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Original Research Article

Indian mustard genetic analysis by calculation of combining ability and heterosis

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ABSTRACT
This study, which used a line x tester design and involved crosses of five mustard lines (female parents) and three testers (male parents), determined the best parents and hybrids based on general, specific combining ability and high heterotic performance for yield attributes. The results of the ANOVA demonstrated that the combining ability varied between lines and testers as a result of their interactions. In terms of GCA impacts, IC-317528 is thought to be the finest general combiner for the greatest number of qualities. For the majority of the features, the optimal combination for SCA effects is IC-589669 × IC-571683. The IC-589669 × IC-571655 cross was determined to be the most promising for seed yield/plant based on mean performance and heterosis estimates. As such, it may be further assessed for detailed heterosis assessment or even in a breeding program to find the best cultivar or cultivars.

1. Introduction

Often referred to as Indian mustard, *Brassica juncea* (L.) Czern and Coss. is a classical amphidiploid ($2n$ = 36) that is derived from *B. nigra* ($2n$ = 16) and *B. rapa* ($2n$ = 20). Over 3,000 species and 370 genera make up the family *Brassicaceae*, many of which are now being grown. There are about 100 species in the genus Brassica, including turnips, Brussels sprouts, broccoli, cabbage, cauliflower, and several kinds of mustards and weeds [1].

In addition to edible roots, stems, leaves, buds, and flowers, the *Brassicaceae* family is a significant supplier of industrial oils, medications, forages, and sauces. The common oilseed crops cultivated worldwide for both industrial and edible purposes are species of the Brassica group, which includes *B. juncea*, *B. napus*, *B. campestris*, and *B. carinata*.

Finding genetic characteristics and parental material with high heterosis for yield are crucial stages in the creation of new cultivars. Knowledge of the preferred parent pairings that may indicate a high level of heterotic response is crucial. According to Pingali [2], production costs could be decreased by boosting yield levels and improving input usage efficiency by taking use of heterosis in F_1 hybrids. Given that Indian mustard is a self-pollinating crop, Kempthorne's [3] line x tester mating technique for combing ability analysis is crucial for quickly screening lines.

2. Materials and methods

2.1 Plant materials

Five Indian mustard lines (IC-589669, IC-589670, IC-317528, IC-335852, IC-335858) were used as females and three testers (IC-571648, IC-571655, IC-571683) were used as males as the experimental material (genotypes) for this study. A Line × Tester mating design was used to cross these. As a check, the Shriram Rani is a selection variety.

2.2 Data collection and analysis

Data on various characteristics, including first flowering, 50% flowering, number of primary and secondary branches, plant height (cm), number of siliqua per plant, siliqua length (cm), number of seeds per siliqua, number of days to maturity, biological yield per plant (g), seed yield per plant (g), harvest index (percentage), and test weight (g), were recorded for five chosen plants from each genotype. Data related to different characters were analyzed using Panse and Sukhatme's [4] RBD technique. Windostat Version 9.3 from Indostat Services, Hyderabad, was used to analyze the data.

3. Results

3.1 Estimation of heterobeltiosis and useful heterosis

Economic heterosis (EH) and heterobeltiosis (HB) magnitudes have been computed in the current study. The percentage rise or reduction in the F_1 hybrid value over the better parent and over the standard check (economic heterosis) has been used to express the extent of heterosis. Tables 1-3 show the character-wise outcomes of improved parental and economic heterosis.

Only one cross combination showed -9.23 (IC-335858 × IC-571683) over better parents, however seven cross combinations exhibit significant positive heterobeltiosis ranging from 9.23 (IC-317528 × IC-571655) to 24.19 (IC-335852 × IC-571683). During the commercial check in days to first flowering, six crosses exhibited substantial negative useful heterosis, ranging from -7.24 (IC-335858 × IC-571683) to -15.86 (IC-589670 × IC-571683). No cross showed significantly positive heterosis over the better parent for days to fifty percent flowering, however four cross combinations showed significant negative heterobeltiosis, ranging from -7.33 (IC-335852 × IC-571655) to -10.47 (IC-335858 × IC-571683).

A total of thirteen cross combinations showed substantial negative useful heterosis above the commercial check, ranging from -7.18 (IC-317528 × IC-571648) to -16.92 (IC-589670 × IC-571683). For primary branches, two cross combinations showed significant positive heterobeltiosis ranging from 39.29 (IC-335858 × IC-571648) to 65.38 (IC-589669 × IC-571683) over the better parent, while two crosses showed critically significant heterobeltiosis ranging from -25.81 (IC-335852 × IC-571648) to -25.81 (IC-335852 × IC-571655) over the better parent. No cross showed significant negative useful heterosis for the number of primary branches, however twelve cross combinations showed significant positive useful heterosis ranging from 47.06 (IC-317528 × IC-571655) to 152.94 (IC-589669 × IC-571683) over the commercial check. In contrast to three cross combinations that showed negatively significant heterobeltiosis ranging from -15.94 (IC-589670 × IC-571683) to -47.83 (IC-589670 × IC-571648) over better parent, two cross combinations showed significant positive heterobeltiosis ranging from 20.37 (IC-335858 × IC-571648) to 78.43 (IC-589669 × IC-571683) over better parent. Fourteen of the fifteen cross combinations showed substantial positive beneficial heterosis over the commercial check in number of secondary branches, ranging from 42.42 (IC-317528 × IC-571648) to 175 (IC-589669 × IC-571683). Only one cross combination demonstrated significant positive heterobeltiosis of 20.36 (IC-335858 × IC-571655) over the better parent, whereas six crosses showed negative significant heterobeltiosis ranging from -5.91 (IC-335852 × IC-571683) to -23.14 (IC-317528 × IC-571683). Plant height is a crucial trait by which growth and vigor of plants are measured. None of the crosses showed significant negative useful heterosis, however 14 crosses showed significant positive useful heterosis, ranging from 10.86 (IC-335852 × IC-571655) to 61.20 (IC-335858 × IC-571655). One cross combination was found to have negatively significant heterobeltiosis ranging from -32.24 (IC-335858 × IC-571655) over better parent, while five cross combinations showed significant positive heterobeltiosis for number of siliquae/plant ranging from 20.89 (IC-589669 × IC-571655) to 32.71 (IC-317528 × IC-571648) over better parent. While none of the cross combinations were found to have significant negative useful heterosis varying from over commercial check for number of siliquae/plant, thirteen cross combinations showed significant positive useful heterosis ranging from 35.58 (IC-589670 × IC-571683) to 89.51 (IC-317528 × IC-571655). In breeding strategies aimed at creating high-yielding cultivars, silica length is crucial: Four cross combinations were found to have negatively significant heterobeltiosis ranging from -14.74 (IC-317528 × IC-571655) to -23.90 (IC-589669 × IC-571655) over better parent, while none of the cross combinations showed significant positive heterobeltiosis for siliqua length ranging over better parent. In comparison to the commercial check for siliqua length, twelve cross combinations showed substantial positive useful heterosis, ranging from 21.37 (IC-317528 × IC-571655) to 37.25 (IC-317528 × IC-571648). For this characteristic, there was no negative significant beneficial heterosis in any of the crossings. The only cross combination with a negatively significant heterosis (IC-589669 × IC-571648) was 8.23 over the superior parent. Over the commercial check for days to maturity, fifteen cross combinations showed substantial positive useful heterosis, ranging from 15.80 (IC-589669 × IC-571648) to 26.43 (IC-317528 × IC-571648). In terms of days to maturity, none of the crosses showed negative significant useful heterosis. Heterobeltiosis was not found to be adversely or favorably significant for any cross combination. From 29.03 (IC-317528 × IC-571683) to 54.84 (IC-335858 × IC-571683) over the commercial check for number of seeds/siliqua, all cross combinations showed substantial positive beneficial heterosis. Significant positive heterobeltiosis varies between 45.39 (IC-317528 × IC-571548) and 45.66 (IC-317528 × IC-571683) for two cross combinations and between -27.03 (IC-335852 × IC-5716478) and -32.65 (IC-589670 × IC-571648) for three F_1 combinations over superior parents. For biological yield/plant, three cross combinations showed significant positive beneficial heterosis, ranging from 61.31 (IC-317528 × IC-571655) to 78.20 (IC-317528 × IC-571683). While four crosses displayed significant negative heterobeltiosis ranging from -26.47 (IC-335852 × IC-571648) to -47.24 (IC-589670 × IC-571683) over better parent, only the IC-589669 × IC-571655 cross demonstrated significant positive heterobeltiosis of 26.30 over better parent. Significant positive beneficial heterosis was found in seven F_1 crosses, with seed yield/plant ranging from 48.60 (IC-317528 × IC-571655) to 107.17 (IC-589669 × IC-571655). Five cross combinations range from -28.01 percent (IC-335852 × IC-571648) to -44.65 percent (IC-589670 × IC-571683) over superior parents, while only one cross combination exhibits considerable positive heterobeltiosis at 59.97 percent (IC-589669 × IC-571655). From 39.36 percent (IC-589669 × IC-571683) to 70.17 percent (IC-589669 × IC-571655) over the commercial check for harvest index, four cross combinations showed considerable positive beneficial heterosis. There was no positive significant heterobeltiosis for test weight in any of the crosses. Significant negative heterobeltiosis was seen in two F_1 pairings, with values ranging from -28.03 (IC-317528 × IC-571683) to -30.81 (IC-317528 × IC-571648) over the better parent. Significant positive beneficial heterosis was shown by two cross combinations, with values ranging from 29.50 (IC-589690 × IC-571648) to 38.70 (IC-335852 × IC-571683).

3.2 Combining abaility

Table 4 displays the findings of the analysis of variance (ANOVA) for combining abilities. The variation between lines, testers, and the result of the interaction between lines and testers was displayed using the ANOVA for combining abilities. Harvest index, biological yield/plant, and siliqua length all had significant variance according to the ANOVA for combining ability and line effect. Days to maturity and silica length showed a substantial variation for the tester influence. For every character except siliqua length, number of seeds/siliqua, days to maturity, biological yield/plant, and test weight, the Line × Tester impact revealed positive significance. The findings for general combining ability impacts are displayed in Table 5. The parents, IC-589669, are important for harvest index, siliqua length, seed yield/plant, and secondary branches/plant. Days to first flowering and secondary branches/plants are important indicators of IC-589670. For plant height, number of siliquae/plant, biological yield/plant, harvest index, and test weight, IC-317528 is significant. Primary branches per plant, plant height, seed production per plant, and harvest index are all covered under IC-335852. Primary branches/plant, secondary branches/plant, plant height, and number of siliquae/plant are all covered under IC-335858. Days to initial flowering, days to 50% flowering, secondary branches/plant, plant height, and days to maturity are all covered under IC-571648. The significance of IC-571655 is limited to plant height. IC-571683 is important for plant height, secondary branches/plant, and days to 50% flowering. The findings are displayed in Table 6 for particular combining ability effects. The cross combination IC-589669 × IC-571683 is important for the majority of the qualities that contribute to yield.

4. Discussion

4.1 Estimation of heterobeltiosis

Understanding the relevance and direction is a more crucial step in utilizing hybrid vigor. Finding the greatest F_1 hybrids and using them to identify better transgressive segregants is made easier by the nature and importance of heterosis. The best parent and F_1 hybrids can be used for heterosis breeding and hybridization programs, respectively. In terms of the concept and application of heterosis breeding in autogamous crops, the dominant linked gene hypothesis, which was suggested by Jones [5] and supported by a number of scientists and researchers, seems to be more acceptable.

Earlyness when crossings are significant in the negative was indicated by the number of days until the first flowering and the number of days till 50% blooming. These results are consistent with those of Dholu et al. [6] and Patel et al. [7]. Primary and secondary branches of plants have different types of heterobeltiosis, and positive heterobeltiosis produces a lot of siliques per plant. During 2017–18, the most cross combinations had positive significant heterosis over check. These results are consistent with the findings of Aher et al. [8], Patel et al. [9], and Singh et al. [10]. One crucial characteristic used to gauge a plant's development and vigor is its height. When comparing the plant height to both the check variety and the superior parent, a highly substantial heterosis was noted. Only one cross shows the highest significant heterosis over the superior parent. The presence of both additive gene effects for plant height was indicated by the positive significant heterosis seen in all 14 crosses over the standard check. These findings concur with those of Meena et al. [11]. A better yield per plant was encouraged by the highest number of siliquae per plant. The largest significant heterosis over the standard check was expressed by IC-317528 × IC-571655, indicating the significance of non-additive gene activity for the number of siliquae/plant. The current investigation aligns with the Singh et al. [12] study. Twelve cross combinations out of fifteen displayed significant heterosis in positive over standard checks. More and bulkier seeds would be found in longer siliqua, which would immediately increase yields. The current findings are comparable to those of Meena et al. [11]. One of the most crucial characteristics for increased output is the quantity of seeds or silica. Over the standard check, all 15 cross combinations displayed positive significant heterosis. This study's findings concur with those of Mahto and Haider [13]. For days to maturity, only one of the fifteen crosses exhibited substantial negative heterobeltiosis. For days to maturity, entire cross combinations showed a significant positive heterosis over the standard check. The current results are consistent with those of Dar et al. [14]. Four crosses showed significant negative heterobeltiosis, indicating early maturity over the normal check. The average number of siliquae/plant and the number of seeds/siliqua rose, which was the primary cause of the current study's higher seed yield/plant. Significant, highly positive heterosis over the better parent was only seen in one cross combination. In a favorable direction, eight F_1 combinations showed considerable and positive heterosis over the conventional check. These results are consistent with those of Yadava et al. [15]. A crucial factor in seed production is the harvest index. Only one cross shows significant heterosis in positive over better parent. In comparison to the usual check, four F_1 crosses out of 15 displayed considerable heterosis. These results are consistent with those published by Dholu et al. [6]. Two of the 15 crossings showed a substantial heterosis in test weight between the negative and better parents. Significant heterosis in positive over standard check was seen in two F_1 combinations.

4.2 Combining ability

The total effect split of F_1 progeny into GCA and SCA effects identifies the reasons of heterosis since increased yields in F_1 combinations may be the result of additive (fixable) and/or non-additive (non-fixable) gene activity. In the majority of the yield traits in this investigation, the variance of specialized combining ability (SCA) was greater than the variance of general combining ability (GCA). The majority of non-fixable gene activity for these observations is shown by this observation. In Indian mustard, similar findings were found by Patel et al. [16] and Kumar et al. [17].

Therefore, efforts to expand the genetic foundation for these three crucial features must be made in the future. Parents IC-317528, IC-571648, and IC-335852 might be regarded as good general combiners when additional economic characteristics are taken into account. On the other hand, two parents, IC-589669 and IC-335852, statistically demonstrated a substantial GCA influence for seed yield. Singh and colleagues [18] reported similar results. After reviewing the data on SCA impacts, it was concluded that the situation was comparable to that of GCA effects for plant height, number of secondary branches per plant, and harvest index. For 1000 seed weight, the expression magnitude of one F_1 cross, IC-335852 × IC-571683, was desirable. Kumar and colleagues found similar results [17]. However, other crosses, including IC-589670 × IC-571655, IC-589669 × IC-571683, and IC-589670 × IC-571683, shown a much larger magnitude of SCA effect for seed yield. However, for other key yield characteristics (such the number of primary branches/plant, the number of secondary branches/plant, the number of siliquae/plant, and the harvest index), all crosses were similarly supported by very significant and larger magnitude SCA effects. Additionally, only one cross—IC-589670 × IC-571655—was linked to a highly significant SCA value of seed yield/plant. In Indian mustard, Gupta et al. [19] and Patel et al. [20] reported similar results. Thus, this cross merits greater study on this basis. The mean performance and GCA effects of a parent can be used to evaluate its potential in hybridization. The findings showed that for the studied features, the majority of genotypes exhibited a comparatively high degree of correlation between mean performance and GCA impacts. This is explained by the fact that additive and additive × additive gene action play a major role in the inheritance of these characteristics. Kumar et al. previously reported similar results [21]. Up to one cross combination showed substantial and SCA beneficial impacts on seed yield/plant, according to assessments of particular combining ability effects. Most significantly, the hybrid IC-589670 × IC-571655 showed the beneficial SCA impact. As a result, they produced good hybrid combinations that increased the output of seeds per plant. Bhusan et al. [22] and Prajapati et al. [23] reported similar results. The crosses cannot be categorized based on the parents' high or low GCA values because IC-317528 and IC-571648 both had a strong GCA effect.

Desirable segregants in the segregating generations are anticipated from an F_1 combination that shows both high SCA effects and high per se performance involving at least one parent as a good general combiner for a particular character. Significant SCA effects of those crossovers with good × good combiners demonstrated that additive (fixable) gene effects had a major role. Nevertheless, the two best general combiners/parents might not always provide the desired segregants. In a same vein, relatively little gain is anticipated in their segregating generation from the better crosses that include both poor × poor general combiners, as high SCA effects may fade with higher homozygosity. Niranjana et al. [24] published similar results. According to Jink [25], better-performing F_1 hybrids with averagely inferior general combiners reveal dominance x dominance (epistasis) type of gene activity. Darrah and Hallauer [26] suggested that these crossings might contribute to the creation of a high-yielding homozygous cultivar or cultivars.

A good general combiner (IC-317528) was involved in one of the top four crosses in the current study that showed high SCA effects for yield per plant. This suggests an additive × dominance type of gene interaction that is likely to result in desirable transgressive segregants in subsequent generations. According to Falk et al. [27], the expression of yield and other supporting features in mustard is influenced by (A x A) additive × additive, (A x D) additive × dominance, and epistasis gene activity. The presence of genetic variation in the form of heterozygous loci for certain yield traits may be the reason why crosses involving poor × poor and poor × good general combiners displayed strong SCA effects. Therefore, the best F_1 combinations would be those with strong heterosis, at least one good general combiner parent, high SCA (special combining ability) effects, and good mean performance. The genotype/parent IC-317528 was a competent general combiner based on combining ability. None of the hybrids were deemed promising for commercial exploitation when mean performance, heterosis, and combining ability were taken into account. This could be because, according to Dar et al. [14], there is genetic variation for these features in the form of scattered genes.

5. Conclusions

The cross combination IC-589669 x IC-571655 was determined to be the most promising for total seed yield/plant based on mean performance and estimates of heterosis; as a result, it may be further assessed to be incorporated into future breeding programs for the production of superior genotypes. According to GCA effects, IC-317528 was the best combiner for the majority of yield-contributing characteristics, with significant and positive GCA effects. On the basis of SCA, the best particular F_1 hybrid for the majority of yield-contributing traits was IC-589669 x IC-571683. IC-317528 is an excellent general combiner, and IC-589669 × IC-571683 is the best specialized combination for better yield. These two combinations should be used in future breeding plans to acquire suitable segregants for the evolution of superior hybrids and genotypes.

Table 1: Average performance of F_1 hybrids and degree of heterosis in Indian mustard for number of primary and secondary branches per plant, days to first flowering, and days to 50% blooming.

Crosses	Days to first flowering			Days to 50% flowering			Number of primary branches			Number 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	51.67	9.93	1.97	62.33	1.63	-4.10	7.67	-11.54	35.29	17.67	-1.85	60.61
IC-589669 × IC-571655	45.33	-3.55	-10.53	59.00	1.72	-9.23	9.00	-6.90	58.82	17.33	-13.33	57.58
IC-589669 × IC-571683	44.33	-5.67	-12.50	53.67	-6.94	-17.44	14.33	65.38	152.94	30.33	78.43	175.76
IC-589670 × IC-571648	50.00	17.19	-1.32	61.67	0.54	-5.13	9.00	-6.90	58.82	12.00	-47.83	9.09
IC-589670 × IC-571655	43.67	2.34	-13.82	55.33	-4.60	-14.87	9.33	-3.45	64.71	19.00	-17.39	72.73
IC-589670 × IC-571683	42.67	0.00	-15.79	54.00	-6.36	-16.92	10.00	3.45	76.47	19.33	-15.94	75.76
IC-317528 × IC-571648	50.00	15.38	-1.32	60.33	-1.63	-7.18	9.67	-3.33	70.59	15.67	-14.55	42.42
IC-317528 × IC-571655	47.33	9.23	-6.58	60.33	4.02	-7.18	8.33	-16.67	47.06	18.67	-6.67	69.70
IC-317528 × IC-571683	48.67	12.31	-3.95	59.67	3.47	-8.21	8.67	-13.33	52.94	18.33	0.00	66.67
IC-335852 × IC-571648	43.00	1.57	-15.13	55.00	-10.33	-15.38	7.67	-25.81	35.29	15.67	-12.96	42.42
IC-335852 × IC-571655	49.33	18.40	-2.63	60.00	3.45	-7.69	7.67	-25.81	35.29	19.33	-3.33	75.76
IC-335852 × IC-571683	51.33	24.19	1.32	60.00	4.05	-7.69	8.67	-16.13	52.94	18.00	5.88	63.64
IC-335858 × IC-571648	50.67	-2.56	0.00	60.33	-5.24	-7.18	13.00	39.29	129.41	21.67	20.37	96.97
IC-335858 × IC-571655	49.00	-5.77	-3.29	59.00	-7.33	-9.23	10.33	6.90	82.35	19.00	-5.00	72.73
IC-335858 × IC-571683	47.00	-9.62	-7.24	57.00	-10.47	-12.31	8.67	-7.14	52.94	20.33	12.96	84.85
SE±		1.75	1.75		2.14	2.14		1.07	1.07		1.55	1.55
CD at 5%		3.59	4.85		4.39	4.39		2.18	2.18		3.17	3.17
CD at 1%		4.85	4.85		5.92	5.92		2.94	2.94		4.27	4.27

Table 2: Average performance of F_1 hybrids and degree of heterosis in Indian mustard for day-to-maturity, number of seeds/siliqua, number of siliquae/plant, siliqua length, and plant height.

Crosses	Plant height (cm)			No. of siliquae/plant			Siliqua length (cm)			Days to maturity			Number 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
C-589669 × IC-571648	197.00	0.51	31.04	653.33	29.37	78.83	4.17	-13.55	22.55	141.67	-8.60	15.80	14.67	12.82	41.94
IC-589669 × IC-571655	200.00	-0.66	33.04	663.67	20.89	81.66	3.68	-23.90	8.33	150.67	-2.80	23.16	14.67	12.82	41.94
IC-589669 × IC-571683	189.67	-6.57	26.16	438.67	-16.87	20.07	3.99	-17.15	17.45	149.67	-3.44	22.34	14.00	7.69	35.48
IC-589670 × IC-571648	197.00	0.51	31.04	495.33	-7.59	35.58	4.43	-0.75	30.39	143.67	-5.90	17.44	13.33	0.00	29.03
IC-589670 × IC-571655	202.67	0.66	34.81	652.67	18.88	78.65	3.93	-18.87	15.49	150.67	-1.31	23.16	15.00	12.50	45.16
IC-589670 × IC-571683	190.00	-6.40	26.39	507.67	-5.29	38.96	4.24	-3.78	24.71	152.67	0.00	24.80	13.67	2.50	32.26
IC-317528 × IC-571648	200.00	-2.91	33.04	666.67	32.71	82.48	4.67	4.48	37.25	144.00	-3.36	17.71	13.67	-4.65	32.26
IC-317528 × IC-571655	190.67	-7.44	26.83	692.33	26.11	89.51	4.13	-14.74	21.37	154.67	1.75	26.43	13.67	-4.65	32.26
IC-317528 × IC-571683	158.33	-23.14	5.32	669.00	26.78	83.12	4.41	0.30	29.80	149.33	-1.75	22.07	13.33	-6.98	29.03
IC-335852 × IC-571648	204.00	2.00	35.70	479.33	-6.01	31.20	4.46	-0.15	31.18	148.33	-0.45	21.25	14.67	15.79	41.94
IC-335852 × IC-571655	166.67	-17.22	10.86	588.67	7.23	61.13	4.38	-9.50	28.82	151.67	-0.22	23.98	13.00	5.41	25.81
IC-335852 × IC-571683	191.00	-5.91	27.05	503.33	-4.61	37.77	4.23	-0.78	24.31	153.33	0.88	25.34	14.33	10.26	38.71
IC-335858 × IC-571648	194.33	-2.18	29.27	529.67	-2.16	44.98	4.43	-6.47	30.39	145.33	-4.80	18.80	14.00	0.00	35.48
IC-335858 × IC-571655	242.33	20.36	61.20	372.00	-32.24	1.82	4.51	-6.75	32.75	148.67	-2.62	21.53	15.67	11.90	51.61
IC-335858 × IC-571683	173.33	-14.61	15.30	552.00	1.97	51.09	4.50	-5.06	32.35	150.33	-1.53	22.89	16.00	14.29	54.84
S.E±		5.62	5.62		54.17	54.17		0.33	0.33		5.06	5.06		1.21	1.21
C.D at 5%		11.52	11.52					0.68	0.68					2.47	2.47
C.D at 1%		15.54	15.54					0.92	0.92					3.34	3.34

Table 3: Average performance of F_1 hybrids and degree of heterosis in Indian mustard for harvest index, test weight, biological yield/plant, and seed yield/plant.

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	164.33	-6.45	34.33	53.67	21.97	95.63	33.24	6.64	48.15	4.07	16.06	22.10
IC-589669 × IC-571655	152.67	-19.22	24.80	56.83	26.30	107.17	38.18	59.97	70.17	3.67	15.41	10.10
IC-589669 × IC-571683	152.00	-13.47	24.25	39.67	-17.93	44.59	31.27	-5.54	39.36	4.28	14.04	28.30
IC-589670 × IC-571648	121.00	-32.65	-1.09	37.43	-14.92	36.45	31.72	1.78	41.39	4.32	23.10	29.50
IC-589670 × IC-571655	170.33	-9.88	39.24	47.90	6.44	74.61	28.55	19.64	27.26	4.05	20.68	21.40
IC-589670 × IC-571683	139.33	-22.45	13.90	25.50	-47.24	-7.05	18.32	-44.65	-18.35	3.49	-7.02	4.60
IC-317528 × IC-571648	210.33	45.39	71.93	36.60	-16.82	33.41	18.12	-41.87	-19.24	3.14	-30.81	-5.70
IC-317528 × IC-571655	197.33	4.41	61.31	40.77	-9.41	48.60	20.67	-13.41	-7.89	3.74	-17.75	12.10
IC-317528 × IC-571683	218.00	45.66	78.20	46.33	-4.14	68.89	21.37	-35.43	-4.74	3.27	-28.03	-1.90
IC-335852 × IC-571648	153.00	-27.03	25.07	33.70	-26.47	22.84	22.44	-28.01	0.01	3.53	-4.85	6.00
IC-335852 × IC-571655	145.00	-30.84	18.53	32.27	-29.60	17.62	22.38	-6.24	-0.27	3.31	-10.95	-0.80
IC-335852 × IC-571683	166.67	-20.51	36.24	38.00	-21.38	38.52	23.45	-29.16	4.50	4.62	23.29	38.70
IC-335858 × IC-571648	167.67	-1.95	37.06	42.27	-14.09	54.07	25.31	-18.80	12.81	4.05	5.10	21.50
IC-335858 × IC-571655	154.33	-18.34	26.16	33.67	-31.57	22.72	22.60	-23.40	0.74	4.15	7.61	24.40
IC-335858 × IC-571683	148.67	-13.06	21.53	41.80	-15.04	52.37	28.86	-12.80	28.64	4.13	7.27	24.00
SE±		24.66	24.66		5.45	5.45		3.48	3.48		0.48	0.48
CD at 5%		50.51	50.51		11.16	11.16		7.12	7.12		0.94	0.94
CD at 1%		68.14	68.14		15.05	15.05		9.51	9.51		1.32	1.32

Table 4: Variance analysis of combining abilities for 13-character Line×Tester analysis.

Source of variation	d.f.	Days to first flowering	Days to 50% flowering	Number of primary branches/plant	Number of secondary branches/plant	Plant height (cm)	Number of siliquae/ plant	Siliqua Length (cm)
Replications	2.00	1.84	0.41	0.54	0.10	42.30	187.19	0.03
Crosses	14.00	28.87	23.42	10.85	45.95	1090.99	29367.95	0.21
Line Effect	4.00	17.48	11.20	10.52	40.81	583.30	47407.25	0.40
Tester Effect	2.00	24.27	35.82	4.87	84.29	1820.00	13384.02	0.35
Line×Tester Eff.	8.00	35.71	26.43	12.51	38.93	1162.58	24344.27	0.07
Error	44.00	4.61	6.88	1.70	3.59	47.46	4402.19	0.17
Total	68.00	16.34	12.43	3.51	13.31	291.72	9800.81	0.18

Source of variation	d.f.	Number of seeds/siliqua	Days to maturity	Biological yield/plant(g)	Seed yield/plant (g)	Harvest Index (%)	Test Weight (g)
Replications	2.00	0.88	9.70	466.84	15.56	0.45	0.06
Crosses	14.00	2.26	42.97	2094.66	203.79	105.09	0.58
Line Effect	4.00	3.58	18.30	5839.92	315.44	255.47	0.72
Tester Effect	2.00	0.42	215.76	10.56	61.86	14.26	0.13
Line×Tester Eff.	8.00	2.06	12.12	743.06	183.44	52.61	0.62
Error	44.00	2.19	38.42	912.16	44.52	18.13	0.34
Total	68.00	2.36	37.86	1223.47	83.40	39.88	0.42

Table 5: Estimates of the impacts of general combining ability (GCA) for different Indian mustard characters.

Character Genotype	Days to first flowering	Days to 50% flowering	Number of primary branches/ plant	Number of secondary branches/ plant	Plant height (cm)	Number of siliquae/ plant	Siliqua length (cm)	Number of seeds/ siliqua	Days to maturity	Biological yield/ plant (g)	Seed yield/ plant (g)	Harvest index (%)	Test weight (g)
IC-589669	-0.49	-0.18	0.87	2.96	2.42	20.93	-0.33	0.20	-1.64	-7.71	9.63	8.46	0.15
IC-589670	-2.16	-1.51	-0.02	-2.04	3.42	-12.40	-0.08	-0.24	0.02	-20.49	-3.48	0.43	0.10
IC-317528	1.07	1.60	-0.58	-1.27	-10.13	111.71	0.12	-0.69	0.36	44.51	0.81	-5.71	-0.47
IC-335852	0.29	-0.18	-1.47	-1.16	-5.91	-40.51	0.08	-0.24	2.13	-9.16	-5.77	-3.01	-0.03
IC-335858	1.29	0.27	1.20	1.51	10.20	-79.73	0.20	0.98	-0.87	-7.16	-1.18	-0.17	0.26
IC-571648	1.47	1.42	-0.07	-2.29	5.33	0.58	0.15	-0.18	-4.38	-0.78	0.31	0.40	-0.03
IC-571655	-0.67	0.22	-0.53	-0.16	7.33	29.58	-0.15	0.16	2.29	-0.11	1.86	0.71	-0.07
IC-571683	-0.80	-1.64	0.60	2.44	-12.67	-30.16	0.00	0.02	2.09	0.89	-2.17	-1.11	0.10
CD 95% GCA (Line)	1.47	1.79	0.89	1.29	4.70	45.30	0.28	1.01	4.23	20.62	4.56	2.91	0.40
CD 95% GCA (Tester)	1.14	1.39	0.69	1.00	3.64	35.09	0.22	0.78	3.28	15.97	3.53	2.25	0.31

Table 6: Estimates of the impacts of specific combining ability (SCA) for different Indian mustard characteristics.

Character Genotype	Days to first flowering	Days to 50% flowering	Number of primary branches/ plant	Number of secondary branches/ plant	Plant height (cm)	Number of siliquae/ plant	Siliqua length (cm)	Number of seeds/ siliqua	Days to maturity	Biological yield/ plant(g)	Seed yield/ plant (g)	Harvest index (%)
IIC-589669 × IC-5716483.09	2.58	-2.60	-1.82	-3.89	67.53	0.06	0.40	-1.29	8.78	3.30	-1.39	0.10
IC-589669 × IC-571655-1.11	0.44	-0.80	-4.29	-2.89	48.87	-0.11	0.07	1.04	-3.56	4.92	3.24	-0.26
IC-589669 × IC-571683-1.98	-3.02	3.40	6.11	6.78	-116.40	0.05	-0.47	0.24	-5.22	-8.22	-1.85	0.17
IC-589670 × IC-5716483.09	3.24	-0.38	-2.49	-4.89	-57.13	0.08	-0.49	-0.96	-21.78	0.18	5.12	0.40
IC-589670 × IC-571655-1.11	-1.89	0.42	2.38	-1.22	71.20	-0.12	0.84	-0.62	26.89	9.10	1.64	0.17
IC-589670 × IC-571683-1.98	-1.36	-0.04	0.11	6.11	-14.07	0.04	-0.36	1.58	-5.11	-9.28	-6.77	-0.57
IC-317528 × IC-571648-0.13	-1.20	0.84	0.40	11.67	-9.91	0.11	0.29	-0.96	2.56	-4.94	-2.33	-0.21
IC-317528 × IC-571655-0.67	0.00	-0.02	1.27	0.33	-13.24	-0.12	-0.04	3.04	-11.11	-2.33	-0.10	0.43
IC-317528 × IC-5716830.80	1.20	-0.82	-1.67	-12.00	23.16	0.01	-0.24	-2.09	8.56	7.27	2.43	-0.22
IC-335852 × IC-571648-6.36	-4.76	-0.27	0.29	11.44	-45.02	-0.05	0.84	1.60	-1.11	-1.26	-0.72	-0.26
IC-335852 × IC-5716552.11	1.44	0.20	1.82	-27.89	35.31	0.18	-1.16	-1.73	-9.78	-4.25	-1.09	-0.44
IC-335852 × IC-5716834.24	3.31	0.07	-2.11	16.44	9.71	-0.13	0.31	0.13	10.89	5.51	1.80	0.70
IC-335858 × IC-5716480.31	0.13	2.40	3.62	-14.33	44.53	-0.20	-1.04	1.60	11.56	2.72	-0.68	-0.03
IC-335858 × IC-5716550.78	0.00	0.20	-1.18	31.67	-142.13	0.18	0.29	-1.73	-2.44	-7.44	-3.70	0.11
IC-335858 × IC-571683-1.09	-0.13	-2.60	-2.44	-17.33	97.60	0.02	0.76	0.13	-9.11	4.72	4.38	-0.08
CD 95% SCA	3.10	1.54	2.24	8.15	78.47	0.48	1.75	7.33	35.72	7.89	5.04	0.69

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