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Full Length Review Article

Determination of heterosis through genetic analysis for some morphological and yield attributes of Indian Mustard (*Brassica juncea* L.)

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Abstract

Edible oil plays vital role in growth and development of human body. Among different sources, *Brassica Juncea* serves as chief source of edible oil in Pakistan. The study on Brassica Juncea L. was an attempt to determine general combining ability and specific combining ability effects of pairs of parental genotypes to deduce the genetic base of significant traits of plant. Five testers viz. ZN-M-6, RBJ-8005, FZ, ZNM-5 & RBJ-27017 and six lines viz. NR-5, R-4, ZN-M-1, ZM-R-7, UCD , RBJ-8003 were crossed in line x tester fashion. Thirty crosses along with parents were evaluated further for various quantitative traits. One Way Analysis of Variance and Least significant difference test at 5% probability level was applied which exhibited considerable differentiation in the first filial generation for characters studied. Parents RBJ-8003 and ZN-M-5 were proved to be good general combiners for yield and yield contributing characters on the basis of significant general combining ability effects. The cross combinations namely NR-5 × FZ, ZN-M-1 × ZN-M-5, NR-5 × RBJ-27017 and ZM-R-7 × ZN-M-6 showed significant heterosis for most of the studied traits thus may be exploited using heterosis breeding. The cross combination R-4 × ZN-M-5 proved best specific combination for the height of plant, primary branches, seeds per silique and harvest index.It was concluded that general combining ability and specific combining ability squares of mean significance determined the existence of gene action both additive and non- additive that execute function for the expression of these characters. The existing variation in the breeding material may be exploited in hybridization program. The identified best lines and crosses would be available for further use in different breeding programs of Brassica Juncea L. which may bring about new promising hybrids and varieties bearing high yield, high oil content, resistance to biotic and abiotic stresses.

Keywords: Gene action, Morphology, Hybrid, Genotype, Filial generation, combining ability

Introduction

Edible oil is one of the basic requirements of human body because it is very important for the growth and improvement of body. The *Brassica* genus is under *Cruciferae* family that comprise of a lot of vital species. In most of Afro-Asian countries *Brassica juncea* L. is a chief resource of edible oil. It contains30-45% oil and 28-36% protein contents (Thakur *et al.*, 2014). *Brassica juncea* L. gives higher seedling vigor, heat & drought tolerance and pod-shattering resistance (Turi *et al*., 2006). Mustard cultivars produce high seed yield and dry matter contents even under semi-arid conditions (Oram *et al*., 1999). It contains 30-45% oil and 28-36% protein contents (Thakur *et al*., 2014). Oil of *Brassica juncea* L. is mostly utilize as edible oil source, lubricants &oil of hair in Indian subcontinent. Residues seed of *Brassica juncea* L. is employed as feed for cattle & fertilizers. In Pakistan, mustard is growing on large scale but in relation to other countries it yields low. Area under rapeseed and mustard in Pakistan is 2.33 million hectares, its seed and oil production is 2.16 and0.66 million tons respectively. Among the numerous factors associated with the lowering of production of rapeseed and mustard in Pakistan is the unavailability of better& high yielding varieties which is the reason to some extent in sinking the production as well as utilization breach of edible oil. Oilseed crops are mainly grown on marginal lands due to competition with other crops for sowing time. Present varieties of *Brassica juncea* L. are late maturing. Therefore, there is a dire requirement to evolve high yielding and short duration cultivars. Plant breeders have predicted for many years that the descendants from a particular cross can out yield either of the two parents used in the cross. This phenomenon refers the term heterosis. An ample study of the combining ability taking part in the inheritance of quantitative characters & in the heterosis phenomenon is essential for interpretation of different breeding methods. In hybrid combinations, the potential of inbred lines is determined by general combining ability & specific combining ability effects (Rameeh, 2012). Information about the extent of gene action controlling polygenic traits may be extracted from these tests (Ceyhan *et al*., 2008). General combining ability (GCA) of an inbred refers to average performance in a series of cross combinations. The performance of individual cross is used to get specific combining ability (SCA) (Fick and Miller, 1997). GCA and SCA variances are attributed to genetic effects additive as well as non-additive (Malik *et al.,* 2004). Line × tester approach is an efficient method to unravel GCA and SCA effects of large number of parents (Farshadfar *et al*., 2013). Therefore, the current research study was chalked out to study combining ability &heterosis of *Brassica juncea* L. genotypes for seed yield & its components. To classify the breeding material for exploitation in breeding programs, this research work will provide guidance to develop new cultivars of *Brassica juncea.*

Materials and Methods

The material of experiment comprised of eleven accessions of *Brassica juncea* L. collected from the Oilseed Research Program, Department of Plant Breeding & Genetics, University of Agriculture Faisalabad. Six accessions viz. NR5, R-4, ZN-M-1,ZM-R-7, UCD and RBJ-8003 were used as lines and five genotypes viz. ZN-M-6,RBJ8005, FZ and ZNM-5 as testers. All eleven genotypes were grown in the field and crossed in Line × Tester fashion through controlled pollinations. In a randomized complete block design, seed of thirty cross hybrids & parents of these crosses were planted with dibbler and replicated 3 times. There were three rows for each entry and the length of each row was 6 meters. Plant to plant and row to row distance was maintained as 0.3m and 0.6m respectively. Agronomy related management methods suggested for *Brassica* were also carried out uniformly for all experimental units throughout growing season. Data were recorded on five randomly selected plants of each entry per replication The recorded data includes parameters such as primary branches per plant, plant height(cm), harvest index (%), seeds per silique, No. of silique per plant, silique length(cm), 1000 seed weight(g), seed yield per plant(g), secondary branches per plant, mature leaf shape, mature leaf dissection, beak shape and seed color. Collected data were analyzed for variances (Steel *et al*., 1997). For evaluation of specific and general Combining ability effects data were further analyzed using equation 1 and 2 proposed by (Kempthorne, 1957). Percent heterosis over mid and better parents was calculated using equation 3 and 4 proposed by Falconer and Mackay (1996).

Statistical analysis

General combining ability and specific combining ability was tested using line x tester statistical method as proposed by Kempthorne (1957). The data was tested by applying one way analysis of variance ($p \geq 0.01 – 0.05$) to find out the level of variation using method proposed by Steel *et al*., 1997.

For General Combining Ability: (a)

Lines:

g_l = X_i… /tr… - X…/ltr ……………………..1

(b) Testers:a

g_t = Xi… /lr… - X…/ltr……………………….1a

g_l = General combining ability for lines. l = Number of lines female parents t = Number of tester male parents r = Number of replication Xi… = Total sum of F_l resulting from crossing i^{th} lines with all testers. X… = Total of all crosses g_t = General combining ability for testers **For Specific Combining Ability**: S_{ij}= $(X_{ij})/r–(X_i)/(txr)–(X_j)/(l_r)–(X)$ /ltr…………2

Where

S_{ij} = Specific combining ability between i^{th} lines and j^{th} testers.

X_{ij} = Total of F1 resulting from crossing the i^{th} and j^{th} lines with ith line.

X_j= Total of all crosses of j^{th} testers with all lines

X_i = Total of all crosses of i^{th} lines with all testers

X = Total of all crosses

For Heterosis

Percent heterosis over mid and better parents was calculated using formulae proposed by Falconer and Mackay, 1996. **Percent heterosis over mid parent**

MPH = 100 x {(Fl - MP)/MP)}…………………3

Where

F1= First Filial Generation

MP= Mid Parent Heterosis

Percent heterosis over better parent

BPH = 100 x {(F1-BP)/BP)}…………………...4

Where

MPH = Mid Parent Heterosis

BPH = Better Parent Heterosis

BP= Better Parent (A parent with higher value)

Results and Discussion

Genetic Variability

The results depicted genetic variation existence in the breeding material to further proceed for combining ability effects and heterosis. The results of analysis of variance for No. of primary branches, height of plant, secondary branches on a plant, No. of seeds on a silique, silique length, weight 0f 1000-seed, siliques per plant, seed yield of a plant &harvest index illustrate significant ($p \geq 0.01 – 0.05$) differences among all the entries (Table I). Mean squares because of lines were significant ($p \geq 0.01 – 0.05$) for height of plant, No. of primary branches & harvest index while for testers, for primary branches, H.I and seed yield the mean sum of squares were significant.

General and Specific Combining Ability

The variances owing to GCA & SCA were calculated to examine the part of additive & nonadditive gene action participating in the inheritance of traits. For height of plant, primary branches, seeds per silique, secondary branches, silique on a plant, weight of 1000-seed, harvest index and yield of the plants due to SCA were more than GCA variances so this indicated the occurrence of dominance genetic effect (Table II). Oram *et al*. (1999) also reported higher SCA variances then GCA variances. RBJ-8003 was good general combiner among lines for No. of primary branches, No. of secondary branches, 1000-seed weight, harvest index &yield of seed on a plant. Among testers, ZN-M-5 was effective general combiner for plant height, secondary branches, silique length, weight of 1000-seeds& harvest index. (Oram *et al*, 1999; Dar *et al*., 2011; Kang *et al*.,2013) carried out studies showing significant GCA effects using Line × Tester approach. The study highlighted that line RBJ-8003 and tester ZN-M-5 may be used as potential parents in the hybridization programs for improvement of *Brassica juncea.*

The cross combination R-4 × ZN-M-5 for height of plant, primary branches, seeds on a silique and 1000-seed weight possessed better specific combining ability (Table III). Seven cross combinations ZM-R-7 × FZ showed better combining ability for seed yield & harvest index, RBJ-8003 × RBJ-27017 for secondary branches per plant, silique length and harvest index, R-4 × FZ for primary branches, silique length & harvest index, NR-5 × RBJ-8005 for plant height, seeds per silique and harvest index, ZN-M-1 × RBJ-8005 for secondary branches on a plant, silique length and weight of 1000 seeds, ZN-M-1× ZN-M-6 for height of plant, primary branches and harvest index and ZN-M-1 × FZ for primary branches on a plant, seeds per silique (Table III). (Oram *et al.,* 1999; Singh *et al.,* 2012; Kang *et al*., 2013) conducted SCA studies exhibiting significant results which are an evidence of authenticity of current study. The outcomes of planned study characterized the selected combinations as potential hybrids to be examined further for production of better hybrids that bring about higher yields.

Heterosis

The cross combination NR-5 × FZ had positive &significant ($p \geq 0.01 – 0.05$) mid and better parent heterosis for secondary branches, seeds on a silique, silique per plant & harvest index (Table IV). The cross combination ZN-M-1 × ZNM-5 showed positive significant heterosis over better as well as mid parent for height of plant and weight for 1000-seed. Cross NR-5 × RBJ-27017 exhibited positive &significant mid and better parent heterosis for silique per plant and yield of seed for a plant. Cross combination ZM-R-7 × ZNM-6 had significant& positive better and mid parent heterosis for plant height.ZM-R-7 × RBJ27017 showed significant positive heterosis for silique per plant for better parent and over both mid and better parents for seed yield per plant. ZM-R-7 × ZN-M-5over both mid and better parents had significant positive heterosis for harvest index and had significant positive heterosis over mid parent for seeds on a silique. RBJ-8003× FZ showed significant positive heterosis over both mid and better parents for silique per plant, for number of secondary branches over better parent heterosis was significant & positive, 1000-seed weight and over mid parent heterosis was significant & positive found for silique length likewise (Mahmood *et al.,*2003; Patel *et al.,* 2012; Singh *et al.,*2012) also found significant positive heterosis supporting the current studies.

The current study entitled "Determination of Heterosis through Genetic Analysis for Some Morphological and Yield Attributes of Indian Mustard (Brassica Juncea L.)" was carried out using line × tester approach. Findings of the study would help breeders in developing varieties through studied promising lines by using them in hybridization program for the improvement of *Brassica juncea* L. By using the promising hybrids and cross combinations breeder could produce varieties which would help farmers as well as minimize the import expenses of the country for edible oil. The identified best lines and crosses should be considered by researchers for further use in different breeding programs of *Brassica juncea* L. which may bring about new promising hybrids and verities bearing high yield, high oil content, resistance to biotic and abiotic stresses. Better results using the indicated best lines and cross combinations could be obtained under climatic conditions in which temperature range from 25°C to 38°C and 45mm rainfall during the crop season.

Conclusion

The line RBJ-8003may be used as potential parents in the hybridization programs for improvement of primary branches, secondary branches, weight of 1000-seeds, harvest index &seed yield per plant & tester ZN-M-5 for plant height, No. of secondary branches, silique length, weight of 1000-seed and harvest index in *Brassica juncea* L. Cross combination NR-5 × FZ for No. of secondary branches, seeds per silique, number of silique on a plant and harvest index, ZN-M-1 × ZN-M-5for height of plant and 1000-seed weight, NR-5 × RBJ-27017for number of silique per plant and seed yield & R-4 × ZN-M-5forheight of plant, primary branches per plant, seeds on a silique and weight for 1000-seeds may be used as potential hybrids and may be evaluated further for the production of better and high yielding *Brassica juncea* L. varieties.

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Table I. Mean squares from analysis of variance of various traits of *Brassica juncea* L.

Parameters	Replications	Entries	Parents	Crosses	Parents vs crosses	Lines	Testers	L × T	Error
Degrees of freedom (n-1)	2	40	10	29	1	5	4	20	80
Plant height (cm)	83.84	82.25*	53.07	94.74**	12.10	156.73**	60.24	86.13**	51
Primary branches per plant	0.09	2.29 **	0.83**	2.80**	2.13**	5.15**	2.93**	2.19**	0.11
Secondary branches per plant	0.89	1.24**	2.08**	0.99	0.18	1.12	1.13	0.92	0.66
Silique length (cm)	0.02	0.04**	0.04	0.05**	0.02	0.02	0.02	0.06**	0.02
Number of seeds per silique	0.96	1.37 **	1.54*	1.35**	0.05	0.77	1.08	1.5**	0.73
Number of silique per plant	711.36	1794.84**	3035.74**	1206.46	6448.88**	159.47	378.59	1633.78**	800.85
1000-seed weight (g)	0.05	0.21*	0.24*	0.20*	0.06	0.21	0.27	0.19	0.12
Seed yield per plant (g)	23.22	43.61**	6.91*	0.76**	6.26	6.62	12.22**	4.98	23.18
Harvest index (%)	3.91	95.53 **	136.69**	80.09**	131.60**	67.77**	106.99**	77.79**	10.05

* Significant (α=0.05) ** Highly significant (α=0.01)

Table II. Estimates of GCA effects of female and male parents for various traits of *Brassica juncea*

Lines/ Traits	PH	PBPP	SBPP	SL	SPS	SPP	SW	SY	HI
UCD	0.48	-0.30	-0.19	-0.01	0.09	-6.06	0.02	-0.05	1.14
ZM-R-7	0.08	0.53	-0.15	-0.04	0.21	-0.72	-0.21	0.33	-3.70
RBJ-8003	-0.10	-0.42	0.35	0.03	0.11	1.58	0.12	0.76	1.98
R-4	3.64	0.88	0.30	0.01	0.15	-0.06	-0.01	0.26	-1.11
NR-5	1.84	-0.61	-0.31	-0.04	-0.30	3.08	0.07	-1.19	1.54
ZN-M-1	-5.94	-0.07	0.06	0.03	-0.27	2.12	-0.02	-0.11	0.14
S.E	1.84	0.08	0.21	0.04	0.22	7.31	0.09	0.45	0.5
Testers									
RBJ-27017	0.67	-0.53	-0.28	0.03	0.13	-0.50	-0.06	1.27	-1.94
ZN-M-5	-2.85	-0.15	0.27	0.08	-0.39	2.15	0.22	-0.20	-2.16
RBJ-8005	1.45	0.23	-0.24	0.02	-0.05	-3.87	-0.04	0.11	-1.09
ZN-M-6	1.45	0.53	0.13	-0.01	0.23	6.67	-0.05	-1.01	3.12
FZ	-0.73	-0.06	0.12	-0.06	0.08	-4.44	-0.05	-0.17	2.08
S.E	1.68	0.08	0.19	0.03	0.20	6.67	0.08	0.41	0.51

List of abbreviations used

PH =Plant height (cm), PBPP= Primary branches per plant, SBPP= Secondary branches per plant, SL =Silique length (cm), SPS= Seeds per silique, SPP=Silique per plant, SW =1000-seed (g) weight, SY =seed yield (g), HI= Harvest index (%)

Table III. Estimates of SCA effects of hybrids for various traits of *Brassica juncea*L.

Hybrids/ Traits	PH	PBPP	SBPP	SL	SPS	SPP	SW	SY	HI
UCD × RBJ-27017	-0.70	1.08	0.38	-0.30	-0.70	-13.66	0.09	0.01	5.21
UCD × ZN-M-5	2.16	-0.62	-0.78	0.1	0.29	41.21	-0.02	0.13	7.74
UCD × RBJ-8005	-0.34	-0.15	0.27	-0.06	-0.12	-13.28	-0.18	2.37	-3.09
UCD × ZN-M-6	-1.34	0.88	0.29	0.15	0.32	-14.96	0.05	-0.36	-6.35
UCD × FZ	0.24	-1.18	-0.16	0.06	0.21	0.68	0.05	-2.15	-3.51
ZM-R-7 × RBJ-27017	-0.30	-0.22	0.47	-0.05	0.17	34.19	0.13	0.08	-0.68
ZM-R-7 × ZN-M-5	0.82	1.13	-0.42	0.09	0.69	-62.72	0.17	-2.02	-1.34
ZM-R-7 × RBJ-8005	1.11	-0.45	-0.43	0.03	0.76	24.23	-0.09	-1.45	-0.2
ZM-R-7 × ZN-M-6	-5.08	-0.82	0.32	0.02	0.73	-0.90	-0.02	1.91	-1.83
ZM-R-7 × FZ	3.44	0.37	0.06	0.04	-0.97	5.20	-0.19	1.47	4.07
RBJ-8003× RBJ-27017	1.01	-0.53	0.56	0.11	-0.45	-27.64	-0.07	-0.96	5.48
RBJ-8003× ZN-M-5	-3.91	-0.04	0.13	0.14	-0.32	15.96	-0.43	0.84	-3.81
RBJ-8003× RBJ-8005	1.70	0.50	-0.14	0.04	0.46	11.66	0.10	-0.73	1.83
RBJ-8003× ZN-M-6	-0.49	1.06	-0.32	0.09	0.24	7.72	0.03	0.20	2.80
RBJ-8003 × FZ	1.69	-0.99	-0.24	-0.07	0.06	-7.70	0.37	0.64	-6.31
R-4 × RBJ-27017	-2.26	-0.03	-0.84	0.17	0.10	-5.06	-0.03	0.58	-1.52
R-4 × ZN-M-5	8.02	0.65	0.45	-0.21	0.77	13.04	0.44	-0.53	-1.81
R-4 × RBJ-8005	-4.84	0.06	0.31	-0.05	-0.70	-12.82	-0.12	0.53	-1.25
R-4 × ZN-M-6	0.55	-0.97	0.26	0.05	0.13	7.22	0.02	-0.69	-1.34
R-4 × FZ	1.45	0.29	-0.18	0.14	-0.30	-2.39	-0.30	0.12	5.93
NR-5 × RBJ-27017	-4.86	0.58	-0.63	0.17	0.49	4.38	0.13	-0.89	-3.54
NR-5 × ZN-M-5	-2.06	-0.78	0.26	0.04	-0.17	-19.00	0.09	0.93	2.8
NR-5 × RBJ-8005	8.95	-0.11	-0.6	-0.01	0.74	8.17	-0.20	0.44	4.92
NR-5 × ZN-M-6	-4.44	-0.81	-0.05	-0.17	-1.54	16.34	-0.11	-0.99	2.80
NR-5 × FZ	2.41	1.12	1.02	-0.02	0.48	6.45	0.09	0.50	-7.02
ZN-M-1 × RBJ-27017	7.12	-0.87	0.04	0.07	0.39	7.74	-0.26	1.18	-4.94
ZN-M-1 × ZN-M-5	-5.01	-0.32	0.34	-0.02	0.13	11.55	-0.25	0.64	-3.62
ZN-M-1 × RBJ-8005	-6.58	0.15	0.60	0.13	-1.14	-1.61	0.51	-1.16	-2.19
ZN-M-1 × ZN-M-6	10.81	0.65	-0.50	-0.04	0.09	-15.42	0.02	-0.06	3.93
ZNM-1 × FZ	-6.33	0.38	-0.49	-0.14	0.52	-2.24	-0.02	-0.59	6.83
S.E	4.12	0.19	0.47	0.09	0.49	16.34	0.20	1.02	1.25

List of abbreviations used

PH= Plant height (cm), PBPP =Primary branches per plant, SBPP= Secondary branches per plant, SL =Silique length (cm), SPS= Seeds per silique, SPP=Silique per plant, SW= 1000-seed (g) weight ,SY= seed yield (g), HI =Harvest index (%)

Table IV. Mid parent and better parent heterosis for various traits of *Brassica juncea* L.

Accessions	PH		PB		SB		SL		SPS		SPP		1000-SW		SY		HI	
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
UCD × RBJ-27017	-2.23	-3.88	1.26	15.94	-8.67*	-7.40	0.80	-3.01	1.63	-6.50	-3.04	4.76	-1.95	0.76	-14.96**	8.90	-3.34	-1.96
UCD × ZN-M-5	-1.39	-0.74	3.79	12.32	-9.13**	-2.45	1.52	-1.96	4.89	2.65	-5.20	-8.11*	0.70	2.88	-15.65**	-8.46	-5.21	2.35
UCD × RBJ-8005	-2.26	-5.74*	-1.2658	0.00	-8.21*	0.00	2.11	1.96	11.41**	9.62*	2.55	-1.51	-2.50	3.40	-14.09*	-3.00	-8.01	-5.37
UCD × ZN-M-6	2.20	4.92*	-10.12	-13.41	-5.47	-5.90	2.18	0.64	2.71	-3.07	-1.76	-3.11	-3.4	-2.26	-3.63	6.21	-3.21	-16.26
UCD × FZ	-2.04	-2.19	-13.92	-25.27**	-9.58**	4.21	4.95*	2.78	-5.97	-4.41	-0.08	12.88**	-1.72	0.60	-9.78	0.61	9.47	2.11
ZM-R-7 × RBJ-27017	-1.32	-4.93*	-19.76*	0.00	-3.75	-5.09	0.72	-2.45	6.17	-5.50	1.42	12.42**	-1.95	3.26	13.62*	28.44**	17.46	15.18
ZM-R-7 × ZN-M-5	-0.42	-1.79	-12.79	2.73	-5.16	-0.98	2.24	-0.63	11.23*	5.31	1.77	1.19	-5.46*	-1.04	3.56	-0.78	20.45*	25.76*
ZM-R-7 × RBJ-8005	4.92*	-0.84	-16.27*	-7.69	-7.51*	-1.99	-0.50	0.00	11.79**	6.41	-4.56	-5.98	-5.46*	2.74	10.83	10.45	14.01	13.39
ZM-R-7 × ZN-M-6	6.84**	7.48*	-8.13	-3.65	-12.20**	-15.00**	-1.66	-2.51	4.49	-4.61	-4.28	-3.16	-8.68**	-5.31*	3.03	0.24	17.54	-1.68
ZM-R-7 × FZ	-0.13	-2.29	-9.30	-14.28	-6.57*	4.73	0.65	-0.78	2.80	1.10	4.53	21.15**	-3.13	1.60	-6.40	-7.86	22.14*	10.15
RBJ-8003× RBJ-27017	-2.80	-3.82	-17.85*	0.00	-2.76	-2.31	1.75	-2.24	12.50**	16.00**	15.19**	11.09**	1.10	0.85	-6.51	9.27	4.14	5.30
RBJ-8003× ZN-M-5	-0.00	1.30	-28.57**	-17.80	0.00	6.37	-3.64	7.10**	13.02**	-11.17*	11.56**	-3.48	-1.89	-0.56	-9.05	-9.92	10.86	19.35
RBJ-8003× RBJ-8005	1.44	-1.53	-15.47	-8.97	-7.37*	0.00	4.23*	-4.50*	-0.52	2.13	13.00**	-3.14	3.7	9.18**	-1.97	1.00	-4.31	-1.87
RBJ-8003× ZN-M-6	-2.28	0.96	-19.04*	-17.07	0.00	-1.36	5.03*	3.29	-0.52	-2.05	12.01**	-1.39	0.03	0.43	-0.20	0.38	5.33	-9.15
RBJ-8003× FZ	-3.44	-2.97	-13.09	-19.78*	0.00	14.21**	4.71*	2.42	-5.20	0.55	16.93**	17.90**	3.8	5.49*	-4.42	-2.72	-4.13	-10.84
R-4 × RBJ-27017	-3.85	-7.13**	-26.43**	-7.24	1.95	-3.24	0.48	2.38	4.83	-2.50	9.72**	9.69*	2.18	-0.00	0.95	25.79**	7.26	-0.56
R-4 × ZN-M-5	0.89	-0.22	-29.88**	-16.43	-3.41	-2.94	-2.54	-0.35	-2.15	-3.19	14.21**	2.41	1.68	-1.08	2.78	8.53	-6.75	-7.96
R-4 × RBJ-8005	2.60	-2.78	-27.58**	-19.23*	1.95	3.98	-0.82	4.87*	3.22	2.67	8.89*	-3.26	-0.16	0.83	-2.19	7.43	1.96	-4.12
R-4 × ZN-M-6	-0.89	-0.03	-24.13**	-19.51	0.73	-6.13	-3.09	1.07	1.07	-3.58	11.42**	1.66	1.5	-2.14	-2.50	4.54	7.80	-14.75
R-4 × FZ	-0.95	-2.84	-8.04	-12.08	-0.48	7.36	-3.02	0.57	3.76	6.62	11.34**	16.37**	6.37*	3.69	-8.84	-1.08	9.29	-6.82

NR-5 × RBJ-27017	-1.48	-2.70	9.45	17.39	1.21	-3.93	3.73	1.12	4.09	-4.75	12.62**	11.28**	0.97	4.43	16.59*	27.30**	27.36*	13.46
NR-5 × ZN-M-5	-1.70	-0.61	14.86	16.43	2.43	2.94	2.30	0.07	-5.73	-8.24	16.39**	3.16	2.49	5.36*	4.89	-2.94	26.22*	19.73
NR-5 × RBJ-8005	-3.41	-6.43**	14.86	8.97	-2.92	-0.99	0.35	1.52	5.46	3.20	7.29*	-5.77	-0.50	6.19*	-1.24	-4.94	23.07*	11.20
NR-5 × ZN-M-6	-6.12**	-3.19	-2.70	-12.19	-3.90	-10.45**	1.79	1.57	-6.01	-11.79*	7.70*	-2.86	2.18	4.04	15.84*	8.85	14.36	-13.09
NR-5 × FZ	0.51	0.80	5.40	-14.28	1.46	9.47*	-0.57	-1.35	9.28*	10.49*	10.76**	14.43**	1.05	4.09	10.80	5.35	28.57**	5.34
ZN-M-1 × RBJ-27017	4.36*	-0.31	-2.94	-4.34	2.88	-0.92	-2. 00	-4.06	-7.32	-11.50*	0.33	7.53*	4.22	1.36	-0.17	13.60	23.85*	11.63
ZN-M-1 × ZN-M-5	4.40*	2.08	19.11	10.95	-8.65*	-6.86	3.65	1.82	1.04	2.65	5.67	1.58	12.58**	8.84**	-0.45	-4.00	22.51*	17.59
ZN-M-1 × RBJ-8005	-0.46	-6.74**	5.88	-7.69	-7.69*	-4.47	2.57	4.21	-0.52	1.60	3.08	-1.82	3.02	3.40	13.62*	13.99*	26.31*	15.47
ZN-M-1 × ZN-M-6	1.66	1.39	20.58*	0.00	-0.96	-6.36	-0.28	-0.07	-1.04	-3.07	-6.87*	-8.91*	0.08	-4.16	3.01	0.89	9.58	-15.74
ZNM-1 × FZ	1.93	-1.13	20.58*	-9.89	-1.44	7.89	-1.21	-1.56	-2.09	3.31	5.71	18.44**	6.70*	3.36	9.85	8.86	16.30	-3.58

*** Significant (α=0.05) ** Highly significant (α=0.01)**

MPH= Mid parent heterosisBPH= Better parent heterosis

PH= Plant height (cm), PBPP =Primary branches per plant, SBPP= Secondary branches per plant, SL =Silique length (cm), SPS= Seeds per silique, SPP=Silique per plant, SW= 1000-seed (g) weight ,SY= seed yield (g), HI =Harvest index (%)