×RAURD-214(51.29). The elite crosses for number of seed per siliqua were RAURD 14-18 ×RAURD-214 (1.64) and RAURD 14-18 ×JD-6 (1.4). Similarly, the best crosses for the character test weight were JD-6×KRANTI (0.77) and VARUNA×RAURD-214 (0.61). These results suggests that maintenance of heterozygosity in the population is important for desired expression of these characters.

3.2 Estimates of heterosis

Heterosis is commonly defined as superiority of F_1 hybrid over any measure of parental performance either in positive or negative direction, it means that definition of heterosis varies depending on the reference used for estimation or comparison. Heterosis refers to superiority of F_1 over mean of the both parents (relative or mid-parent heterosis) over the mean of better parent (heterobeltiosis). These two definition coincide with that of Hayes *et al*. (1955) [11], who defined heterosis as superiority of F_1s in terms of hybrid vigour over the mean of the parents or over the better parents and this definition is generally accepted by scientific diaspora. Virmani and Edwards (1983) [25] definedheterosis which have commercial significance, as superiority of the hybrid performance over best available commercial variety or superior check of that region.

For days to fifty per cent flowering, negative heterosis is considered to be desirable in order to develop early maturing genotypes. Out of the 21 crosses, six crosses showed significant relative heterosis (ranged from -7.4 to 6.8), ten crosses showed significant negative heterobeltiosis (ranged from -14.52 to 1.72) and 9 cross combination exhibited significant economic heterosis (ranged from -11.73 to 10.49). Out of 9 crosses, only 3 cross combination i.e. JD-6 ×RAURD-214 (-11.73**), RAURD 14-18×RAURD-214 (-11.11**) and VARUNA ×JD-6(-6.79**) showed significant negative economic heterosis over best check of this trait, NRCHB-101.

In case of days to maturity, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant negative direction were observed for two, five and seven crosses, and these heterosis ranged from -2.92 to 3.2 per cent, -5.95 to 2.71 percent, and -5.17 to 3.65 per cent, respectively. Cross combination KRANTI×RAURD-214 (-2.92**) was identified as best heterotic for relative heterosis (-2.92**) and heterobeltiosis (-5.95**). The top two cross showed significant negative economic heterosis over best check NRCHB-101 was JD-6 ×RAURD-214 (-5.17**) and RGN-73×RAURD-214 (-4.26**).

In case of plant height, only two types of heterosisi. eheterobeltiosis, and economic heterosis in significant negative direction were observed for four and three crosses, and these heterosis ranged from -17.33 to 12.99 percent, and -24.18 to1.14 percent, respectively. None of the cross combination showed relative heterosis in desired direction *i.e*. for dwarfness. Cross PM-5 ×RAURD-214 (-17.33**) was found to be the best for heterobeltiosis. The top two cross shown significant economic heterosis in desired direction *i.e*. for dwarfness estimated over best check Rajendra suflam was PM-5 ×RAURD-214 (-24.18**) and RAURD 14-18 ×RAURD-214 (-23.67**).

Five cross combination was identified showing significant positive relative and economic heterosis, while only two crosses showed significant positive heterobeltiosis for number of primary branches per plant and their range varied from -5.19 to 28.05%, -8.07 to 22.22 percent and -1.46 to 41.61%. The best check identified for this trait was CS-56. Cross combination RAURD 14-18×RAURD-214 was the best heterotic cross identified preceding RGN-73×RAURD-214 for relative and economic heterosis estimated over best check NRCHB-101 in desired direction while cross RAURD 14-18 ×JD-6 was the best cross in terms of heterobeltiosis.

For number of secondary branches, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant positive direction were observed for seventeen, ten and eleven crosses, and these heterosis ranged from 4.05 to 45.15%, 0.43 to 41.04% and -6.49 to 37.39 respectively. Cross combination VARUNA ×RGN-73 was the best heterotic cross identified for relative heterosis (45.15%), heterobeltiosis (41.14%) while cross combination RAURD 14-18 ×RAURD-214 was best for economic heterosis (37.39%) estimated over best check NRCHB-101.

For siliqua length, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant positive direction were observed for nine, four and four crosses, and these heterosis ranged from -8.08 to 23.65%, -15.42 to 18.13% and -11.9 to 16.72 respectively. Cross VARUNA ×KRANTI was the best heterotic cross identified for relative heterosis (23.65%) and heterobeltiosis (18.13%). For standard heterosis or heterosis estimated over best check NRCHB-101, VARUNA ×RGN-73 (16.72%) was found to be the best.

For number of siliqua per plant, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant positive direction were observed for Seventeen, fifteen and fourteen crosses, and these heterosis ranged from 1.89 to 69.25%, -0.5 to 53.13% and -17.8 to 44.94%, respectively. Cross RGN-73 ×RAURD-214 was the best heterotic cross identified for relative heterosis (69.25%), heterobeltiosis (53.13%). However, for economic heterosis (44.94%) estimated over best check NRCHB-101, cross combination JD-6×PM-25 was best.

For number of seed per siliqua, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant positive direction were observed for seven, five and six crosses, and these heterosis ranged from -12.53 to 26.02%, -13.76 to 24.55% and -11.43 to 11.83%, respectively. Cross RAURD 14-18 ×RAURD-214 was the best heterotic cross identified for relative heterosis (26.02%), heterobeltiosis (24.55%) and also for economic heterosis (11.83%) which was estimated over best check NRCHB-101.

For 1000-seed weight, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant positive direction were observed for fifteen, fifteen and thirteen crosses, and these heterosis ranged from -6.87 to 36.24%, -9.1 to 36.03% and -11 to 33.59%, respectively. Cross RAURD 14-18 ×RAURD-214 was the best heterotic cross identified for relative heterosis (36.24%), heterobeltiosis (36.03%) as well as economic heterosis (33.59%) which was estimated over best check NRCHB-101.

For seed yield per plant, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant positive direction were observed for twenty, ninteen and seventeen crosses, and these heterosis ranged from 14.06 to 126.84%, -11.89 to 96.54% and -3.07 to 60.79%, respectively. Cross RAURD 14-18 ×RAURD-214 was the best heterotic cross identified for relative heterosis (126.84%), heterobeltiosis (96.54%) as well as economic heterosis (60.79%) which was estimated over best check NRCHB-101.

For seed yield per plot, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant positive direction were observed for twenty, eighteen and seventeen crosses, and these heterosis ranged from 14.43 to 125.18%, -7.7 to 107.67% and 2.79 to 66.63%, respectively. Cross RAURD 14-18 ×RAURD-214 was the best heterotic cross identified for relative heterosis (125.18%), heterobeltiosis (107.67%) as well as economic heterosis (66.63%) which was estimated over best check NRCHB-101.

The results of heterosis corroborates with the findings of Singh *et al* (2003) [21], Parmar *et al* (2004) [16], Tyagi *et al* (2004), Singh *et al* (2007) [23], Sohan Ram (2009) [19], Gupta *et al* (2011) [10] and Rashmi *et al* (2018) [18].

4. Summary and Conclusion

The present investigation was carried out to obtain information on combining ability and heterosis for yield and its contributing characters in Indian mustard. Data recorded foreleven characters were subjected to statistical analysis and result obtained were summarized as follows:

The GCA effects for seed yield per plant ranged from -0.334 (RGN-73) to 0.492 (Varuna). Among seven parents, only two parents viz; Varuna and RAURD 14-18 showed significant positive GCA effects for seed yield per plant. Besides seed yield per plant, RAURD 14-18 was also observed good general combiner for plant height and test weight. While Varuna was also good general combiner for test weight. RAURD-214 was found to be the best parent (good general combiner) for days to 50% flowering, days to maturity, plant height, number of primary branches, number of secondary branches, siliqua length and seed per siliqua, but poor combiner for seed yield per plant. JD-6 was also observed as moderate general combiner for seeds yield and good general combiner for days to 50% flowering, days to maturity, plant height and number of siliqua per plant.

The SCA effects for seed yield per plant ranged from -1.6 (PM-25× RAURD-214) to 3.84 in (RAURD 14-18 ×RAURD-214). Among all 21 crosses, ten cross combination showed significant positive SCA effects for seed yield per plant. The best crosses selected on the basis of specific combining ability effects were RAURD 14-18 ×RAURD-214, RAURD 14-18 ×JD-6, VARUNA ×RGN-73, KRANTI×RAURD-214 and RGN-73 ×RAURD-214 for seed yield per plant.

Based on SCA effects, the crosses VARUNA ×JD-6 (-2.76) followed by PM-25 ×RAURD-214 (-2.35), RAURD 14-18 ×VARUNA and RAURD 14-18 ×RAURD-214 (-1.87) appeared promising crosses for days to 50% of flowering.

Similarly, RGN-73 ×RAURD-214 (-2.54), VARUNA ×JD-6 (-2.13) and KRANTI× RAURD-214 (-2.06) were identified as superior crosses for earliness of maturity.

Highest significant positive SCA effects for seed yield per plant of RAURD 14-18 ×RAURD-214 was associated with significant and desirable SCA effects of days to 50% flowering, primary branches per plant, secondary branches per plant, siliqua length, number of siliqua per plant, number of seed per siliqua and test weight. This cross combination also registered significantly superior performance for all three types of heterosis and mean performance for seed yield per plant, as well as significantly superior for earliness of maturity over best check and best parents.

For seed yield per plant, all three types of heterosisi.e relative heterosis, heterobeltiosis, and economic heterosis in significant positive direction were observed for twenty, ninteen and seventeen crosses, and these heterosis ranged from 14.06 to 126.84%, -11.89 to 96.54% and -3.07 to 60.79%, respectively. Cross RAURD 14-18 ×RAURD-214 was the best heterotic cross identified for relative heterosis (126.84%), heterobeltiosis (96.54%) as well as economic heterosis (60.79%) which was estimated over best check NRCHB-101.The other top two crosses for relative hetrosis were Varuna ×RAURD-214 (104.21) and RGN-73×RAURD-214 (98.02), for heterobeltiosis were RAURD 14-18 ×JD-6 (79.52) and RGN-73×RAURD-214 (68.78), similarly for economic heterosis were Varuna ×RAURD-214(58.76) and Varuna ×RGN-73 (54.77).

Both additive and non-additive gene activities were shown to be relevant in the expression of the characters investigated in this study. Non-additive gene effects, on the other hand, were predominant over additive effects in magnitude for all the characters except days to 50% flowering, days to maturity and plant height.

Table 3: Analysis of variance for all the characters under study of all 32 treatments of Indian mustard.

		MEAN SUM OF SQUARE										
S.V	**D.F**	**DFF**	**DM**	**PH**	**PBPP**	**SBPP**	**SL**	**SPP**	**SPS**	**TW**	**SYPT**	**SYPP**
Replication	2	7.5815	48.3973	42.0357	0.865	1.1939	0.1842	558.0357	0.1054	0.0046	1.8901	1930.2142
Treatments	31	46.89**	27.1582**	959.29**	0.939**	3.15**	0.36**	3336.93**	2.49**	0.73**	13.43**	21571.98**
Error	62	4.0525	3.8865	217.599	0.362	0.448	0.0618	133.7225	0.1506	0.0173	0.5189	979.183

**, * = Significant at 5% and 1% probability level, respectively.

Table 4: Mean sum of square of general and specific combining ability for various character under study

		MEAN SUM OF SQUARE										
S.V	**D.F**	**DFF**	**DM**	**PH**	**PBPP**	**SBPP**	**SL**	**SPP**	**SPS**	**TW**	**SYPT**	**SYPP**
GCA	6	59.90**	33.05**	983.93**	0.42**	1.001**	0.133**	340.242**	0.63**	0.35**	0.58**	663.98**
SCA	21	2.98*	2.198	130.001*	0.266*	1.065**	0.12**	1332.90**	0.88**	0.21**	5.59**	9055.40**
Error	54	1.3508	1.2955	72.533	0.1295	0.1493	0.0206	44.57417	0.0502	0.00576	0.172967	326.3943
σ^2gca		6.5058	3.5289	101.2671	0.033	0.0947	0.0126	32.852	0.065	0.0392	0.0455	37.5098
σ^2sca		1.633	0.903	57.4689	0.137	0.916	0.0989	1288.33	0.8369	0.2051	5.4186	8729.0127
σ^2gca/ σ^2 sca		3.9838	3.9081	1.7621	0.241	0.1034	0.1272	0.0255	0.0777	0.1912	0.0084	0.0043

DFF: Days to 50% flowering**, DM:** Days to maturity**, PH:** Plant height**, PMPP:** Number of primary branches per plant**, SBPP:** Number of Secondary branches per plant**, SL:** Siliqua length**, SPP:** Number of siliqua per plant**, SPS:** Number of seed per siliqua**, TW:** Test weight**, SYPT:** Seed yield per plant**, SYPP:** Seed yield per plot

Table 5: Estimates of GCA effects of seven parents for all the characters under study

	DFF	**DM**	**PH**	**PBPP**	**SBPP**	**SL**	**SPP**	**SPS**	**TW**	**SYPT**	**SYPP**
RAURD 14-18	-0.026	0.497	-7.283**	-0.015	-0.355**	-0.135**	-9.522**	-0.430**	0.354**	0.387**	10581**
VARUNA	0.974**	0.905*	8.358**	-0.211	-0.013	-0.061	-0.222	-0.091	0.141**	0.492**	17.016**
JD-6	-2.286**	-1.799**	-13.228**	0.030	0.058	-0.074	6.323**	-0.169*	-0.037	0.003	-2.216
KRANTI	2.418**	1.720**	11.521**	-0.144	-0.344**	0.101*	0.586	0.083	0.055*	0.055	0.507
RGN-73	2.640**	1.868**	5.947*	-0.063	0.065	0.177**	-0.955	0.347**	-0.200**	-0.158	-10.536
PM-25	0.788*	0.164	6.721*	-0.056	-0.054	-0.105*	8.519**	-0.011	-0.158**	0.020	2.429
RAURD-214	-4.508**	-3.335**	-12.035**	0.459*	0.643**	0.096*	-4.729*	0.272**	-0.156**	-0.334*	-2.018

**, * = Significant at 5% and 1% probability level, respectively.

DFF: Days to 50% flowering**, DM:** Days to maturity**, PH:** Plant height**, PMPP:** Number of primary branches per plant**, SBPP:** Number of Secondary branches per plant**, SL:** Siliqua length**, SPP:** Number of siliqua per plant**, SPS:** Number of seed per siliqua**, TW:** Test weight**, SYPT:** Seed yield per plant**, SYPP:** Seed yield per plot.

Table 6: Estimates of SCA effects of seven parents for all the characters under study

	DFF	**DM**	**PH**	**PMPP**	**SBPP**	**SL**	**SPP**	**SPS**	**TW**	**SYPT**	**SYPP**
RAURD 14-18×VARUNA	-2.02**	-0.43	-9.06*	-0.17	0.03	-0.25**	-5.29	-0.8**	0.32**	0.03	-0.65
RAURD 14-18×JD-6	0.91	0.28	0.32	0.72**	0.73**	0.45**	32.5**	1.4**	0.39**	2.66**	99.72**
RAURD 14-18×KRANTI	-0.46	-0.91	-7.43*	-0.41**	-0.62**	0.51**	-19.86**	-0.78**	0.53**	-0.11	3.79
RAURD 14-18×RGN-73	1.98**	1.61**	11.91**	0.04	0.02	-0.35**	-17.32**	-0.18*	0	-0.55**	-25.34**
RAURD 14-18×PM-25	-1.17*	-0.35	12.24**	-0.33*	0.11	-0.1	-10.93**	-0.16	0.34**	0.18	13.07
RAURD 14-18×RAURD-214	-1.87**	-0.17	-5.4	0.89**	1.64**	0.26**	52.52**	1.88**	0.44**	3.84**	155.48**
VARUNA ×JD-6	-2.76**	-2.13**	-7.72*	0.31*	0.29	0.23**	35.7**	-0.02	-0.12**	1.33**	55.92**
VARUNA ×KRANTI	-1.13*	2.02**	-3.4	-0.14	-0.01	0.45**	-27.39**	-0.59**	0.26**	-0.88**	-42.86**
VARUNA ×RGN-73	0.65	1.87**	3.31	0.54**	1.68**	0.63**	32.81**	0.8**	0.21**	2.59**	115.84**
VARUNA ×PM-25	1.83**	-0.43	12.47**	-0.37*	-0.14	-0.2**	10.17**	-1.27**	0.03	-0.13	-15.72*

VARUNA ×RAURD-214	1.46**	-0.57	32.09**	-0.15	1.23**	0.02	16.42**	1.21**	0.61**	3.1**	125.6**
JD-6×KRANTI	0.8	0.06	-3.95	0.15	0.45**	-0.26**	10.9**	-0.03	0.77**	2.05**	83.99**
JD-6×RGN-73	2.57**	0.57	-4.44	-0.5**	-0.66**	-0.41**	-20.2**	-0.18	-0.02	-0.87**	-31.71**
JD-6×PM-25	-0.57	-0.06	3.98	0.29*	0.83**	0.1	41.66**	0.35**	-0.09**	1.35*	58.62**
JD-6×RAURD-214	0.06	0.13	1.01	-0.19	-0.4*	0.28**	-1.42	0.53**	-0.39**	-0.52**	-29.68
KRANTI×RGN-73	-0.8	0.72	12.74**	-0.03	0.51**	0.26**	31.24**	-0.36**	-0.47**	0.38*	3.44
KRANTI×PM-25	2.06**	1.09*	1.44	0.83**	1.46**	0.07	37.1**	0.77**	-0.37**	0.78**	36.85**
KRANTI×RAURD-214	-1.31**	-2.06**	-2.68	-0.51**	0.03	-0.2**	29.15**	0.68**	0.12**	1.38**	58.95**
RGN-73×PM-25	0.17	1.94***	-1.39	-0.08	0.89**	-0.26**	3.21	0.08	0.28**	1.15**	46.76**
RGN-73×RAURD-214	-1.2*	-2.54**	-7.83*	0.84**	0.16	0.09	51.29**	0.21*	0.15**	2.48**	92.06**
PM-25×RAURD-214	-2.35**	-0.17	-20.54**	0.5**	-0.36*	0.11	-18.89**	-0.91**	-0.17**	-1.6**	-62.28**

**, * = Significant at 5% and 1% probability level, respectively.

Table 7: Percent decrease or increase of hybrids over mid parent (relative heterosis), better parent (heterobeltiosis) and best check (standard heterosis) and its test of significance.

Name of cross	Seed yield/plant (g)		
	Heterosis over		
	MP	BP	SH
RAURD 14-18×VARUNA	41.07**	30.94**	25.09 **
RAURD 14-18×JD-6	81.86**	79.52**	50.74 **
RAURD 14-18×KRANTI	30.42**	18.79**	18.27 *
RAURD 14-18×RGN-73	32.36**	29.82**	10.45
RAURD 14-18×PM-25	26.43**	10.22	21.26 **
RAURD 14-18×RAURD-214	126.84**	96.54**	60.79 **
VARUNA ×JD-6	57.91**	48.35**	41.72 **
VARUNA ×KRANTI	18.75**	16.35*	15.84 *
VARUNA ×RGN-73	71.38**	62**	54.77 **
VARUNA ×PM-25	21.02**	13.05*	24.37 **
VARUNA ×RAURD-214	104.21**	66.18**	58.76 **
JD-6×KRANTI	58.14**	45.75**	45.11 **
JD-6×RGN-73	27.32**	26.49**	7.62
JD-6×PM-25	40.49**	23.86**	36.26 **
JD-6×RAURD-214	52.33**	30.55**	9.61
KRANTI×RGN-73	33.38**	23.68**	23.14 **
KRANTI×PM-25	24.13**	18.24**	30.08 **
KRANTI×RAURD-214	66.79**	33.61**	33.03 **
RGN-73×PM-25	35.23**	19.91**	31.91 **
RGN-73×RAURD-214	98.02**	68.78**	43.60 **
PM-25×RAURD-214	14.06	-11.89	-3.07

**, * = Significant at 5% and 1% probability level, respectively

Table 8: Top 5 best crosses based on mean performance, GCA effects, SCA effects and heterosis for seed yield per plant

Cross	*Per* se performance	GCA effects of parents and status			SCA effects	Heterosis over			Other significant character
		P1	P2	Status		MP	BP	SH	
Raurd 14-18 X Raurd-214	13.44	0.387**	-0.334*	G X P	3.84**	126.84**	96.54**	60.79 **	DFF, PBPP, SBPP, SL, SPP, SPS, TW
Varuna x Raurd-214	13.27	0.492**	-0.334*	G X P	3.10**	104.21**	66.18**	58.76 **	SBPP, SPP, SPS, TW
Varuna x RGN-73	12.93	0.492**	-0.158	G X P	2.59**	71.38**	62**	54.77 **	PBPP, SBPP, SL, SPP, SPS, TW
Raurd 14-18 X JD-6	12.60	0.387**	0.003	G X M	2.66**	81.86**	79.52**	50.74 **	PBPP, SBPP, SL, SPP, SPS, TW
JD-6 x Kranti	12.13	0.003	0.055	M X M	2.05**	58.14**	45.75**	45.11 **	SBPP, SPP, SPS, TW

Table 9: Best crosses based on mean performance, GCA effects, SCA effects and heterosis for days to maturity

Cross	*Per* se performance	GCA effects of parents and status			SCA effects	Heterosis over			Other significant character
		P1	P2	Status		MP	BP	SH	
JD-6 X RAURD-214	104	-1.799**	-3.335**	G X G	0.13	-1.42	-1.89	-5.17**	SL, SPS
RGN-73 x RAURD-214	105	1.868**	-3.335**	P X G	-2.54**	-2.63*	-5.12**	-4.26**	DFF, PH, PBPP, SPP, SPS, TW, YPT. YPP
Kranti x RAURD-214	105.33	1.720**	-3.335**	P X G	-2.06**	-2.92*	-5.95**	-3.95**	DFF, SPP, SPS, TW, YPT, YPP
PM-25 X RAURD-214	105.67	0.164	-3.335**	P X G	-0.17	-0.94	-2.46	-3.65*	DFF, PH, PBPP
RAURD 14-18 X RAURD-214	106	0.497	-3.335**	P X G	-0.17	-1.4	-3.64*	-3.34*	DFF, PBPP, SBPP, SL, SPP, SPS, TW, YPT. YPP
Varuna X RAURD-214	106	0.905*	-3.335**	P X G	-0.57	-1.7	-4.22**	-3.34*	SBPP, SPP, SPS, TW, YPT. YPP
Varuna X JD-6	106	0.905*	-1.799**	P XG	-2.13**	-2.15	-4.22**	-3.34*	DFF, PH, PBPP, SL, SPP, YPT. YPP

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