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Character association and path analysis of yield and yield-contributing traits in Indian mustard (*Brassica juncea* L. czern and coss.)

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Abstract
The experimental material consisted of 50 genotypes of Indian mustard, grown in a Randomised Block Design to estimate heritability, genetic advance, correlation, and path analysis. Observations on twelve important yield traits were recorded on five competitive plants randomly selected from each plot, while flowering traits were recorded on a row basis. The analysis of variance revealed significant differences among genotypes for all studied characters, indicating ample genetic variability. High heritability estimates in the broad sense, along with high genetic advance as a percentage of the mean, were observed for the number of siliquae per plant and biological yield. Association studies revealed that days to 50% flowering showed a significant positive correlation with seed yield. Harvest index exhibited the highest positive direct effect on seed yield, followed by biological yield per plant, days to 50% flowering, number of primary branches, siliqua length, number of siliquae per plant, and plant height.

Keywords: Heritability, genetic variability, genetic advance, cluster analysis, path analysis, correlation

Introduction
Mustard (*Brassica juncea* L.) is a member of the Cruciferae family under the genus *Brassica*, which comprises 37 species. Among them, *Brassica campestris*, commonly known as rapeseed, is the most widely cultivated. Indian mustard, or brown mustard, is a natural amphidiploid (2n = 36) formed by hybridization between *Brassica rapa* (2n = 20) and *Brassica nigra* (2n = 16). Although it is predominantly a self-pollinated crop, up to 30% natural cross-pollination can occur under field conditions, depending on wind and pollinator activity. It originated in Asia, with its primary centre of diversity in China (Vaughan, 1977) [28]. Mustard was introduced to India from China and subsequently spread to Afghanistan and other regions. Although it is largely self-pollinated, cross-pollination rates may vary from 0 to 16.5%. In India, mustard is cultivated as a rabi crop (Singh *et al.*, 2013).

Mustard can thrive in both tropical and temperate climates. It requires temperatures ranging between 10°C and 25°C and grows best in areas receiving 625-1000 mm of annual rainfall (Reddy, 2015) [15]. The crop adapts to various soil types, from sandy loam to clay loam, but performs best in well-drained light loam soils. Waterlogged or heavy soils are unsuitable. The ideal soil pH ranges from 6.0 to 7.0 (Madhusoodanan *et al.*, 2016) [11].

Heritability (in the broad sense), phenotypic and genotypic coefficients of variation, and genetic advance as a percentage of the mean are essential parameters for making effective selections (Lodhi, 2014). Evaluating available germplasm enables identification of genetic sources for desirable traits (Tomooka, 1992) [27].

Understanding genetic diversity helps breeders select appropriate parents for targeted breeding programs. Evaluating genetic diversity in a germplasm collection simplifies classification and facilitates the identification of useful genotypes for specific breeding goals (Choudhary *et al.*, 2016) [3]. Hence, the current study was designed to evaluate and categorize fifty genotypes of Indian mustard using principal component and factor analysis. Genetic parameters such as heritability and genetic advance are crucial in selecting genotypes with greater potential by eliminating environmental effects from total variability (Salam *et al.*, 2017) [16].

Materials and Methods

The experiment was conducted at the Experimental Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib. The farm is located at an altitude of 246 meters above mean sea level, at 30°27' north latitude and between 76°04' and 76°38' east longitude. It lies 42 km from Chandigarh and 35 km from Patiala.

A total of 50 genotypes of Indian mustard (*Brassica juncea* L.) were evaluated. These included:

IC 589686, IC 405235, IC 589690, IC 447111, IC 571630, IC 355856, IC 5716277, IC 571661, IC 571630, IC 571662, IC 311734, IC 571697, IC 589680, IC 589670, IC 597991, IC 335858, IC 538719, IC 571678, IC 571648, IC 317528, IC 401560, IC 393232, IC 597879, IC 424414, IC 1976789, IC 335852, IC 571655, IC 589681, IC 571649, IC 339953, IC 571668, IC 589662, IC 589669, IC 598692, IC 599679, IC 342777, IC 338586, and local varieties such as Ashirwad, Geeta, CS-54, Kranti, Maya, Jaganath, Navinder Roy, BR-40, and Jawahar Mustard Kranti.

The crop was sown in a Randomized Block Design (RBD) with three replications. The genotypes were obtained from two major research institutions:

- **NBPGR**: National Bureau of Plant Genetic Resources, New Delhi
- **IIRMR**: Indian Institute of Rapeseed-Mustard Research, Bharatpur, Rajasthan

In each replication, five competitive plants were randomly selected for recording observations on all traits. For statistical analysis, the mean values from each replication were used for each character.

The following twelve quantitative traits were recorded:

- Days to first flowering
- Days to 50% flowering
- Number of primary branches per plant
- Number of secondary branches per plant
- Plant height (cm)
- Number of siliquae per plant
- Siliqua length (cm)
- Number of seeds per siliqua
- Days to maturity
- Biological yield per plant (g)
- Seed yield per plant (g)
- Harvest index (%)

Results and Discussion

Analysis of Variance

The analysis of variance conducted for 50 treatments across 12 yield and yield-contributing traits during the rabi season of 2022-2023 revealed significant differences for all characters studied. These included: days to first flowering, days to 50% flowering, number of primary branches, number of secondary branches, plant height, number of siliquae per plant, siliqua length, number of seeds per siliqua, days to maturity, biological yield, seed yield per plant, and harvest index. The significant mean sum of squares for all these traits confirmed the presence of substantial genetic variability among genotypes. Similar findings were also reported by Pant and Singh (2001) and Shekhawat *et al.* (2014) [13, 35].

Heritability and Genetic Advance: High heritability estimates were observed for the number of siliquae per plant (98.2%), followed by biological yield (78.1%), harvest index (73.1%), seed yield per plant (67.942%), days to first flowering (60.839%), and days to 50% flowering (50.255%). Moderate to low heritability was recorded for the number of seeds per siliqua (35.0%), number of primary branches (40.0%), plant height (35.0%), and the number of secondary branches (18.648%), siliqua length (25.0%), and days to maturity (4.1%).

High heritability indicates that most of the observed phenotypic variation is governed by genetic factors rather than environmental influences. Thus, simple selection would be effective for improving these traits. In contrast, the low heritability observed in days to maturity suggests that environmental factors play a greater role than genetic ones in the expression of this trait.

The highest estimates of genetic advance were recorded for number of siliquae per plant (145.80), followed by biological yield per plant (26.64), harvest index (6.74), seed yield per plant (8.012), days to first flowering (5.603), days to 50% flowering (5.246), number of seeds per siliqua (2.10), number of primary branches (1.20), plant height (8.50), number of secondary branches (1.231), siliqua length (0.50), and days to maturity (1.80).

In terms of genetic advance as percent of mean, the highest value was again observed for number of siliquae per plant (65.7%), followed by harvest index (43.3%), seed yield (39.991%), biological yield per plant (20.5%), number of seeds per siliqua (12.0%), number of primary branches (10.0%), number of secondary branches (8.019%), days to first flowering (7.395%), days to 50% flowering (6.204%), siliqua length (5.0%), plant height (6.5%), and days to maturity (1.5%). These results indicate that traits with low GA as percent of mean, such as days to maturity, offer limited scope for improvement through direct selection.

Traits such as number of siliquae per plant, biological yield, harvest index, and seed yield per plant showed both high heritability and high genetic advance, suggesting the influence of additive gene action. For traits such as harvest index, total number of branches per plant, and days to 50% flowering, high heritability was coupled with moderate genetic advance, indicating that both additive and non-additive gene effects might be involved. These findings are in accordance with those reported by Mehla *et al.* (2003), Brar *et al.* (2007), and Singh *et al.* (2011) [2, 12].

At the 1% level of significance, genetic advance as percent of mean was highest for number of siliquae per plant, followed by harvest index and seed yield. These results align with earlier findings reported by Singh *et al.* (2011), Singh *et al.* (2012), and Tiwari *et al.* (2016) [20, 22, 25], who also observed high heritability and high genetic advance for these traits.

The presence of high heritability in combination with high genetic advance implies that additive gene effects play a major role in the inheritance of these characters, making them ideal for improvement through simple selection. For traits such as number of siliquae per plant and biological yield, where high heritability was associated with moderate genetic advance at the 1% significance level, it suggests that these characters are governed by both additive and non-additive gene action with minimal environmental influence. Similar results were also reported by Synrem *et al.* (2014) [24].

Moderate heritability combined with moderate genetic advance suggests limited environmental influence, but the involvement of both additive and non-additive gene action implies that selection may lead to only modest gains in the next generations. Traits like plant height and siliqua length, which showed low heritability and genetic advance, may not respond effectively to selection. These findings are consistent with the reports of Johnson *et al.* (1995) and Tiwari (2019) [9, 26].

Genetic Variability (PCV and GCV)

Analysis of variance revealed significant differences for all twelve traits studied. The estimates of genetic variability parameters are presented in Table 4.2. The results clearly indicate that the phenotypic coefficient of variation (PCV) was higher than the corresponding genotypic coefficient of variation (GCV) for all traits, suggesting the influence of environmental factors on trait expression.

Among the yield and yield-contributing traits, the highest PCV and GCV were recorded for number of siliquae per plant (32.453 and 32.163, respectively), followed by harvest index (28.785 and 24.602), seed yield (28.573 and 23.552), number of secondary branches (20.874 and 9.014), number of primary branches (19.199 and 9.470), number of seeds per siliqua (17.767 and 9.793), siliqua length (13.559 and 4.643), biological yield (12.746 and 11.263), plant height (7.589 and 3.333), days to 50% flowering (5.993 and 4.248), days to first flowering (5.901 and 4.602), and days to maturity (1.659 and 0.106), respectively.

These findings indicate that for all traits, PCV was consistently higher than GCV, confirming the role of environmental factors in the expression of these traits. The degree of variation across 50 genotypes of Indian mustard demonstrated considerable genetic diversity.

Table 4.2 also provides phenotypic and genotypic coefficients of variation for 14 traits. For all characters, the phenotypic coefficients were slightly higher than the genotypic ones, indicating minor environmental influence. Similar trends were reported by Akabari and Niranjana (2015), Dilip *et al.* (2016), Srivastava *et al.* (2016), and Hyder *et al.* (2021) [1, 6, 8, 23].

The highest PCV and GCV values were found for number of siliquae per plant, followed by traits like seed yield and harvest index. This suggests that substantial variability exists for these traits, offering scope for effective selection. In contrast, traits like days to maturity showed low PCV and GCV values, confirming limited variability. Devi *et al.* (2017) [4] also observed low PCV and GCV for days to maturity, further supporting this result.

Correlation Coefficient Analysis

Phenotypic Correlation

Correlation coefficient analysis, first introduced by Karl Pearson in 1902, is a statistical method to assess the strength and direction of the relationship between two or more variables. Phenotypic correlation coefficients are presented in Table 4.3. In general, positive correlations are desirable in plant breeding, as they enable simultaneous improvement of multiple traits, whereas negative correlations may hinder combined improvement.

- Days to first flowering showed a strong positive correlation with days to 50% flowering (0.748), but a negative correlation with number of siliquae per plant (-0.446), biological yield per plant (-0.107), siliqua length (-0.150), and seed yield per plant (-0.105).
- Days to 50% flowering was significantly positively correlated with days to first flowering (0.748), and days to maturity (0.090), but showed negative correlations with number of siliquae per plant (-0.299), number of primary branches (-0.144), biological yield (-0.141), siliqua length (-0.137), and number of secondary branches (-0.103).
- Number of primary branches had a significant positive correlation with number of secondary branches (0.499), harvest index (0.201), seed yield per plant (0.207), number of siliquae per plant (0.174), number of seeds per siliqua (0.197), and siliqua length (0.065). It showed negative correlation with plant height (-0.080), biological yield (-0.023), and days to maturity (-0.023).
- Number of secondary branches showed positive correlation with number of siliquae per plant (0.179), siliqua length (0.002), harvest index (0.191), number of seeds per siliqua (0.192), and seed yield per plant (0.168), but was negatively correlated with plant height (-0.055) and biological yield (-0.061).
- Plant height exhibited positive correlation with siliqua length (0.097), number of seeds per siliqua (0.176), and biological yield (0.122), while negatively correlated with number of siliquae per plant (-0.066), seed yield per plant (-0.157), and harvest index (-0.214).
- Number of siliquae per plant showed positive correlation with siliqua length (0.163), number of seeds per siliqua (0.242), biological yield (0.029), seed yield (0.123), and harvest index (0.098).
- Siliqua length had positive correlations with number of seeds per siliqua (0.304), biological yield (0.005), seed yield per plant (0.110), and harvest index (0.086), with no negative correlation observed.
- Number of seeds per siliqua showed significant positive correlation with seed yield per plant (0.202) and harvest index (0.190), but a slight negative correlation with biological yield (-0.002).
- Days to maturity exhibited positive correlations with number of primary branches (0.153) and number of siliquae per plant (0.50), and negative correlations with number of secondary branches (-0.013), plant height (-0.010), siliqua length (-0.063), number of seeds per siliqua (-0.001), biological yield (-0.013), seed yield (-0.048), and harvest index (-0.041).
- Biological yield per plant showed a significant positive correlation with seed yield per plant (0.197) and a significant negative correlation with harvest index (-0.264).
- Seed yield per plant had strong positive correlation with number of seeds per siliqua (0.202), number of primary branches (0.207), and negative correlation with plant height (-0.157) and days to first flowering (-0.105).
- Harvest index showed a strong positive correlation with seed yield (0.885) and number of secondary branches (0.191), while being negatively correlated with biological yield (-0.264) and plant height (-0.214

Genotypic Correlation

Correlation coefficient analysis, first introduced by Karl Pearson in 1902, is a statistical method used to measure the degree and direction of association between two or more variables. The genotypic correlation coefficients are presented in Table 4.5.

Days to first flowering showed a highly significant positive correlation with days to 50% flowering (0.981), days to maturity (1.207), and plant height (0.338), whereas it exhibited a significant negative correlation with number of primary branches (-0.290), number of secondary branches (-0.491), and number of siliquae per plant (-0.579). Days to 50% flowering was positively and significantly correlated with days to maturity (2.158) and plant height (0.286), but negatively correlated with number of secondary branches (-0.357), biological yield per plant (-0.231), and number of siliquae per plant (-0.431).

Days to maturity was positively and significantly correlated with number of primary branches (1.835), number of siliquae per plant (2.342), and days to 50% flowering (2.158), while it was negatively correlated with plant height (-2.484), number of seeds per siliqua (-1.677), and seed yield (-0.748).

Number of primary branches showed a significant positive correlation with days to maturity (1.835), number of siliquae per plant (0.334), siliqua length (0.814), and seed yield (0.247), but negative correlation with plant height (-0.540) and biological yield (-0.141). Number of secondary branches had a positive correlation with number of primary branches (1.098) and days to maturity (1.541), and a negative correlation with days to first flowering (-0.491), days to 50% flowering (-0.357), and plant height (-0.707).

Plant height showed significant positive correlation with number of primary branches (6.334) and days to 50% flowering (0.286), while it was negatively correlated with siliqua length (-0.292) and harvest index (-0.609).

Number of siliquae per plant was positively correlated with number of secondary branches (0.431), number of primary branches (0.334), and days to maturity (2.342), whereas it had a negative correlation with days to 50% flowering (-0.431) and plant height (-0.166).

Siliqua length showed a significant positive correlation with number of primary branches (0.814), number of seeds per siliqua (0.764), and number of siliquae per plant (0.468), while it had a negative correlation with days to maturity (-0.521) and days to 50% flowering (-0.395).

Number of seeds per siliqua showed positive correlation with harvest index (0.316), siliqua length (0.764), and number of siliquae per plant (0.427), but negative correlation with days to maturity (-1.677) and days to 50% flowering (-0.175).

Biological yield per plant was positively correlated with plant height (6.330) and days to maturity (0.194), but negatively correlated with harvest index (-0.316) and days to 50% flowering (-0.231).

Seed yield showed a significant positive correlation with number of primary branches (0.247), number of secondary branches (0.378), and siliqua length (0.461), while it had a negative correlation with days to first flowering (-0.216), days to maturity (-0.748), and plant height (-0.464).

Harvest index showed significant positive correlation with number of primary branches (0.263), number of secondary branches (0.388), and siliqua length (0.256), and a negative correlation with biological yield (-0.364), plant height (-0.609), and days to maturity (-0.833).

These data indicate that number of siliquae per plant, siliqua length, biological yield, and seed yield were positively and significantly associated with seed yield per plant at the genotypic level. Similar observations were reported by Ray *et al.* (2014) and Priyamedha *et al.* (2013) [14, 34]. Phenotypic associations also revealed that seed yield, harvest index, number of seeds per siliqua, and siliqua length were significantly and positively correlated with seed yield per plant. Similar findings were recorded by Gangapur *et al.* (2009) and Lyngdsoh *et al.* (2017) [7, 10].

Path Analysis: Path analysis, introduced by Wright in 1921 [29] and first applied to plant selection by Dewey and Lu in 1959 [5], provides insight into the cause-and-effect relationships between variables. It quantifies both direct and indirect effects of different independent traits on a dependent trait. Path coefficient analysis thus assists in selecting superior genotypes from diverse breeding populations. Phenotypic path coefficients for yield and its contributing characters are presented in Table 4.6.

4.5.1 Path Analysis at the Phenotypic Level

Direct Effects at the Phenotypic Level

The highest positive direct effect on seed yield per plant was observed for harvest index (1.00078), followed by biological yield per plant (0.46339), days to 50% flowering (0.02774), number of primary branches (0.01976), siliqua length (0.00857), number of siliquae per plant (0.00179), and plant height (0.00091). Strongly negative direct effects were recorded for the number of secondary branches (-0.00448), days to maturity (-0.00615), and days to first flowering (-0.0122).

Indirect Effects at the Phenotypic Level

- **Days to first flowering**: Maximum positive indirect effect via days to 50% flowering (0.02075); maximum negative effect via harvest index (-0.05644) and biological yield (-0.0494).
- **Days to 50% flowering**: Positive effect via number of secondary branches (0.00046); negative via biological yield (-0.06511) and harvest index (-0.01715).
- **Number of primary branches**: Positive via harvest index (0.20119); negative via biological yield (-0.01059).
- **Number of secondary branches**: Positive via harvest index (0.19104); negative via biological yield (-0.0282).
- **Plant height**: Positive via biological yield (0.05636); negative via harvest index (-0.21405).
- **Number of siliquae per plant**: Positive via harvest index (0.09804); negative via days to 50% flowering (-0.00829).
- **Siliqua length**: Positive via harvest index (0.19052); negative via days to 50% flowering (-0.00132).
- **Number of seeds per siliqua**: Positive via harvest index (0.19052); negative via days to 50% flowering (-0.00132).
- **Days to maturity**: Positive via number of primary branches (0.00303); negative via harvest index (-0.04063).
- **Biological yield per plant**: Positive via number of seeds per siliqua (0.000); negative via harvest index (-0.26406).
- **Harvest index**: Positive via number of primary branches (0.00397); negative via biological yield (-0.250).

Path Analysis at the Genotypic Level

Path coefficient analysis at the genotypic level provides insights into the direct and indirect effects of yield-contributing traits on seed yield per plant. The phenotypic path coefficient values discussed in this section are presented in Table 4.6.

Direct Effects at the Genotypic Level

Analysis of direct effects revealed that the highest positive direct effect on seed yield per plant was exerted by harvest index (0.82523), followed by number of seeds per siliqua (0.59951), biological yield (0.56491), plant height (0.53913), days to 50% flowering (0.17803), number of secondary branches (0.02098), number of siliquae per plant (0.01033), siliqua length (0.29233), and days to maturity (0.00566).

In contrast, days to first flowering (-0.19844) and number of secondary branches (-0.48289) showed highly negative direct effects on seed yield per plant.

Indirect Effects at the Genotypic Level

- **Days to First Flowering**: Positive indirect effects were observed via number of secondary branches (0.23687), days to 50% flowering (0.17473), siliqua length (0.05001), days to maturity (0.00684), number of primary branches (0.00609), and number of siliquae per plant (0.00598). Negative indirect effects were recorded via plant height (-0.18240), harvest index (-0.09801), number of seeds per siliqua (-0.10657), and biological yield (-0.11129).
- **Days to 50% flowering**: Exhibited positive indirect effects through number of secondary branches (0.17244), siliqua length (0.11557), days to maturity (0.01223), number of primary branches (0.00481), and number of siliquae per plant (0.00445). Negative indirect effects were through the number of seeds per siliqua (-0.1051), harvest index (-0.03473), biological yield (-0.13046), plant height (-0.15437), and days to first flowering (-0.19477).
- **Days to Maturity**: Showed positive indirect effects via days to 50% flowering (0.38424), plant height (1.33893), siliqua length (0.15239), and biological yield (0.1097). Negative effects were recorded through the number of siliquae per plant (-0.02418), the number of primary branches (-0.03848), days to first flowering (-0.23955), harvest index (-0.68743), number of secondary branches (-0.74394), and number of seeds per siliqua (-1.00542).
- **Number of Primary Branches**: Showed positive indirect effects through plant height (0.29108), harvest index (0.21683), number of seeds per siliqua (0.5841), days to maturity (0.01039), and days to first flowering (0.05759). Negative indirect effects were via the number of siliquae per plant (-0.00344), days to 50% flowering (-0.04085), biological yield (-0.07992), siliqua length (-0.23782), and number of secondary branches (-0.53018).
- **Number of Secondary Branches**: Positive effects were seen through plant height (0.38096), harvest index (0.32038), number of seeds per siliqua (0.29188), days to first flowering (0.09734), and days to maturity (0.00873). Negative effects were recorded via number of siliquae per plant (-0.00445), number of primary branches (-0.02303), siliqua length (-0.05887), days to 50% flowering (-0.06357), and biological yield (-0.08874).
- **Plant Height**: Positive effects were through biological yield (0.18651), number of secondary branches (0.34122), days to 50% flowering (0.05097), siliqua length (0.08538), number of primary branches (0.01133), and number of siliquae per plant (0.00171). Negative indirect effects were via days to maturity (-1.507), days to first flowering (-0.06714), number of seeds per siliqua (-1.8026), and harvest index (-0.50254).
- **Number of Siliquae per Plant**: Positive indirect effects were observed through number of seeds per siliqua (0.25616), days to first flowering (0.11492), harvest index (0.09183), plant height (0.08929), biological yield (0.02593), and days to maturity (0.01326). Negative effects were recorded through the number of primary branches (-0.007), days to 50% flowering (-0.07673), siliqua length (-0.13688), and number of secondary branches (-0.20815).
- **Siliqua Length**: Positive indirect effects were contributed by the number of seeds per siliqua (0.45793), harvest index (0.21096), plant height (0.15746), biological yield (0.08525), and days to first flowering (0.03395). Negative effects included days to maturity (-0.00295), number of siliquae per plant (-0.00484), number of primary branches (-0.01707), days to 50% flowering (-0.07038), and number of secondary branches (-0.09724).
- **Number of Seeds per Siliqua**: Positive effects came from harvest index (0.26103), days to first flowering (0.03528), and plant height (0.01642). Negative indirect effects were through days to maturity (-0.0095), number of siliquae per plant (-0.00441), biological yield (-0.01324), number of primary branches (-0.02044), number of secondary branches (-0.2351), and siliqua length (-0.22329).
- **Biological Yield per Plant**: Positive indirect effects were seen through the number of secondary branches (0.07586), days to first flowering (0.03909), number of primary branches (0.00297), and days to maturity (0.0011). Negative effects included number of siliquae per plant (-0.00047), number of seeds per siliqua (-1.505), days to 50% flowering (-0.04111), siliqua length (-0.04411), and plant height (-0.17799).
- **Harvest Index**: Showed positive indirect effects via plant height (0.32831), number of seeds per siliqua (0.18964), and days to first flowering (0.02357). Negative effects were through the number of siliquae per plant (-0.00551), days to maturity (-0.18747), and biological yield (-0.20554).

Path coefficient analysis is a valuable method for separating direct and indirect effects and for evaluating the relative importance of causal traits that ultimately influence seed yield per plant. A character with a high direct effect on seed yield suggests that direct selection for that trait would be effective in improving seed yield in breeding programs. Indirect effects reflect the interrelationships among component traits that contribute to seed yield.

Simple correlation coefficients measure bilateral associations between two variables, without considering complex multivariate relationships (Kempthorne, 1957; Niehaus and Pickett, 1966) [30]. Path analysis, however, allows for a deeper understanding of these interactions.

A significantly high positive direct effect on seed yield was observed for harvest index and biological yield per plant. Similar findings were reported by Rout *et al.* (2018) [31]. This implies a true relationship between biological yield and seed yield, as well as between harvest index and seed yield. Singh *et al.* (2014) [32] also observed a strong positive direct effect of harvest index on seed yield. Therefore, based on these results, biological yield per plant and harvest index emerge as the most reliable selection criteria for yield improvement in mustard. Similar results were supported by Mandal and Sinha (2004) [33].

Interestingly, traits such as number of secondary branches, number of siliquae per plant, and days to maturity, which did not show strong correlation with seed yield, exhibited considerable negative direct effects. However, these negative contributions were largely neutralized by positive indirect effects, primarily through biological yield per plant. Similar trends were also reported by Shekhawat *et al.* (2014) [18].

Table 1: Analysis of variance for different characters in Indian mustard (*Brassica juncea* L.)

Source of variation	DF	Days to first flowering	Days to 50% flowering	No. of primary branches	No. of secondary branches	Plant height(cm)	No. of siliqua/plant
Replication	2	166.264	187.547	0.318	25.553	4,186.42	713.666
Treatment	49	44.309	51.478	2.753	14.096	160.186	15,388.44
Error	98	7.827	12.771	1.401	8.352	93.287	92.504

Source of variation	DF	Siliqua length(cm)	No. of seeds/siliqua	Days to maturity	Biological yield	Seed yield (gm)	Harvest index (%)
Replication	2	7.595	713.666	312.087	56.046	14.532	4.202
Treatment	49	0.443	15,388.44	4.612	702.588	77.3	49.391
Error	98	0.317	92.504	4.556	60.114	10.506	5.408

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

Table 2: Genotypic correlation analysis showing effects of twelve characters on seed component in Indian mustard

Characters	Days to first flowering	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches	Plant height (cm)	No. of siliqua /plant	Siliqua length (cm)	No. of seeds/ siliqua	Biological yield	Seed yield (gm)	Harvest index (%)
Days to first flowering	1.00	0.981**	1.207**	-0.290**	-0.491**	0.338**	-0.579**	-0.171*	-0.178*	-0.197*	-0.216**	-0.119
Days to 50% flowering		1.00	2.158**	-0.229**	-0.357**	0.286**	-0.431**	-0.395**	-0.175*	-0.231**	-0.132	-0.042
Days to maturity			1.00	1.835**	1.541**	-2.484**	2.342**	-0.521**	-1.677**	0.194*	-0.748**	-0.833**
No. of primary branches				1.00	1.098**	-0.540**	0.334**	0.814**	0.974**	-0.141	0.247**	0.263**
No. of secondary branches					1.00	-0.707**	0.431**	0.201*	0.487**	-0.157	0.378**	0.388**
Plant height(cm)						1.00	-0.166*	-0.292**	-0.030	0.330**	-0.464**	-0.609**
No. of siliqua/plant							1.00	0.468**	0.427**	0.046	0.152	0.111
Siliqua length(cm)								1.00	0.764**	0.151	0.461**	0.256**
No. of seeds/siliqua									1.00	-0.023	0.375**	0.316**
Biological yield										1.00	0.106	-0.364**
Seed yield (gm)											1.00	0.880**
Harvest index (%)												1.00

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

Table 3: Phenotypic correlation analysis showing effects of twelve characters on seed component in Indian mustard

Characters	Days to first flowering	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches	Plant height (cm)	No. of siliqua /plant	Siliqua length (cm)	No. of seeds/ siliqua	Biological yield	Seed yield (gm)	Harvest index (%)
Days to first flowering	1.00	0.748**	0.090	-0.044	-0.087	0.113	-0.446**	-0.150	-0.041	-0.107	-0.105	-0.056
Days to 50% flowering		1.00	0.090	-0.144	-0.103	0.019	-0.299**	-0.137	-0.048	-0.141	-0.072	-0.017
Days to maturity			1.00	0.153	-0.013	-0.010	0.50	-0.063	-0.001	-0.013	-0.048	-0.041
No. of primary branches				1.00	0.499**	-0.080	0.174*	0.065	0.197*	-0.023	0.207*	0.201*
No. of secondary branches					1.00	-0.055	0.179*	0.002	0.192*	-0.061	0.168*	0.191*
Plant height(cm)						1.00	-0.066	0.097	0.176*	0.122	-0.157	-0.214**
No. of siliqua/plant							1.00	0.163*	0.242**	0.029	0.123	0.098
Siliqua length(cm)								1.00	0.304**	0.005	0.110	0.086
No. of seeds/siliqua									1.00	-0.002	0.202*	0.190*
Biological yield										1.00	0.197*	-0.264**
Seed yield (gm)											1.00	0.885**
Harvest index (%)												1.00

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

Table 4: Path coefficient analysis showing direct and indirect effects of twelve characters on seed yield at phenotypic level.

Characters	Days to first flowering	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches	Plant height (cm)	No. of siliqua /plant	Siliqua length (cm)	No. of seeds/ siliqua	Biological yield	Harvest index (%)
Days to first flowering	-0.0122	0.02075	-0.00055	-0.00087	0.00039	0.0001	-0.00382	-0.00305	-0.00007	-0.0494	-0.05644
Days to 50% flowering	-0.00913	0.02774	-0.00055	-0.00284	0.00046	0.00002	-0.00256	-0.0028	-0.00009	-0.06511	-0.01715
Days to maturity	-0.00109	0.0025	-0.00615	0.00303	0.00006	-0.00001	0.00124	-0.00128	0	-0.00615	-0.04063
No. of primary branches	0.00054	-0.00399	-0.00094	0.01976	-0.00224	-0.00007	0.00149	0.00132	0.00035	-0.01059	0.20119
No. of secondary branches	0.00106	-0.00287	0.00008	0.00986	-0.00448	-0.00005	0.00154	0.00003	0.00034	-0.0282	0.19104
Plant height (cm)	-0.00138	0.00052	0.00006	-0.00159	0.00025	0.00091	-0.00057	0.00199	0.00032	0.05636	-0.21405
No. of siliqua/plant	0.00544	-0.00829	-0.00089	0.00343	-0.0008	-0.00006	0.00857	0.00332	0.00043	0.01347	0.09804
Siliqua length (cm)	0.00183	-0.00381	0.00039	0.00127	-0.00001	0.00009	0.00139	0.02039	0.00054	0.00224	0.08603
No. of seeds/siliqua	0.0005	-0.00132	0.00001	0.00389	-0.00086	0.00016	0.00208	0.0062	0.00179	-0.00081	0.19052
Biological yield	0.0013	-0.0039	0.00008	-0.00045	0.00027	0.00011	0.00025	0.0001	0	0.46339	-0.26406
Harvest index (%)	0.00069	-0.00048	0.00025	0.00397	-0.00086	-0.00019	0.00084	0.00175	0.00034	-0.12227	1.00078

Residual = 0.01671, *, ** significant at 5% and 1% level, respectively

Table 5: Path coefficient analysis showing direct and indirect effects of twelve characters on seed yield at genotypic level.

Characters	Days to first flowering	Days to 50% flowering	Days to maturity	No. of primary branches	No. of secondary branches	Plant height (cm)	No. of siliqua /plant	Siliqua length (cm)	No. of seeds/ siliqua	Biological yield	Harvest index (%)
Days to first flowering	-0.19844	0.17473	0.00684	0.00609	0.23687	-0.1824	0.00598	0.05001	-0.10657	-0.11129	-0.09801
Days to 50% flowering	-0.19477	0.17803	0.01223	0.00481	0.17244	-0.15437	0.00445	0.11557	-0.1051	-0.13046	-0.03473
Days to maturity	-0.23955	0.3842	0.00566	-0.03848	-0.74394	1.33893	-0.02418	0.15239	-1.00542	0.1097	-0.68743
No. of primary branches	0.05759	-0.0408	0.01039	-0.02098	-0.53018	0.29108	-0.00344	-0.23782	0.5841	-0.07992	0.21683
No. of secondary branches	0.09734	-0.06357	0.00873	-0.02303	-0.48289	0.38096	-0.00445	-0.05887	0.29188	-0.08874	0.32038
Plant height (cm)	-0.06714	0.05097	-1.507	0.01133	0.34122	-0.53913	0.00171	0.08538	-1.8026	0.18651	-0.50254
No. of siliqua/plant	0.11492	-0.07673	0.01326	-0.007	-0.20815	0.08929	-0.01033	-0.13688	0.25616	0.02593	0.09183
Siliqua length (cm)	0.03395	-0.07038	-0.00295	-0.01707	-0.09724	0.15746	-0.00484	-0.29233	0.45793	0.08525	0.21096
No. of seeds/siliqua	0.03528	-0.03121	-0.0095	-0.02044	-0.2351	0.01642	-0.00441	-0.22329	0.59951	-0.01324	0.26103
Biological yield	0.03909	-0.04111	0.0011	0.00297	0.07586	-0.17799	-0.00047	-0.04411	-1.505	0.56491	-0.30026
Harvest index (%)	0.02357	-0.00749	-0.00472	-0.00551	-0.18747	0.32831	-0.00115	-0.07473	0.18964	-0.20554	0.82523

Residual = 0.04750, *, ** significant at 5% and 1% level, respectively

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