Journal of Oilseed Brassica, 10 (1) : 38-46, January 2019

Heterosis and combining ability analysis in Indian mustard (*Brassica juncea* L.)

Satveer Kaur, Ravindra Kumar*, Ramandeep Kaur, Ikbal Singh, Harjinder Singh and Vijay Kumar

Department of Agriculture, Mata Gujri (Autonomous) College, Fatehgarh Sahib-140406 Punjab, India
**Corresponding author: godwalravindra@gmail.com*
(Received: 01 August 2018; Revised: 10 October 2018; Accepted: 15 December 2018)

Abstract

Line × Tester effect showed positive significance for all the characters except plant height, siliqua length, days to maturity and test weight. Significant differences were observed for both general combining ability and specific combining ability effects. IC-597919 found to be good general combiner for most of the traits. The cross combinations namely, IC-597879 × IC-571648 was found to be most significant for yield/plant. On the basis of *per se* performance and estimates of heterosis, the cross IC-597879 × IC-571648 found to be most promising followed by IC-597919 × IC-335852 and IC-589669 × IC-338586 for seed yield/plant. The above best parents and best crosses can be used in hybridization and heterosis breeding respectively.

***Key words**: Combining ability, Heterosis, Indian mustard, Line × Tester mating*

Introduction

Brassica juncea (L.) commonly known as Indian mustard is globally used as oilseed, vegetable and condiments (Saleem *et al*., 2017 and Kumar *et al*., 2018). Mustard belongs to family Brassicaceae and genus Brassica. Indian mustard (*Brassica juncea* L.) is a natural amphidiploids (2n=36) of *B. rapa* (2n=20) and *B. nigra* (2n=16). Indian mustard (*B. juncea* L.) popularly known as rai or raya is one of the most important oilseed crops of the country and it occupies considerably large acreage among the *Brassica* group of oil seed crops. The mustard grown in an area 6.41 million hector with a production of 6.57 million tonnes and productivity of 7399 kg per hectare during 2016-17 (SEA, 2018). In India, Rajasthan ranks first in area (2.56 million ha) and production (2.95 million tonnes) followed by Eastern India and others, Uttar Pradesh, Haryana, Punjab and West Bengal (SEA, 2018). Breeding for heterosis is one of the most successful technological options being employed for the improvement of crop varieties (Gupta *et al*., 2010). Exploitation of heterosis may play a very significant role in boosting up the production and productivity of Indian mustard (Meena *et al*., 2015)

Evaluation of breeding material for general and specific combining ability as well as the extent of heterosis for seed yield and yield contributing characters is a prerequisite in any breeding programme aimed for the development of improved genotypes or a hybrid. The combining ability analysis also provides information about the nature and magnitude of gene action involved in the expression of various quantitative characters. Keeping the view the present investigation was undertaken with view to make an assessment of combining ability and heterosis of parents and their specific crosses in mustard. Various workers have reported different types of gene action and combining abilities in different sets of material studies. Combining ability studies highlighted the predominance effects of GCA on yield and most of the yield components indicating the importance of additive gene action (Wos *et al*. 1999). While Pandey *et al*. (1999) review evidence for the presence of significant SCA effects for yield and yield components indicating importance of non-additive gene action. It is imperfect that before understanding any breeding approach, the prepondrance of the gene action and combining ability should be accessed in the material in which the breeding program is undertaken based on the line x tester mating design has been widely used in crop plants for testing the performance of genotypes in hybrid combinations and also for estimating the magnitude and nature of gene action (Kempthorne, 1957).

Materials and Methods

Plant materials

The experimental material consisted of five lines (IC-589669, IC-589670, IC-589680, IC-597879 and IC-597919) and three testers (IC-571648, IC-335852 and IC-338586) were collected from the National Bureau of Plant Genetic Resource (NBPGR) New Delhi, India. The parental lines were chosen in a systematic random way to represent the phenotypic diversity, and a study was conducted for yield and yield-related parameters.

Field experiment

During the Rabi season of the years 2016–17 and 2017–18, all eight parents were crossed in a line X tester mating design as per the method suggested by Kempthorne (1957) at Research Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib, This place is situated between 30-27’ and 30-46’ latitudes and 76-04’ and 76-38’E latitudes and a mean height of 247 meters above sea level. The annual precipitation rate is around 710 mm, and soil is sandy loam. The parents were sown in Randomized Block Design (RBD) with three replications. Each plot consisted of a single row of 5 meter length. The distance between rows and plants was kept at 70 cm and 25 cm, respectively. The recommended doses of nutrients were applied. Half of N and the entire P_2O_5 and K_2O were applied at the time of field preparation as the basal dose. The remaining quantity of nitrogen was given as the top dressing. Other operations were undertaken to keep the field free from weeds.

Data collection and analysis

Observations were recorded for developmental, quantitative and qualitative characters on a single plant basis. Phenotypic traits were recorded in days from sowing until about days to first flowering, days to 50% flowering, number of primary branches, number of secondary branches, plant height (cm), number of siliqua per plant, siliqua length (cm), number of seeds per siliqua, days to maturity, biological yield per plant (g), seed yield per plant (g), harvest index (%) and test weight (g) respectively. The data pertaining to various characters were analysed as per the procedure of RBD given by Panse and Sukhatme (1978). The combining ability analysis was performed for a Line × Tester mating design as per the method suggested by Kempthorne (1957). The average F_1 value was used for estimation of heterosis expressed in percentage over mid parent (MP) and better parent (BP) values, where MP value = (P_1ÿP_2)/2, Relative heterosis = [(F_1-MP)/MP] x 100, heterobeltiosis = [(F_1 – BP)/BP] x100.

Results and Discussion

Analysis of variance for combining ability

Analysis of variance for combining ability, for line effect showed significant variance only for days to maturity. None of the character exhibited significant variance for tester effect. Line × Tester effect showed positive significance for all the characters except plant height, siliqua length, days to maturity and test weight. The similar results were reported by Singh *et al*. (2007) and Patel *et al*. (2013).

Table 1. Estimates of GCA effects of parental lines for 13 characters in line x tester of *B. juncea* (L.)

Character/ Genotype	Days to First Flowering	Days to 50% Flowering	Primary Branches /Plant	Secondary Branches /Plant	Plant Height (cm)	Siliquae /Plant	Siliqua Length (cm)	Seeds /Siliqua	Days to Maturity	Biological Yield/ Plant (g)	Seed Yield/ Plant (g)	Harvest Index (%)	Test Weight (g)
IC-589669	-0.44	0.31	-0.30	-1.31	-0.98	-19.76	0.01	0.51*	1.82*	18.49	5.6**	1.38	-0.04
IC-589670	0.78	-0.36	0.59	-0.20	-3.53	-33.42*	-0.14	-0.16	-1.29	-1.62	-2.7	-0.72	-0.03
IC-589680	0.78	-0.02	-0.74*	-2.64**	-8.3**	-21.98	-0.05	-0.04	-1.62*	-41.29**	-9.5**	0.95	-0.03
IC-597879	0.67	1.09	0.14	1.80*	6.58*	-24.87	-0.08	-0.38	0.16	8.49	3.16*	-0.13	0.34
IC-597919	-1.78*	-1.02	0.31	2.36**	6.24*	100.0**	0.25*	0.07	0.93	15.93	3.49*	-1.49	-0.23
IC-571648	-0.22	-0.22	0.06	-0.96	1.36	-16.87	-0.05	-0.11	0.87	-18.84*	-1.44	2.7**	-0.14
IC-335852	1.31*	0.84	0.52*	0.04	2.89	-1.80	0.02	-0.24	0.20	23.36**	3.9**	-1.50	0.23
IC-338586	-1.09	-0.62	-0.58*	0.91	-4.24	18.67	0.03	0.36	-1.07	-4.51	-2.44*	-1.22	-0.09
CD 95% GCA(Line)	1.47	1.64	0.65	1.34	5.79	27.60	0.19	0.46	1.44	19.87	2.84	2.21	0.36
CD 95% GCA(Tester)	1.14	1.27	0.51	1.04	4.48	21.38	0.15	0.36	1.11	15.39	2.20	1.72	0.28

General combining ability (GCA) and specific combining ability (SCA) analysis

The results of *gca* effects are given in table 1. The parents namely, IC-589669 is significant for number of seeds/ siliqua, days to maturity and seed yield/plant. IC-589670 for number of siliquae/plant, IC-589680 for number of primary branches/plant, number of secondary branches/ plant, plant height, days to maturity, biological yield/plant and seed yield/plant. IC-597879 for number of secondary branches/plant, plant height and seed yield/plant, IC-597919 for days to first flowering, secondary branches/ plant, plant height, number of siliquae/plant, siliqua length and seed yield/plant, IC-571648 for biological yield/plant and harvest index, IC-335852 for days to first flowering, primary branches/plant, biological yield and seed yield/ plant, IC-338586 for primary branches/plant and seed yield/plant. IC-597919 found to be good general combiner for most of the traits. Similar finding were also reported by Patel *et al*. (2013) and Gideon *et al*. (2015). The results of specific combining ability (SCA) effects are presented in table 2. The cross combinations namely, IC-597879 × IC-571648 was found to be most significant for yield/ plant followed by IC-589669 × IC-338586 and IC-589670 × IC-335852. The similar findings were reported by Gupta *et al*. 2006 and Ahsan *et al*. (2013).

Estimation of Heterosis

Exploitation of hybrid vigour for yield characters content provides an additional opportunity to improve and develops hybrids for yield traits along with adaptability for specific production environments. Estimates of mean squares for all the characters studied were highly significant indicating wide genetic differences among the genotypes. The heterotic effect in F_1 generation over better parent and standard check are presented in Table 3, 4 and 5.

Significant negative heterosis is desirable for days to first flowering. A significant and high degree of heterosis for days to first flowering was observed in comparison to the better parent and the commercial genotype as well. Six cross combinations showed significant negative desirable heterosis varies from -8.05 (IC-589669 × IC-571648) to -16.78 (IC-597919 × IC-571648) over better parents. Seven cross combinations showed significant negative useful heterosis having -7.53 (IC-597919 × IC-338586) to -15.07 (IC-589670 × IC-338586) over the commercial check. The similar findings were reported by Meena *et al*. (2014).

Days to 50% flowering significant negative heterosis is useful for earliness. Three cross combinations exhibited significant negative heterobeltiosis ranging from -7.60 (IC-589670 × IC-338586) to -13.19 (IC-589680 × IC-571648). Ten cross combinations exhibited significant negative useful heterosis ranging from -7.10 (IC-597879 × IC-571648) to -13.66 (IC-589670 × IC-338586) over the commercial check. The same results were also reported by Patel *et al*. (2012) and Dholu *et al*. (2014).

Four cross combinations exhibited significant positive heterobeltiosis for primary branches/plant ranging from 31.25 (IC-597879 × IC-571648) to 38.89 (IC-597919 × IC-571648). Seven cross combinations exhibited significant positive useful heterosis which is ranging from 33.33 (IC-589669 × IC-571648) to 66.67 (IC-589670 × IC-335852) over the commercial check. Similar results were also reported by Patel *et al*, 2010 and Meena *et al*. (2014).

Five cross combinations exhibited significant positive useful heterobeltiosis ranging from 29.55 (IC-597919 × IC-571648) to 51.35 (IC-597879 × IC-335852), while one cross IC-589670 × IC-571648 (-36.73) showed negatively significant for number of secondary branches/plant. Eleven cross combinations exhibited significant positive useful heterosis which ranging from 37.93 (IC-589669 × IC-335852) to 113.79 (IC-597919 × IC-338586) over the commercial check. The similar results were also reported by Singh *et al*. 2007 and Aher *et al*. (2009).

The plant height is an important trait by which growth and vigour of plants are measured. A significant and high degree of heterosis for plant height was observed in comparison to the better parent and the commercial genotype as well. One cross IC-597879 × IC-571648 (9.72) showed significant positive heterobeltiosis. Fifteen cross combinations exhibited significant positive heterosis ranging from 14.45 (IC-589680 × IC-338586) to 32.51 (IC-597879 × IC-571648). The similar findings were also reported by Meena *et al*. (2014).

Seven cross combinations exhibited significant positive heterobeltiosis for number of siliquae/plant ranging from 29.57 (IC-597879 × IC-571648) to 72.47 (IC-597919 × IC-338586). Fifteen cross combinations exhibited significant positive useful heterosis ranging from 40.33 (IC-589670 × IC-335852) to 229.20 (IC-597919 × IC-338586) over commercial check for number of siliquae/plant. The similar results were also reported by Singh *et al*. (2007) and Singh *et al*. (2012).

Fourteen cross combinations exhibited significant positive useful heterosis was ranging from 13.73 (IC-589670 × IC-571648) to 32.35 (IC-589669 × IC-571648) over the commercial check for siliqua length which matched with the results of Meena *et al*. (2014).

Table 2. Estimates of SCA effects of parental lines for 13 characters in line x tester of *Brassica juncea* (L.)

Character/ Genotype	Days to First Flowering	Days to 50% Flowering	Primary Branches /Plant	Secondary Branches /Plant	Plant Height (cm)	Siliquae /Plant	Siliqua Length (cm)	Seeds /Siliqua	Days to Maturity	Biological Yield/ Plant (g)	Seed Yield/ Plant (g)	Harvest Index (%)	Test Weight (g)
IC-589669×IC-571648	1.44	0.89	0.50	3.18**	2.98	4.09	0.38*	0.56	-1.76	-12.49	-1.00	0.56	-0.12
IC-589669×IC-335852	-3.42*	-3.18*	-0.97	-0.82	1.11	31.36	-0.26	0.36	0.58	19.98	-5.33*	-6.1**	-0.12
IC-589669×IC-338586	1.98	2.29	0.47	-2.36*	-4.09	-35.44	-0.13	-0.91*	1.18	-7.49	6.33*	5.57**	0.24
IC-589670×IC- 571648	2.56*	3.56*	-1.72**	-3.93**	-8.80	66.09**	-0.10	-0.11	0.02	-51.04**	-10.67**	3.20	-0.30
IC-589670×IC-335852	0.69	-0.84	0.81	3.73**	4.33	-153.98**	-0.08	0.02	-0.31	16.76	5.67*	-0.60	0.00
IC-589670×IC-338586	-3.24*	-2.71	0.91	0.20	4.47	87.89**	0.18	0.09	0.29	34.29	5.00*	-2.59	0.29
IC-589680×IC-571648	-2.44	-3.44*	-0.72	-0.49	-1.36	-49.36*	-0.23	0.11	0.69	-4.71	-3.56	-0.74	0.40
IC-589680×IC-335852	1.69	2.82	0.14	-0.16	0.11	115.58**	0.30	0.24	-0.98	1.42	0.44	-0.95	-0.23
IC-589680×IC-338586	0.76	0.62	0.58	0.64	1.24	-66.22**	-0.07	-0.36	0.29	3.29	3.11	1.69	-0.18
IC-597879×IC-571648	0.00	-0.56	0.39	-0.93	7.42	47.53	0.04	-0.22	-0.09	47.84**	11.44**	-1.52	0.47
IC-597879×IC-335852	2.47	2.38	-0.41	1.40	-8.11	-24.20	-0.03	-0.76	0.91	-42.69*	-5.22*	5.20**	-0.26
IC-597879×IC-338586	-2.47	-1.82	0.02	-0.47	0.69	-23.33	-0.01	0.98*	-0.82	-5.16	-6.22*	-3.69	-0.21
IC-597919×IC-571648	-1.56	-0.44	1.56**	2.18	-0.24	-68.36**	-0.09	-0.33	1.13	20.40	3.78	-1.50	-0.46
IC-597919×IC-335852	-1.42	-1.18	0.42	-4.16**	2.56	31.24	0.07	0.13	-0.20	4.53	4.44	2.48	0.60
IC-597919×IC-338586	2.98*	1.62	-1.98**	1.98	-2.31	37.11	0.03	0.20	-0.93	-24.93	-8.22**	-0.97	-0.14
CD 95% SCA	2.55	2.84	1.13	2.32	10.03	47.81	0.33	0.80	2.49	34.42	4.92	3.84	0.63

Table 3: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for Days to first flowering, Days to 50% flowering, Number of Primary branches/plant and Number of Secondary branches/plant

Crosses	Days to first flowering			Days to 50% flowering			No. of Primary branches			No. of Secondary branches		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
IC-589669×IC-571648	45.67	-8.05*	-6.16	57.33	-5.49	-6.01	6.67	0.00	33.33*	16.33	32.43*	68.97**
IC-589669×IC-335852	42.33	1.60	-13.01**	54.33	-1.81	-10.93**	5.67	-15.00	13.33	13.33	8.11	37.93*
IC-589669×IC-338586	45.33	7.09	-6.85	58.33	5.42	-4.37	6.00	-10.00	20.00	12.67	2.70	31.03
IC-589670×IC- 571648	48.00	-3.36	-1.37	59.33	-2.20	-2.73	5.33	0.00	6.67	10.33	-36.73**	6.90
IC-589670×IC-335852	47.67	1.42	-2.05	56.00	-1.75	-8.20*	8.33	31.58*	66.67**	19.00	16.33	96.55**
IC-589670×IC-338586	41.33	-12.06**	-15.07**	52.67	-7.60*	-13.66**	7.33	37.50*	46.67**	16.33	0.00	68.97**
IC-589680×IC-571648	43.00	-13.42**	-11.64**	52.67	-13.19**	-13.66**	5.00	-11.76	0.00	11.33	-15.00	17.24
IC-589680×IC-335852	48.67	14.06**	0.00	60.00	7.14	-1.64	6.33	0.00	26.67	12.67	-5.00	31.03
IC-589680×IC-338586	45.33	6.25	-6.85	56.33	0.60	-7.65*	5.67	0.00	13.33	14.33	7.50	48.28**
IC-597879×IC-571648	45.33	-8.72*	-6.85	56.67	-6.59	-7.10*	7.00	31.25*	40.00*	15.33	24.32	58.62**
IC-597879×IC-335852	49.33	8.82*	1.37	60.67	4.00	-0.55	6.67	5.26	33.33*	18.67	51.35**	93.10**
IC-597879×IC-338586	42.00	-7.35	-13.70**	55.00	-5.71	-9.84**	6.00	12.50	20.00	17.67	43.24**	82.76**
IC-597919×IC-571648	41.33	-16.78**	-15.07**	54.67	-9.89**	-10.38**	8.33	38.89**	66.67**	19.00	29.55*	96.55**
IC-597919×IC-335852	43.00	-11.03**	-11.64**	55.00	-4.62	-9.84**	7.67	21.05	53.33**	13.67	-6.82	41.38*
IC-597919×IC-338586	45.00	-6.90	-7.53*	56.33	-2.31	-7.65*	4.17	-30.56*	-16.67	20.67	40.91**	113.79**
S.E±		1.76	1.76		1.96	1.96		0.78	0.78		1.60	1.60
C.D at 5%		3.61	3.61		4.02	4.02		1.60	1.60		3.28	3.28
C.D at 1%		4.87	4.87		5.42	5.42		2.16	2.16		4.42	4.42

Table 4: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for Plant height, Number of siliquae/plant, Siliqua length, Days to maturity and Number of seeds/siliqua

Crosses	Plant height (cm)			No. of siliquae/plant			Siliqua length (cm)			Days to maturity			No. of seeds/siliqua		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
IC-589669 × IC-571648	183.67	0.92	24.38**	413.00	-11.81	126.09**	4.50	0.75	32.35**	149.00	2.05	-6.49**	12.67	2.70	40.74**
IC-589669 × IC-335852	183.33	-2.14	24.15**	455.33	-2.78	149.27**	3.93	-11.94*	15.69*	150.67	3.20*	-5.44**	12.33	0.00	37.04**
IC-589669 × IC-338586	171.00	-6.04	15.80**	409.00	-12.67	123.91**	4.07	-8.96	19.61**	150.00	2.04	-5.86**	11.67	-5.41	29.63**
IC-589670 × IC- 571648	169.33	-5.05	14.67**	461.33	32.44**	152.55**	3.87	-11.45*	13.73*	147.67	0.91	-7.32**	11.33	3.03	25.93**
IC-589670 × IC-335852	184.00	-1.78	24.60**	256.33	-28.60**	40.33*	3.97	-5.56	16.67*	146.67	0.23	-7.95**	11.33	9.68	25.93**
IC-589670 × IC-338586	177.00	4.73	19.86**	518.67	48.76**	183.94**	4.23	0.79	24.51**	146.00	-0.68	-8.37**	12.00	12.50*	33.33**
IC-589680 × IC-571648	172.00	-3.55	16.48**	357.33	2.58	95.62**	3.83	-12.21*	12.75	148.00	0.91	-7.11**	11.67	2.94	29.63**
IC-589680 × IC-335852	175.00	-6.58	18.51**	537.33	49.68**	194.16**	4.43	3.91	30.39**	145.67	-0.68	-8.58**	11.67	2.94	29.63**
IC-589680 × IC-338586	169.00	-5.06	14.45**	376.00	7.84	105.84**	4.07	-4.69	19.61**	145.67	-0.91	-8.58**	11.67	2.94	29.63**
IC-597879 × IC-571648	195.67	9.72*	32.51**	451.33	29.57**	147.08**	4.07	-6.87	19.61**	149.00	1.13	-6.49**	11.00	-2.94	22.22**
IC-597879 × IC-335852	181.67	-3.02	23.02**	394.67	9.94	116.06**	4.07	-5.43	19.61**	149.33	1.36	-6.28**	10.33	-8.82	14.81*
IC-597879 × IC-338586	183.33	4.56	24.15**	416.00	19.31	127.74**	4.10	-4.65	20.59**	146.33	-0.68	-8.16**	12.67	11.76*	40.74**
IC-597919 × IC-571648	187.67	5.23	27.09**	460.33	32.15**	152.01**	4.27	-6.57	25.49**	151.00	3.19*	-5.23**	11.33	-5.5*6	25.93**
IC-597919 × IC-335852	192.00	2.49	30.02**	575.00	60.17**	214.78**	4.50	-1.46	32.35**	149.00	1.82	-6.49**	11.67	-2.78	29.63**
IC-597919 × IC-338586	180.00	3.05	21.90**	601.33	72.47**	229.20**	4.47	-2.19	31.37**	147.00	0.00	-7.74**	12.33	2.78	37.04**
S.E±		6.92	6.92		33.00	33.00		0.40	0.54		1.72	1.72		0.56	0.56
C.D at 5%		14.18	14.18		67.61	67.61		0.46	0.63		3.52	3.52		1.14	1.14
C.D at 1%		19.13	19.13		91.20	91.20		0.46	0.63		4.75	4.75		1.53	1.53

checkcheckTable 5: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for biological yield/plant, seed yield/plant, harvest index and test weight

Crosses	Biological yield/plant (g)			Seed yield/plant (g)			Harvest index (%)			Test weight (g)		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
IC-589669×IC-571648	121.67	-18.53	7.67	39.00	13.59	98.31**	32.47	37.66**	85.70**	3.30	11.24	23.75
IC-589669×IC-335852	196.33	18.04	73.75**	40.00	16.50	103.39**	21.56	-1.93	23.31	3.67	23.60	37.50*
IC-589669×IC-338586	141.00	0.95	24.78	45.33	32.04**	130.51**	33.53	49.75**	91.77**	3.70	24.72	38.75*
IC-589670×IC- 571648	63.00	-57.81**	-44.25*	21.00	-47.93**	6.78	33.01	32.86*	88.79**	3.13	-1.05	17.50
IC-589670×IC-335852	173.00	4.01	53.10*	42.67	5.79	116.95**	24.98	7.48	42.87**	3.80	20.00	42.50*
IC-589670×IC-338586	162.67	8.93	43.95*	35.67	-11.57	81.36**	23.27	-1.60	33.09*	3.77	18.95	41.25*
IC-589680×IC-571648	69.67	-53.35**	-38.35	21.33	-31.91**	8.47	30.74	14.71	75.81**	3.83	11.65	43.75*
IC-589680×IC-335852	118.00	-29.06	4.42	30.67	-2.13	55.93**	26.30	4.37	50.38**	3.57	3.88	33.75*
IC-589680×IC-338586	92.00	-23.33	-18.58	27.00	-13.83	37.29*	29.22	14.11	67.08**	3.30	-3.88	23.75
IC-597879×IC-571648	172.00	15.18	52.21*	49.00	56.38**	149.15**	28.89	11.58	65.21**	4.27	26.73*	60.00**
IC-597879×IC-335852	123.67	-25.65	9.44	37.67	20.21	91.53**	31.38	29.20	79.45**	3.90	15.84	46.25**
IC-597879×IC-338586	133.33	11.11	17.99	30.33	9.64	54.24**	22.77	-7.81*	30.19**	3.63	7.92	36.25*
IC-597919×IC-571648	152.00	1.79	34.51	41.67	16.82	111.86**	27.54	12.30	57.51**	2.77	7.79	3.75
IC-597919×IC-335852	178.33	7.21	57.82*	47.67	33.64*	142.37**	27.29	19.06	56.08**	4.20	51.81**	57.50**
IC-597919×IC-338586	121.00	-10.37	7.08	28.67	-19.63*	45.76*	24.12	3.39	37.93*	3.13	5.62	17.50
S.E±		23.77	23.77		3.40	3.40		2.65	2.65		0.43	0.43
C.D at 5%		48.68	48.68		6.96	6.96		5.42	5.42		0.89	0.89
C.D at 1%		65.67	65.67		9.39	9.39		7.32	7.32		1.20	1.20

Two crosses IC-597879 × IC-338586 (11.76) and IC-589670 × IC-338586 (12.50) were found to be positively significant over better parent for number of seeds/siliqua. Fifteen cross combinations exhibited significant positive useful heterosis which ranging from 14.81 (IC-597879 × IC-335852) to 40.74 (IC-589669 × IC-571648) over commercial check for number of seeds/siliqua. The similar results were also reported by Mahto and Haider (2004).

For days to maturity significant negative heterosis is desirable. Fifteen cross combinations exhibited negative significant useful heterosis ranging from -5.23 (IC-597919 × IC-571648) to -8.58 (IC-589680 × IC-571648) over the commercial check. The same findings were also reported by Turi *et al*. (2006) and Dar *et al*. (2012). Five cross combinations exhibited significant positive useful heterosis which ranging from 43.95 (IC-589670 × IC-338586) to 73.75 (IC-589669 × IC-335852) over commercial check for biological yield/plant. The similar results were accounted by Shehzad *et al*. (2015).

Three cross combinations showed significant positive heterobeltiosis ranging from 32.04 (IC-589669 × IC-338586) to 56.38 (IC-597879 × IC-571648) for seed yield/plant. Thirteen cross combinations showed significant positive useful heterosis ranging from 37.29 (IC-589680 × IC-338586) to 149.15 (IC-597879 × IC-571648). The similar results were also reported by Aher *et al*. (2009) and Yadava *et al*. (2012). Although, three cross combinations showed significant positive heterobeltiosis varies from 32.86% (IC-589670 × IC-571648) to 49.75% (IC-589669 × IC-338586) over better parent for harvest index. Fourteen cross combinations exhibited significant positive useful heterosis which ranging from 30.19% (IC-597879 × IC-338586) to 91.77% (IC-589669 × IC-338586) over the commercial check for harvest index. The similar results were also reported by Dholu *et al*. (2014).

Two crosses IC-597879 × IC-571648 (26.73) and IC-597919 × IC-335852 (51.81) exhibited positive significant heterobeltiosis for test weight. Ten cross combinations exhibited significant positive useful heterosis which ranging from 33.75 (IC-589680 × IC-335852) to 60.00 (IC-597879 × IC-571648) for test weight. The similar results were also reported by Meena *et al*. (2014).

Conclusion

GCA effects revealed that the IC-597919 having significant and positive GCA effects was found to be the best combiner for most of the yield contributing traits, while on the basis of SCA, IC-597879 × IC-571648 was recorded best specific combination for most of the yield contributing traits *viz.,* biological yield/plant, seed yield/plant. It may be concluded that IC-597919 is good general combiner and IC-597919 × IC-571648 is a best specific combination for higher yield. For heterosis, six cross combinations exhibited significant heterobeltiosis for seed yield/plant. On the basis of *per se* performance and estimates of heterosis, the cross IC-597879 × IC-571648 found to be most promising followed by IC-597919 × IC-335852 and IC-589669 × IC-338586 for seed yield/plant, hence could be evaluated further to exploit the heterosis and utilized in future breeding programmes to obtain desirable and superior genotypes.

References

Aher CD, Chinchane VN, Shelke LT, Borgaonkar SB and Gaikwad AR. 2009. Genetic study in Indian mustard [*B. juncea* (L.) Czern and Coss]. *Intl J Pl Sci* **4**: 83-85.

Ahsan MZ, Farooq A, Kang S and Rasheed K. 2013. Combining Ability and Heterosis analysis for seed yield and yield components in *B. napus* L. *Biol Agricd Healthcare* **3**: 31-36.

Dar ZA, Wani SA, Gulzaffar, Habib M , Sofi NR, Ahmed I , Ahmed Z and Khan MH. 2012. Heterosis studies in Brown Sarson (*B. rapa* L.). *Elect J Pl Breed* **3**:676-681.

Dholu VK, Sasidharan N, Suthar K , Bhusan B and Patel JN. 2014. Heterosis and combining ability analysis in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *Intl J Agril Sci* **10**:102-107.

Gideon JS, Rangare NR, Choudhary AK, Kumar S and Myrthong I. 2015. Combining ability analysis for seed yield and component traits in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *Elect J Pl Breed* **6**: 445-453.

Gupta P, Chaudhary HB and Lal SK. 2010. Heterosis and combining ability analysis for yield and its components in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *Front Agric* China. **4**: 299–307. DOI 10.1007/s11703-010-1016-8

Gupta SK, Karuna N and Dey T. 2006. Heterosis and Combining Ability in Rapeseed (*B. napus* L.). *SKAUST- J Res* **5**: 42–47.

Kempthorne O. 1957. An introduction to genetical statistics. John Willey and Sons Inc., New York, pp. 323-331.

Kumar R, Kaur R, Singh I, Kaur S and Singh H. 2018. Trait association and morphological diversity in IC lines of Indian mustard (*B. juncea* L.). *J Oilseed Brassica* **9**: 195-200.

Mahto J L and Haider Z A. 2004. Heterosis in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *J Trop Agric* **42**: 39-41.

Meena HS, Ram B, Kumar A, Singh BK, Meena PD, Singh VV and Singh D. 2014. Heterobeltiosis and standard heterosis for seed yield and important traits in Indian mustard (*B. juncea* L.). *J Oilseed Brassica* **5**: 134 -140.

Meena HS, Kumar A, Ram B, Singh VV, Meena PD, Singh BK and Singh D. 2015. Combining ability and heterosis for seed yield and its components in Indian mustard (*B. juncea* L.) *J Agric Sci Tech* **17**: 1861-1871

Pandey LD, Singh B and Sachan JN.1999. Brassica hybrid research in India. Status and Prospects Paper 263.

Panse VG and Sukhatme PV. 1985. Statistical methods for agricultural workers, Indian Council of Agricultural Research, New Delhi, pp.145.

Patel AM, Arha MD and Khule AA. 2013. Combining ability analysis for seed yield and its attributes in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *Asian J Biol Sci* **8**: 11-14.

Patel AM, Prajapati DB, and Patel DG. 2012. Heterosis and combining ability studies in Indian mustard (*B. juncea* L.). *Indian J Sci Res Technol* **1**: 38-40.

Patel CG, Parmer MB, Patel KR and Patel KM. 2010. Exploitation of heterosis breeding in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *J Oilseeds Res* **27**: 47-48.

Saleem N, Jan SA, Atif MJ, Khurshid H, Khan SA, Abdullah M, Jahanzaib M, Ahmed H, Ullah SF, Iqbal A, Naqi S, Ilyas M, Ali N, Rabbani MA. 2017. Multivariate based variability within diverse Indian mustard (*B. juncea* L.) genotypes. *Open J Genet* 7: 69-83.

Shehzad M J, Ahmad M, Khan F A, Alin J , Ahmad Z, Farooq M, Latif M and Iqbal M J. 2015. Line × Tester Analysis for Seed Yield and Yield Components in *B. napus* L. genotypes. *Intl J Adv Multidiscipl Res* **2**: 15–21.

Singh DK, Kumar K and Singh P. 2012. Heterosis and heritability analysis for different crosses in *B. juncea* with inheritance of white rust resistance. *J Oilseed Brassica* **3**: 18-26.

Singh RK and Dixit P. 2007. Heterosis and combining ability studies for seed yield, its attributes and oil content in Indian mustard [*B. Juncea* (L.) Czern & Coss.]. *Crop Improv* **34**: 23-25.

Solvent Extractors of Agriculture (SEA, 2018). Https://www.business-standard.com/article/economy-policy/rapeseed-mustard production estimate-dips-marginally-by-4-says-118030100849_1.html.

Turi NA, Raziuddin SS and Ali S. 2006. Estimation of heterosis for some important traits in mustard (*B. juncea* L.). *J Agril BiolSci* **1**: 6-10.

Wos H, Bartkowiak-Broda I, Budzianowski G and Krzymanski J. 1999. Breeding of Winter and Spring Oilseed Rape Hybrids at Malyszyn: Paper 544. In: "Proceeding of 10th International Rapeseed Conference [CD-ROM], Canberra, Australia. pp: 26-29.

Yadava DK , Singh N, Vasudev S, Singh R, Singh S, Giri SC, Dwivedi VK and Prabhu KV. 2012. Combining ability and Heterobeltiosis for yield and yield contributing traits in Indian mustard (*B. juncea* L.). *Indian J Agril Sci* **82**: 563-567.