Pak. J. Bot., 52(4): 1361-1368, 2020. DOI: http://dx.doi.org/10.30848/PJB2020-4(8)

SELECTION OF ROBUST PARENTAL GENOTYPES THROUGH HETEROTIC STUDIES IN *BRASSICA JUNCEA*

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Abstract

Present investigations were made with the aim to identify the robust parental genotype through heterosis in *Brassica juncea* L. For this purpose, the present research was conducted during the two consecutive years 2013-14 and 2014-15 at Department of Plant Breeding and Genetics, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan. Seven cultivars of *Brassica juncea* including four exotic (Oriental Mustard, Mustard Florida, Dacca Raya, Elight) and three local genotypes (S-9, Bard-I and BR) were crossed in a diallel fashion during 2013-14. The seeds of parental genotypes and F_1 crosses were grown during 2014-15 in a randomized complete block design for further comparison. Data were recorded for plant height, pods per the main inflorescence, and main inflorescence length, and pod length, seeds per pod, thousand grain weight and yield per plant. Amongst seven cultivars, Dacca Raya showed heterosis for plant height, pod length and pods per main inflorescence when treated as female parent. Whereas for seeds per pod and thousand grains weight, Mustard Florida exhibited heterosis when treated as male parent. However, F_1 hybrids of these cultivars revealed significant heterosis for yield trait. Amongst other exotic cultivars, Elight and Oriental Mustard showed heterosis for traits like main inflorescence length and thousand grains weight. In case of better parent heterosis, Mustard Florida was found as the best genotype for seeds per pod, thousand grains weight and seed yield. Hence, it is suggested that exotic cultivars Dacca Raya and Mustard Florida could be included in future breeding program for improvement in seed yield and its attributes.

Key words: *Brassica juncea*, F_1 hybrids, Best cross combinations, Heterosis and heterobeltiosis, Yield related traits.

Introduction

Pakistan agriculture sector plays an important role in strengthening the country's economy by sharing 18.9% GDP and engaging 42.3% labour. Most of the people are dependent either directly or indirectly to this sector (Anon., 2017-18). Nevertheless the fact is that this sector still lacks progressive farmers. This is the main reason that our country could not capture the world attention towards improvement in agriculture in term of evolution of new cultivars or introduction of exotic cultivars superseding the local lot (Gul *et al*., 2018a, 2019; Ali *et al*., 2018; 2019). Hence the available resources remain neglected and could not be expedited for the cash crops like industrial crops, sugar crops, cereals crops, narcotic crops and oilseed crops. Amongst these, oilseed crops are of pivotal importance.

Probing into statistics regarding oilseed crops it has been noticed that there is huge gap between potential yield and actual yield (Anon., 2017-18). However, that breach can be bridge up by adopting innovative technologies and introduction of exotic cultivars and their involvement in various cross combinations for evolution of new cultivars having higher yield with favourable dominating genetics configuration. On the other side, in Pakistan the edible oil consumption is also rising day by day that is why our country is deficient in edible production Anonymous, (2013), Kumar (2017) and Gul *et al*., (2018b) also highlighted the importance of oilseed crops and narrated that edible oil demand and consumption is progressively increasing. Therefore, the country demand for edible oil is fulfilled by huge import. In this connection, the Brassica ranks second after cottonseed oil to meet the country demand (Surin *et al*., 2018).

Furthermore, the importance of vegetable oil in progressively increasing because of its safe usage in human diet Arifullah, (2011). Hence, it is inevitable to narrow the potential yield gap which might be possible by increasing the crop area, sowing of improved genotypes by effective selection, underdeveloped or poor farmers should be persuaded by effective extension services and introduction and acclimatization of exotic genotypes and to cross them with local genotypes for further improvement in the yield. Amongst these aforementioned points the most important is introduction of exotic cultivars of *Brassica juncea* species and their compatibility with the existing local improved cultivars Meena *et al*., (2015). Because *Brassica juncea* specie is most widely cultivated for edible oil as it ranks 3rd after soybean on the world level. By doing this, the robust parental genotypes can be picked up and further explored for seed yield and oil quality traits. For this purpose. Heterosis is the best way to improve crop varieties in term of increased vigor, size, fruitfulness, development speed, resistance to disease and insect pests or climatic vigor's, manifested by cross-bred organisms as compared with corresponding inbreds. Heterosis explores the magnitude and extent of change which a progeny shows over its parents. So while studying the heterosis finding of hybrids that is more productive than best parent is very necessary Bharti *et al*., (2018). Keeping in view the role and importance of average and better parent heterosis, the present study has been designed with the aim to know the compatibility of the exotic and local cultivars and to select vigorous parental genotypes for future breeding program.

Materials and Methods

Plant material and procedure: A study was conducted during the cropping seasons 2013-14 and 2014-15 at Research area of the Department of Plant Breeding and Genetics, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan. Seven Brassica cultivars have been collected from National Agricultural Research Centre (NARC), Islamabad and Agricultural Research Institute, Dera Ismail Khan. The exotic cultivars were Oriental Mustard, Mustard Florida, Dacca Raya, and Elight while local genotypes were S-9, Bard-I and BR. These genotypes were sown in a crossing block by following the standard agronomic practices. The plant to plant and row to row distance was maintained at 30 and 60 cm, respectively. During the first year 2013-14, all the parental genotypes were crossed in all possible combination using 7 × 7 diallel mating system. During the second year 2014-15, the seeds of parental genotypes and their 42 F_1 hybrids were sown in a randomized complete block design (RCBD) with three replications for further comparison and by following the same standard cultural practices for all the genotypes to minimize the field environmental variations.

Traits measurement and analyses: Plant height (cm), pods per main inflorescence, main inflorescence length (cm), pod length (cm), seeds per pod, thousand grain weight (g) and seed yield per plant (g) were the parameters for recording data. All the collected data was initially subjected to the analysis of variance technique as outlined by Steel *et al*., (1997). Upon getting the significant differences among the genotypes, the data were further subjected to heterotic analysis. All the analyses were carried out through computer software Statistix 8.1. The significance of heterosis and heterobeltiosis was indicated by percent increase (+) or decrease (-) of F_1 hybrids by comparing with their mid and better parents mean values (Fehr, 1987; Fonseca, 1965).

$$\text{Heterosis}\,(\%) = \frac{\overline{F1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis}\,(\%) = \frac{\overline{F1} - \overline{BP}}{\overline{BP}} \times 100$$

The heterotic data were further analyzed by "t" test to check the significance of heterosis and heterobeltiosis (Wynne *et al*., 1970).

$tij = F_1\text{-MP} / \sqrt{3/8\ \text{EMS}}$
$t1ij = F_1\text{-BP} / \sqrt{1/2\ \text{EMS}}$

where
F_1 ij = The Mean of the ijth F_1 cross
MP ij = The mid parent for the ijth cross
BP ij = The better parent values for ijth cross
EMS = Error mean square

Results and Discussion

Analyzed data revealed highly significant differences ($p\leq0.05$) among the parents and their F_1 hybrids for different traits in *Brassica juncea* (Table 1). This depicts that parental genotypes and F_1 hybrids are genetically diverse and have genetic variability for traits like plant height (cm), pods per main inflorescence, main inflorescence length (cm), pod length (cm), seeds per pod, thousand grain weight (g) and seed yield per plant (g). Similarly, Singh *et al*., (2010), Maurya *et al*., (2012), Meena *et al*., (2014), Kaur *et al*., (2019) and Singh *et al*., (2020) have also reported considerable genetic variability in this oilseed crop. Results of present research for various genotypes have been described and discussed in the following paragraphs.

Table 1. Mean squares for various traits in *Brassica juncea* L.

Parameters	Mean squares		CV (%)
	Genotypes	Error	
Plant height	2977.24*	404.57	8.97
Main inflorescence length	30.32*	6.439	5.11
Pods per main inflorescence	33.70*	1.225	1.96
Pod length	0.43*	0.025	4.97
Seeds per pod	0.61*	0.168	2.68
Thousand grain weight	1.14*	0.07	8.87
Seeds yield per plant	10.94*	0.5478	2.58

* = Significant at $p\leq0.05$

Plant height: For plant height, the genotypes revealed significant ($p\leq0.05$) differences (Table 2). Furthermore, it is evident that minimum plant height was noted in S9 × BR cross (191.67 cm) and maximum value (269.67 cm) was noted in cross S9 × Elight. Whereas range of plant height for average heterosis was -1.70 to 39.90% and for heterobeltiosis was -7.48 to 36.40% (Table 3). Out of 42 F_1 hybrids, the significant heterosis was observed in 36 crosses and better parent heterosis was noted in 24 crosses (Table 4). The best cross combination for mid parent heterosis was noted in S9 × BR (-1.71%) for plant height and better parent heterosis (-7.48%) was expressed by cross Dacca Elight × Mustard Florida. Hence, while studying heterosis it is noted that the F_1 should be intermediate or dwarf with respect to their parent. Because in case of Brassica tallness cause lodging and shattering which consequently affects the yield. In present study approximately 40% significant and positive heterosis has been observed for this trait. Mehmood *et al*., (2003), Patel *et al*., (2012), Gami & Chauhan (2013), Surin *et al*., (2018) and Gul *et al*., (2018b, 2019) have also observed negative heterosis for plant height in different studies. For plant height trait negative heterosis is encouraged in *Brassica juncea*. Because if plants are taller the crop can face seed shattering and lodging which consequently declines the seed yield. However, some researchers have observed positive heterosis for this character Sabaghnia *et al*., (2010). Yet it is better if the plants with negative heterosis for the plant height are chosen for the purpose of improvement in crop.

Main inflorescence length: Means obtained for this parameter were significantly different at 5% probability level which revealed the diverse nature of all genotypes (Table 1). Main inflorescence length (52.96 cm) was noted in cross BR × S-9 and smallest length (48.00 cm) was measured in Mustard Florida × BR cross (Table 2). The growth of main stem ends in main inflorescence which actually determines the height of plant and also elaborate the earliness in the genotypes. In case of average heterosis maximum magnitude (31.78%) for this parameter was noted in the cross Elight × BARD-I and for heterobeltiosis maximum magnitude 24.90% for main inflorescence length was observed in Elight × BARD-I cross Table 4). Changming *et al*., (2001), Gupta *et al*., (2010), Choudhary *et al*., (2002), Surin *et al*., (2018) and Synrem *et al*., (2015) reported that raceme length increase also showed greater numbers of seeds that consequently enhance seed yield. Hence for this trait the positive heterosis is desirable.

Table 2. Mean performance of *Brassica juncea* parental genotypes and their F_1 hybrids for various traits.

Parental genotypes & F_1 hybrids	Plant height (cm)	Main infl. length (cm)	Pods per main infl.	Pod length (cm)	Seeds pod^{-1}	1000-grain weight (g)	Seeds yield plant^{-1} (g)
Oriental Mustard	209.00	44.47	55.47	3.63	14.20	2.53	27.14
Mustard Florida	197.00	41.13	52.80	4.37	14.60	2.53	26.02
Dacca Raya	185.00	47.60	60.07	3.79	15.20	2.47	31.33
Elight	267.33	36.93	60.83	3.53	15.30	2.47	31.94
BARD-I	196.33	41.23	52.53	3.29	15.40	3.03	26.13
S-9	197.67	43.87	52.73	3.15	16.20	3.00	27.04
BR	192.33	46.56	51.96	3.20	15.63	2.93	26.67
Oriental Mustard × Mustard Florida	209.33	50.13	55.30	4.26	14.93	4.97	27.39
Oriental Mustard × Dacca Raya	258.00	52.47	61.27	4.16	14.53	3.50	31.11
Oriental Mustard × Elight	259.33	51.57	60.80	4.11	15.03	3.17	31.27
Oriental Mustard × BARD-I	212.00	50.93	55.03	3.57	15.37	2.30	27.34
Oriental Mustard × S-9	210.00	51.50	54.83	3.93	15.67	4.13	26.98
Oriental Mustard × BR	211.00	50.00	54.53	3.68	15.00	3.91	26.18
Mustard Florida × Oriental Mustard	207.67	49.97	55.33	4.26	14.37	2.57	27.17
Mustard Florida × Dacca Raya	246.00	51.17	59.93	4.04	14.80	3.37	30.35
Mustard Florida × Elight	248.67	50.93	60.53	4.22	15.13	3.93	29.89
Mustard Florida × BARD-I	198.67	49.40	54.93	4.17	15.03	3.13	25.93
Mustard Florida × S9	197.00	49.47	52.83	3.84	15.63	3.50	27.19
Mustard Florida × BR	192.67	48.00	53.67	3.82	15.14	3.47	27.37
Dacca Raya × Oriental Mustard	259.33	52.27	60.47	4.29	14.80	3.43	30.56
Dacca Raya × Mustard Florida	244.67	51.00	59.80	4.04	14.87	3.40	30.55
Dacca Raya × Elight	270.00	52.20	61.30	4.16	15.33	3.13	30.98
Dacca Raya × BARD-I	266.33	50.00	60.50	4.30	15.37	3.37	30.43
Dacca Raya × S9	267.67	50.97	60.31	4.39	15.90	4.57	29.93
Dacca Raya × BR	262.33	50.67	61.00	4.21	14.87	4.60	30.33
Elight × Oriental Mustard	258.00	50.67	60.03	3.49	14.90	3.17	31.25
Elight × Mustard Florida	247.33	50.90	59.73	3.09	15.40	2.33	30.28
Elight × Dacca Raya	268.33	51.53	61.40	3.64	15.30	2.57	30.96
Elight × BARD-I	268.33	51.50	60.03	4.16	15.30	3.63	29.79
Elight × S-9	268.00	51.20	60.07	4.18	15.67	2.70	30.42
Elight × BR	274.67	51.22	59.93	4.12	15.12	2.96	31.00
BARD-I × Oriental Mustard	211.33	49.80	53.79	3.56	15.27	2.57	27.38
BARD-I × Mustard Florida	196.67	50.47	52.27	4.16	15.07	3.10	25.92
BARD-I × Dacca Raya	260.00	50.30	51.87	4.32	15.13	3.23	30.49
BARD-I × Elight	263.33	51.20	60.53	4.24	15.30	2.30	30.00
BARD-I × S-9	197.00	51.27	54.13	3.48	15.67	2.60	27.14
BARD-I × BR	195.50	52.33	55.04	3.36	15.71	2.53	26.44
S-9 × Oriental Mustard	211.33	50.33	53.17	3.85	15.70	3.73	26.99
S-9 × Mustard Florida	197.33	50.37	55.60	4.24	16.10	3.30	27.44
S-9 × Dacca Raya	257.67	50.27	55.57	4.37	15.93	3.17	28.57
S-9 × Elight	269.33	49.27	51.80	4.28	16.10	2.63	30.50
S-9 × BARD-I	196.00	51.33	54.40	3.34	15.30	2.43	27.37
S-9 × BR	191.67	53.00	56.00	3.88	14.86	2.70	26.67
BR × Oriental Mustard	212.00	49.67	54.33	3.97	15.60	3.45	26.72
BR × Mustard Florida	194.67	51.47	55.67	4.03	16.09	3.22	27.37
BR × Dacca Raya	259.67	49.00	55.08	4.18	15.36	3.33	30.67
BR × Elight	255.00	48.33	51.00	4.27	15.63	2.87	30.33
BR × BARD-I	195.67	51.76	54.33	3.28	15.45	2.60	28.11
BR × S-9	196.00	52.96	55.67	3.47	15.78	2.66	28.44
$LSD_{0.05}$	16.42	2.072	0.903	0.129	0.33	0.1299	0.22

Table 3. Heterotic Effects for various traits in F1 hybrids of *Brassica juncea*.

Parameters	Crosses with heterosis (over mid- and better-parent)				Crosses with significant heterosis (over mid- and better-parent)		Crosses with highest heterosis in rank order (over mid- and better-parent)	
	MP (%)		BP (%)		MP	BP	MP	BP
	Max.	Min.	Max.	Min.				
Plant height	39.90	-1.71	36.40	-7.48	4	18	Dacca Raya × S-9	S9× BR
Main inflorescence length	31.78	4.08	24.90	2.94	42	42	Elight × BARD-I	Elight × BARD I
Pods per main inflorescence	8.90	-9.57	6,20	-16.16	34	18	Dacca Raya × BR	S9 × BR
Pod length	32.61	-24.30	21.48	-29.29	39	25	Dacca Raya × Bard-I	S-9 × BR
Seeds per pod	6.47	-5.75	2.96	-8.25	15	4	BR × Mustard Florida	BR × Mustard Florida
Thousand grain weight	98.67	-70.11	96.05	-82.03	23	17	Oriental Mustard × Mustard Florida	Oriental Mustard × Mustard Florida
Seed yield per plant	6.55	-2.70	5.40	-8.80	32	12	Dacca Raya × Mustard Florida	BR × Bard I

MP = Mid-parent, BP = Better-parent

Pods per main inflorescence: In present study significant ($p \leq 0.05$) variations have been noted among genotypes for pods per main inflorescence (Table 1). Maximum pods per main inflorescence have been found in cross combination Oriental Mustard × Dacca Raya (61.267) (Table 2). Likewise least pods on the main inflorescence have been noted in cross S-9 × Dacca Raya with the value of 51.867. Siliqua or pod numbers present on main inflorescence is an indicator of plant growth as well as earliness of the crop. Greater number of pods reflects the yield of plant and vice versa. Although other factors like grain filling, and size of seed reflects the yield. However, the said trait is very useful in determining the yield of crop. For mid parent heterosis the cross Dacca Raya x BR showed highest value i.e., (8.90%), whereas maximum magnitude of heterobeltiosis (6.20%) was observed in S9 × BR cross. Out of 42 crosses 34 crosses showed significant heterosis over mid parent and 18 crosses exhibited significance for heterobeltiosis. Range of heterosis and heterobeltiosis for this parameter was 9.57 to 8.90% and -16.16 to 6.20%, respectively (Table 3). The cross combination Dacca Raya × BR was the best for this trait for average heterosis whereas for heterobeltiosis the best cross combination was Oriental Mustard × Dacca Raya. Changming *et al*., (2001), Mehmood *et al*., (2003), Gupta *et al*., (2010), Surin *et al*., (2018) and Synrem *et al*., (2015) also observed significant and positive heterosis for this trait. Hence for number of siliqua, positive heterosis is good for high seed yield in *Brassica juncea* species.

Pod length: Genotypes means under the study were significantly ($p \leq 0.05$) different for pod length (Table 1). Pod length is an important parameter which can be long, intermediate or short. It depicts the growth of fruit of *Brassica juncea*. In this study, the lengthy pods have been noted in hybrid Dacca Raya × S-9 with value 4.38 cm while shorter pods have been observed in cross BR × BARD-I (3.28) (Table 2). Highest magnitude of average heterosis percentage was noted in cross combination Dacca Raya × Bard-I (32.61%) and for heterobeltiosis the best cross combination was S-9 × BR (21.48%) (Table 4). Amongst 42 crosses, the 39 crosses showed significant average heterosis and 25 crosses showed significant heterobeltiosis (Table 3). Pradhan *et al*., (1993) and Rameah *et al*., (2003) and Synrem *et al*., (2015) also recorded positive heterosis for length of siliqua. Lengthy siliqua means greater number of seed inside. It means for the enhancement of seed yield long silique should be focused. So positive heterosis in this is the best for getting higher seed yield.

Seeds per pod: Seeds per pod is also an important yield attribute which is also associated with other yield related traits. Greater the seed number certainly the yield will also be higher provided the seeds are healthy and massive. Results further revealed that genotypes were significantly ($p \leq 0.05$) different for seeds per pod (Table 1). Heterosis range for seeds per pod was observed as -5.75 to 6.47 while range for heterobeltiosis was -8.25 to 2.96. As indicated in Table 2, the maximum number of seeds (16.1) in pod has been noted in two crosses i.e., S-9 × Elight and S-9 × Mustard Florida. However, the lowest seed count per pod (14.3) has been noted in cross combination Mustard Florida × Oriental Mustard. In this parameter the significance level of heterosis was poor and out of 42 crosses only 15 exhibited significant heterosis and like wise only four crosses showed significance for better parent heterosis. The best cross combination was BR × Mustard Florida for average heterosis with the value 6.47% whereas desirable magnitude of heterobeltiosis was noted for this trait in F_1 hybrid Br × Mustard Florida (2.96 %) (Table 3). Pradhan *et al*., (1993), Mehmood *et al*., (2003), Sabaghnia *et al*., (2010), Yadev *et al*., (2004) and Synrem *et al*., (2015) have also calculated positive heterosis for number of seeds in *Brassica juncea* and elaborated further that number of seeds are linked with yield. Greater the number of seeds per siliqua greater will be the seed yield. So for this trait positive heterosis is desirable for enhancement in seed yield trait. Singh *et al*., (2020) also reported better parent heterosis in mustard.

Thousand grains weight: Genotypes revealed significant ($p \leq 0.05$) differences for thousand grains weight which indicated the greater genetic variability in the breeding material (Table 1). Maximum thousand grains weight (4.97 g) was observed in F_1 Oriental Mustard × Mustard Florida. cross and minimum thousand grains weight (2.30 g) was noted in two crosses i.e. Oriental Mustard × BARD-I and BARD-I × Elight. (Table 1). Average heterosis range for thousand grains weight -70.11 to 98.67% and for heterobeltiosis it was -82.03 to 96.05%. Out of 42 crosses, 23 F_1 hybrids exhibited significant heterosis over mid parent and 17 showed significant heterosis over better parent (Table 3). Maximum average heterosis for thousand grains weight (98.67%) was noted in Oriental Mustard × Mustard Florida cross. And heterobeltiosis magnitude (96.05%) was observed in Oriental Mustard × Mustard Florida (Table 5). Identical findings regarding mid parent and better parents for the trait under consideration have been reported by findings of the results were similar to the work performed by Mehmood *et al*., (2003), Sabaghnia *et al*., (2010), Gupta *et al*., (2010) and Liton *et al*., (2017) and suggested that positive heterosis and heterobeltiosis is desirable for the thousand grains weight while selecting parents for the purpose of breeding and research.

Seed yield per plant: Yield is the ultimate demand of every research program, however, it is very complex trait and depends upon various attributes which manage it either directly or indirectly. Means obtained for this parameter were significantly different at 5% probability level which revealed the diverse nature of all genotypes (Table 1). Maximum yield per plant (31.275 g) has been noted in cross combination Oriental Mustard × Dacca Raya (Table 2). Whereas lowest yield 25.9 g has been observed in BARD-I × Mustard Florida cross. The range of the average and better parent heterosis for seed yield per plant was -2.70 to 6.55% and –8.80 to 5.40% respectively. Significance for heterosis have been noted in 32 out of 42 crosses whereas only 12 crosses showed significant heterobeltiosis for the trait under consideration (Table 3). The cross combination Dacca Raya × Mustard showed maximum average heterosis (6.55%) and cross BR × Bard 1 showed maximum heterobeltiosis (5.40%) for this trait (Table 5). Amit *et al*., (2013), Meena *et al*., (2015), Synrem *et al*., (2015), Liton *et al*., (2017 and Surin *et al*., (2018) have great analogy with the findings. Singh *et al*., (2020) also reported better parent heterosis response in mustard. In the light of above findings it is clear that positive heterosis and heterobeltiosis is preferred to select the genotypes in any breeding program with the goals to develop varieties with higher yield. And the crosses which are showing higher values for heterosis and heterobeltiosis should be given prime importance.

In this study, the exotic cultivars have been used and crossed with local and indigenous cultivars of *Brassica juncea*. It is very important to note that almost all exotic cultivars showed positive acclimatization and also responded well when crossed with local cultivars. Therefore, heterosis is a best tool for identifying vigorous parental genotype amongst the segregants. Such type of study not only help in selection of parents with desirable traits but also identify the general and specific combinations of the hybrids with reference to peculiar trait. In present findings, the Dacca Raya showed significant heterosis when mated with Oriental Mustard, Mustard Florida, BARD-1, S9 and BR for yield per plant. However, non-significant and negative heterosis has also been noticed for seed yield in cross of Dacca Raya and Elight. Thus, the present investigations revealed the significance of heterosis, its utilization and exploration for discovering sterility/restorer lines and other goals prefixed by breeder.

Conclusion

Amongst seven cultivars, the genotype Dacca Raya showed heterosis for plant height, pods per main inflorescence and pod length when treated as female. Whereas for seeds per pod and thousand grains weight, the Mustard Florida exhibited heterosis when treated as Male. However, by crossing these cultivars with each other, the significant heterosis was noted for yield trait. Amongst other exotic cultivars, Elight and Oriental Mustard showed heterosis for traits like main inflorescence length and thousand grains weight. In case of better parent heterosis, Mustard Florida was found as the best genotype for seeds per pod, thousand grains weight and seed yield.

Table 4. Heterosis and heterobeltiosis in F_1 hybrids of *Brassica juncea* for various traits.

F_1 hybrids	Plant height		Infl. length		Pods/main infl.		Pod length	
	Het (%)	Hbt (%)	Het (%)	Hbt (%)	Het (%)	Hbt (%)	Het (%)	Hbt (%)
Oriental Mustard × Mustard Florida	3.12*	0.16*	17.13*	12.74*	2.15*	-0.30	6.54*	-2.44
Oriental Mustard × Dacca Raya	30.96*	23.44*	13.98*	10.22*	6.06*	2.00*	12.17*	9.75*
Oriental Mustard × Elight	8.89*	-2.99	26.70*	15.97*	4.56*	-0.05	14.75*	13.22*
Oriental Mustard × BARD-I	4.61*	1.44*	18.86*	14.54*	1.91*	-0.78	3.23*	-1.56
Oriental Mustard × S-9	3.28*	0.48*	16.60*	15.82*	1.35*	-1.14	15.87*	8.26*
Oriental Mustard × BR	5.15*	0.96*	9.86*	7.40*	1.52*	-1.68	7.91*	1.47*
Mustard Florida × Oriental Mustard	2.30*	-0.64	16.75*	12.37*	2.22*	-0.24	25.60*	17.36*
Mustard Florida × Dacca Raya	28.80*	24.87*	15.33*	7.49*	6.20*	-0.22	-0.94	-7.48
Mustard Florida × Elight	7.11*	-6.98	30.49*	23.83*	6.54*	-0.49	6.71*	-3.51
Mustard Florida × BARD-I	1.02*	0.85	19.96*	19.81*	4.30*	4.04*	8.83*	-4.58
Mustard Florida × S9	-0.17	-0.34	16.40*	12.77*	0.13*	0.06*	2.17*	-12.05
Mustard Florida × BR	-1.02	-2.20	9.48*	3.10*	2.45*	1.64*	0.88*	-12.66
Dacca Raya × Oriental Mustard	31.64*	24.08	13.54*	9.80*	4.67*	0.67*	7.29*	-1.76
Dacca Raya × Mustard Florida	28.10*	24.20*	14.96*	7.14*	5.97*	-0.44	6.78*	-7.55
Dacca Raya × Elight	19.38*	1.00*	23.49*	9.66*	1.40*	0.77*	13.52*	9.68*
Dacca Raya × BARD-I	39.68*	35.65*	12.57*	5.04*	7.46*	0.72*	21.51*	13.54*
Dacca Raya × S9	39.90*	35.41*	11.44*	7.07*	6.94*	0.40*	26.36*	15.74*
Dacca Raya × BR	39.05*	36.40*	7.62*	6.44*	8.90*	1.55*	20.42*	10.99*
Elight × Oriental Mustard	8.33*	-3.49*	24.49*	13.94*	3.24*	-1.32	-6.06	-8.08
Elight × Mustard Florida	6.53*	-7.48	30.41*	23.75*	5.13*	-1.81	-24.30	-29.29
Elight × Dacca Raya	18.64*	0.37*	21.92*	8.26*	1.57*	0.93*	4.20*	-3.96*
Elight × BARD-I	15.74*	0.37*	31.78*	24.90*	5.91*	-1.31	21.88*	17.74*
Elight × S-9	15.27*	0.25*	26.74*	16.72*	5.79*	-1.25*	25.03*	18.30*
Elight × BR	19.51*	2.75*	22.69*	10.01*	6.26*	-1.48	22.34*	16.51*
BARD-I × Oriental Mustard	4.28*	1.11*	16.22*	11.99*	-0.39	-3.03	-0.70	-2.02
BARD-I × Mustard Florida	0.00	-0.17	22.55*	22.39*	-0.76	-1.01	5.27*	-4.81
BARD-I × Dacca Raya	36.36*	32.43*	13.25*	5.67*	-7.88	-13.66	17.89*	13.90*
BARD I × Elight	13.59*	-1.50	31.01*	24.17*	6.79*	-0.49	25.90*	19.91*
BARD-I × S-9	0.00	-0.34	20.49*	16.87*	2.85*	2.65*	8.07*	5.77*
BARD-I × BR	0.60*	-0.42	19.23*	12.41*	5.35*	4.78*	3.65*	2.13*
S-9 × Oriental Mustard	3.93*	1.11*	13.96*	13.19*	-1.72	-4.15	11.31*	6.15*
S-9 × Mustard Florida	0.00	-0.17	18.51*	14.82*	5.37*	5.30*	10.74*	-2.90
S-9 × Dacca Raya	34.67*	30.35*	9.91*	5.60*	-1.48	-7.50	23.39*	15.30*
S9 × Elight	15.84*	0.75*	21.95*	12.31*	-8.77	-14.84	25.39*	21.13*
S-9 × BARD-I	-0.51	-0.84	20.65*	17.02*	3.36*	3.16*	3.03*	1.52*
S-9 × BR	-1.71	-3.04	17.22*	13.84*	6.98*	6.20*	22.31*	21.48*
BR × Oriental Mustard	5.65*	1.44*	9.13*	6.68*	1.15*	-2.04	16.95*	9.28*
BR × Mustard Florida	0.00	-1.18	17.39*	10.55*	6.27*	5.43*	7.13*	-7.78
BR × Dacca Raya	37.64*	35.01*	4.08*	2.94*	-1.68	-8.31	20.40*	10.29*
BR × Elight	10.95*	-4.61	15.79*	3.81*	-9.57	-16.16	27.82*	20.94*
BR × BARD-I	0.69*	-0.34	17.93*	11.18*	3.99*	3.43*	1.86*	-0.30
BR × S-9	0.51*	-0.84	17.14*	13.76*	6.35*	5.57*	9.19*	8.45*

Het = Heterosis, Hbt = Heterobeltiosis

Table 5. Heterosis and heterobeltiosis in F_1 hybrids of *Brassica juncea* for various traits.

F_1 hybrids	Seeds per pod		1000-grain weight		Seed yield	
	Het (%)	Hbt (%)	Het (%)	Hbt (%)	Het (%)	Hbt (%)
Oriental Mustard × Mustard Florida	3.70*	2.28*	98.67*	96.05*	3.06*	0.93*
Oriental Mustard × Dacca Raya	-1.14	-4.39	40.00*	38.16*	6.42*	-0.69
Oriental Mustard × Elight	1.92*	-1.75	13.77*	4.40*	5.86*	-2.10
Oriental Mustard × BARD-I	3.83*	-0.21*	-16.87	-23.33	2.64*	0.74*
Oriental Mustard × S-9	3.07*	-3.29	51.22*	40.91*	-0.41	-0.59
Oriental Mustard × BR	0.57*	-4.03	56.40*	54.34*	-2.70	-3.55
Mustard Florida × Oriental Mustard	-0.23	-1.60	-24.77	-40.17	2.23*	0.12*
Mustard Florida × Dacca Raya	-0.67	-2.63	34.67*	32.89*	5.85*	-3.12
Mustard Florida × Elight	1.22*	-1.09	41.32*	29.67*	3.12*	-6.44
Mustard Florida × BARD-I	0.22*	-2.38	13.25*	4.44*	-0.57	-0.79
Mustard Florida × S9	1.51*	-3.50	28.05*	19.32*	2.48*	0.54*
Mustard Florida × BR	0.19*	-3.12	40.54*	40.54*	3.89*	2.62*
Dacca Raya × Oriental Mustard	0.68*	-2.63	14.06*	-1.53	4.53*	-2.46
Dacca Raya × Mustard Florida	-0.22	-2.19	20.92*	10.03*	6.55*	-2.48
Dacca Raya × Elight	0.22*	0.22*	13.94*	3.30*	-2.08	-3.02
Dacca Raya × BARD-I	0.11*	-0.21	23.17*	12.22*	5.90*	-2.88
Dacca Raya × S9	0.95*	-1.85	69.14*	55.68*	2.56*	-4.46
Dacca Raya × BR	-3.87	-4.88	67.27*	51.65*	4.60*	-3.18
Elight × Oriental Mustard	1.02*	-2.61	4.00*	-10.97	5.78*	-2.17
Elight × Mustard Florida	3.01*	0.65*	-30.28	-43.91	4.48*	-5.21
Elight × Dacca Raya	0.00*	0.00*	-24.32	-40.54	-2.13	-3.07
Elight × BARD-I	-0.65	-0.65*	32.93*	21.11*	2.58*	-6.74
Elight × S-9	-0.84	-3.29	0.00*	-7.95	3.14*	-4.77
Elight × BR	-2.57	-3.28	-1.77	-2.31*	5.79*	-2.94
BARD-I × Oriental Mustard	3.16*	-0.86	-19.62	-33.39	2.78*	0.87*
BARD-I × Mustard Florida	0.45*	-2.16	-8.51*	-26.94	-0.61	-0.83
BARD-I × Dacca Raya	-1.41	-1.73	-5.41	-26.01	6.12*	-2.68
BARD I × Elight	-0.65*	-0.65	-31.82	-46.26	3.31*	-6.08
BARD-I × S-9	-3.29	-3.29	-13.81	-14.29*	2.09*	0.37*
BARD-I × BR	-1.31	-3.04	-14.61	-15.56*	0.16*	-0.85
S-9 × Oriental Mustard	3.29*	-3.09	14.77*	-5.97	-0.36	-0.54
S-9 × Mustard Florida	4.55*	-0.62	0.56*	-18.11	3.43*	1.48*
S-9 × Dacca Raya	1.16*	-1.65	-4.71	-24.24	-2.10	-8.80
S9 × Elight	1.90*	-0.62	-21.86	-38.38	3.44*	-4.50
S-9 × BARD-I	-5.56	-5.56	-22.95	-25.89	2.94*	1.21*
S-9 × BR	-6.61	-8.25	-20.51	-36.62*	-0.70	-1.38
BR × Oriental Mustard	4.59*	-0.19	5.07*	-14.52	-0.67	-1.54
BR × Mustard Florida	6.47*	2.96*	5.46*	-11.54	3.91*	2.65*
BR × Dacca Raya	-0.70	-1.75	-0.55	-21.32	5.75*	-2.12
BR × Elight	0.74*	0.00*	-10.09	-14.26	3.51*	-5.03
BR × BARD-I	-2.92	-4.63	-70.82	-82.45	6.47*	5.40*
BR × S-9	-0.87	-2.61	-94.12	-94.29	5.90*	5.18*

Het = Heterosis, Hbt = Heterobeltiosis

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(Received for publication 29 October 2018)