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Trait association and path coefficient analysis in Indian mustard (*Brassica juncea* L. Czern and Coss)

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Abstract
The present experiment was conducted during *Rabi* 2022-23 with forty diverse genotypes of Indian mustard in Randomized Block Design with three replications for thirteen yield related attributes. The analysis of variance revealed highly significant differences among all the forty genotypes of Indian mustard for all the thirteen quantitative characters under study. Seed yield per plant exhibited highly significant and positive relationship with biological yield per plant, number of siliquae per plant, harvest index, 1000-seed weight, number of primary and secondary branches per plant and plant height at both genotypic and phenotypic levels, indicating that these traits are essential yield contributing components. Whereas, days to maturity, day to 50% flowering and oil content were found to be negatively correlated with seed yield per plant. Through the study of path coefficient analysis, it was uncovered that seed yield per plant was directly and highly positively influenced by biological yield per plant and harvest index. Moreover, plant height, number of siliquae per plant, 1000-seed weight and number of secondary branches per plant were also found to have a positive direct effect on seed yield per plant. Therefore, these traits have been identified as key attributes for enhancing seed yield in Indian mustard.

Keywords: Indian mustard, seed yield, correlation and path coefficient analysis

1. Introduction
The genus Brassica plays a significant role in the family Cruciferae. It is made up of several economically significant species that produce edible seeds, stems, leaves, buds and flowers. Most of the species are grown as oilseed crops, while others are cultivated as pasture. Indian mustard (*Brassica juncea* L. Czern and Coss) is also referred to rai, raya, or laha, a naturally occurring amphidiploid of *Brassica campestris* (2n=20) and *Brassica nigra* (2n=16) (Roy *et al*., 2018) [17]. Due to its high oil content, which ranges from 38 to 43 percent, it is one of the most significant oil seed crops in the nation. Rapeseed and mustard crops are cultivated in a variety of agro-climatic circumstances from the north-eastern to north-western hills and southern regions of India, including irrigated or rainfed, timely or late sown, saline soils and mixed cropping systems. India leads Asia in terms of acreage and production of rapeseed and mustard. In the year 2021-22, these crops covered an extensive area of 8.1 million hectares in India, resulting in a total production of 11.70 million tons and a productivity rate of 1458 kg per hectare. Rajasthan is called as 'mustard state' because it is the largest producer of mustard in India. In Rajasthan, this crop is grown in 4.159 million hectares area, yielding 7.139 million tones and achieving a productivity rate of 1717 kg per hectare (Anonymous. 2021-22) [2].
However, oilseed production has not yet attained self-sufficiency to meet the demands of a growing population and the supply-demand gap. Even though, there are several varieties with significant yield potential, but there are still wide variations in area, production and productivity, which is primarily due to its cultivation on marginal areas that may be rainfed or have insufficient irrigation facilities, as well as the lack of biotic and abiotic stress-resistant or tolerant varieties for the different mustard-growing zones of the nation. The nature and degree of variation for different yield components determines whether any crop improvement effort for creating a high yielding cultivar will be successful. (Singh *et al*., 2020) [21].
Breeding such crops in which correlation is particularly productive for the advancement of hybrid mustard seed production benefits much from genetic evaluation. As a result, character association studies have become essential for commencing a successful breeding project. Yield is a complicated quantitative attribute that is influenced by environmental changes. So, there is a requirement of the indirect selection of just highly heritable characteristics which are positively correlated with yield. This is made feasible by estimates of correlations that aid in figuring out how closely related different traits that contribute to yield.

Path coefficient analysis is used which separates the direct and indirect impacts of yield and its component characters when correlation is exceptionally effective. The decision performs effectively when the breeding population exhibits a significant amount of variability. Any breeding strategy for high yields must take into consideration the type and degree of variability in the current material as well as the relationships between multiple morphological features. An accurate assessment of key crop species aids in the discovery and use of better genotypes. Therefore, the current work was started to suit selection principles for Indian mustard genotypes through the analysis of the relationships between yield and its contributing attributes. (Shar *et al*. 2020) [18].

2. Materials and methods

The experiment was conducted to study thirteen yield contributing traits among forty distinct genotypes of Indian mustard with high genetic variability. It was performed at the Agricultural Research Station, Ummedganj, Agriculture University, Kota during *Rabi*, 2022-23. The experiment was employed in Randomized Block Design (RBD) with three replications. Each genotype was sown in 3 rows of 4.0-meters length, with row to row and plant to plant spacing of 30 cm and 10 cm, respectively. All the recommended agronomic practices for Indian mustard were followed to raise a healthy crop. Different quantitative traits like plant height (cm), number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, length of siliqua (cm), number of seeds per siliqua and 1000-seed weight (g) were analysed using mean values of randomly selected five plants per plot. Biological yield per plant, seed yield per plant (g) and harvest index (%) were analysed using the mean of ten randomly selected plants. The characters days to 50% flowering, days to maturity and oil content (%) were recorded based on the entire plot. Thus, data on thirteen quantitative traits were recorded and correlation coefficients were computed by employing the methodology described by Singh and Choudhary (1979) [2] and path analysis as per the formula given by Dewey and Lu (1959) [6].

3. Results and Discussion

All the attributes under investigation showed a wide range of variability, demonstrating that there is plenty of opportunity for successful decision-making based on the linked and non-linked consequence. Several alternative variables, collectively known as the yield component, interact in multiplicative ways to produce the superior character referred as seed yield. So, it is crucial to identify key characteristics that contribute to yield and to be aware of how these traits are related to seed yield and to each other for effectively selection of genotypes for the development of high yielding varieties. To investigate the relationship between yield and its component characters, correlational analyses were conducted using the experimental data to calculate the coefficient of correlation at the phenotypic and genotypic levels. The inter characters genotypic and phenotypic correlation coefficients are presented in Table-1.

The values of genotypic correlation coefficients generally had larger values but similar in signs with corresponding phenotypic correlation coefficients. It demonstrates the innate relationships between the attributes. Seed yield per plant had positive and significant association with the number of siliquae per plant (0.660**, 0.389**), number of primary branches per plant (0.438**, 0.227*), 1000-seed weight (0.375**, 0.245**), plant height (0.318**, 0.218*), harvest index (0.307**, 0.232*), number of secondary branches per plant (0.299**, 0.187*) and biological yield per plant (0.262**, 0.479**) at both genotypic and phenotypic level, respectively. The interrelationships between seed yield and these characteristics are similarly positive and substantial also reported in mustard by Ompal *et al.* (2018) [13], Kumar *et al.* (2019) [9], Shar *et al.* (2020) [18], Chaubey *et al*. (2022) [3] and Lavanya *et al.* (2022) [11]. At phenotypic level, number of seeds per siliqua (0.142) and length of siliqua (0.137) exhibited positive and non-significant correlation with seed yield per plant. Verma *et al.* (2016) [24], Dawar *et al.* (2018) [4] and Akoju *et al*. (2020) [1] also obtained similar results. Whereas, seed yield per plant exhibited positive and significant correlation with length of siliqua (0.284**) and number of seeds per siliqua (0.240**) at genotypic level. Similar finding also obtained by Lodhi *et al.* (2014) [12] and Lakra *et al.* (2020) [10].

Seed yield per plant had negative and non-significant association with oil content (-0.061, -0.077) at both genotypic and phenotypic levels, correspondingly. Ompal *et al.* (2018) [13] and Swetha *et al.* (2019) [22] also in agreement with this result. Day to 50% flowering showed positive and significant association with days to maturity and number of siliquae per plant, whereas negative and non-significant interrelationship with seed yield per plant and 1000-seed weight at both genotypic and phenotypic levels. Gupta *et al.* (2018) [8], Tripathi *et al.* (2019) [23], Akoju *et al*. (2020) [1] and Lavanya *et al.* (2022) [11] also reported negative and non-significant correlation between this trait and seed yield per plant.

Analyzing at the genotypic level, days to maturity exhibited a negative and significant association with seed yield per plant and similar findings were also achieved by Shekhawat *et al.* (2014) [19] and Tripathi *et al.* (2019) [23]. Whereas, at phenotypic level, days to maturity had negative and non-significant association with seed yield per plant and similar results also reported by Akoju *et al*. (2020) [1] and Lavanya *et al.* (2022) [11].

Number of primary and secondary branches per plant as well as number of siliquae per plant had sustainable and positive association with seed yield per plant and among themselves at both levels and these results were in accordance with the findings of Roy *et al.* (2018) [17] and Tantuway *et al.* (2018) [10]. It is obvious that as the overall number of branches increases, more pods should be produced by each plant. The number of siliquae per plant exhibited positive correlation with all the traits except days to maturity, plant height and oil content at both genotypic and phenotypic levels. Finding of Shekhawat *et al.* (2014) [19] and Kumar *et al*. (2019) [9] were in the agreement with these results for number of siliquae per plant.

The correlation of 1000-seed weight was reported positive and highly significant with length of siliqua, days to maturity, harvest index and oil content at both genotypic and phenotypic levels. Dawar *et al.* (2018) [4] also obtained similar finding for 1000-seed weight. A significantly negative association was obtained between biological yield per plant and harvest index at both levels. These results agreed with the previous correlation recorded by Gupta *et al*. (2018) [8] and Kumar *et al.* (2019) [9].

In order to measure the direct impact of one variable on another, a path coefficient is employed as a standardized partial regression coefficient. It allows for the disentanglement of correlation coefficients into their direct and indirect effects. The path-coefficient study in this context involved the utilization of genotypic and phenotypic correlation coefficients among thirteen traits to distinguish between their direct and indirect effects on seed yield per plant. The results are displayed in Table-2.

The current analysis reveals that the biological yield per plant and harvest index exerted the most pronounced positive direct effects on seed yield per plant. As a result, these traits have been identified as key attributes for enhancing seed yield. Previous studies conducted by Devi (2018) [5], Gupta *et al.* (2018) [8], Ompal *et al.* (2018) [13], Kumar *et al.* (2019) [9], Ray *et al.* (2019) [15], Rout *et al.* (2019) [16], Tripathi *et al.* (2019) [23] and Chaubey *et al.* (2022) [3] also resembles the findings.

Positive direct effect on seed yield per plant was also showed by plant height, number of siliquae per plant, 1000-seed weight and number of secondary branches per plant. This confirms the previous findings reported by Shekhawat *et al.* (2014) [19], Tripathi *et al.* (2019) [23], Akoju *et al.* (2020) [1], Lakra *et al.* (2020) [10], Chaubey *et al.* (2022) [3], Lavanya *et al.* (2022) [11] and Evangelin *et al.* (2023) [7].

The relationship between days to 50% flowering and seed yield per plant exhibited a negative non-significant correlation, along with a negative indirect effect. This finding has been consistent with previous studies carried out by Shekhawat *et al.* (2014) [19], Tripathi *et al.* (2019) [23] and Akoju *et al.* (2020) [1]. Days to maturity demonstrated a significant negative correlation with seed yield per plant, accompanied by positive indirect effects at the genotypic level. These results corroborate the earlier discoveries made by Gupta *et al.* (2018) [8] and Ompal *et al.* (2018) [13]. Conversely, at the genotypic level, a non-significant negative correlation and negative indirect effect were observed. Akoju *et al.* (2020) [1] also reached at similar conclusions.

Biological yield per plant had positive and significant correlation with seed yield per plant and the direct impact of this trait was reported positive. Ompal *et al.* (2018) [13], Kumar *et al.* (2019) [9] and Chaubey *et al.* (2022) [3] also showed agreement with direct and indirect effect of this trait on seed yield per plant. At genotypic level, oil content showed negative and non-significant relationship with seed yield per plant. Furthermore, the direct effect of oil content was positive. Gupta *et al.* (2018) [8] and Patel *et al.* (2021) [14] also obtained positive direct effect of this trait. Although, direct impact of oil content on seed yield per plant was found negative at phenotypic level and this result in agreement with finding of Ompal *et al.* (2018) [13].

The residual effect was determined to be 0.02038 and 0.06489 at the genotypic and phenotypic levels, respectively. These results suggest that the unconsidered unknown characters in this research had a negligible influence on the seed yield per plant.

Table 1: Estimation of genotypic (rg) and phenotypic (rp) correlation coefficients for thirteen characters in Indian mustard

S. No.	Characters	r	Day to 50% flowering	Days to maturity	Plant height	No. of primary branches per plant	No. of sec. branches per plant	No. of siliquae per plant	Length of siliqua	No. of seeds per siliqua	1000-seed weight	Biological yield per plant	Harvest index	Oil content	Seed yield per plant
1	Days to 50% flowering	G	1.000	0.365**	0.017	0.014	0.132	0.200*	0.111	-0.256**	-0.088	0.126	-0.224*	0.050	-0.173
		P	1.000	0.329**	0.034	0.022	0.096	0.186*	0.056	-0.217*	-0.091	0.100	-0.187*	0.044	-0.089
2	Days to maturity	G		1.000	-0.073	-0.298**	-0.199*	-0.133	0.530**	0.059	0.440**	-0.335**	0.205*	0.270**	-0.228*
		P		1.000	-0.045	-0.250**	-0.173	-0.128	0.366**	0.064	0.411**	-0.236**	0.167	0.245**	-0.149
3	Plant height	G			1.000	0.119	0.019	-0.030	0.182*	0.057	-0.039	0.262**	-0.124	-0.246**	0.318**
		P			1.000	0.087	0.008	-0.022	0.135	0.037	-0.039	0.197*	-0.096	-0.212*	0.218*
4	No. of primary branches per plant	G				1.000	0.742**	0.614**	-0.125	-0.113	-0.266**	0.333**	-0.081	-0.165	0.438**
		P				1.000	0.501**	0.465**	-0.075	-0.082	-0.208*	0.214*	-0.073	-0.115	0.227*
5	No. of sec. branches per plant	G					1.000	0.590**	0.019	-0.010	-0.143	0.128	0.008	-0.056	0.299**
		P					1.000	0.483**	0.000	-0.021	-0.135	0.083	0.019	-0.057	0.187*
6	No. of siliquae per plant	G						1.000	0.252**	0.160	0.153	0.161	0.193*	-0.171	0.660**
		P						1.000	0.094	0.133	0.127	0.105	0.150	-0.140	0.389**
7	Length of siliqua	G							1.000	0.539**	0.716**	0.384**	0.537**	0.268**	0.284**
		P							1.000	0.399**	0.527**	0.208*	0.354**	0.219*	0.137
8	No. of seeds per siliqua	G								1.000	0.497**	-0.089	0.215*	0.256**	0.240**
		P								1.000	0.463**	-0.070	0.179	0.233*	0.142
9	1000-seed weight	G									1.000	-0.345**	0.557**	0.315**	0.375**
		P									1.000	-0.279**	0.510**	0.294**	0.245**
10	Biological yield per plant	G										1.000	-0.828**	-0.160	0.262**
		P										1.000	-0.720**	-0.150	0.479**
11	Harvest index	G											1.000	0.147	0.307**
		P											1.000	0.132	0.232*
12	Oil content	G												1.000	-0.061
		P												1.000	-0.077
13	Seed yield per plant	G													1.000
		P													1.000

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

Table 2: Path coefficient analysis showing the direct and indirect effect of twelve characters on seed yield at genotypic and phenotypic level in Indian mustard

S. No.	Character		Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of sec. branches per plant	No. of siliquae per plant	Length of siliqua (cm)	No. of seeds per siliqua	1000-seed weight (g)	Biological yield per plant (g)	Harvest index (%)	Oil content (%)	Correlation with seed yield per plant
1	Days to 50% flowering	G	-0.0886	0.0055	0.0033	-0.0016	0.0102	0.0508	-0.0127	0.0036	-0.0078	0.1683	-0.3056	0.0018	-0.173
		P	-0.0047	-0.0080	0.0028	-0.0005	0.0037	0.0132	-0.0020	-0.0030	-0.0035	0.1273	-0.2132	-0.0005	-0.089
2	Days to maturity	G	-0.0324	0.0151	-0.0142	0.0332	-0.0154	-0.0337	-0.0604	-0.0008	0.0390	-0.4470	0.2792	0.0098	-0.228*
		P	-0.0015	-0.0242	-0.0037	0.0056	-0.0066	-0.0091	-0.0129	0.0009	0.0159	-0.3015	0.1904	-0.0027	-0.149
3	Plant height (cm)	G	-0.0015	-0.0011	0.1938	-0.0133	0.0014	-0.0077	-0.0208	-0.0008	-0.0034	0.3490	-0.1688	-0.0090	0.318**
		P	-0.0002	0.0011	0.0814	-0.0020	0.0003	-0.0016	-0.0048	0.0005	-0.0015	0.2518	-0.1093	0.0023	0.218*
4	No. of primary branches per plant	G	-0.0012	-0.0045	0.0231	-0.1115	0.0574	0.1557	0.0143	0.0016	-0.0236	0.4439	-0.1110	-0.0060	0.438**
		P	-0.0001	0.0061	0.0071	-0.0224	0.0190	0.0330	0.0027	-0.0011	-0.0081	0.2732	-0.0831	0.0013	0.227*
5	No. of sec. branches per plant	G	0.0117	-0.0030	0.0036	-0.0827	0.0774	0.1498	-0.0022	0.0001	-0.0127	0.1713	0.0115	-0.0021	0.299**
		P	-0.0005	0.0042	0.0007	-0.0112	0.0379	0.0343	0.0000	-0.0003	-0.0052	0.1053	0.0216	0.0006	0.187*
6	No. of siliquae per plant	G	0.0177	-0.0020	-0.0059	-0.0684	0.0457	0.2536	-0.0288	-0.0022	0.0135	0.2150	0.2636	-0.0063	0.660**
		P	-0.0009	0.0031	-0.0018	-0.0104	0.0183	0.0710	-0.0033	0.0018	0.0049	0.1340	0.1709	0.0015	0.389**
7	Length of siliqua (cm)	G	-0.0099	0.0080	0.0353	0.0140	0.0015	0.0640	-0.1140	-0.0075	0.0633	-0.5125	0.7320	0.0098	0.284**
		P	-0.0003	-0.0089	0.0110	0.0017	0.0000	0.0067	-0.0353	0.0055	0.0204	-0.2656	0.4037	-0.0024	0.137
8	No. of seeds per siliqua	G	0.0227	0.0009	0.0110	0.0126	-0.0008	0.0405	-0.0614	-0.0140	0.0440	-0.1184	0.2940	0.0093	0.240**
		P	0.0010	-0.0016	0.0030	0.0019	-0.0008	0.0094	-0.0141	0.0138	0.0180	-0.0896	0.2038	-0.0026	0.142
9	1000-seed weight (g)	G	0.0078	0.0067	-0.0075	0.0297	-0.0111	0.0387	-0.0816	-0.0070	0.0885	-0.4603	0.7596	0.0115	0.375**
		P	0.0004	-0.0100	-0.0032	0.0047	-0.0051	0.0090	-0.0186	0.0064	0.0387	-0.3555	0.5817	-0.0032	0.245**
10	Biological yield per plant (g)	G	-0.0112	-0.0051	0.0507	-0.0371	0.0099	0.0408	0.0438	0.0012	-0.0305	1.3347	-1.1293	-0.0058	0.262**
		P	-0.0005	0.0057	0.0161	-0.0048	0.0031	0.0075	0.0074	-0.0010	-0.0108	1.2760	-0.8210	0.0017	0.479**
11	Harvest index (%)	G	0.0198	0.0031	-0.0240	0.0091	0.0007	0.0490	-0.0612	-0.0030	0.0493	-1.1049	1.3641	0.0054	0.307**
		P	0.0009	-0.0040	-0.0078	0.0016	0.0007	0.0106	-0.0125	0.0025	0.0198	-0.9186	1.1404	-0.0015	0.232*
12	Oil content (%)	G	-0.0044	0.0041	-0.0477	0.0184	-0.0044	-0.0435	-0.0306	-0.0036	0.0279	-0.2139	0.2006	0.0365	-0.061
		P	-0.0002	-0.0059	-0.0172	0.0026	-0.0022	-0.0099	-0.0077	0.0032	0.0114	-0.1910	0.1510	-0.0110	-0.077

*, ** significant at 5% and 1% respectively Genotypic residual effect = 0.02038 Phenotypic residual effect = 0.06489

Conclusion

The findings of the current research demonstrated that traits such as biological yield per plant, harvest index, number of siliquae per plant, 1000-seed weight, plant height and number of secondary branches per plant have been identified as crucial factors in boosting seed yield as these traits exhibited significantly positive association and direct effect on seed yield per plant, at both genotypic and phenotypic levels. Therefore, it can be inferred that emphasizing on any of these traits, singly or in combination, will make more straightforward to identify genotypes with high seed yield performance.

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