Journal of Oilseed Brassica, 16 (1) : 29-39, January, 2025

Heterosis and combining ability for seed yield and its component traits in Indian mustard (*Brassica juncea* L.)

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(Received: 5 October 2024; Revised: 1 November 2024; Accepted: 15 November 2024)
https://doi.org/10.56093/JOB.v16i1.4

Abstract

In a randomized block design, 15 F_1s from line x tester crossings with a set of 8 parents and one check were raised during winter 2022-2023 and 2023-2024 with the goal of estimating heterosis and combining ability. The analysis of variance revealed that the mean square due to genotypes, parent crosses, and parent's v/s crosses were significant for all the traits. On the basis of per se performance and estimates of heterosis, the cross IC-342777 × Maya was found to be most promising, followed by IC-538719 × Maya for seed yield/plant. The GCA effects of the parents, IC-589670, were significantly positive for most of the traits. On the other hand, the SCA effects of the IC-342777 × Maya cross combinations were both significantly positive and negative for seed yield/plant.

Keywords **:** *Crosses, heterosis, mustard, yield*

Introduction

Indian mustard (*Brassica juncea* L.) is an important oilseed crop grown in India during the winter season and holds a distinguished place among oilseed crops. It is a member of the genus *Brassica* and family Cruciferae (*Brassicaceae)*. In terms of cytogenetics, Indian mustard is a naturally occurring amphidiploid (2n=36), resulting from interspecific cross between *Brassica nigra* (2n=16) and *Brassica campestris* (2n=20), which was followed by the F_1s spontaneous chromosome doubling. It is an autogamous species by nature, with a 5-30% outcross rate according on pollinator frequency and environmental conditions (Shrimali *et al.,* 2016). Mustard seed contains 30–46% oil, 23–30% of protein, 12–18% of carbohydrate and 4% of mineral matter. Kachi Ghani and refined mustard oil are its two forms that are popular among the people (Malaviya and Yadav, 2020).

Heterosis breeding could be an alternative to achieve quantum leaps in productivity and production. The commercial use of heterosis in a number of crop species has since led to a significant breakthrough in yield levels. In particular, the amount of heterosis has a significant impact on yield; if heterosis is partially and commercially viable, it can help to achieve high yield levels, which will increase mustard's oil output (Barupal *et al.,* 2017). Heterosis breeding may be a practical solution, to achieve huge increases in output and productivity. Since then, yield levels have significantly increased as a result of the commercial exploitation of heterosis in a range of agricultural species. The main goal of heterosis is to increase the vigour, size, fruitfulness, development and speed of cross-bred organisms when compared to related inbreds, as well as resistance to insect pests and disease and climatic vigour (Gupta *et al.,* 2010).

To achieve huge increases in production and productivity, heterosis breeding may be a practical solution. Since then, the commercial exploitation of heterosis in a variety of agricultural species has led to a significant increase in yield levels. Mustard oil yield can be increased by achieving high yield levels using partial and economically feasible heterosis. The magnitude of heterosis is crucial, especially in terms of yield.

Combining ability analysis is a potent technique for evaluating the potential of parental lines to produce valuable recombinants and superior hybrids (Singh *et al.,* 2013). In crop plants, the line × tester mating design has been widely used to test genotype performance in hybrid combinations and to estimate the magnitude and nature of gene action. The genetic value of inbreds can be assessed by combining ability analysis, which also aids in choosing the best parents for hybridization. This method also identifies the superior cross-combinations. Combining ability analysis is important for quickly screening of parents. In light of these considerations, the present investigation was conducted to determine to ascertain the genotypes of combining ability and heterosis of various cross combinations in Indian mustard (Kumar *et al.,* 2019).

Materials and Methods

The experiments conducted at Experimental Farm, Mata Gujri College, Fatehgarh Sahib. It is situated at an altitude of 246 km above mean sea level at 30"27’ and 30"46’ North latitude and 76"04’ and 76"38’ East. The climate of Fatehgarh Sahib is characterized by subtropical semi-arid type of climate with three distinct seasons namely hot and dry summer, monsoon and cold winter. The minimum temperature may go down to 4 °C in December-January while the maximum temperature may go high as 42 °C in May - June.The experimental material comprised of eight mustard genotypes namely IC-597919, IC-538719, IC-571678, IC-571655, IC-342777, Jagannath, Maya and IC-589670 and their 15 F_1 crosses. The parents were crossed in line x tester mating design during *rabi* season 2022-23 and evaluated all F_1 s and parents in the year 2023-24.

Experiments were conducted according to Randomized Block Design (RBD) with three replications. The sowing was done in 120 m^2 area by hand in rows with spacing of 30 cm between the rows and 10-15 cm between plants. Genotypes were received from NBPGR, New Delhi and ICAR-DRMR, Bharatpur (Rajasthan). All the recommended package of practices was adopted to raise a good crop.

Results and Discussion

Analysis of variance for the design of the experiment

ANOVA for line × tester data is presented in Table 1. For all the characters, including days to first flowering, days of 50% flowering, no. of primary branches/plant, no. of secondary branches/plant, plant height, no. of siliqua/plant, siliqua length, number of seeds/siliqua, days to maturity, biological yield/plant, seed yield/plant and harvest index analysis of variance revealed highly significant differences among the genotypes, exhibiting abundant variability for these traits. Similar finding has been found by Akbari *et al.* (2017).

Nature and magnitude of heterosis

The first important step in the exploitation of heterosis is to know its magnitude and direction. Type and size help to recognize better cross combinations and their exploitation to get better transgressive segregation. The combinations give data on the degree of hereditary differing qualities in parents of a crops and help in choosing the parents for predominant F_1, so as to exploit hybrid vigour. The commercial use of heterosis is considered to be an excellent application of genetic principles in the field of plant breeding. The magnitude of heterosis effects depends on the ecological and genetically differences and also on diversity of origin of parents by Dhawan and Singh, (1961) and Moll *et al.* (1962). The heterotic effect in F_1 generation over better

Table 1: ANOVA for parents and hybrids of various traits of Indian mustard (*Brassica juncea* L.)

Source of Variation	DF	Days to first flowering	Days to 50% flowering	No. of Primary Branches /plant	No. of Secondary Branches /plant	Plant Height (cm)	No. of Siliquae /Plant	Siliqua Length (cm)	Number of Seeds /Siliqua	Days to Maturity	Biological Yield /plant (g)	Seed Yield /plant (g)	Harvest Index (%)
Replication	2	0.00	2.54	1.37*	3.20	180.90	850.86	0.03	0.04	7.09*	50.60	12.79	8.40**
Treatments	22	13.00**	4.86*	4.25**	56.56**	2654.66**	10531.02**	0.66**	8.00**	12.60**	4029.88**	35.21**	33.36**
Error	44	1.38	2.25	0.42	3.57	115.68	270.11	0.04	0.92	1.68	125.49	5.57	0.85

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

Table 2 : Estimation of percent heterosis based on better parent (BP) and standard check (SC) for days to first flowering, days to 50% flowering, number of primary branches/plant, number of secondary branches/plant

Cross combination	Days to first flowering		Days to 50% flowering		Number of primary branches/plant		Number of secondary branches/plant	
	BP	SC	BP	SC	BP	SC	BP	SC
IC-597919 × Jagannath	-15.52 **	-9.26 **	-0.70	0.00	14.41	9.76	28.70 **	57.63 **
IC-597919 × Maya	-8.55 **	-0.93	0.00	1.42	16.36	4.07	21.84 *	49.24 **
IC-597919 × IC-589670	-6.09 *	0.00	-1.40	0.00	34.09 **	19.92 *	-7.98	32.06 **
IC-538719 × Jagannath	-7.76 **	-0.93	-3.52	-2.84	5.08	0.81	48.85 **	23.28 *
IC-538719 × Maya	-3.42	4.63	-2.80	-1.42	25.63 **	1.63	20.38 *	46.56 **
IC-538719 × IC-589670	-0.87	5.56	0.70	2.13	48.53 **	23.17 **	-8.11	31.87 **
IC-571678 × Jagannath	-15.52 **	-9.26 **	-9.86 **	-9.22 **	7.63	3.25	75.65 **	54.20 **
IC-571678 × Maya	-10.26 **	-2.78	0.70	2.13	8.18	-3.25	21.63 *	48.09 **
IC-571678 × IC-589670	0.87	7.41 *	-0.70	0.71	29.09 **	15.45 *	-6.52	34.16 **
IC-571655 × Jagannath	-15.52 **	-9.26 **	-4.23	-3.55	3.39	-0.81	47.49 **	45.80 **
IC-571655 × Maya	-13.68 **	-6.48 *	0.70	2.13	-0.49	-17.89 *	-23.20 **	-6.49
IC-571655 × IC-589670	0.87	7.41 *	0.00	1.42	41.67 **	17.48 *	1.99	46.37 **
IC-342777 × Jagannath	-5.17	1.85	-6.25 *	-4.26	-5.08	-8.94	48.93 **	32.44 **
IC-342777 × Maya	-3.42	4.63	-2.78	-0.71	27.17 *	-4.88	20.69 *	46.95 **
IC-342777 × IC-589670	0.87	7.41 *	-2.08	0.00	39.71 **	15.85 *	-2.39	40.08 **
SE±	1.02	1.02	1.33	1.33	0.61	0.61	1.72	1.72
CD at 5%	2.08	2.08	2.73	2.73	1.26	1.26	3.53	3.53
CD at 1%	2.81	2.81	3.68	3.68	1.70	1.70	4.76	4.76

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

parent and standard check are presented in Table 2 and 3.

As the days before first flowering, it is ideal to have a significant negative heterosis. When compared to both the superior parent and the commercial variety, there was a marked and high level of heterosis in the number of days until first flowering. Out of fifteen, eight cross combinations ranging from -6.09% (IC-597919 × IC-589670) to -15.52% (IC-597919 × Jagannath, IC-571678 × Jagannath and IC-571655 × Jagannath) showed significant negative heterosis, whereas two cross combinations namely IC-571655 × IC-589670 (7.41%) and IC-342777 × IC-589670 (7.41%) possessed significant positive heterosis over better parent. Four cross combinations showed significant negative heterosis ranged -6.48% (IC-571655 × Maya) to -9.26% (IC-571655 × Jagannath) over the commercial check. Meena *et al.* (2014) and in, Kumar *et al.* (2019) both reported results that were similar.

Days to 50% flowering significant negative heterosis is useful for earliness. Two cross combinations namely IC-571678 × Jagannath (-9.86%) and IC-342777 × Jagannath (-6.25%) showed significant negative heterosis over better parent as well as only one cross combination IC-571678 × Jagannath (-9.22%) showed highly significant negative heterosis over commercial check. Because it allows for prolonged grain feeling, certainly early maturity, and produces a high seed production, early flowering is favourable for brassica species. The crosses having significant negative heterosis can select for harnessing the economic values of the related traits in the further breeding programme. These findings were reported by Patel *et al.* (2010) and Meena *et al.* (2014).

Because vigorous plants with more branches have a better chance of producing higher yields, positive heterosis for the number of main branches is advantageous in Brassica. Out of 15, only seven cross combinations showed significant positive heterosis ranged 25.63% (IC-538719 × Maya) to 48.53% (IC-538719 × IC-589670) while five cross combinations ranging from 15.45% (IC-571678 × IC-589670) to 23.17% (IC-538719 × IC-589670) showed significant positive heterosis as well as one cross combination IC-571655 × Maya (-17.89) showed significant negative useful heterosis commercial check. These findings are in accordance with Tyagi *et al.* (2000); Monpara and Dobariya (2007).

For number of secondary branches/plant, nine cross combinations ranged 20.38% (IC-538719 × Maya)to 75.65% (IC-571678 × Jagannath) showed significant positive heterosis while one cross combination IC-571655 × Maya (-23.20) shows highly significant negative heterosis over better whilefourteen cross combinations showed highly significant positive heterosis ranged 23.28% (IC-538719 × Jagannath) to 57.63% (IC-597919 × Jagannath) over commercial check. Positive heterosis for the secondary branches is desirable because a short plant with a vigorous structure and many branches has a better chance of producing a higher yield. The similar findings were reported by Singh *et al.* (2007) and Aher *et al.* (2009).

One of the most important characteristics of a plant's health and development is its height. When compared to both the superior parent and the commercial genotype, there was a significant and high degree of heterosis in terms of plant height. Eleven F_1 hybrids showed significant and highly significant positive heterosis ranged 11.45% (IC-597919 × Jagannath) to 48.32% (IC-342777 × IC-589670) heterosis over better whereas 14 cross combinations showed significant positive useful heterosis ranged 17.42% (IC-538719 × Jagannath) to 48.81% (IC-597919 × IC-589670) over commercial check. These findings were reported by Meena *et al.* (2014) and Singh *et al.* (2020).

For number of siliquae per plant, three cross combinations ranged 12.17% (IC-597919 × Jagannath) to 27.56% (IC-342777 × Jagannath) showed significant positive heterosis over better parent as well asfour cross combinations showed significant negative heterosis ranged -9.47% (IC-571678 × IC-589670) to 18.88% (IC-538719 × Jagannath)over better parent. Three cross combinations ranged8.87% (IC-538719 × IC-589670) to 11.46% (IC-571655 × Maya) showed significant positive heterosis whereasfive cross combinations showed significant negative heterosis ranged -9.97% (IC-342777 × Maya) to-24.50% (IC-538719 × Jagannath) over commercial check for this trait. The present studies are in accordance with reports of Kumar *et al.* (2016) and Patel *et al.* (2015).

The length of siliqua may reflect the number of seeds inside it. If the siliqua is longer, it will hold more seeds, and this ultimately influences the seed yield. Therefore, a positive heterosis is desirable in the case of the length of the siliqua trait. Eight cross combinations showed significant and highly significant positive useful heterosis ranged 10.33% (IC-342777 × Jagannath) to 25.14% (IC-342777 × Maya) over better parent. While six cross combinations showed significant negative heterosis ranged 12.74% (IC-538719 × IC-589670) to 23.40% (IC-597919 × IC-589670) for siliqua length. Present study is similar to the findings of Mahto and Haider (2004).

For number of seeds per siliqua, which directly contributes

Table 3: Estimation of percent heterosis based on better parent (BP) and standard check (SC) for Plant height (cm), number of siliquae/plant, siliquae length (cm), number seeds/siliqua

Cross combination	Plant height (cm)		Number of siliquae/plant		Siliqua length (cm)		Number of seed/siliqua	
	BP	SC	BP	SC	BP	SC	BP	SC
IC-597919 × Jagannath	11.45 *	31.88 **	18.67 **	7.61	12.17 *	0.30	-0.44	16.41 **
IC-597919 × Maya	26.03 **	36.33 **	-16.23 **	-10.19 *	5.79	-12.82 **	-23.44 **	7.18
IC-597919 × IC-589670	46.76 **	48.81 **	-2.70	-0.10	-1.15	-23.40 **	-17.48 **	-4.36
IC-538719 × Jagannath	-0.77	17.42 **	-18.80 **	-24.50 **	11.17 *	-0.60	2.19	19.49 **
IC-538719 × Maya	18.04 **	27.69 **	-3.22	3.77	23.15 **	1.49	-16.85 **	16.41 **
IC-538719 × IC-589670	33.88 **	36.91 **	6.04	8.87 *	12.60 *	-12.74 **	-10.13	4.15
IC-571678 × Jagannath	5.97	25.39 **	11.00 *	-15.10 **	2.50	-8.35	2.19	19.49 **
IC-571678 × Maya	14.01 *	23.33 **	1.88	9.22 *	18.44 **	-2.38	-19.41 **	12.82 *
IC-571678 × IC-589670	39.73 **	44.99 **	-9.47 *	-7.05	-1.71	-23.10 **	-10.57 *	4.10
IC-571655 × Jagannath	4.58	23.75 **	2.15	-3.62	6.00	-5.22	-2.19	14.36 *
IC-571655 × Maya	23.34 **	33.42 **	3.96	11.46 **	22.84 **	5.81	-15.75 **	17.95 **
IC-571655 × IC-589670	40.85 **	41.28 **	0.08	2.74	-3.98	-17.29 **	-11.06 *	3.08
IC-342777 × Jagannath	-5.47	11.86	27.56 **	-16.09 **	10.33 *	-1.34	-1.32	15.38 *
IC-342777 × Maya	28.37 **	38.87 **	-16.03 **	-9.97 *	25.14 **	3.13	-25.27 **	4.62
IC-342777 × IC-589670	48.32 **	37.99 **	-0.30	2.36	5.58	-18.18 **	-3.98	11.28
SE±	10.64	10.64	15.68	15.68	0.18	0.18	0.75	0.75
CD at 5%	21.78	21.78	32.12	32.12	0.38	0.38	1.54	1.54
CD at 1%	29.39	29.39	43.33	43.33	0.51	0.51	2.07	2.07

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

Table 4: Estimation of percent heterosis based on better parent (BP) and standard check (SC) for days to maturity, biological yield/plant (g), seed yield/plant (g), harvest index (%)

Cross combinations	Days to maturity		Biological yield/plant (g)		Seed yield/plant (g)		Harvest index (%)	
	BP	SC	BP	SC	BP	SC	BP	SC
IC-597919 × Jagannath	-3.18 **	-3.80 **	-0.85	23.68 **	-6.52	5.91	-20.20 **	-14.32 **
IC-597919 × Maya	-2.53 **	-2.53 **	-1.72	22.60 *	-13.48	-1.97	-12.37 *	-20.40 **
IC-597919 × IC-589670	-3.18 **	-3.80 **	41.98 **	77.11 **	-12.57	6.24	-59.18 **	-40.00 **
IC-538719 × Jagannath	-2.54 **	-2.74 **	30.80 **	18.89 *	21.68	18.88	-7.61	-0.23
IC-538719 × Maya	-1.48 *	-1.48 *	48.85 **	31.32 **	37.77 **	25.78 *	-11.00 *	-3.89
IC-538719 × IC-589670	-1.27	-1.48 *	63.32 **	37.73 **	2.84	24.96 *	-38.21 **	-9.17
IC-571678 × Jagannath	-2.54 **	-2.74 **	27.77 **	26.12 **	-1.78	19.54	-22.90 **	-4.86
IC-571678 × Maya	-2.53 **	-2.53 **	42.25 **	40.41 **	6.04	29.06 *	-25.79 **	-8.42
IC-571678 × IC-589670	-1.27	-1.48 *	75.34 **	73.06 **	-5.02	15.60	-54.55 **	-33.19 **
IC-571655 × Jagannath	-3.58 **	-3.38 **	27.30 **	25.62 **	11.80	24.47 *	-12.16 *	-0.91
IC-571655 × Maya	-2.11 **	-1.90 **	14.37	12.86	8.11	20.36	-5.48	6.62
IC-571655 × IC-589670	-3.58 **	-3.38 **	77.07 **	74.73 **	3.92	26.27 *	-50.82 **	-27.71 **
IC-342777 × Jagannath	1.06	0.21	7.57	-2.22	1.18	-1.15	-6.38	0.52
IC-342777 × Maya	-2.74 **	-2.74 **	13.65	0.26	85.12 **	38.92 **	55.15 **	39.23 **
IC-342777 × IC-589670	-1.49 *	-2.32 **	14.15	-5.66	-12.34	6.52	-23.18 **	12.93 *
SE±	1.06	1.06	10.66	10.66	2.19	2.19	0.82	0.82
CD at 5%	2.17	2.17	21.84	21.84	4.49	4.49	1.68	1.68
CD at 1%	2.92	2.92	29.46	29.46	6.06	6.06	2.27	2.27

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

to the positive heterosis for seed yield per plant. Eight cross combinations ranged 10.57% (IC-571678 × IC-589670) to -25.27% (IC-342777 × Maya) showed negatively significant heterosis over better parent. Eight cross combinations showed significant positive useful heterosis ranged 12.82% (IC-571678 × Maya) to 19.49% (IC-571678 × Jagannath) significant heterosis over commercial check. The results of this study agree with Mahto and Haider (2004), Prajapati *et al.* (2007) and Sharmali (2018).

Most plant species benefit from early maturity, but brassicas in particular suffer from yield losses caused by rising temperatures if they wait until maturity; therefore, crosses exhibiting heterosis in negative direction are of immense value for earliness.Twelve cross combinations ranged -1.48% (IC-538719 × Maya) to -3.58% (IC-571655 × IC-589670) showed highly significant negative heterosis over better parent while fourteen cross combinations ranged -1.48% (IC-538719 × Maya) to 9.19% (IC-597919 × IC-589670) showed significant negative heterosis over commercial check. The present findings are in accordance with the findings of Turi *et al.* (2006) and Dar *et al.* (2012).

For biological yield per plant, nine F_1 hybrids ranged 27.30% (IC-571655 × Jagannath) to 77.07% (IC-571655 × IC-589670) showed significant positive heterosis while eleven F_1 hybrids exhibited significant positive useful heterosis ranged 18.89% (IC-538719 × Jagannath) to 77.11% (IC-597919 × IC-589670) over commercial check. Similar findings have been reported by Gupta *et al.* (2010).

In the present investigation the seed yield/plant increased mainly due to increase in average number of siliquae/plant and number of seeds/siliqua. Two cross combinations namely IC-538719 × Maya (37.77%) and IC-342777 × Maya (85.12%) showed highly significant positive heterosis. Whereas six cross combinations showed significant positive heterosis ranged 24.47% (IC-571655 × Jagannath) to 38.92% (IC-342777 × Maya) over commercial check. These findings are in accordance with the results reported by Tripathi *et al.* (2016) and Bharti *et al.* (2018).

Harvest index (%) are one of the important components for seed yield. Only one cross combination namely IC-342777 × Maya (15.15%) exhibited highly significant positive heterosis for harvest index while eleven cross combinations showed significant negative heterosis ranged -11.00% (IC-538719 × Maya) to -19.18% (IC-597919 × IC-589670) over better parent. Two cross combinations namely IC-342777 × IC-589670 (12.93%) and IC-342777 × Maya (39.23%) showed significant positive heterosis over commercial check. Five cross combinations ranged 14.32% (IC-597919 × Jagannath) to - 40.0% (IC-597919 × IC-

Table 5: Estimation of general combining ability (GCA) effect for yield and its component in Indian mustard (*Brassica juncea* L.)

Name of parent	Days to first flowering	Days to 50% flowering	No. of Primary Branches /plant	No. of Secondary Branches /plant	Plant Height (cm)	No. of Siliquae /Plant	Siliqua Length (cm)	Number of Seeds /Siliqua	Days to Maturity	Biological Yield /plant (g)	Seed Yield /plant (g)	Harvest Index (%)
Lines												
IC-597919	-1.22 **	0.60	0.51	1.31	11.98 *	7.57	-0.19 *	-0.57	-1.53 **	13.47 **	-2.82 **	-2.90 **
IC-538719	1.11 *	0.04	0.29	-0.86	-7.95	-5.22	0.17 *	0.33	0.80	-1.41	1.20	0.40
IC-571678	-0.56	-0.62	0.01	1.16	-1.29	-6.70	-0.16 *	0.17	0.24	20.27 **	0.83	-1.38 **
IC-571655	-1.00 *	0.38	-0.45	-1.79 *	1.41	26.04 **	0.09	0.13	-0.76	9.20 *	1.30	-0.07
IC-342777	1.67 **	-0.40	-0.36	0.18	-4.14	-21.70 **	0.10	-0.05	1.24 **	-41.54 **	-0.51	3.94 **
Testers												
Jagannath	-1.93 **	-1.49 **	-0.35	0.67	-16.98 **	-31.88 **	0.21 **	0.81 **	-0.13	-15.14 **	-0.76	0.48
Maya	-0.07	0.71	-0.75 **	-0.34	-0.11	14.88 **	0.30 **	0.13	0.27	-11.27 **	1.04	1.54 **
IC-589670	2.00 **	0.78	1.09 **	-0.33	17.09 **	17.00 **	-0.51 **	-0.93 **	-0.13	26.40 **	-0.28	-2.01 **

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

Table 6: Estimation of specific combining ability (SCA) effects for yield and its component traits in Indian mustard (*Brassica juncea* L.)

Crosses	Days to first flowering	Days to 50% flowering	No. of Primary Branches /plant	No. of Secondary Branches /plant	Plant Height (cm)	Siliquae /Plant	Siliqua Length (cm)	Number of Seeds /Siliqua	Days to Maturity	Biological Yield /plant (g)	Seed Yield /plant (g)	Harvest Index (%)
IC-597919 × Jagannath	-0.18	1.27	0.22	1.30	4.79	67.42 **	0.34 *	0.49	-0.53	-6.84	1.27	1.23 *
IC-597919 × Maya	0.96	-0.27	0.16	0.85	-4.46	-53.72 **	-0.34 *	-0.03	1.07	-12.08	-2.13	-0.81
IC-597919 × IC-589670	-0.78	-1.00	-0.38	-2.16	-0.34	-13.70	-0.01	-0.47	-0.53	18.92 *	0.86	-0.42
IC-538719 × Jagannath	0.49	0.49	-0.29	-2.53 *	0.02	-53.93 **	-0.06	-0.01	-1.20	2.01	-0.11	0.20
IC-538719 × Maya	0.62	-1.04	0.18	2.55 *	0.71	17.37	-0.06	0.27	0.40	13.79	-0.52	-1.45 *
IC-538719 × IC-589670	-1.11	0.56	0.11	-0.02	-0.73	36.56 **	0.11	-0.26	0.80	-15.80 *	0.63	1.25 *
IC-571678 × Jagannath	-0.84	-1.84	0.19	0.85	6.99	-13.18	-0.07	0.15	-0.64	-10.57	0.39	1.24 *
IC-571678 × Maya	-0.38	1.29	0.06	0.80	-13.40	41.65 **	0.10	-0.04	-0.71	3.56	0.51	-0.40
IC-571678 × IC-589670	1.22	0.56	-0.25	-1.64	6.41	-28.46 *	-0.02	-0.11	1.36	7.02	-0.90	-0.84
IC-571655 × Jagannath	-0.40	-0.18	0.31	2.34	1.48	2.02	-0.19	-0.47	-0.64	-0.13	0.92	0.56
IC-571655 × Maya	-1.27	0.29	-0.69	-5.78 **	1.14	18.25	0.21	0.67	1.29	-20.07 *	-1.72	0.71
IC-571655 × IC-589670	1.67 *	-0.11	0.37	3.44 **	-2.63	-20.26	-0.02	-0.20	-0.64	20.20 *	0.80	-1.27 *
IC-342777 × Jagannath	0.93	0.27	-0.44	-1.96	-13.29	-2.32	-0.02	-0.16	3.02 **	15.54 *	-2.47	-3.22 **
IC-342777 × Maya	0.07	-0.27	0.29	1.58	16.00 *	-23.55 *	0.09	-0.88	-2.04 *	14.80	3.86 *	1.95 **
IC-342777 × IC-589670	-1.00	-0.00	0.15	0.38	-2.71	25.87 *	-0.06	1.04	-0.98	-30.34 **	-1.39	1.27 *

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

589670) showed highly significant negative heterosis for harvest index. The similar findings were reported by Dholu *et al.* (2014) and Meena *et al.* (2014).

General combining ability

The results of general combining ability (gca) effects are given in Table 4. For parent IC-597919 showed the significant gca for all the twelve traits except 50% flowering, primary branches, secondary branches, number of siliquae and seeds per siliqua. Genotype IC-538719 shown the significant values for first flowering and siliquae length. For parent IC-571678 was found to be significant value for siliquae length, biological yield and harvest index. Parent IC-571655 showed significant value of general combining ability for first flowering, secondary branches, number of siliquae and biological yield. Parent IC-342777 showed significant value of general combining ability for first flowering, number of siliquae, days to maturity, biological yield and harvest index. For tester Jagannath showed the significant value of general combining ability for all the twelve traits expects primary branches, secondary branches, maturity, seed yield and harvest index. For Maya gca effect showed significant for primary branches, number of siliquae, siliquae length, biological yield and harvest index. For parents IC-589670 shown the significant value for all the twelve traits expects 50% flowering, secondary branches, maturity and seed yield. This was reported similar findings by Synrem *et al*., (2014) and Kumar *et al*., (2019).

The gca effects of a parent can be used to assess its hybridization potential. The findings revealed that the majority of the genotypes had a high degree of correspondence between per se performance and gca effects for the observed characters. This can be attributed to the dominant role of additive × additive types of gene action in the inheritance of these traits. This was reported similar findings by Kumar *et al.* (2019).

Specific combining ability

Specific combining ability is important parameter for judging and selecting superior cross combinations, which might be exploited through heterosis breeding. The SCA effect of crosses for yield and its components are given in Table 5. The estimates of specific combining ability effect revealed that as many as all the fifteen crosses showed significant values as compare with their parents. Cross namely IC-597919 × Jagannath shows the significant values for number siliquae, siliquae length and harvest index. Cross like IC-597919 × Maya shows the significant values number of siliquae and siliquae length followed by IC- 597919 × IC-589670 shows the significant values for biological yield, IC-538719 × Jagannath shows the significant values for secondary branches and number of siliquae, IC-538719 × Maya shows the significant values for secondary branches and harvest index, IC-538719 × IC-589670 shows the significant values for number of siliquae, biological yield and harvest index, IC-571678 × Jagannath shows the significant values for harvest index, IC- 571678 × Maya shows the significant values for number of siliquae per plant, IC-571678 × IC-589670 shows the significant values for number of siliquae. IC-571655 × Maya shows the significant values for secondary branches, biological yield. IC-571655 × IC-589670 shows the significant values for first flowering, secondary branches, biological yield and harvest index. IC-342777 × Jagannath shows the significant values for days to maturity, biological yield and harvest index. IC-342777 × Maya shows the significant values for plant height, number of siliquae, days to maturity, seed yield and harvest index. IC-342777 x IC-589670 shows the significant values for number of siliquae, biological yield and harvest index. This was reported similar findings by Chaudhary *et al.* (2019), Chaurasiya *et al.* (2018), Malviya *et al.* (2019) and Maurya *et al.* (2012).

With one parent act as a good general combiner for a specific feature and the other showing strong per se performance, a cross combination is likely to produce attractive segregants in subsequent generations. Additive gene effects play a crucial role, as evidenced by the significant SCA impacts of crosses between good combiners. Still, two top general combiners may not produce the desired segregants. Also, because high sea effects might get weaker as homozygosity goes up, the generation that comes from superior crossings, which includes both poor and poor general combiners, probably won't do much good. Niranjana *et al.* (2014) also revealed similar results in their study.

Conclusion

Investigations have produced substantial genetic diversity for the majority of the traits. Two different cross combinations demonstrated significant heterobeltiosis in terms of seed yield/plant. The most promising cross for seed yield/plant was determined to be IC-538719 × Maya, following closely by IC-342777 × Maya, based on heterosis estimates and per se performance. When looking at the effects of genetic combiners, the best combiner for most biological yield contributing traits was IC-589670, which had significant and positive GCA effects. When looking at the effects of specific combiners, the best specific combination for most yield-contributing traits, such as plant height and harvest index, was IC-342777 x Maya.

One possible outcome is that IC-342777 x Maya is a good cross for increased yield, while IC-589670 makes excellent general combiners. These crossings, showing promise for additional desired features, could undergo further evaluation in a heterosis breeding program. Simultaneously, by self-generating these hybrids, we could develop excellent genotypes and obtain desired recombinants in successive generations.

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