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Research Note

Estimation of heterosis for seed yield and yield attributing traits in Indian mustard (*Brassica juncea* L. Czern & Coss.)

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Abstract

Forty eight F_1s along with their 12 lines and 4 testers were evaluated during *Rabi* 2009-10 for nine quantitative traits to estimate relative heterosis (Ha), heterobeltiosis (Hb) and economic heterosis (Hc) for screening of superior cross combinations of Indian mustard [*Brassica juncea* (L.) Czern. & Coss.]. All the genotypes were grown in Field Experimentation Center, SHIATS, Allahabad in randomized block design (RBD). Analysis of variance showed significant differences among the genotypes for all characters studied.

Keywords

Indian mustard, heterosis, seed yield

Mustard is predominantly a self pollinated crop and the exploitation of hybrid vigour will depend upon the direction and magnitude of heterosis, biological feasibility and the gene action involved. Since, heterosis has an important role in all plant breeding programmes; it would be very helpful to know the relationship between heterosis for seed yield and its components (Azizinia, 2011). The hybrid technology is a modern approach to enhance the genetic yield potential and it has been widely acclaimed and established in various crops. Heterosis expressed as percent increase or decrease in the mean value of F_1 hybrid over better parent (heterobeltiosis) and standard heterosis (economic heterosis). Both positive and negative heterosis is useful in crop improvement. In general positive heterosis is desired for yield and negative heterosis is desired for early maturity and plant height. Standard heterosis is most important because it is desired to develop the hybrids which are better than the existing high yielding varieties grown commercially by farmers. Selection of desirable heterotic crosses at an early stage is very important in developing high-yielding genotypes. Effective utilization of heterosis to develop high-yielding hybrids, therefore, has been the major objective of *Brassica* oilseed breeding in recent years (Wang, 2005). The main objective of the present study is therefore to screen superior cross combination(s) by estimating heterobeltiosis (better parent heterosis) and standard heterosis (economic heterosis) in F_1 crosses of Indian mustard [*Brassica juncea* (L.) Czern & Coss].

The present investigation was undertaken to study the extent of heterosis in F_1 hybrids for seed yield and its contributing traits in Indian mustard during rabi 2009-10 at the Field Experimentation Centre, Department of Genetics and Plant Breeding, SHIATS, Allahabad. The experiment was laid in Randomized Block Design (RBD) with two replications. The experimental material comprised of 12 lines (L_1- GM-1, L_2- RL-1359, L_3- KRISHNA, L_4- PUSABOLD, L_5- JD-6, L_6- JM-3, L_7- BASANTI, L_8- PM-67, L_9-LAHI, L_{10}-CS 54, L_{11}- RH-819 and L_{12}- GM-2) and 4 testers (T_1- DURGAMANI, T_2- VARUNA, T_3- LAXMI and T_4- JM-2) and check Rohini. Forty-eight intra specific crosses of Indian mustard *Brassica juncea* (L.) were generated by crossing between the twelve lines and four testers during *rabi* 2008-09 in L x T mating design (Kempthrone, 1957). Row to row and plant to plant distance was kept at 45 and 10 cm, respectively. The recommended fertilizer dose was followed for N: $P_2 O_5$: K_2O @ 80: 40: 40, kg ha^{-1}. The recommended agricultural package of practices was followed to raise a healthy crop. Five randomly selected plants were selected to record the data for seven quantitative characters *viz.* plant height (cm), number of siliquae main $branch^{-1}$, number of primary branches $plant^{-1}$, number of secondary branches $plant^{-1}$, length of siliquae (cm), number of seeds $siliqua^{-1}$ and seed yield plant $(g)^{-1}$ while the two characters *viz.,* days to 50% flowering and days to maturity were recorded on plot basis. The analysis of variance was carried out for nine characters as per the procedure described by Panse and Sukhatame (1967). The estimate of heterosis was calculated using the procedure of Turner, J.H. (1953), heterobeltiosis by Fonesca, S. and Patterson, P. (1968) and economic heterosis by Meredith and Bridges (1972).

The analysis of variance (Table 1) revealed considerable genetic variation among parents and hybrids for almost all the traits under study. The average performance of hybrids differed significantly from the average performance of parents indicating the presence of overall heterosis, which was also evident from the significance of parents vs. hybrids comparison for all the traits except for seed yield plant^{-1}. Highly significant differences were recorded among the treatments for all the characters namely, days to 50% flowering, plant height (cm), number of siliquae main branch^{-1}, number of primary branches plant^{-1}, number of secondary branches plant^{-1}, length of siliquae (cm), number of seeds siliqua^{-1}, days to maturity and seed yield plant (g)$^{-1}$. Vaghela *et al.* (2011) earlier reported that the analysis of variance showed highly significant differences existed among genotypes for all the characters studied. Arifullah *et al.* (2013) revealed that there was highly significant differences among the treatments for all the characters studied also supports the experimental results of analysis of variance.

Estimation of heterosis: All the 48 hybrids were compared with mid parent, better parents and commercial cultivar for the estimation of relative heterosis (Ha), heterobeltiosis (Hb) and standard heterosis (Hc), respectively (Table 2 a, b & c). Considerable amount of relative heterosis (Ha), heterobeltiosis (Hb) and standard heterosis (Hc) 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.

Seed yield per plant:Among 48 hybrids, 16, 5 and 1 crosses displayed significant positive heterosis over mid-parent (Ha), better parent (Hb) and commercial cultivars (Hc), respectively (Table 2c). Among them, hybrid L2×T4 resulted in positive significant relative heterosis (64.95**), heterobeltiosis (98.43**) and economic heterosis (31.77**) compared to others. Hybrid L3×T4 also showed positive significant for relative heterosis (111.27**) and heterobeltiosis (53.26**), however, positive but non-significant for economic heterosis (4.17). Moreover, hybrid L10 × T2 resulted in positive significant relative heterosis (21.20**), heterobeltiosis (18.41**), eventhough it has significant negative heterosis for economic heterosis (-26.30**).

Likewise, among other hybrid, hybrid L12×T4 found with positive significant heterosis for relative heterosis (41.53**) and heterobeltiosis (29.04**). Hybrid L1×T2 showed positive significant heterosis for relative heterosis (22.27**), heterobeltiosis (21.74**), but, has negative but significant economic heterosis (-27.08**). And, hybrid L9 X T2 obtained with positive significant relative heterosis (16.59**), positive but non-significant heterobeltiosis (14.04) and significant but negative economic heterosis (-32.29**). Positive significant relative heterosis, heterobeltiosis and standard heterosis is preferred to select the genotypes for inclusion in the further breeding programme so that the trait can be utilized in development of new high yielding varieties. The ultimate aim of heterosis breeding is to gain the heterotic crosses for seed yield and other associated heterotic character. From the present study the high yielding cross combinations can be utilized in future breeding programmes for developing high seed yielding genotypes. Earlier studies done by Aher *et al*. (2009), Verma *et al.* (2011), Gupta *et al.* (2011) Patel *et al.* (2012), Kumar *et al.* (2013), Kumar *et al.* (2014), Meena *et al*. (2014) and Dholu *et al.* (2014) also reported positive significant heterobeltiosis (Hb) and economic heterosis (Hc) for seed yield plant^{-1}.

Days to 50 % flowering: Out of 48 hybrids, 3 & 2 hybrids showed significant negative heterosis over mid-parent (Ha) & better parent (Hb), respectively while none of the crosses has negative economic heterosis (Table 2a). Among them, hybrid L8 × T2 showed negative significant relative heterosis (-4.91**) and heterobeltiosis (-10.64*) along with hybrid L8 × T4 (-5.70** & -12.06*, respectively for Ha & Hb). Negative heterosis is preferred for flowering as it indicates earliness in flowering. Early flowering is desirable for *Brassica* species as it offers longer duration for grain feeling and certainly cause early maturity and high seed yield. The crosses having significant negative heterosis can select for harnessing the economic values of the related traits in the further breeding programme. Nassimi *et al.* (2006) reported desirable negative significant better parent heterosis for days to 50 % flowering, in *Brassica* genotypes.

Days to maturity: About 16, 26 & 15 crosses exhibited negative significant heterosis over mid-parent (Ha), better parent (Hb) and commercial cultivars (Hc), respectively (Table 2c). Among them, hybrid L2 × T4 showed desirable negative significant mid parent heterosis (-2.60**), heterobeltiosis (-3.20**) and economic heterosis (-3.20**). Similarly, hybrid L3 × T4 also reflects negative significant mid parent heterosis (-2.17**), heterobeltiosis (-3.20**) and economic heterosis (-3.20**). Early maturity is useful in most plant species especially *Brassica* where delayed maturity cause losses in yield and quality of oil due to high temperature (Turi *et al.*, 2006). Negative heterosis, therefore, is useful regarding days to maturity Nassimi *et al.* (2006). These results were well supported by similar findings of Yadava *et al.*,

(2012) who reported desirable significant negative heterobeltiosis for days to maturity.

Primary branches per plant: Out of 48 crosses, 15, 10 and 13 hybrids obtained with significant positive heterosis over mid-parent (Ha), better-parent (Hb) and commercial varieties (Hc), respectively (Table 2b). Among them, hybrid L2 × T4 showed positive significant mid parent heterosis (82.93**), heterobeltiosis (81.45**) and economic heterosis (70.45**), and hybrid L3 × T4 also has positive significant mid parent heterosis (46.51**), heterobeltiosis (38.97**) and economic heterosis (43.18**). In addition, hybrid L10 × T2 showed positive significant mid parent heterosis (24.91**) and economic heterosis (27.27**). Hybrid L9 × T2 exhibited positive significant mid parent heterosis (23.68**) and economic heterosis (42.42**). In *Brassica*, positive heterosis for number of primary branches is desirable, because plants with vigorous stature containing more branches provide opportunity for higher yields. Earlier, Gupta (2009) reported desirable positive heterobeltiosis for primary branches plant^{-1}. Also, significant positive heterobeltiosis for number of primary branches plant $^{-1}$ was also reported by Nasrin *et al.* (2011).

Secondary branches per plant: Of the crosses, 24, 15 and 7 hybrids reflected significant positive heterosis over mid-parent (Ha), better-parent (Hb) and commercial varieties (Hc), respectively (Table 2b). Out of them, hybrid L2 × T4 showed positive significant mid parent heterosis (171.55**), heterobeltiosis (144.91**) and economic heterosis (106.69**), and hybrid L3 × T4 also obtained with positive significant mid parent heterosis (141.48**), heterobeltiosis (125.71**) and economic heterosis (76.11**). Moreover, hybrid L10 × T2 showed positive significant mid parent heterosis (23.81**) and heterobeltiosis (22.64**). Short stature with vigorous structure containing more branches will provide high yield opportunity, so positive heterosis is desirable for number of secondary branches. Niranjana *et al.* (2014) earlier reported positive significant heterosis for secondary branches per plant.

Siliqua per main branch: Among 48 crosses, 30, 18 and 1 hybrids obtained with significant positive heterosis over mid-parent (Ha), better-parent (Hb) and commercial varieties (Hc), respectively (Table 2a). Out of them, hybrid L2 × T4 showed positive significant mid parent heterosis (20.68**), heterobeltiosis (16.52**), however, it has negative economic heterosis (-20.90**). Hybrid L12 × T4 displayed positive significant mid parent heterosis (26.88**) and heterobeltiosis (16.25**). Similarly, hybrid L1×T2 showed positive significant mid parent heterosis (9.94**), heterobeltiosis (9.61**), while it has negative but significant economic heterosis (-25.59**). Also, hybrid L9 × T2 obtained with positive significant mid parent heterosis (30.70**) and heterobeltiosis (17.47**). More number of siliqua in main branch is desirable trait in the *Brassica* species for harvesting high seed yield, so positive heterosis is desirable for this trait.

Number of seeds per siliqua: Out of 48 crosses, 20, 11 and 9 hybrids showed significant positive heterosis over mid-parent (Ha), better-parent (Hb) and commercial varieties (Hc), respectively (Table 2c). Among them, hybrid L3 × T4 obtained with positive significant mid parent heterosis (25.00**) and economic heterosis (38.69**). In addition, hybrid L9 X T2 showed positive significant mid parent heterosis (49.19**), heterobeltiosis (38.06**) and economic heterosis (35.04**). Number of seed per siliqua characters has a direct correlation with the seed yield as its alteration definitely change the seed yield per plant. So, positive heterosis is desirable regarding number of seeds per siliqua.

Length of siliqua: Among the crosses, 10 and 3 hybrids exhibited significant positive heterosis over mid-parent (Ha) and better-parent (Hb), respectively, while none of the crosses has significant positive economic heterosis (Hc) (Table 2b). Among them, hybrid L3 × T4 showed positive significant mid parent heterosis (20.44**) and heterobeltiosis (19.78**). And, hybrid L2 × T4 has positive significant mid parent heterosis (18.09**) but it showed positive non significant heterobeltiosis (13.27). Length of siliqua may reflect the number of seeds inside it. Longer the siliqua, more will be the number of seeds per siliqua, which ultimately linked with seed yield. Therefore, a positive heterosis is desirable in case of length of siliqua trait.

Plant height: Of the total crosses, about 14, 19 and 19 hybrids displayed significant negative heterosis over mid-parent (Ha), better-parent (Hb) and commercial varieties (Hc), respectively (Table 2a). Out of them, hybrid L10 × T2 has desirable negative significant mid parent heterosis (-11.78**), heterobeltiosis (-14.85**) and economic heterosis (-13.55**). Likewise, hybrid L1×T2 showed negative significant heterobeltiosis (-5.00**) and economic heterosis (-10.27**). Short and medium plant height of *Brassica* species is desirable as it resist more towards the high wind velocity and hence, reduce the lodging and mechanical breakage. So, negative heterosis is desirable regarding plant height. Desirable negative and significant heterosis for plant height has been earlier reported by Tyagi *et al.*, 2000, Pourdad and Sachan (2003) and Nassimi *et al.* (2006).

Among the 48 hybrids, hybrid RL-1359 x JM-2 (L_2 X T_4) exhibited superior performance for seed yield and its component traits as reflected by significant positive estimates for relative heterosis (Ha), heterobeltiosis (Hb) and economic heterosis (Hc). Desirable negative heterosis for days to 50 percent flowering, days to maturity and plant height was noted in PM-67×Pusa bold (L8×T4). Five crosses *viz.*, GM-1 × VARUNA ($L_1 \times T_2$), RL-1359 × JM-2 ($L_2 \times T_4$), KRISHNA × JM-2 ($L_3 \times T_4$), CS-54 × VARUNA ($L_{10} \times T_2$) and GM-2 × JM-2 ($L_{12} \times T_4$) also possessed positive significant relative heterosis (Ha) and heterobeltiosis (Hb) for seed yield plant $^{-1}$, and other associated characters like primary branches plant^{-1}, secondary branches plant^{-1}, siliquae main branch^{-1}, number of seeds siliqua^{-1} and length of siliquae. The crosses with favourable traits obtained from this study can be utilized in further breeding programmes for development of high seed yielding cultivars.

References

Aher, C. D., Shelke L. T., Chinchane, V. N., Borgaonkar, S. B. and Gaikwad, A. R. 2009. Heterosis for yield and yield components in Indian mustard [*Brassica juncea* (L.) Czern and Coss]. *Int. J. Plant Sci*. 4 (1): 30-32.

Arifullah, M., Munir, M., Mahmood, A., Ajmal K. S., and Hassan, U. F. 2013. Genetic analysis of some yield attributes in Indian mustard (*Brassica juncea L.) Afri. J. Pl. Sci*. 7 (6): 219-226.

Azizinia, S. 2011. Combining ability analysis for yield component parameters in winter rapeseed genotypes (*Brassica napus* L.). *J. Oilseed Brassica.*, 2(2): 67-75.

Dholu, V.K., Sasidharan, N., Suthar, K., Bhusan, B. and Patel, J.N. 2014. Heterosis and combining ability analysis in Indian mustard, *Brassica Juncea* (L.) Czern & Coss, *Int. J. Agric. Sci,* 10 (1): 102-107.

Fonesca, S. and Patterson, P. 1968. Hybrid vigour in a seven parent diallel cross in common winter wheat. *Crop Sci*., 8: 85-88.

Gupta, P. 2009. Heterosis and correlation analysis for and its components in Indian mustard. *Proceedings of the National Seminar on Designing crops for the changing climate*, Ranchi, India, 69 (4): 267-402.

Gupta, P., Chaudhry and Lal, S. K. 2011. Heterosis and combining ability analysis for yield and its components in Indian mustard (*Brassica juncea* (L.) Czern and Coss). *Academic J. Plant Sci.* 4 (2), 45-52.

Kempthorne, O. 1957. *An Introduction to Genetic Statistics*, John Willy and Sons. Inc. New York, Pp.545.

Kumar, B., Pandey, A. and Singh., S. K., 2014. Combining ability and economic heterosis for yield and oil quality traits in Indian mustard (*Brassica juncea* L. Czern & Coss). *Electronic J. Plant Breed.* 5 (2): 203-207.

Kumar, P., Lamba, A., Yadav, R. K., Singh, L. and Singh, M., 2013. Analysis of yield and its components based on heterosis and combining ability in Indian mustard (*Brassica juncea* L. Czern & Coss), *The bioscan*, 8 (4): 1497-1502.

Meena, H.S., Ram, B., Kumar, A., Singh, B.K., Meena, P.D., Singh, V.V. and Singh, D. 2014. Heterobeltiosis and standard heterosis for seed yield and important traits in *Brassica juncea* (L.) *J. Oilseed Brassica*, 5 (2): 134-140.

Meredith, W.R. and Bridge, R.R. 1972. Heterosis and gene action in cotton *Gossypium hirsutum, Crop Sci.,* 12: 304-310.

Nasrin, S., Nur, F., Nasreen M.K., Bhuriyan, M.S.R., Sarkar, S. and Islam, M.M. 2011. Heterosis and combining ability analysis in Indian mustard (*Brassica juncea* L.). *Bangladesh Res. Pub. J* 6 (1): 65-71.

Nassimi, A., Raziuddin, W. and Naushad, A., 2006. Heterotic studies for yield associated traits in *Brassica napus* L. using 8 x 8 diallel crosses. *Pakistan J. Biol. Sci* 9 (11): 2132-2136.

Niranjana M., Akabari, V. R., Sasidharan, N. and Jadeja, G. C 2014. Diallel analysis for yield and its contributing characters in Indian mustard [*Brassica juncea* (L.) Czern&Coss]. *Electronic J. Plant Breed.* 5(2): 197-202.

Panse, V. G. and Sukhatme, P. V. 1967. *Statistical method for agricultural workers* (2nd Ed. ICAR, New Delhi: Pp. 381.

Patel, A. M., Prajapati D. B., and Patel, D. G., 2012. Heterosis and combining ability studies in Indian mustard (*Brassica juncea* L.) *Ind. J. Sci. Res. and Tech.* 1 (1): 38-40.

Pourdad and Sachan, 2003. Study on heterosis and inbreeding depression in agronomic and oil quality characters of rapeseed (*Brassica napus* L.). *Seed and Plant Imp. J.* 19 (3): 413-427.

Turi, N.A., Raziuddin, S., Shah, S. and Ali, S. 2006. Estimation of heterosis for some important traits in mustard (*Brassica juncea* L.). *J. Agri. Biol. Sci.* 1 (4): 6-10.

Turner, J.H. 1953. A study of heterosis in upland cotton, combining ability and inbreeding effects. *Agron. J.,* 43: 478-490.

Tyagi, M. K., Chauhan, J. S., Yadav, S. K., Kumar, P. R., Tyagi, Poonam and P. Tyagi, 2000. Heterosis in intervarietal crosses in Indian mustard [*Brassica juncea* (L.) Czern and Coss.]. *Ann. Bio*. 16 (2): 191-194.

Vaghela, P. O., Thakkar, D. A., Bhadauria, H. S., Sutariya, D. A., Parmar, S. K. and Prajapati, D.V. 2011. Heterosis and combining ability for yield and its component traits in Indian mustard [*Brassica juncea* (L.)] *J.Oilseed Brassica,* 2 (1): 39-43.

Verma, O. P., Yadav, R., Kumar, K., Singh, R., Maurya, K.N., and Ranjana. (2011). Combining ability and heterosis for seed yield and its components in Indian mustard (*Brassica juncea*). *Plant Archives* 11 (2): 863–865.

Wang, H.Z. 2005. The potential problems and strategy for the development of biodiesel using oilseed rape. *Chinese J. Oil. Crop. Sci.,* 2: 74-76.

Yadava D.K., Singh N., Vasudev, S., Singh R., Singh, S., Giri, S.C., Dwivedi, V.K. and Prabhu, K.V. 2012. Combining ability and heterobeltiosis for yield and yield contributing traits in Indian mustard (*Brassica juncea*). *Indian J. Agric. Sci.* 82 (7): 563-570.

Table 1. Analysis of variance for parents and hybrids for yield and its contributing traits in Indian mustard (*Brassica juncea* L.).

Source of variation	d.f.	Characters								
		Days to 50 % flowering	**Plant height (cm)**	**Siliquae per main branch**	**Primary branches per plant**	**Secondary branch per plant**	**Length of siliquae (cm)**	**No. of seeds per siliqua**	**Days to maturity**	**Seed yield per plant (g)**
Replicate	1	0.87	3.64	11.18*	1.95	2.79	2.79	10.46**	10.69**	16.10**
Treatment	63	33.18**	206.39**	47.66**	4.64**	28.33**	0.30**	6.84**	6.94**	13.70**
Parent	15	14.08**	157.64**	59.55**	0.95	5.37**	0.28	5.02**	4.68**	8.31**
Hybrid	47	27.54**	209.24**	41.73**	5.48**	33.47**	0.26	5.98**	7.11**	15.67**
Parent Vs Hybrid	1	585.09**	803.88**	148.37**	20.25**	131.48**	2.48**	74.73**	33.25**	2.16
Error	63	1.70	2.96	2.10	2.10	1.63	0.15	1.14	1.45	0.98

* and **significant at 0.05 and 0.01 level of significance, d.f. =degrees of freedom

Table 2 (a). Estimates of heterosis for nine quantitative traits in F_1 crosses of Indian mustard (*Brassica juncea* L.)

SN	Crosses	Days to 50 per cent flowering			Plant height			Siliquae per main branch		
		Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc
1.	L1 X T1	4.49*	1.59	7.56**	7.19 **	-1.46	-0.53	9.54 **	-4.06	-13.35 **
2.	L2 X T1	12.35**	11.90**	18.49**	3.69 **	-1.46	-0.53	16.87 **	-0.68	-10.30 **
3.	L3 X T1	15.20**	14.29**	21.01**	24.21 **	15.06 **	16.15 **	5.59	-5.19	-14.37 **
4.	L4 X T1	18.03**	14.29**	21.01**	3.93 **	0.58	1.53	4.67	-6.32	-15.39 **
5.	L5 X T1	-3.97*	-3.97	1.65	-4.52 **	-7.31 **	-6.43 **	-3.96	-9.71 **	-18.45 **
6.	L6 X T1	11.65**	10.32**	16.81**	-1.84 *	-3.27 **	-2.36 *	-8.88 **	-9.71 **	-18.45 **
7.	L7 X T1	8.13**	5.56**	11.76**	-14.06 **	-15.22 **	-12.04 **	-11.41 **	-13.04 **	-18.45 **
8.	L8 X T1	7.87**	2.13	21.01**	3.30 **	0.58	1.53	-8.00 **	-10.64 **	-14.37 **
9.	L9 X T1	4.35*	3.94	10.92**	-3.09 **	-8.19 **	-7.32 **	13.05 **	9.48 **	-1.12
10.	L10 X T1	11.29**	9.52**	15.97**	-8.16 **	-8.43 **	-7.02 **	-11.29 **	-13.09 **	-21.51 **
11.	L11 X T1	5.18**	4.76*	10.92**	-8.73 **	-11.40 **	-10.57 **	-2.64	-4.95	-9.89 **
12.	L12 X T1	1.22	-1.59	4.20	0.69	-1.67	-0.74	-30.49 **	-33.86 **	-40.27 **
13.	L1 X T2	16.87**	14.52**	19.33**	0.20	-5.00 **	-10.27 **	9.94 *	9.61 *	-25.59 **
14.	L2 X T2	6.02**	5.60*	10.92**	4.30 **	2.34 *	-3.34 **	13.10 **	9.52 *	-26.10 **
15.	L3 X T2	17.74**	17.74**	22.69**	15.76 **	10.63 **	4.49 **	22.90 **	19.15 **	-14.37 **
16.	L4 X T2	12.40**	9.68**	14.29**	6.31 **	6.31 **	0.41	17.47 **	14.29 **	-18.45 **
17.	L5 X T2	9.60**	8.73**	15.13**	7.73 **	7.39 **	2.07 *	-14.01 **	-20.51 **	-36.80 **
18.	L6 X T2	12.55**	12.10**	16.81**	-4.97 **	-6.69 **	-8.56 **	8.62 *	-4.37	-15.19 **
19.	L7 X T2	1.64	0.00	4.20	0.13	-4.35 **	-0.77	5.94	-8.91 **	-14.58 **
20.	L8 X T2	-4.91**	-10.64**	5.88**	6.99 **	6.33 **	1.68	18.10 **	0.64	-3.57
21.	L9 X T2	-3.59	-4.72	1.66	8.95 **	6.56 **	0.65	30.70 **	17.47 **	-0.61
22.	L10 X T2	1.63	0.81	5.04*	-11.78 **	-14.85 **	-13.55 **	5.82	-5.88	-18.45 **
23.	L11X T2	7.63**	7.20**	12.61**	-1.93 *	-2.24 *	-7.08 **	8.04 *	-7.53 *	-12.33 **
24.	L12X T2	14.40**	12.10**	16.81**	4.02 **	3.07 **	-0.83	14.91 **	5.00	-14.37 **
25.	L1 X T3	6.94**	3.97	10.08**	17.29 **	10.40 **	5.90 **	15.96 **	13.14 **	-19.27 **
26.	L2 X T3	1.99	1.59	7.56	0.47	-2.15 *	-6.14 **	36.36 **	28.57 **	-8.26 **
27.	L3 X T3	5.60**	4.76*	10.92**	5.94 **	0.49	-3.60 **	15.30 **	14.89 **	-17.43 **
28.	L4 X T3	13.11**	9.52**	15.97**	7.19 **	6.37 **	2.04	27.57 **	27.57 **	-8.97 **
29.	L5 X T3	10.32**	10.32**	16.81**	4.79 **	4.31 **	0.06	31.08 **	24.36 **	-1.12
30.	L6 X T3	-0.40	-1.59	4.20	7.46 **	6.33 **	4.19 **	12.10 **	1.15	-10.30 **
31.	L7 X T3	-1.63	-3.97	1.67	-2.73 **	-6.40 **	-2.89 **	-3.70	-15.22 **	-20.49 **
32.	L8 X T3	1.87	-3.55	14.29**	-2.93 **	-3.08 **	-7.02 **	-4.88	-17.02 **	-20.49 **
33.	L9 X T3	10.67**	10.24**	17.65**	1.05	-1.91	-5.90 **	10.33 **	1.69	-13.97 **
34.	L10X T3	6.45**	4.76*	10.92**	-0.09	-2.85 **	-1.36	21.29 **	10.59 **	-4.18
35.	L11X T3	9.16**	8.73**	15.13**	8.25 **	7.75 **	3.36 **	2.33	-10.32 **	-14.98 **
36.	L12X T3	12.65**	9.52**	15.97**	3.66 **	3.50 **	-0.41	12.27 **	5.25	-14.17 **
37.	L1 X T4	9.54**	8.20**	10.92**	5.16 **	-2.67 *	-3.19 **	19.52 **	19.52 **	-18.86 **
38.	L2 X T4	12.55**	11.20**	16.81**	7.91 **	3.26 **	2.72 *	20.68 **	16.52 **	-20.90 **
39.	L3 X T4	4.07*	3.23	7.56**	8.81 **	1.48	0.94	0.66	-2.13	-29.66 **
40.	L4 X T4	10.83**	9.02**	11.76**	5.48 **	2.82 **	2.27 *	14.20 **	11.43 **	-20.49 **
41.	L5 X T4	16.94**	15.08**	21.85**	5.61 **	3.26 **	2.72 *	31.40 **	21.79 **	-3.16
42.	L6 X T4	20.00**	19.51**	23.53**	10.01 **	9.20 **	8.62 **	-17.19 **	-26.90 **	-35.17 **
43.	L7 X T4	12.40**	11.48**	14.29**	5.74 **	3.56 **	7.44 **	13.49 **	-2.17	-8.26 **
44.	L8 X T4	-5.70**	-12.06**	4.20	-7.41 **	-9.20 **	-9.68 **	4.61	-10.64 **	-14.37 **
45.	L9 X T4	10.04**	7.87**	15.13**	-6.38 **	-10.68 **	-11.16 **	42.25 **	28.19 **	8.46 *
46.	L10 X T4	7.38**	7.38**	10.08**	-6.02 **	-6.98 **	-5.55 **	9.50 **	-2.35	-15.39 **
47.	L11 X T4	17.41**	16.00**	21.85**	8.83 **	6.41 **	5.84 **	6.39 *	-8.71 **	-13.46 **
48.	L12 X T4	0.41	-0.82	1.68	7.75 **	5.99 **	5.43 **	26.88 **	16.25 **	-5.20
Range	Minimum	-5.70**	-12.06**	1.68	-14.06 **	-15.22**	-13.55 **	-30.49 **	-33.86 **	-40.27 **
	Maximum	20.00**	19.51**	23.53**	24.21 **	15.06**	16.15**	42.25 **	28.57 **	8.46 *

*and**= 0.05 and 0.01 level of significance, respectively, Ha (heterosis), Hb (heterobeltiosis), Hc (economic heterosis), L-Line , T-Tester, L_1= GM-1, L_2= RL-1359, L_3= Krishna, L_4= Pusa bold, L_5= JD-6, L_6= JM-3, L_7= Basanti, L_8= PM-67, L_9= Lahi, L_{10}= CS-54, L_{11}= RH-819 and L_{12}= GM-2. T_1= Durgamani, T_2= Varuna, T_3= Laxmi and T_4= JM-2.

Table 2 (b). Estimates of heterosis for nine quantitative traits in F_1 crosses of Indian mustard (*Brassica juncea* L.)

SN	Crosses	Primary branches per plant			Secondary branches per plant			Length of siliqua		
		Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc
1.	L1 X T1	2.99	-6.76	4.55	-0.92	-8.19	-14.33	10.55	8.91	-5.17
2.	L2 X T1	-17.65	-24.32 *	-15.15	10.68	7.55	-9.24	2.51	0.99	-12.07
3.	L3 X T1	-7.04	-10.81	0.00	17.98	16.80	-7.01	4.17	-0.99	-13.79*
4.	L4 X T1	-24.09 *	-29.73 **	-21.20	15.42	14.06	-7.01	-1.41	-6.25	-9.48
5.	L5 X T1	0.00	-8.78	2.27	10.38	-2.74	1.59	3.85	0.93	-6.90
6.	L6 X T1	-10.03	-12.16	-1.52	23.88 **	20.38 *	1.59	15.18 *	8.91	-5.17
7.	L7 X T1	-14.81	-22.30 *	-12.88	0.84	-13.04	-4.46	5.47	4.95	-8.62
8.	L8 X T1	-17.46	-29.72 **	-21.21	16.01	15.42	-7.01	9.37	3.96	-9.48
9.	L9 X T1	-19.74*	-22.98*	-6.06	0.95	-3.64	-15.61	-7.55	-11.71	-15.52 *
10.	L10 X T1	0.73	-6.76	4.55	23.14 *	20.77 *	0.00	5.37	3.85	-6.09
11.	L11 X T1	-2.88	-8.78	2.27	45.56 **	32.52 **	25.16 **	5.94	5.94	-7.76
12.	L12 X T1	-14.39	-21.62 *	-12.12	3.02	-2.50	-13.06	17.95 *	13.86	-0.86
13.	L1 X T2	-1.14	-9.09	-1.52	-24.73 **	-28.33 **	-33.12 **	-0.96	-6.36	-11.21
14.	L2 X T2	15.36	7.69	16.67	-1.89	-1.89	-17.20 *	5.77	0.00	-5.17
15.	L3 X T2	7.53	4.90	13.64	-12.94	-16.23	-29.30 **	-2.49	-10.91	-15.52 *
16.	L4 X T2	-3.35	-9.09	-1.52	22.84 **	20.75 *	1.91	-8.11	-8.93	-12.07
17.	L5 X T2	45.66 **	34.97 **	46.21 **	55.14 *	40.24 **	46.50 **	-8.76	-10.00	-14.66 *
18.	L6 X T2	-4.23	-4.90	3.03	19.25 *	19.25	0.64	12.00	1.82	-3.45
19.	L7 X T2	-13.21	-19.58	-12.88	11.48	-1.45	8.28	-8.57	-12.72	-17.24
20.	L8 X T2	-7.69	0.00	31.27 **	28.30 **	8.28	5.47	-3.64	-3.64	-8.62
21.	L9 X T2	23.68 **	16.77	42.42 **	0.00	-1.82	-14.01	1.36	0.90	-3.45
22.	L10 X T2	24.91 *	17.48	27.27 *	23.81 **	22.64 *	3.50	-9.35	-11.82	-16.38 *
23.	L11X T2	9.89	4.90	13.64	21.08 *	15.86	7.01	9.95	5.45	0.00
24.	L12X T2	21.80 *	13.29	22.73	21.10 *	17.86	5.10	3.92	-3.64	-8.62
25.	L1 X T3	0.00	-1.67	-10.61	9.64	-1.02	-7.64	16.26 *	12.38	1.72
26.	L2 X T3	10.00	6.45	0.00	23.75 **	16.98	-1.27	1.48	-1.90	-11.21
27.	L3 X T3	0.00	-7.35	-4.55	28.90 **	26.53 *	-1.27	6.12	-0.95	-10.34
28.	L4 X T3	-10.74	-14.29	-18.18	20.73 *	16.02	-5.41	6.91	3.57	0.00
29.	L5 X T3	-0.84	-3.28	-10.61	13.48	-2.44	1.91	-8.76	-10.00	-14.66 *
30.	L6 X T3	25.29 *	14.18	21.97	47.70 **	39.62 **	17.83 *	12.00	1.82	-3.45
31.	L7 X T3	-3.36	-5.74	-12.88	15.66 *	-2.61	7.01	-8.57	-12.73	-17.24 *
32.	L8 X T3	106.36 **	95.69 **	71.97 **	22.70 *	18.58	-4.46	8.16	0.95	-8.62
33.	L9 X T3	50.18 **	29.19 **	57.58 **	1.76	-5.45	-17.20 *	4.63	1.80	-2.59
34.	L10X T3	47.11 **	41.27 **	34.85 **	24.19 **	18.46	-1.91	-8.13	-8.57	-17.24 *
35.	L11X T3	54.47 **	46.15 **	43.94 **	21.67 *	10.34	1.91	-3.88	-5.71	-14.66 *
36.	L12X T3	52.30 **	47.97 **	37.88 **	39.53 *	28.57 **	14.65	14.13	11.70	-9.48
37.	L1 X T4	94.21 **	92.62 **	78.03 **	-1.19	-14.68	-20.38 *	10.64	6.12	-10.34
38.	L2 X T4	82.93 **	81.45 **	70.45 **	171.55 **	144.91 **	106.69 **	18.09 *	13.27	-4.31
39.	L3 X T4	46.51 **	38.97 **	43.18 **	141.48 **	125.71 **	76.11 **	20.44 **	19.78 *	-6.03
40.	L4 X T4	40.32 **	38.10 **	31.82 **	-3.62	-11.72	-28.03 **	20.79 **	8.93	5.17
41.	L5 X T4	9.84	9.84	1.52	-47.13 **	-56.40 **	-54.46 **	8.63	0.00	-7.76
42.	L6 X T4	9.51	2.13	9.09	-3.77	-13.21	-26.75 **	24.44 **	24.44 **	-3.45
43.	L7 X T4	18.85	18.85	9.85	43.37 **	15.94 *	27.39 **	-5.26	-10.00	-22.41 **
44.	L8 X T4	23.01 *	13.93	5.30	15.88	6.72	-14.01	18.23 *	17.58 *	-7.76
45.	L9 X T4	-3.89	-15.53	3.03	37.70 **	22.18 *	7.01	17.41 *	6.31	1.72
46.	L10 X T4	8.87	7.14	2.27	52.22 **	38.46 **	14.65	13.40	5.77	-5.17
47.	L11 X T4	11.90	8.46	6.82	63.42 **	41.72 **	30.89 **	15.18 *	8.91	-5.17
48.	L12 X T4	0.41	0.00	-6.82	2.64	-9.64	-19.43 *	14.13	11.70	-9.48
Range	Minimum	-24.09 *	-29.73 **	-21.21	-47.13 **	-56.40 **	-54.46 **	-9.35	-12.73	-22.41 **
	Maximum	106.36 **	95.69 **	78.03**	171.55 **	144.91 **	106.69 **	24.44 **	24.44**	5.17

*and**= 0.05 and 0.01 level of significance, respectively, L-Line, T-Tester, Ha (heterosis), Hb (heterobeltiosis), Hc (economic heterosis), L_1= GM-1, L_2= RL-1359, L_3= Krishna, L_4= Pusa bold, L_5= JD-6, L_6= JM-3, L_7= Basanti, L_8= PM-67, L_9= Lahi, L_{10}= CS-54, L_{11}= RH-819 and L_{12}= GM-2. T_1= Durgamani, T_2= Varuna, T_3= Laxmi and T_4= JM-2.

Table 2 (c). Estimates of heterosis for nine quantitative traits in F_1 crosses of Indian mustard (*Brassica juncea* L.)

SN	Crosses	Number of seeds per siliqua			Days to maturity			Seed yield per plant		
		Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc
1.	L1 X T1	34.78 **	32.48 **	13.14	-2.14 *	-2.14 *	-1.29	-1.54	-11.46	-33.59 **
2.	L2 X T1	12.18	-1.30	10.95	-1.30	-2.56 *	-1.72	-16.76 *	-21.53 **	-41.15 **
3.	L3 X T1	23.13 **	9.27	20.44 *	-1.72	-2.56 *	-1.72	-8.56	-12.85	-34.64 **
4.	L4 X T1	29.06 **	29.06 **	10.22	-1.72	-2.14 *	-1.29	2.02	-3.47	-27.60 **
5.	L5 X T1	8.00	1.50	-1.46	-2.38 *	-3.42 **	-2.59 *	-8.00	-20.14 **	-40.10 **
6.	L6 X T1	44.70 **	34.19 **	14.60	-3.20 **	-3.40 **	-2.15 *	-19.86 **	-20.83 **	-40.63 **
7.	L7 X T1	13.21	1.35	9.49	-0.66	-2.99 **	-2.16 *	-23.02 **	-23.81	-41.67 **
8.	L8 X T1	24.28 **	19.84 *	10.22	-1.51	-2.14 *	-1.29	31.13 **	-3.47	-27.60 **
9.	L9 X T1	12.55	11.11	-5.11	-2.58 **	-2.99 **	-2.16 *	-12.25	-22.92 **	-42.19 **
10.	L10 X T1	1.22	-3.13	-9.49	0.22	-0.85	0.00	-18.41 **	-25.35 **	-44.01 **
11.	L11 X T1	20.16 **	9.93	13.14	0.86	0.43	1.27	-10.47	-12.83	-30.99 **
12.	L12 X T1	19.76 *	13.36	8.39	-0.21	-0.43	0.86	-22.86 **	-25.00 **	-43.75 **
13.	L1 X T2	2.43	-5.60	-7.66	-1.07	-1.28	-0.43	22.27 **	21.74 *	-27.08 **
14.	L2 X T2	-2.78	-9.09	2.19	-1.08	-2.15 *	-1.72	-1.04	-6.27	-37.76 **
15.	L3 X T2	5.26	-0.66	9.49	0.22	-0.43	0.00	13.29	6.13	-27.86 **
16.	L4 X T2	19.52 *	11.94	9.49	-1.08	-1.29	-0.86	0.62	-5.06	-36.46 **
17.	L5 X T2	6.37	5.97	3.65	-1.30	-2.15 *	-1.72	20.91 *	16.67	-30.73 **
18.	L6 X T2	13.25	-1.12	-3.28	-1.28	-1.70	-0.43	-0.20	-9.61	-33.85 **
19.	L7 X T2	44.70 **	4.73	13.14	-3.20 **	-2.58 *	-2.16 *	-19.86 **	-18.37 **	-37.50 **
20.	L8 X T2	26.92 **	23.13 **	20.44 *	0.00	-0.43	0.00	32.97 *	6.14	-36.98 **
21.	L9 X T2	49.19 **	38.06 **	35.04 **	1.08	0.86	1.28	16.59 *	14.04	-32.29 **
22.	L10 X T2	10.69	8.21	5.84	-0.87	-1.72	-1.29	21.20 **	18.41 *	-26.30 **
23.	L11X T2	4.00	1.42	4.38	-1.94 *	-2.15 *	-1.72	8.27	-5.26	-25.00 **
24.	L12X T2	9.43	8.21	5.84	-1.71	-2.13 *	-0.86	-8.00	-15.44 *	-40.10 **
25.	L1 X T3	23.97 **	16.28	9.49	0.00	-0.85	0.00	-11.57	-15.75 *	-44.27 **
26.	L2 X T3	-18.73 **	-25.32 **	-16.06 *	-3.06 **	-3.48 **	-4.31 **	-11.59	-11.76	-41.41 **
27.	L3 X T3	-17.86 **	-23.84 **	-16.06 *	-0.43	-0.43	-1.29	-2.91	-4.21	-34.90 **
28.	L4 X T3	9.76	4.65	-1.46	-3.03 **	-3.45 *	-3.45 **	13.50	12.84	-24.48 **
29.	L5 X T3	14.50 *	12.78	9.49	1.09	0.87	0.00	15.02 *	5.51	-30.21 **
30.	L6 X T3	44.10 **	27.91 **	20.44 *	-3.23 **	-4.26 **	-3.02 **	-18.50 **	-22.42 **	-43.23 **
31.	L7 X T3	8.30	1.35	9.49	-1.55	-3.04 **	-3.88 **	-28.47 **	-33.33 **	-48.96 **
32.	L8 X T3	-17.65 *	-18.60 *	-23.36 **	-1.95 *	-2.16 *	-2.59 *	4.62	-19.69 *	-46.88 **
33.	L9 X T3	27.57 **	20.16 *	13.14	1.30	0.86	0.86	-6.78	-13.39	-42.71 **
34.	L10X T3	5.06	4.65	-1.46	-0.22	-0.43	-1.29	18.46 *	14.96	-23.96 **
35.	L11X T3	11.11	6.38	9.49	0.87	0.43	0.43	-9.68	-17.11 *	-34.38 **
36.	L12X T3	11.54	10.69	5.84	-1.94 *	-2.98 **	-1.72	-9.89	-12.87	-38.28 **
37.	L1 X T4	13.21	-1.32	9.49	-1.72	-2.14 *	-1.29	-16.30 *	-17.39 *	-50.52 **
38.	L2 X T4	25.41 **	-0.65	11.68	-2.60 **	-3.02 **	-3.02 **	64.95 **	98.43 **	31.77 **
39.	L3 X T4	0.00	25.00 **	38.69 **	-2.17 *	-3.02 **	-3.02 **	111.27 **	53.26 **	4.17
40.	L4 X T4	30.11 **	15.13 *	27.74 **	0.00	0.00	0.00	16.42 *	8.95	-27.08 **
41.	L5 X T4	-14.39 *	-19.74 **	-10.95	-0.65	-1.29	-1.29	16.51 *	13.39	-33.85 **
42.	L6 X T4	22.22 **	1.32	12.41	-1.07	-1.07	-0.43	-45.35 **	-50.89 **	-64.06 **
43.	L7 X T4	11.67	10.20	22.26 **	-5.05 **	-6.90 **	-6.90 **	-20.46 **	-29.93 **	-46.35 **
44.	L8 X T4	29.50 **	18.42 *	31.39 **	-3.24 **	-3.45 **	-3.45 **	12.22	-9.82	-47.40 **
45.	L9 X T4	9.02	-4.61	5.84	-3.02 **	-3.02 **	-3.02 **	7.69	6.25	-38.02 **
46.	L10 X T4	17.86 **	8.55	20.44 *	0.22	-0.43	-0.43	-2.38	-5.44	-41.15 **
47.	L11 X T4	5.12	1.32	12.41	1.29	1.29	1.29	13.26 *	-1.64	-22.14 **
48.	L12 X T4	-6.01	-12.50	-2.92	-0.21	-0.85	0.43	41.53 **	29.04 **	-8.59
Range	Minimum	-18.73 **	-25.32**	-23.36**	-5.05 **	-6.90**	-6.90**	-45.35 **	-50.89**	-64.06**
	Maximum	49.19 **	38.06**	38.69**	1.30	1.29	1.29	111.27 **	98.43**	31.77**

*and**= 0.05 and 0.01 level of significance, respectively, L-Line, T-Tester, Ha (heterosis), Hb (heterobeltiosis), Hc (economic heterosis), L_1= GM-1, L_2= RL-1359, L_3= Krishna, L_4= Pusa bold, L_5= JD-6, L_6= JM-3, L_7= Basanti, L_8= PM-67, L_9= Lahi, L_{10}= CS-54, L_{11}= RH-819 and L_{12}= GM-2. T_1= Durgamani, T_2= Varuna, T_3= Laxmi and T_4= JM-2.