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Studies on correlation and path coefficient analysis to explore the inter-relationships among grain yield and related traits in Indian mustard (*Brassica juncea* L. Czern and Coss.) particularly under timely and late sown conditions

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Abstract
Achieving enhancement in Indian mustard traits through indirect selection by prioritizing more heritable and easily identifiable characteristics is crucial. In this study, we examined 12 yield-related traits across ten varieties/strains of Indian mustard (*Brassica juncea* L. Czern & Coss). The study assessed twelve traits contributing to yield, including the duration to 50% flowering, maturity duration, plant height (cm), length of the main raceme (cm), primary and secondary branches per plant, siliquae count on the main raceme, seeds per siliquae, 1000-seed weight (g), plant's biological yield (g), harvest index (%), and grain yield (g) per plant. During rabi season 2020-2021, set of parental lines were grown and made 45 crosses in 10 x 10 diallel fashion mating design (excluding reciprocals) with help of hand emasculation. The F1 seeds of 45 crosses were advanced during the Rabi season of 2021-2022 to raise the F1's with their parents and two checks/standard varieties under two different environments i.e., timely sown (E1) and late sown (E2) conditions at Students Instructional Farm (SIF) of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya and were left for natural or open pollination. The value of correlation coefficient at phenotypic level, grain yield per plant (g) was recorded with highly positive significant correlation with harvest index (%), no. of siliqua on main raceme, biological yield per plant, no. of secondary branches per plant, no. of seeds per siliqua, 1000-seed weight (g) and some other traits. Traits harvest index (%) was observed with highest direct effect on grain yield in followed by biological yield per plant and some other traits in genotypic path analysis at both the (E1 & E2) conditions. Resultant direct selection for these traits would be more effective and applicable for further yield improvement in given genotype of Indian mustard. At phenotypic path analysis, most of the traits except days to 50% flowering and plant height, exerted high order of positive indirect effects on seed yield/plant via biological yield per plant *viz*., length of main raceme, number of primary branches per plant, no. of secondary branches per plant, no. of silique on main raceme, number of seeds per siliqua, 1000-seeds weight and harvest index in E1 and E2.

Keywords: Indian mustard, correlation coefficient, inter-relationship, direct effect, path coefficient, indirect effect

1. Introduction

Indian mustard (*Brassica juncea* (L.) Czern & Coss) is a significant oilseed crop that is well particularly adapted to the sub-continent. This plant is a member of the Brassicaceae family. Both temperate and tropical regions are good places for mustard to grow, but it needs cool, dry weather for their better growth and development. During flowering, the crop needs a temperature range of 180 to 250 degrees Celsius, low humidity, and almost no rainfall. Based on cytology, Indian mustard, scientifically known as *Brassica juncea* (L.) Czern & Coss, is an amphidiploid plant with a chromosome count of 2n=36. It originated from an interspecific cross between *Brassica campestris* (2n=20) and *Brassica nigra* (2n=16), with subsequent natural chromosome doubling, as proposed by Nagaharu in 1935.

Indian mustard is classified within the rapeseed-mustard category, alongside other closely related cultivated Brassica species. These include Yellow/brown mustard/toria (*B. campestris syn. Brassica rapa* (L.) var. yellow/brown sarson/toria, 2n (AA) = 20), Black mustard (*B. nigra* (L.) Koch, 2n (BB) = 16), Taramira (*Eruca sativa*. Mill, 2n (EE) = 22), Ethiopian mustard or Karan rai (*B. carinata A. Braun*, 2n (BBCC) = 34), and Gobhi sarson (*B. napus ssp. oleifera* DC var. annua (L.), 2n (AACC) = 38). This annual herbaceous plant is characterized by a deep taproot system with lateral roots that extend towards the soil surface, functioning as the primary feeding roots for the plant. The plants are upright, tall (90-200 cm), and have many branches. The leaves lack stipules and are pinnately incised, wide, and alternating in shape. Flowers are actinomorphic, hypogynous, pedicellate, ebracteate, and complete. The siliquae fruits are erect, cylindrical, beaded, and typically measure between 2 and 6.5 cm in length. The seed has a brown or dark brown color. The seed coat has a smooth texture. The Indian mustard exhibits a corymbose raceme inflorescence pattern. Flowering begins indeterminately at the base of the main stalk and progresses upwards. The calyx consists of four sepals arranged in two whorls: The outer whorl comprises anteroposterior sepals, while the inner whorl consists of lateral sepals. The corolla consists of four cruciform petals. Two non-functional nectaries are located at the base of the two long stamens, while four functional nectaries are positioned on the short stamens. The androecium is tetra-dynamous, consisting of six stamens arranged in two whorls. The outer whorl comprises two shorter stamens located laterally. Anthers are bi-thecous and basifixed. The gynoecium is typically syncarpous, bicarpellary, and superior, with carpels transversely positioned. It is bilocular due to the presence of a false septum.

India stands as the world's second-largest producer of rapeseed mustard, trailing only behind China, and ranks third globally in terms of production, following China and Canada (Kumari *et al*., 2019) [4]. The estimated worldwide figures for rapeseed-mustard encompass an area of 36.59 million hectares (mha), production of 72.37 million tonnes (mt), with a productivity rate of 1980 kg/ha. India contributes to 19.8% of the total acreage and 9.8% of the production globally (USDA). Within India, rapeseed-mustard cultivation spans across 8.06 million hectares (mha), yielding 11.75 million tonnes (mt) of produce, with a productivity rate of 1458 kg/ha during 2021-22 (Anonymous, 2022) [1]. Rajasthan leads the production in India, covering approximately 42%, followed by Madhya Pradesh (15.21%), Haryana (8.86%), Uttar Pradesh (9.37%), West Bengal (7.57%), Gujarat (3.12%), and Assam (3.56%). Uttar Pradesh contributes an estimated area of 0.76 million hectares (mha) to rapeseed-mustard cultivation, producing 1.37 million tonnes (mt) with a productivity of 1438 kg/ha during 2021-22 (Anonymous, 2022).

The success of any breeding method employed for the genetic enhancement of crop plants relies heavily on understanding the variability, nature, and magnitude of gene action governing the expression of both the qualitative and quantitative traits. In the pursuit of developing high-yielding varieties, breeders often encounter challenges in selecting suitable parental lines for hybridization. A thorough understanding of the genetic mechanisms underlying the inheritance of various quantitative and qualitative traits is indispensable for effectively employing breeding techniques to enhance yield and quality parameters. Selecting parents solely based on grain yield, a trait influenced by multiple genes, is typically not highly efficient (Singh and Singh, 1973; Sastri, 1974) [17, 11]. Hence, identifying and manipulating traits contributing to grain yield is crucial for enhancing breeding efficiency. Breeders consistently seek genetic variation among traits to identify desirable characteristics. Some of these traits are closely interrelated, both among themselves and with seed yield. Therefore, analyzing the relationships among these traits and their correlation with seed yield is imperative for establishing effective selection criteria (Singh *et al*., 1990) [15].

Path coefficient analysis serves as a standardized partial regression coefficient, facilitating the measurement of direct influence between variables and enabling the separation of correlation coefficients into direct and indirect effects. In agriculture, plant breeders utilize path analysis to pinpoint traits useful as selection criteria for enhancing crop yield. With an increasing number of characters involved in correlation studies, discerning the key contributors to yield becomes challenging. Path coefficient analysis offers a more effective approach by distinguishing direct and indirect factors, enabling a critical examination of the specific forces driving a given correlation and assessing the relative importance of causal factors. Particularly in complex traits like crop yield, which are influenced by various environmental factors, selecting superior genotypes based solely on mean performance may compromise accuracy (Piepho *et al*., 2008) [8]. Moreover, crop yield is influenced by numerous yield-contributing characters such as plant height, primary and secondary branches per plant, length of the main raceme, length of siliqua, seeds per siliqua, etc. (Saroj *et al*., 2021). Consequently, direct selection for improved seed yield is challenging. Therefore, this study aims to evaluate the relationship among yield and yield-contributing traits and identify the traits with the most direct and indirect effects on grain yield.

2. Materials and Methods

The experimental material for this study consisted of ten varieties/strains of Indian mustard, including RH-749-12-18-19, UJM-11, CS-54, KMR-15-5, KMR-19-3, KMR-850, KMR-17-5, UJM-8, SAURAVEE, and RH-819, along with two checks namely, Kranti and NDR-8501, sourced from the germplasm maintained at the Oilseed Section, Department of Genetics and Plant Breeding, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya. The experimental setup comprised 57 treatments, including 10 parents, 45 F1 hybrids, and 2 checks/standard varieties, which were evaluated using a randomized block design (RBD) with three replications during the Rabi season of 2021-2022 under two different environments: Timely sown (E1) and late sown (E2) conditions. Each parent and F1 hybrid were planted in a single row, spaced 5 meters apart, with a plant-to-plant distance of 15 cm achieved through thinning. Standard agronomic practices were followed to ensure optimal crop growth. Various quantitative traits, including days to 50% flowering, days to maturity, plant height (cm), length of the main raceme (cm), number of primary branches/plant, number of secondary branches/plant, number of siliquae on the main raceme, number of seeds per siliquae, 1000-seed weight (g), biological yield/plant (g), harvest index (%), and grain yield (g)/plant, were recorded. Observations were made on five randomly selected competitive plants in each row of each replication for all traits, except for days to 50% flowering and days to maturity, which were recorded on a plot basis. Statistical analyses were conducted to determine the correlation coefficient and direct and indirect effects of yield contributing traits on seed yield, following the methods suggested by Searle (1961) [12] and Dewey and Lu (1959) [2], respectively.

3. Results and Discussion

3.1 Correlation and path coefficient analysis across two environmental conditions

3.2 Genotypic and phenotypic correlation coefficients: Exploring relationships between traits and genetic and observable characteristics

At genotypic level of correlation, Seed yield per plant highly positive and significant association with harvest index (%) (0.943 in E1 & 0.929 in E2) followed by biological yield per plant (g) (0.817 in E1 and 0.614 in E2), no. of siliqua on main raceme (0.648 in E1 and 0.644 in E2), no. of secondary branches per plant (0.643 in E1 and 0.612 in E2), no. of seed per siliqua (0.612 in E1 and 0.612 in E2), length of main raceme (cm) (0.495 in E1 and 0.459 in E2), 1000-seed weight (g) (0.420 in E1 and 0.421 in E2), no. of primary branches per plant (0.357 in E1 and 0.324 in E2), and days to maturity (0.203 in E1 and 0.259 in E2). Positive and significant association found between seed yield per plant with days to 50% flowering (0.162 in E1) only. Positive with non-significant association between plant height (cm) (0.148 in E1 and 0.128 in E2). Negative and non-significant association not found in any observations at genotypic level of association. At phenotypic level, seed yield per plant exhibited positive highly significant association with harvest index (%) (0.859in E1 and 0.885 in E2), no. of siliqua on main raceme (0.628in E1 and 0.640 in E2), biological yield per plant (0.510 in E1 and 0.524 in E2), no. of secondary branches per plant (0.482 in E1 and 0.583 in E2), no. of seeds per siliqua (0.398 in E1 and 0.496 in E2), 1000-seed weight (g) (0.430 in E1 and 0.396 in E2), length of main raceme (cm) (0.339 in E1 and 0.349 in E2), no. 0f primary branches per plant (0.339 in E1 and 0.137in E2). Positive and significant correlation with days to maturity (0.150 in E2) and non-significant positive correlation with plant height (cm) (0.101 in E1 and 0.145 in E2), days to 50% flowering (0.051 in E1). Negative and non-significant association not found in any observation. Similar finding were reported by Yohannes and Belete (2013) [22], Dipti *et al.* (2016) [3], Kumar *et al.* (2018) [9], and Tripathi *et al.* (2020) [19].

3.3 Path coefficient analysis: Investigating Direct and Indirect Influences on Traits

The direct and indirect effects of 12 traits on seed yield per plant, determined through path coefficient analysis utilizing both phenotypic and genotypic correlations Table 3 (a & b) illustrates respectively. This analytical approach dissects the correlation coefficient, revealing the direct and indirect influences of each character (independent variable) on yield (dependent variable). It provides valuable insights into the cause-and-effect relationships among various trait combinations. Path coefficient analysis was initially proposed by Wright (1921) [20] and further elucidated by Dewey and Lu (1959) [2].

At genotypic level, the highest positive direct effect on seed yield/plant was exerted by harvest index (0.7579 and 0.8176 respectively) followed by biological yield per plant (0.3377 and 0.3896) respectively in E1 and E2 conditions. Therefore, it is suggested that the traits which exhibited maximum direct effect on grain yield should be considered for selection programme for enhancing yield potential in Indian mustard. The traits except days to 50% flowering and plant height, exerted high order of positive indirect effects on seed yield/plant *via* biological yield per plant *viz*., no. of silique on main raceme (0.2700 and 0.3062 in E1 and E2 respectively), no. of secondary branches per plant (0.2583 and 0.3049 in E1 and E2 respectively), number of seeds per siliqua (0.2067 and 0.2772 in E1 and E2 respectively), number of primary branches per plant (0.2208 and 0.2117 in E1 and E2 respectively), 1000-seeds weight (0.1811 and 0.2346 in E1 and E2 respectively), length of main raceme (0.1620 and 0.1801 in E1 and E2 respectively), harvest index (0.1849 and 0.1089 in E1 and E2 respectively) and days to maturity (0.1029) in E1 only.

All the traits except plant height and primary branching exerted high extent of positive indirect effects on seed yield per plant *via* harvest index in both E1 and E2 conditions i.e., biological yield per plant (0.4150 and 0.2284), number seeds per siliqua (0.3789 and 0.3324), secondary branching (0.3435 and 0.3093), no. of silique on main raceme (0.3324 and 0.3346), length of main raceme (0.3046 and 0.2714), days to maturity (0.2140 and 0.1620), 1000-seeds weight (0.2125 and 0.1887), and days to 50% flowering (0.1965 and 0.2292), Similar finding were reported by Yadava *et al.* (2012) [21], Yohannes and Belete (2013) [22], Singh *et al.* (2013) [14], Lodhi *et al.* (2014) [5], Shekhawat *et al.* (2014) [13], Tahira *et al.* (2015) [18], Dipti *et al.* (2016) [3], Singh *et al.* (2017) [16], Rauf and Rahim (2018) [9], Nur-E-Nabi *et al.* (2019) [7] and Tripathi *et al.* (2020) [19].

At phenotypic level, the highest positive direct effect on seed yield/plant was exerted by harvest index (0.8102 and 0.8463 respectively) followed by biological yield per plant (0.4382 and 0.4529) respectively in E1 and E2 conditions. Path analysis revealed that the amount of phenotypic path coefficient was very close to their genotypic path coefficient in most cases, suggesting the existence of inherent direct and indirect effects on seed yield per plant *via* biological yield per plant and harvest index as presented in table (3b). The rest of the estimates of direct and indirect effects obtained in genotypic and phenotypic path analysis were too low to be of any consequences. The estimate of residual factors 0.0162 and 0.0059 in E1 and 0.0364 and 0040 in E2, obtained in this path analysis was low. The presence of both negative and positive direct and indirect effects of the same trait on grain yield per plant, mediated through other characters simultaneously, creates a complex scenario where achieving a proper balance of different yield components is necessary to define the ide type for high grain yield.

Table 1: Analysis of variance for 12 traits in a diallel mating design in Indian mustard, encompassing both parents and progeny.

Sourced of variation	df	Evn.	Days to 50% flowering	Days to maturity	Plant height (cm)	Length of main raceme (cm)	Number of primary branches/ plant	Number of secondary branches/ plant	Number of Siliquae on main raceme	Number of seeds/ siliqua	1000-seed weight (g)	Biological yield/plant (g)	Harvest index (%)	Seed yield/plant (g)
REP	2	E1	2.83	10.69	75.50	22.86	0.19	1.27	10.41	0.50	0.22	2.28	2.82	1.91
		E2	1.95	0.08	20.80	7.58	0.03	0.43	9.06	1.03	0.04	13.16	1.00	0.29
Treatment	54	E1	18.88**	26.50**	179.45**	51.82**	2.96**	6.58**	275.49**	2.36**	1.78**	22.32**	13.50**	8.60**
		E2	17.96**	24.98**	182.33**	51.47**	2.20**	6.74**	273.41**	2.37**	1.81**	17.57**	25.37**	7.59**
PAR	9	E1	15.95**	44.03**	334.96**	63.21**	4.54**	8.73**	310.20**	1.69**	0.80**	35.01**	10.20**	6.63**
		E2	15.48**	37.74**	399.55**	60.46**	1.73**	10.35**	288.16**	1.90**	1.07**	30.39**	22.28**	7.49**
F1	44	E1	14.87**	16.61**	151.75**	48.44**	2.10**	5.64**	258.56**	2.20**	1.99**	11.58**	13.10**	6.91**

		E2	15.98**	16.80**	142.03**	48.44**	2.17**	5.64**	258.56**	2.20**	1.99**	14.11**	24.49**	6.91**
PVF1	1	E1	222.03**	304.69**	2.27	97.75**	26.59**	28.73**	708.14**	15.48**	1.48**	380.30**	60.68**	101.02**
		E2	127.48**	271.04**	0.78	104.23**	8.01**	22.92**	794.01**	14.08**	0.63**	54.65**	92.07**	38.77**
EROR	108	E1	3.35	7.79	38.51	6.77	0.06	0.43	2.94	0.27	0.03	3.21	2.53	0.34
		E2	1.32	6.61	19.51	3.81	0.03	0.21	2.60	0.17	0.02	2.65	1.30	0.19

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

Note: E1 = timely sown, E2 = Late sown.

Table 2 (a): Genotypic correlation coefficients for 12 traits in Indian mustard separately for environments E1 and E2.

Chrs	Env.	Days to 50% flowering	Days to maturity	Plant height (cm)	Length of main raceme (cm)	Number of primary branches/plant	Number of secondary branches/plant	Number of siliquae on main raceme	Number of seeds/siliqua	1000-seed weight (g)	Biological yield/plant (g)	Harvest index (%)	Seed yield/plant (g)
Days to 50% flowering	E1	1.000	1.192**	0.264**	0.049	-0.181*	0.116	0.271**	-0.023	0.166*	-0.068	0.259**	0.162*
	E2	1.000	1.212**	0.294**	-0.009	0.009	0.185*	0.300**	0.107	0.192*	0.104	0.280**	0.266**
Days to maturity	E1		1.000	0.305**	-0.143	-0.126	0.023	0.287**	-0.225**	0.110	0.055	0.282**	0.203**
	E2		1.000	0.726**	-0.123	-0.075	0.126	0.287**	0.093	0.119	0.264**	0.198**	0.259**
Plant height (cm)	E1			1.000	0.093	-0.156*	0.219**	0.392**	0.249**	0.030	0.186*	0.105	0.148
	E2			1.000	0.040	-0.091	0.015	0.353**	-0.044	0.072	0.173*	0.083	0.128
Length of main raceme (cm)	E1				1.000	0.721**	0.651**	0.547**	0.518**	0.496**	0.480**	0.402**	0.495**
	E2				1.000	0.685**	0.650**	0.497**	0.599**	0.455**	0.462**	0.332**	0.459**
No of primary branches/plant	E1					1.000	0.704**	0.532**	0.596**	0.381**	0.654**	0.105	0.357**
	E2					1.000	0.760**	0.608**	0.622**	0.479**	0.543**	0.130	0.324**
No of secondary branches/plant	E1						1.000	0.844**	0.750**	0.583**	0.765**	0.453**	0.643**
	E2						1.000	0.817**	0.791**	0.528**	0.783**	0.378**	0.612**
No of siliquae on main raceme	E1							1.000	0.708**	0.526**	0.800**	0.439**	0.648**
	E2							1.000	0.727**	0.531**	0.786**	0.409**	0.644**
Number of seeds/siliqua	E1								1.000	0.733**	0.612**	0.500**	0.611**
	E2								1.000	0.705**	0.711**	0.407**	0.612**
1000-seed weight (g)	E1									1.000	0.536**	0.280**	0.420**
	E2									1.000	0.602**	0.231**	0.421**
Biological yield/plant (g)	E1										1.000	0.548**	0.817**
	E2										1.000	0.279**	0.614**
Harvest index (%)	E1											1.000	0.943**
	E2											1.000	0.929**
Seed yield/plant (g)	E1												1.000
	E2												1.000

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

Table 2 (b): Phenotypic correlation coefficients for 12 traits in Indian mustard separately for environments E1 and E2.

Chrs	Env.	Days to 50% flowering	Days to maturity	Plant height (cm)	Length of main raceme (cm)	Number of primary branches/ plant	Number of secondary branches/plant	Number of siliquae on main raceme	Number of seeds/siliqua	1000-seed weight (g)	Biological yield/plant (g)	Harvest index (%)	Seed yield/plant (g)
Days to 50% flowering	E1	1.000	0.504**	0.326**	-0.117	-0.070	0.020	0.219**	-0.065	0.123	0.023	0.084	0.051
	E2	1.000	0.535**	0.259**	-0.043	0.008	0.204**	0.241**	0.123	0.127	0.201**	0.139	0.213**
Days to maturity	E1		1.000	-0.028	0.136	-0.200**	0.127	0.187*	0.005	0.028	0.029	0.153*	0.149
	E2		1.000	0.236**	0.029	-0.085	0.053	0.240**	-0.086	0.121	-0.077	0.221**	0.150*
Plant height (cm)	E1			1.000	-0.170*	-0.027	0.001	0.363**	0.037	0.054	0.069	0.072	0.101
	E2			1.000	-0.086	-0.056	0.017	0.286**	0.076	0.017	0.176*	0.085	0.145
Length of main raceme (cm)	E1				1.000	0.487**	0.637**	0.385**	0.547**	0.340**	0.374**	0.177*	0.339**
	E2				1.000	0.545**	0.565**	0.440**	0.428**	0.449**	0.188*	0.301**	0.349**
No of primary branches/plant	E1					1.000	0.554**	0.534**	0.423**	0.394**	0.455**	0.126	0.339**

	E2					1.000	0.681**	0.587**	0.559**	0.447**	0.508**	0.089	0.317**
No of secondary branches/plant	E1						1.000	0.702**	0.709**	0.458**	0.669**	0.183*	0.482**
	E2						1.000	0.746**	0.701**	0.492**	0.547**	0.324**	0.531**
No of siliquae on main raceme	E1							1.000	0.538**	0.529**	0.581**	0.387**	0.628**
	E2							1.000	0.600**	0.521**	0.624**	0.403**	0.640**
Number of seeds/siliqua	E1								1.000	0.533**	0.575**	0.139	0.398**
	E2								1.000	0.573**	0.548**	0.287**	0.496**
1000-seed weight (g)	E1									1.000	0.343**	0.295**	0.430**
	E2									1.000	0.410**	0.243**	0.396**
Biological yield/plant (g)	E1										1.000	0.048	0.510**
	E2										1.000	0.072	0.524**
Harvest index (%)	E1											1.000	0.859**
	E2											1.000	0.885**
Seed yield/plant (g)	E1												1.000
	E2												1.000

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

Table 3 (a): Genotypic path with seed yield per plant (g) for 12 characters in Indian mustard in E1 and E2

Chrs	**Env.**	**Days to 50% flowering**	**Days to maturity**	**Plant height (cm)**	**Length of main raceme (cm)**	**Number of primary branches/ plant**	**Number of secondary branches/ plant**	**Number of siliquae on main raceme**	**Number of seeds/siliqua**	**1000-seed weight (g)**	**Biological yield/plant (g)**	**Harvest index (%)**	**Seed yield/plant (g)**
Days to 50% flowering	E1	-0.0996	0.0743	0.0033	-0.0004	-0.0085	-0.0009	0.0135	0.0010	0.0054	-0.0229	0.1965	0.162*
	E2	0.0104	-0.0093	-0.0042	-0.0001	0.0001	-0.0094	0.0100	0.0012	-0.0027	0.0406	0.2292	0.266**
Days to maturity	E1	-0.1188	0.0623	0.0038	0.0012	-0.0059	-0.0002	0.0144	0.0098	0.0036	0.0186	0.2140	0.203**
	E2	0.0126	-0.0077	-0.0102	-0.0018	-0.0009	-0.0064	0.0096	0.0010	-0.0017	0.1029	0.1620	0.259**
Plant height (cm)	E1	-0.0263	0.0190	0.0124	-0.0008	-0.0073	-0.0016	0.0196	-0.0109	0.0010	0.0630	0.0799	0.1480
	E2	0.0031	-0.0056	-0.0141	0.0006	-0.0012	-0.0008	0.0118	-0.0005	-0.0010	0.0675	0.0680	0.128
Length of main raceme (cm)	E1	-0.0049	-0.0089	0.0012	-0.0086	0.0338	-0.0048	0.0274	-0.0226	0.0161	0.1620	0.3046	0.495**
	E2	-0.0001	0.0010	-0.0006	0.0143	0.0087	-0.0331	0.0165	0.0067	-0.0064	0.1801	0.2714	0.459**
No of primary branches/plant	E1	0.0180	-0.0078	-0.0019	-0.0062	0.0469	-0.0052	0.0266	-0.0260	0.0124	0.2208	0.0796	0.357**
	E2	0.0001	0.0006	0.0013	0.0098	0.0126	-0.0387	0.0203	0.0070	-0.0067	0.2117	0.1066	0.324**
No of secondary branches/plant	E1	-0.0116	0.0014	0.0027	-0.0056	0.0330	-0.0074	0.0422	-0.0327	0.0190	0.2583	0.3435	0.643**
	E2	0.0019	-0.0010	-0.0002	0.0093	0.0096	-0.0509	0.0272	0.0089	-0.0074	0.3049	0.3093	0.612**
No of siliquae on main raceme	E1	-0.0270	0.0179	0.0049	-0.0047	0.0249	-0.0062	0.0500	-0.0309	0.0171	0.2700	0.3324	0.648**
	E2	0.0031	-0.0022	-0.0050	0.0071	0.0077	-0.0416	0.0333	0.0081	-0.0075	0.3062	0.3346	0.644**
Number of seeds/siliqua	E1	0.0023	-0.0141	0.0031	-0.0044	0.0280	-0.0055	0.0354	-0.0436	0.0239	0.2067	0.3789	0.611**
	E2	0.0011	-0.0007	0.0006	0.0086	0.0079	-0.0403	0.0242	0.0112	-0.0099	0.2772	0.3324	0.612**
1000-seed weight (g)	E1	-0.0165	0.0069	0.0004	-0.0042	0.0179	-0.0043	0.0263	-0.0320	0.0326	0.1811	0.2125	0.420**
	E2	0.0020	-0.0009	-0.0010	0.0065	0.0061	-0.0269	0.0177	0.0079	-0.0141	0.2346	0.1887	0.421**
Biological yield/plant (g)	E1	0.0067	0.0034	0.0023	-0.0041	0.0307	-0.0056	0.0400	-0.0267	0.0175	0.3377	0.4150	0.817**
	E2	0.0011	-0.0020	-0.0024	0.0066	0.0069	-0.0398	0.0262	0.0080	-0.0085	0.3896	0.2284	0.614**
Harvest index (%)	E1	-0.0258	0.0176	0.0013	-0.0034	0.0049	-0.0033	0.0219	-0.0218	0.0091	0.1849	0.7579	0.943**
	E2	0.0029	-0.0015	-0.0012	0.0048	0.0017	-0.0193	0.0136	0.0046	-0.0033	0.1089	0.8176	0.929**

Resi E1 = 0.0162, E2 = 0.0059

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

Table 3(b): Phenotypic path with seed yield per plant (g) for 12 characters in Indian mustard in E1 and E2

Chrs	Env.	Days to 50% flowering	Days to maturity	Plant height (cm)	Length of main raceme (cm)	Number of primary branches/ plant	Number of secondary branches/ plant	Number of siliquae on main raceme	Number of seeds/siliqua	1000-seed weight (g)	Biological yield/plant (g)	Harvest index (%)	Seed yield/plant (g)
Days to 50% flowering	E1	-0.0667	0.0195	0.0043	0.0001	-0.0009	-0.0003	0.0131	0.0008	0.0028	0.0100	0.0679	0.0510
	E2	0.0112	-0.0066	-0.0042	-0.0003	0.0000	-0.0034	0.0091	-0.0009	-0.0007	0.0909	0.1180	0.213**
Days to maturity	E1	-0.0336	0.0388	-0.0004	-0.0002	-0.0027	-0.0017	0.0112	-0.0001	0.0006	0.0127	0.1239	0.1490
	E2	0.0060	-0.0124	-0.0038	0.0002	-0.0001	-0.0009	0.0091	0.0007	-0.0007	-0.0351	0.1867	0.150*
Plant height (cm)	E1	-0.0218	-0.0011	0.0133	0.0002	-0.0004	0.0000	0.0216	-0.0005	0.0012	0.0304	0.0581	0.1010
	E2	0.0029	-0.0029	-0.0161	-0.0006	-0.0001	-0.0003	0.0108	-0.0006	-0.0001	0.0799	0.0717	0.145
Length of main raceme (cm)	E1	0.0078	0.0053	-0.0023	-0.0011	0.0065	-0.0083	0.0230	-0.0068	0.0077	0.1639	0.1436	0.339**
	E2	-0.0005	-0.0004	0.0014	0.0070	0.0006	-0.0095	0.0166	-0.0033	-0.0025	0.0852	0.2544	0.349**
No of primary branches/plant	E1	0.0047	-0.0078	-0.0004	-0.0006	0.0133	-0.0072	0.0318	-0.0052	0.0090	0.1992	0.1023	0.339**
	E2	0.0001	0.0011	0.0009	0.0038	0.0012	-0.0114	0.0221	-0.0043	-0.0025	0.2301	0.0756	0.317**
No of secondary ranches/plant	E1	-0.0013	0.0049	0.0000	-0.0007	0.0073	-0.0130	0.0419	-0.0087	0.0104	0.2934	0.1479	0.482**
	E2	0.0023	-0.0007	-0.0003	0.0040	0.0008	-0.0168	0.0281	-0.0054	-0.0028	0.2476	0.2744	0.531**
No of siliquae on main raceme	E1	-0.0146	0.0073	0.0048	-0.0004	0.0071	-0.0091	0.0596	-0.0066	0.0120	0.2547	0.3135	0.628**
	E2	0.0027	-0.0030	-0.0046	0.0031	0.0007	-0.0125	0.0377	-0.0046	-0.0029	0.2826	0.3407	0.640**
Number of seeds/siliqua	E1	0.0044	0.0002	0.0005	-0.0006	0.0056	-0.0092	0.0321	-0.0123	0.0121	0.2521	0.1129	0.398**
	E2	0.0014	0.0011	-0.0012	0.0030	0.0007	-0.0118	0.0226	-0.0076	-0.0032	0.2482	0.2430	0.496**
1000-seed weight (g)	E1	-0.0082	0.0011	0.0007	-0.0004	0.0052	-0.0059	0.0316	-0.0066	0.0227	0.1502	0.2393	0.430**
	E2	0.0014	-0.0015	-0.0003	0.0032	0.0005	-0.0083	0.0196	-0.0044	-0.0056	0.1857	0.2059	0.396**
Biological yield/plant (g)	E1	-0.0015	0.0011	0.0009	-0.0004	0.0060	-0.0087	0.0347	-0.0071	0.0078	0.4382	0.0385	0.510**
	E2	0.0023	0.0010	-0.0028	0.0013	0.0006	-0.0092	0.0235	-0.0042	-0.0023	0.4529	0.0605	0.524**
Harvest index (%)	E1	-0.0056	0.0059	0.0010	-0.0002	0.0017	-0.0024	0.0231	-0.0017	0.0067	0.0208	0.8102	0.859**
	E2	0.0016	-0.0027	-0.0014	0.0021	0.0001	-0.0054	0.0152	-0.0022	-0.0014	0.0324	0.8463	0.885**

Resi E1 = 0.0364, E2 = 0.0040

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

4. Conclusion

The study focused on enhancing Indian mustard traits through indirect selection, prioritizing heritable and easily identifiable characteristics. Twelve yield-related traits were examined across ten varieties/strains of Indian mustard. In genotypic path analysis, harvest index showed the highest direct effect on grain yield, followed by biological yield per plant and other traits, in both E1 and E2 conditions. Direct selection for these traits was deemed effective for further yield improvement in Indian mustard genotypes. Phenotypic path analysis indicated that most traits, except flowering duration and plant height, exerted positive indirect effects on seed yield per plant through biological yield per plant. In conclusion, the study suggests that focusing on traits such as harvest index, biological yield per plant, and others identified through genotypic and phenotypic path analyses can lead to effective indirect selection strategies for enhancing grain yield in Indian mustard. At the genotypic and phenotypic level of correlation, seed yield per plant exhibited highly positive and significant associations with several key traits. The study highlights the significance of traits such as harvest index, biological yield per plant, number of siliquae on the main raceme, and secondary branches per plant in enhancing seed yield per plant in Indian mustard. These findings provide valuable insights for breeders aiming to develop high-yielding varieties through targeted trait selection and breeding strategies.

5. References

1. Anonymous. E&S Division, DA&FW, Ministry of Agriculture and Farmers Welfare, Government of India; c2022.
2. Dewey DR, Lu KH. Correlation and path coefficient analysis of components of crested wheatgrass seed production. J Agron. 1959;57(3):515-518.
3. Dipti CV, Priyanka. Correlation and path coefficient analysis for yield-contributing parameters in Indian mustard [*Brassica juncea* L. Czern & Coss]. Am J Pharm Tech Res. 2016;6(2):2249-3387.
4. Kumari V, Jambhulka S, Chaudhary HK, Sharma BK, Sood P, Guleria SK. Phenotypic stability for seed yield and related traits in Trombay mustard genotypes under Northwestern Himalayas. J Oilseed Brassica. 2019;10:33-37.
5. Lodhi B, Thakral NK, Ram A, Amit S. Genetic variability, association and path analysis in Indian mustard (*Brassica juncea* L.). J Oilseed Brassica. 2014;5(1):50-55.
6. Nagaharu UJJJB, Nagaharu NJJJJ. Genome analysis in Brassica with special reference to the experimental formation of B. napus and peculiar mode of fertilization. Jpn J Bot. 1935;7(7):389-452.
7. Nur-E-Nabi M, Haq ME, Ahmed M, Hossain MM, Shefat-al-Maruf M, Mahmud F, Shahanaz P, Harun-Ur-Rashid M. Genetic variability, correlation and path coefficient analysis in advanced generation of *Brassica napus* (L.). J Sci Res Rep. 2019;22(3):1-12.
8. Piepho HP, Möhring J, Melchinger AE, Büchse A. BLUP for phenotypic selection in plant breeding and variety testing. Euphytica. 2008;161(1-2):209-228.
9. Rauf MA, Rahim MA. Genetic variability studies among yield and its contributing traits in mustard (*Brassica napus*

L.). Adv Zool Bot. 2018;6(4):101-108.

10. Saroj R, Soumya SL, Singh S, Sankar SM, Chaudhary R, Yashpal, Yadava DK. Unraveling the relationship between seed yield and yield-related traits in a diversity panel of *Brassica juncea* using multi-traits mixed model. Front Plant Sci. 2021;12:651936.
11. Sastri AB. Path analysis of yield components in tobacco. Indian J Genet. 1974;34:57-58.
12. Searle SR. Phenotypic, genotypic and environmental correlations. Biometrics. 1961;17:474-480.
13. Shekhawat N, Jadeja GC, Singh J. Genetic variability for yield and its components in Indian mustard (*Brassica juncea* L. Czern & Coss). Electron J Plant Breed. 2014;5(1):117-119.
14. Singh A, Avtar R, Singh D, Sangwan O, Balyan P. Genetic variability, character association and path analysis for seed yield and component traits under two environments in Indian mustard. J Oilseed Brassica. 2013;4(1):43-48.
15. Singh KB, Bejiga G, Malhotra RS. Associations of some characters with seed yield in chickpea collections. Euphytica. 1990;49:83-88.
16. Singh M, Kumar R, Tomar A. Selection parameter analysis for selecting the best cross combinations in Indian mustard (*Brassica juncea* (L.) Czern & Coss). J Pharmacogn Phytochem. 2017;6(1):385-387.
17. Singh TP, Singh KB. Association of grain yield and its components in segregating populations of green gram. Indian J Genet. 1973;33:112-117.
18. Tahira R, Ihsanullah, Ata-ur-Rehman, Saleem M. Studies on variability for quality traits, association and path analysis in raya (*Brassica juncea*) germplasm. Int J Agric Biol. 2015;17(2):381-386.
19. Tripathi N, Kumar K, Tiwari R, Verma OP. Correlation and path coefficient analysis for seed yield, its components and oil content in Indian mustard (*Brassica juncea* L. Czern and Coss.) under normal and saline/alkaline condition. J Pharmacogn Phytochem. 2020;9(5):2846-2850.
20. Wright S. Correlation and causation. J Agric Res. 1921;20(7):557-585.
21. Yadava DK, Singh N, Vasudev S, Singh R, Singh S, Giri SC, Dwivedi VK, Prabhu KV. Combining ability and heterobeltiosis for yield and yield-contributing traits in Indian mustard (*Brassica juncea*). Ind J Agric Sci. 2012;82(7):563-570.
22. Yohannes MTW, Belete YS. Genetic variability of Ethiopian mustard (*Brassica carinata* A. Brun) accessions based on some morphological characters. Int J Plant Breed Genet. 2013;7(3):169-175.