Journal of Oilseed Brassica, 11 (1) : 77-87, January 2020

Line × Tester analysis for quantitative traits in Indian mustard (*Brassica juncea* L.)

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(Received: 11 November 2019; Revised: 25 Novemberr 2019; Accepted: 15 December 2019)

Abstract

This study identified the best parents and F_1 hybrids on the basis of general, specific combining ability and high heterotic performance for yield characters, involving crosses of five Indian mustard (*Brassica juncea* L.) lines female parent (lines) and three male parent (testers), in line x tester mating design. The analysis of variance revealed significant differences for all genotypes for all characters studied, indicating sufficient genetic variability for all the characters. On the basis of *per se* performance and estimates of heterosis, the crosses Geeta x IC-571678, Maya x IC-571649 and Maya x IC-571668 were most promising hybrids for seed yield/plant. The comparative variances due to general combining ability revealed that the highest positive significant effect for the traits biological yield/plant followed by number of siliqua/plant and test weight. Parent Geeta was found to be the best combiner for seed yield with significant and positive GCA effect. Out of fifteen, four cross combination shows positive significant SCA effect for seed yield/plant (g) trait. The best SCA effect was seen in cross combination Maya x IC-571649 and Geeta x IC 571668 has been recorded best specific combiner for seed yield.

Keywords: *Genotypes, heterosis, significant, quantitative traits*

Introduction

Yield is one of the most important economic characters and is product of multiplicative interaction of contributing characters (Kant and Gulati, 2001). Hence, the important objective in mustard improvement of originated to develop varieties which have high yield potential. The other objectives are oriented to develop new varieties with wider adaptability, earlier maturity, disease resistance and high oil content with high yield potential.

Breeding in mustard (*Brassica juncea* L) has primarily been confined to exploitation of available genetic variability resulting in establishment of homozygous lines (Akanksha *et al*., 2017). It is highly desirable to increase productivity and stability through efficient plant type, which may be having the genes for higher seed and oil content. The development of such lines depends on the knowledge of combining ability and genetic architecture of the population. Many researcher applied various strategies for improving yield attributes of Brassica (Singh *et al.,* 2003), reported different type of gene action and combining abilities in different sets of material studies. The sample analysis of incident of heterosis is necessary for the evaluation of various possible breeding procedures (Allard, 1960).

Identification of parental material with strong heterosis for seed yield and obtain genetic parameters is the prime steps in the development of new variety (Singh *et al*., 2019a). It is important to have information about the desirable hybrid combination which can represent a high degree of heterosis. By exploiting heterosis in the hybrid combination, production cost could be reduced by increasing yield level and enhancing input use efficiency by Pingali (1997). Indian mustard is a autogamous crop, line x tester mating design proposed by Kempthorne (1957) for combing ability analysis is very important for screening of parents with rapidity. Keeping these points in view, the present investigation was undertaken to determine combining ability of genotypes and heterosis of different cross combinations in Indian mustard.

Materials and Methods

The experiments were conducted at experimental Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib, Punjab, India, is situated at an altitude of 246 m above mean sea level at 30°27' north latitude and 76°04' and 76°38' east. The average annual rainfall is 960 mm in sub-mountain region and 460 mm in plains. Fog is common in the winter, while hot dry winds, blow in the summer. The minimum temperature may go down to 4° C in December- January while maximum temperature may go as high as 42° C in May- June.

The experimental material comprised of eight mustard genotypes (Basanti, Geeta, Maya, Kranti, CS 54, IC571649, IC-571668 and IC-571678) and their 15 line × tester crosses. The parents were crossed in line x tester mating design during Rabi season 2017-18 and evaluated all F_1s and parents in the year 2018-19.

Experiments were concluded in randomized block design with 3 replications in 2 rows in each replication. The sowing was done by hand in rows with spacing of 60cm between the rows and 25cm within plant on 25th October (Timely sown environment 2018). The seeds of 15 F_1 hybrids were produced by hand emasculation, pollination and selfed seeds were maintained by selfing in the experiment. All the recommended package of practices was adopted to raise a good crop. Eight elite lines of the mustard raised in the field with three replication in the crossing block for producing F_1's in a line x tester (Kempthorne, 1957) method.

Results and Discussion

Combining ability analysis

The success of any breeding programme largely depends upon the choice of parents and breeding procedure adopted. Combining ability is an efficient tool to discriminate good as well as poor combiners and for choosing suitable parental lines in hybridization programme. It also provides information of specific promising combinations to exploit heterosis. The estimation of general combining ability (GCA) effect's (table 2) and specific combing ability (SCA) effect's (table 3) of the crosses was for twelve characters. For days to first flowering, one cross Basanti x IC-571678 (-3.0) had recorded exhibited significant negative SCA effects for this trait. The estimates of combining ability effects for plant height revealed that one parent Geeta (12.156) expressed positive significant GCA effects whereas one parent Kranti (-14.07) was exhibited significant negative GCA effects and for this trait. For positive significant SCA effects, one cross CS-54 x IC-571668 (21.33) had recorded significant positive SCA effects for this trait. The estimates of combining ability effects for number of siliqua length/plant revealed that one parent Geeta (56.96) expressed positive significant GCA effects for this trait. Only one cross Maya x IC-571649 (81.04) had recorded significant positive SCA effects while two crosses Geeta x IC-571649 (-79.96) and Maya x IC 571678 (-55.56) exhibited significant negative sca effects for silique per plant.

The estimates of combining ability effects for siliqua length/plant revealed that one parent Geeta (0.19) expressed positive significant GCA effects for this trait.

Table 1: Analysis of variance for combining ability estimates of components of variance and their relation with various traits

Sourced of variation	d.f.	Days to first flowering	No. of primary branches	No. of secondary branches	Plant height (cm)	No. of silique per plant	Silique length (cm)
Replicates	2	6.47	1.87	9.76	647.62	4481.67	0.03
Crosses	14	7.06	1.90	7.41	776.90*	8430.34**	0.19**
Line Effect	4	5.20	1.36	14.72**	1286.76	11037.70	0.18
Tester Effect	2	5.00	0.60	15.09*	436.16	552.07	0.07
Line * Tester Effect	8	8.50	2.49	1.84	607.16	9096.23*	0.23**
Error	28	8.04	1.68	7.42	346.74	3004.95	0.04
Total	44	7.66	1.76	7.53	497.29	4798.34	0.09
Sourced of variation	**d.f.**	**No. of seeds/ siliqua**	**Days to maturity**	**Biological yield / plant (g)**	**Harvest index**	**Test weight (g)**	**Seed yield / plant (g)**
Replicates	2	3.47	22.47	532.47	53.37	4.65	274.85*
Crosses	14	8.44**	117.30**	1531.91**	59.99*	3.99*	550.84**
Line Effect	4	7.48	47.26	29026.92	60.64	9.64*	558.53
Tester Effect	2	5.27	22.07	5508.87	63.83	0.49	70.08
Line * Tester Effect	8	9.71**	176.12**	10905.17**	58.72*	2.04	667.18**
Error	28	1.21	27.42	1538.90	24.62	1.65	63.87
Total	44	3.61	55.79	5875.47	37.19	2.53	228.41

*, ** significant at 5% and 1% level, respectively

Table 2: Estimates for GCA effect for various characters in Indian mustard

Genotypes	Days to first flowering	Primary branches	Secondary branches	Plant height (cm)	Silique per plant	Silique length (cm)	Seeds /siliqua	Days to maturity	Biological yield / plant (g)	Seed yield / plant (g)	Harvest index	Test weight (g)
Basanti	-1.07	0.24	1.00	2.38	-1.93	0.06	-1.04*	-1.40	4.38	0.22	1.34	1.21*
Geeta	0.71	-0.20	0.67	12.16*	56.96**	0.19*	0.84*	1.38	80.27**	13.45**	0.06	0.32
Maya	0.71	0.02	-1.44	10.27	-30.04	0.03	-0.93*	-2.40	-1.73	-6.19*	-3.73*	-1.28**
Kranti	-0.40	-0.53	-1.33	-14.07*	-27.38	-0.16	0.62	3.27*	-80.18**	-3.04	3.23	-0.85
CS-54	0.04	0.47	1.11	-10.73	2.40	-0.12	0.51	-0.84	-2.73	-4.44	-0.91	0.60
IC-571649	0.67	0.00	-1.04	2.02	0.73	0.08	-0.47	0.67	9.60	1.50	2.37	0.14
IC-571668	-0.33	-0.20	0.09	-6.11	5.67	-0.05	0.67*	0.73	-22.07	-2.48	-1.41	-0.20
IC-571678	-0.33	0.20	0.96	4.09	-6.40	-0.03	-0.20	-1.40	12.47	0.97	-0.96	0.07
CD 95% GCA (Line)	1.64	0.90	2.45	11.25	30.75	0.17	0.79	2.94	33.10	5.10	3.54	0.86
CD 95% GCA (Tester)	1.272	0.700	1.90	8.71	23.82	0.13	0.62	2.28	25.64	3.95	2.74	0.67

Table 3: Estimates of SCA effects for various characters in Indian mustard

Genotypes	First flowering	No. of primary branches	No. of secondary branches	Plant height (cm)	No. of silique per plant	Silique length (cm)	No. of seeds /siliqua	Days to maturity	Biological yield / plant (g)	Seed yield /plant(g)	Harvest Index	Test weight (g)
Basanti x IC-571649	2.00	0.22	-0.73	0.09	-11.07	0.22	1.24	3.33	1.96	-1.33	-3.37	-0.54
Basanti x IC-571668	1.00	-1.24	0.80	5.56	-33.00	0.05	-1.22	-0.73	14.62	-2.22	0.07	-0.45
Basanti x 571678	-3.00*	1.02	-0.07	-5.64	44.07	-0.27	-0.02	-2.60	-16.58	3.55	3.30	0.98
Geeta x IC-571649	-0.44	-0.33	0.27	-7.36	-79.96**	0.19	-0.64	0.56	-82.93**	-19.16**	-2.64	-0.14
Geeta x IC-571668	-0.78	0.20	0.47	-5.89	44.78	-0.09	0.22	0.49	60.40*	9.29*	2.02	-0.78
Geeta x IC-571678	1.22	0.13	-0.73	13.24	35.18	-0.10	0.42	-1.04	22.53	9.87*	0.62	0.92
Maya x 571649	-0.78	0.78	0.38	9.53	81.04**	-0.45**	0.13	-13.33**	54.07	27.03**	0.19	0.42
Maya x 571668	0.56	0.31	-0.09	-9.67	-25.89	-0.02	0.00	6.60*	-10.27	-13.84**	-0.94	-0.04
Maya x IC-571678	0.22	-1.89	-0.29	0.13	-55.16*	0.47**	-0.13	6.73*	-43.80	-13.19**	0.74	-0.38
Kranti x IC-571649	-0.67	0.33	0.60	14.53	12.38	0.04	1.58*	-1.33	69.18*	1.13	3.64	0.27
Kranti x IC-571668	0.67	-0.13	-0.53	-11.33	15.44	0.07	1.11	-1.07	-54.82	-0.44	-5.72	0.76
Kranti x IC-571678	0.00	-0.20	-0.07	-3.20	-27.82	-0.11	-2.69**	2.40	-14.36	-0.69	2.09	-1.03
CS-54 x IC-571649	-0.11	-1.00	-0.51	-16.80	-2.40	-0.00	-2.31**	10.78**	-42.27	-7.66	2.18	-0.01
CS-54 x IC-571668	-1.44	0.87	-0.64	21.33*	-1.33	-0.01	-0.11	-5.29*	-9.93	7.21	4.57	0.51
CS-54 x 571678	1.56	0.13	1.16	-4.53	3.73	0.01	2.42**	-5.49*	52.20	0.46	-6.75*	-0.50
CD 95% SCA	2.85	1.57	4.25	19.48	53.26	0.30	1.38	5.09	57.34	8.83	6.13	1.49

*, ** significant at 5% and 1% level, respectively

Table 4: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for first flowering, primary branches/plant and secondary branches/plant

Crosses	First flowering			Primary branches/plant			Secondary branches/plant		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
Basanti x IC-571649	48.67	2.10	3.55	7.67	9.52	9.52	23.67	-12.35	-6.58
Basanti x IC-571668	46.67	-6.67	-0.71	6.00	-21.74**	-14.29**	26.33	9.72	3.95
Basanti x IC-571678	42.67	-9.22*	-9.22*	8.67	18.18**	23.81**	26.33	9.72	3.95
Geeta x IC-571649	48.00	0.70	2.13	6.67	-4.76	-4.76	24.33	-9.88	-3.95
Geeta x IC-571668	46.67	-6.67	-0.71	7.00	-8.70	0.00	25.67	10.00	1.32
Geeta x IC-571678	48.67	11.45*	3.55	7.33	0.00	4.76	25.33	8.57	0.00
Maya x IC-571649	47.67	0.00	1.42	8.00	0.00	14.29	22.33	-17.28**	-11.84**
Maya x IC-571668	48.00	-4.00	2.13	7.33	-8.33	4.76	23.00	-4.17	-9.21
Maya x IC-571678	47.67	4.38	1.42	6.33	-20.83**	-9.52	23.67	-1.39	-6.58
Kranti x IC-571649	46.67	-2.10	-0.71	7.00	0.00	0.00	22.67	-16.05**	-10.53
Kranti x IC-571668	47.00	-6.00	0.00	6.33	-17.39	-9.52	22.67	-1.45	-10.53
Kranti x IC-571678	46.33	1.46	-1.42	6.67	-9.09	-4.76	24.00	10.77*	-5.26
CS-54 x IC-571649	47.67	-4.67	1.42	6.67	-4.76	-4.76	24.00	-11.11	-5.26
CS-54 x IC-571668	45.33	-9.33*	-3.55	8.33	8.70	19.05**	25.00	8.70	-1.32
CS-54 x IC-571678	48.33	-3.33	2.84	8.00	9.09	14.29	27.67	27.69**	9.21
SE (d)		1.96	1.96		2.07	2.07		2.93	2.93
C.D. at 5%		4.02	4.02		4.24	4.95		6.01	6.01
C.D. at 1%		5.43	5.43		5.71	5.71		8.10	8.10

*, ** significant at 5% and 1% level, respective

For positive significant SCA effects, one cross Maya x IC-571678 (0.47) had recorded significant positive SCA effects while one cross Maya x IC-571649 (-0.45) exhibited significant highly negative SCA effects for this trait.

The estimates of combining ability effects for number of seeds/siliqua revealed that one parent Geeta (0.84) expressed positive significant and one parent Basanti (-1.04) exhibited significant negative GCA effects for this trait. For positive significant SCA effects, two crosses CS-54 x IC-571678 (2.42) and Kranti x IC- 571649 (1.58) had recorded significant positive SCA effects while 2 crosses Kranti x IC-571678 (-2.69) and CS-54 x IC-571649 exhibited significant negative SCA effects for this trait. For days to maturity, one parent Kranti (6.07) had recorded significant positive GCA effect for days to maturity. For days to maturity, Out of 15 crosses, one cross CS-54 x IC-571649 (10.78) had recorded highly significant positive SCA effects while one cross Maya x IC-571649 (-13.33) exhibited significant negative SCA effects for this trait.

The estimates of combining ability effects for biological yield/plant revealed that one parent Geeta (80.27) expressed positive significant GCA effects whereas one parent Kranti (-80.18) was exhibited significant negative GCA effects for this trait. For positive significant sca effects, two crosses Kranti x IC-571649 (69.18) and Geeta x IC 571668 (60.40) had recorded significant positive SCA effects while one cross Geeta x IC-571649 (-82.93) exhibited significant negative SCA effects for this trait.

The **es**timates of combining ability effects for harvest index revealed that one parent Maya (-3.73) was exhibited significant negative GCA effects for this trait. None of the cross exhibit significant positive or negative SCA effect for harvest index. The estimates of combining ability effects for test weight revealed that whereas one parent Basanti (1.21) positive significant and one parent Maya (-1.28) was exhibited significant negative GCA effects for this trait.

The **es**timates of combining ability effects for seed yield revealed that one parent Geeta (13.45) expressed positive significant GCA effects whereas, one parent Maya (-6.19) was exhibited significant negative GCA effects for this trait. For positive significant SCA effects, one cross Maya x IC-571649 (27.03) had recorded significant positive SCA effects while one cross Geeta x IC-571649 (-19.16) exhibited significant highly negative SCA effects for this traits.

However for seed yield certain crosses such as Maya x IC-571649, Geeta x IC-571678, Geeta x IC-571668, Geeta x IC-571649, Maya x IC-571668 and Maya x IC-571678 showed higher magnitude of significantly higher *SCA* effect. Similar results reported by Singh *et. al.* (2010). Only one cross, like Maya x IC-571649 associated with highly significant *SCA* value of seed yield per plant as well. Similar findings were reported by Gupta *et al.* (2010) and Patel *et al.* (2016) in Indian mustard.

The potentiality of a parent in hybridization may be assessed by its *per se* performance and *GCA* effects. The results revealed that most of the genotypes had relatively high degree of correspondence between *per se* performance and *GCA* effects for the observed characters. This can be ascribed to the predominant role of additive and additive x additive type of gene action for the inheritance of these traits. These findings are in accordance with Synrem *et al.* (2014).

The estimates of specific combining ability effects revealed that as many as three cross combinations exhibited significant and positive *SCA* effects for seed yield per plant. The maximum significant positive *SCA* effect was exhibited by hybrid Maya x IC-571649 (27.03), Geeta x IC-571678 (9.87) and Geeta x IC-571668 (9.30), thus they were good hybrid combinations, contributing towards higher seed yield. The similar findings were reported by Patel *et al.* (2015)

In the present study, one of the top three crosses which exhibited high *SCA* effects for yield per plant, the cross, Maya x IC-571649 involved no one good general combiner indicating additive x dominance type of gene interaction which is expected to produce desirable transgressive segregants in subsequent generations. Patel *et al.* (2005), Akbar *et al*. (2008) and Singh *et al*. (2010) have reported the involvement of additive x additive, additive x dominance and epistasis type of gene action in expression of yield and its traits in Indian mustard.

The crosses, where poor x poor and poor x good general combiners produced high *SCA* effects may be attributed due to presence of genetic diversity in the form of heterozygous loci for specific traits. Thus, the superior F_1 combination would be the one, which have good *per se* performance, high heterobeltiosis, at least one good general combiner and high *SCA* effects. On the basis of combining ability, the parent Geeta was good general combiner. Considering mean performance, heterosis and combining ability, none of the F_1 combination was found promising for commercial exploitation. These results are in accordance with Dar *et al.* (2011).

Estimation of heterosis

The hybrid vigour has so far not been extensively

Table 5: Mean performance of F_1 hybrids and extent of heterosis (%) in Indian mustard for plant height and siliqua/plant, silique/plant and siliqua length

Crosses	Plant height			Silique/plant			Siliqua length		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
Basanti x IC-571649	187.7	2.74	-0.71	217.0	7.43	-3.13	4.7	11.90*	11.02*
Basanti x IC-571668	185.0	4.13	-2.12	200.0	-20.95	-10.71	4.4	0.00	3.94
Basanti x IC-571678	184.0	-1.08	-2.65	265.0	11.81	18.30	4.1	-8.21	-3.15
Geeta x IC-571649	190.0	-0.52	0.53	207.0	1.97	-7.59	4.8	4.35	13.39*
Geeta x IC-571668	220.0	-4.01	-3.00	336.7	33.07*	50.30**	4.4	-4.35	3.94
Geeta x IC-571678	212.7	11.34	12.52	315.0	32.91*	40.63*	4.4	-4.35	3.94
Maya x IC-571649	205.0	7.89	8.47	281.0	-6.33	25.45	4.0	-8.40	-5.51
Maya x IC-571668	177.7	-6.49	-6.00	179.0	-40.33**	-20.09	4.3	-2.27	1.57
Maya x IC-571678	197.7	4.04	4.59	137.7	-54.11**	-38.54*	4.8	7.46	13.39*
Kranti x IC-571649	185.7	-8.54	-1.76	215.0	-0.92	-4.02	4.3	-3.01	1.57
Kranti x IC-571668	151.3	-25.29**	-19.75**	223.0	-11.86	-0.45	4.2	-5.26	-0.79
Kranti x IC-571678	170.0	-16.26*	-10.05	167.7	-29.25	-25.15	4.0	-9.70*	-4.72
CS-54 x IC-571649	157.0	-17.31*	-16.58*	230.0	-31.75**	2.68	4.3	10.26*	1.57
CS-54 x IC-571668	187.7	-1.57	-0.71	236.0	-29.97*	5.36	4.2	-5.30	-1.57
CS-54 x IC-571678	172.0	-9.79	-8.99	229.0	-32.05**	2.23	4.2	-5.97	-0.79
SE (d)		13.45	13.45		36.77	36.77		0.21	0.21
C.D. at 5%		27.55	27.55		75.33	75.33		0.42	0.42
C.D. at 1%		37.16	37.16		101.61	101.61		0.57	0.57

Table 6: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for seeds/siliqua, days to maturity and Biological yield/plant

Crosses	Seeds/siliqua			Days to maturity			Biological yield/plant		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
Basanti x IC-571649	15.0	7.14**	-6.25	120.7	0.00	1.40	264.0	55.29**	15.28
Basanti x IC-571668	13.7	-2.38**	-14.58*	116.7	-4.63*	-1.96	245.0	-7.55	6.99
Basanti x IC-571678	14.0	0.00	-12.50*	112.7	-8.15**	-5.32	248.3	7.97	8.44
Geeta x IC-571649	15.0	-6.25**	-6.25	120.7	0.00	1.40	255.0	-29.17*	11.35
Geeta x IC-571668	17.0	6.25**	6.25	120.7	-1.36	1.40	366.7	1.85	60.12**
Geeta x IC-571678	16.3	2.08**	2.08	117.0	-4.62**	-1.68	363.3	0.93	58.66**
Maya x IC-571649	14.0	7.69**	-12.50*	103.0	-14.64**	-13.45**	310.0	-17.33	35.37
Maya x IC-571668	15.0	15.38**	-6.25	123.0	0.54	3.36	214.0	-42.93**	-6.55
Maya x IC-571678	14.0	0.00	-12.50*	121.0	-1.36	1.68	215.0	-42.67**	-6.11
Kranti x IC-571649	17.0	21.43**	6.25	120.7	0.00	1.40	246.7	-0.40	7.71
Kranti x IC-571668	17.7	26.19**	10.42	121.0	-1.09	1.68	91.0	-65.66**	-60.26**
Kranti x IC-571678	13.0	-7.14**	-18.75**	122.3	-0.27	2.80	166.0	-32.97*	-27.51
CS-54 x IC-571649	13.0	5.41**	-18.75**	128.7	6.63*	8.12*	212.7	-31.40**	-7.13
CS-54 x IC-571668	16.3	25.64**	2.08	112.7	-7.90**	-5.32	213.3	-31.18**	-6.84
CS-54 x IC-571678	18.0	28.57**	12.50*	110.3	-10.05**	-7.28*	310.0	0.00	35.37
SE (d)		0.95	0.95		3.52	3.52		39.58	39.58
C.D. at 5%		1.95	1.95		7.20	7.20		81.09	81.09
C.D. at 1%		2.63	2.63		9.72	9.72		109.38	109.38

exploited in self-pollinated crop in comparison to cross pollinated ones. However, heterosis as a means of increasing productivity has been an object of considerable study in Indian mustard. The heterotic effect in F_1 generation over better parent and standard check are presented in tables 4 to 7.

Days to first flowering are important trait for early maturity. The mean performance for days to first flowering were varies in cross combination from Basanti x IC-571678 (42.7) to Geeta x IC-571678 (48.7). Cross Geeta x IC-571678 (11.5%) exhibited positive significant heterosis over batter parent. For negative heterobeltiosis for this trait with the magnitude ranged from -9.2% to -9.3% in two crosses. One cross Basanti x IC 571678 (-9.2%) showed negative heterosis over commercial check for this trait. These findings are in accordance with Meena *et al*. (2014) and Barupal *et al.* (2017).

In *Brassica*, positive heterosis for number of primary branches is desirable, because plants with vigorous stature containing more branches provide opportunity for higher yields. The mean performance branches per plant were varies in cross combination from Basanti x IC-571668 (6.0) to Basanti x IC-571678 (8.7). One cross Basanti x IC 571678 (18.2%) exhibited positive significant heterobeltosis while two cross combinations Basanti x IC 571678 (23.8%) and CS 54 x IC 571668 (19.1%) showed positive significant heterobeltiosis. Two cross combination indicates positive significant heterosis over standard check and one cross shows negative significant heterosis and standard check. The present results similar to the findings by Gami *et al.* (2013) and Singh *et al.* (2019b).

The mean performance for number of secondary branches per plant were varies in cross combination from Maya x IC-571649 (22.3) to CS-54 x IC-571678 (27.7). Two crosses showed positive significant heterobeltiosis is maximum by CS-54 x IC-571678 (27.7%). For useful heterosis, only one cross Maya x IC-571649 exhibited significant negative heterosis. These results are in accordance with the results reported by Akabari *et al.* (2016).

The mean performance for plant height were varies in cross combination from Kranti x IC-571668 (151.3) to Geeta x IC-571678 (212.7). Negative heterosis is useful regarding plant height, shorter plants with greater numbers of branches are desirable due to their ability to withstand winds. The plant height is an important trait by which growth and vigour of plants measured. A significant and high degree of heterosis for plant height was observed in comparison to the better parent and the commercial variety as well. The highest significant heterosis over better parent in desirable direction is exhibited by one cross Kranti x IC-571668 (-25.3%). Two cross combinations Kranti x IC-571668 (-19.8%) and CS 54 x IC571649 (-16.6%) showed negative significant heterosis over the standard check. The results are in accordance with Singh *et al.* (2012).

The mean performance for number of siliqua/plant were varies in cross combination from Maya x IC-571678 (137.7) to Geeta x IC-571668 (336.7). Two crosses Geeta x IC-571668 (33.1%) and Geeta x IC-571678 (32.9%) showed positive significant over better parent and five cross exhibited significant negative heterobeltiosis. Only one cross Geeta x IC-571668 (50.3%) and Geeta x IC 571678 (40.6%) showed significant positive heterosis over standard check. The similar results were reported by Patel *et al.* (2015).

The mean performance for siliqua length were varies in cross combination from Maya x IC-571649 (4.0) to Geeta x IC-571649 (4.8). Two cross combination Basanti x IC-571649 (11.9%) and CS-54 x IC-571649 (10.3%) showed significant positive heterosis and one cross showed the negative significant heterosis over the better parent. Three crosses showed the positive significant heterosis ranging from 11.0% (Basanti x IC 571649) to 13.4% (Maya x IC 571678) over the standard check variety. The present results is similar to the findings by Meena *et al.* (2014).

The mean performance for number of seeds/siliqua were varies in cross combination from Kranti x IC-571678 (13.0) to CS-54 x IC-571678 (18.0). For number of seeds/siliqua, ten crosses exhibited positive significant heterosis range from 2.08% (Geeta x IC 571678) to 28.6% (CS 54 x IC 571678) over better parent. Only one cross CS-54 x IC-571678 (12.5%) showed significant positive heterosis over the standard check. The present study is in accordance with Singh *et al.* (2012).

The mean performance for days to maturity per plant were varies in cross combination from Maya x IC-571649 (103.0) to CS-54 x IC-571649 (128.7). Negative heterosis, is useful regarding days to maturity because early maturing genotypes suffer lower losses due to shattering, tolerate or escape heat stress and provide sufficient time for seeding the next crop. Six crosses showed significant negative heterobeltosis with range -4.62% (Geeta x IC 571678) to -14.64% (Maya x IC 571649) for days to maturity. Significant and desirable heterosis over standard check was exhibited by two crosses Maya x IC-571649 (-13.5%) and CS-54 x IC-571678 (-7.3%). The results are in accordance with Dar *et al.* (2012).

Table 7: Mean performance of F_1 hybrids and extent of heterosis in Indian mustard for harvest index and test weight and yield/plant

Crosses	Harvest index			Test weight			Yield/plant		
	Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
Basanti x IC-571649	17.6	-35.73*	5.97	8.8	-10.51	21.47	46.4	4.91	-3.33
Basanti x IC-571668	16.9	-20.84	3.93	8.6	-11.68	17.93	41.5	11.05	-13.47
Basanti x IC-571678	20.5	-4.35	26.20	10.3	11.59	39.77**	50.8	34.66*	5.74
Geeta x IC-571649	16.4	-40.00**	2.63	8.7	-11.86	13.75	41.8	-34.10*	-12.92
Geeta x IC-571668	15.3	-13.02	8.00	7.3	-24.40*	1.14	66.3	4.47	38.08**
Geeta x IC-571678	19.4	9.62	2.16	9.3	1.09	28.27	70.3	10.83	46.46**
Maya x IC-571649	15.8	-41.95**	-3.13	7.3	-25.76*	0.32	68.4	48.19**	42.40**
Maya x IC-571668	11.0	-21.75	-32.85**	6.5	-32.99**	-10.71	23.5	-45.77**	-51.04**
Maya x IC-571678	13.2	-19.72	-20.00	6.4	-30.43*	-11.72	27.6	-36.31*	-42.50**
Kranti x IC-571649	18.5	-32.44*	59.89*	7.6	-23.05*	4.13	45.6	-1.16	-5.00
Kranti x IC-571668	20.7	15.21*	-19.69	7.7	-20.62	6.20	40.1	-11.03	-16.56
Kranti x IC-571678	26.1	45.45**	30.32**	6.2	-32.61**	-14.68	43.3	-4.63	-9.90
CS-54 x IC-571649	16.7	-38.90*	25.95	8.7	-11.19	20.32	35.5	-23.12*	-26.22*
CS-54 x IC-571668	21.7	52.69**	17.59	8.9	-8.87	22.75	46.3	4.99	-3.54
CS-54 x IC-571678	13.9	-15.45	-48.30**	8.2	-16.38	12.64	43.0	-2.49	-10.42
SE (d)		4.23	4.23		1.03	1.03		6.09	6.09
C.D. at 5%		8.66	8.66		2.11	2.11		12.48	12.48
C.D. at 1%		11.69	11.69		2.85	2.85		16.84	16.84

The mean performance for biological yield/plant were varies in cross combination from Kranti x IC-571668 (91.0) to Geeta x IC-571668 (366.7). For biological yield/plant one cross combination Basanti x IC-571649 (55.3%) exhibited significant positive heterosis over the better parent. Two cross combinations Geeta x IC-571668 (60.1%) and Geeta x IC-571678 (58.7%) showed significant positive heterosis and one cross Kranti x IC-571668 (-60.3%) showed negative significant heterosis over the standard check. The mean performance for harvest index were varies in cross combination from Maya x IC-571668 (11.0) to Kranti x IC-571678 (26.1). Harvest index (%) are one of the important components for seed yield. Significant positive heterosis over better parent is exhibited by three cross combinations ranged from 15.2% (Kranti x IC 571668) to 52.69% (CS 54 x IC 571678). Two cross combinations exhibited positive heterosis is Kranti x IC-571678 (30.3%) and Kranti x IC-571649 (59.9%) and two crosses shows significant negative heterosis over the standard check. The result of this study is in agreement with Dholu *et al.* (2014).

The mean performance for test weight were varies in cross combination from Kranti x IC-571678 (6.2) to Basanti x IC-571678 (10.3). Out of the 15 crosses, six crosses exhibited significant negative heterosis over the better parent for test weight. Only the one cross Basanti x IC-571678 (39.8%) showed significant positive heterosis over the standard check. The present study agrees with those reported Meena *et al.* (2014) and Kaur et al. (2019). In the present investigation the seed yield/plant increased mainly due to increase in average number of siliqua/plant and number of seeds/siliqua. The mean performance for seed yield/plant were varies in cross combination from Maya x IC-571668 (23.5) to Geeta x IC-571678 (70.3). Two cross combination showed significant positive heterosis over better parent. Basanti x IC-571678 (34.7%) and Maya x IC-571649 (48.2%) while three crosses exhibited significant negative heterosis over the better parent. Three cross combinations exhibited significant positive heterosis over standard check varied from 38.1% (Geeta x IC 571668) to 46.5% (Geeta x IC 571678) and three crosses shows significant negative heterosis ranging from -26.2% (CS 54 x IC 571649) to -51.0% (Maya x IC-571668) over the standard check variety. These findings are in accordance with the results reported by Yadava *et al.* (2012), Kumar *et al.* (2016) and Singh *et al.* (2019a).

Conclusion

On the basis of mean performance and estimates of heterosis, the cross combination Geeta × IC-571678, Maya × IC-571649 and Maya × IC-571668 was found most promising for seed yield, hence could be evaluated further to included in future breeding programme for the development of superior genotypes. GCA effects revealed that Geeta having significant and positive GCA effects was found to be the top combiner for most of the yield contributing traits, while on the basis of SCA, Maya × IC-571649 and Geeta x IC 571668 was recorded best specific F1 hybrid for most of the yield contributing traits. It may be concluded that IC-317528 is good general combiner and Maya × IC-571649 is a best specific combination for higher yield and included in future breeding scheme to obtain desirable segregants for the evolution of superior hybrid/genotypes.

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