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Correlation and Path Analysis for Seed Yield and Its Component Traits in Indian Mustard (*Brassica juncea* L. Czern and Coss.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A study for 17 agronomic traits was conducted to evaluate correlation and path analysis in *Brassica juncea* L. Czern and Coss. Ten lines with diverse genetic makeup and their crosses which were performed in half diallel fashion were grown in Randomized Block Design in three replications during rabi season (2021-22). At phenotypic and genotypic level, seed yield per plant exhibited significant positive correlation and positive direct effect on seed yield via plant height, total siliqua per plant and biological yield per plant in both F_1 and F_2 generations, while number of primary branches, seeds per siliqua and oil content showed negative direct correlation with seeds yield per plant at genotypic and phenotypic level in both F_1 and F_2 generations. The results of the study

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concluded that plant height, total siliqua per plant and biological yield per plant exerted high correlation and direct effect on seed yield per plant generations. Hence, these characters might be considered for selection and in improvement of seed yield of mustard genotypes.

Keywords: Indian mustard; correlation coefficient; genotype; path analysis; phenotype.

1. INTRODUCTION

Indian mustard [*Brassica juncea* (L.) Czern and Coss] ranks second in oil seed crops around the world as well as India. It is an allopolyploid species having 36 chromosomes and amphidiploid of *Brassica campestris* (2n=20) and *Brassica nigra* (2n=16). It is largely self-pollinated crop (85-90%) and self-compatible. Afghanistan and its adjoining regions (Central Asia) has been recognized as the primary Center of its origin, while central and western China, Eastern India and Asia minor, Iran are considered as the secondary centers of origin according to Vavilov [1]. Although it is widespread in Europe, Africa, North America, and Asia, several authors believe that Eastern India, the Caucasus, and China are the main genetic center for *Brassica juncea*.

Among the seven edible oilseeds cultivated in India, rapeseed-mustard contributes 27% in the total oilseeds production. *Brassica juncea* contributes to about 80 per cent of the total rapeseed-mustard production in the country. Globally, India is the largest grower of the rapeseed-mustard, occupying the first position in area and second position in production after China. India has witnessed increasing trends in both, area and production of rapeseed and mustard during last 5-6 years whereas in Uttar Pradesh area and production showed fluctuation, therefore ample scope exists for bringing additional area under rapeseed and mustard in India including state of Uttar Pradesh [2]. Rapeseed and mustard production 128.18 lakh tonnes, productivity 1447 kg/ha and in the area of 88.58 lakh ha in 2022-23 [3]. As India`s population continues to grow, our country is importing large quantities of edible oil from various countries. To meet the increasing demand, it is crucial to focus on enhancing the production of oil seeds, specifically by developing new and advanced varieties of Indian mustard and other oilseed crops. Achieving improvement in seed yield can be done through direct selection for seed yield and its component traits. Seed yield is usually controlled by polygenes and highly influenced by its component traits. Hence, identifying relative correlation and contribution of component characters to seed yield can be facilitated by understanding the association of the characters.

2. MATERIALS AND METHODS

In the present investigation the basic material comprised of ten varieties of Indian mustard namely, Varuna, Urvashi, Azad Mahak, RH-749, Maya, IJ-31, KMR 17-3, KMR 17-4, RH-406 and NRC-DR-2 were taken from the germplasm maintained at Oilseed Section, Department of Genetics and Plant Breeding, C.S. Azad University of Agriculture and Technology, Kanpur. The experimental material comprising of 100 treatments (10 parents + 45 F_1's and 45 F_2's) was evaluated in Randomized Block Design with three replications during Rabi 2021-2022. Each parent and F_1's planted in one row, and F_2's in two rows of 5m length with a spacing of 45 cm between rows and 15 cm between plants. All the recommended agronomic practices were adopted for raising a good crop. Ten plants in parents and F_1's and 20 plants in F_2's were taken randomly for each treatment in each replication and tagged for recording observations for days to 50% flowering, days to reproductive maturity, plant height (cm), length of main axis (cm), leaf area index, chlorophyll content, number of primary branches per plant, number of secondary branches per plant, number of siliqua on main axis, number of siliquae per plant, siliqua length(cm), number of seeds per siliqua, biological yield per plant (g), 1000-seed weight (g), harvest index (%), oil content (%) and seed yield per plant (g).

3. RESULTS AND DISCUSSION

3.1 Correlation Coefficient Analysis

Correlation studies provides association estimates between various characters. The prime objective for the breeder is yield, which is a complex, polygenic and highly environmentally influenced trait. So direct selection for yield will not be effective. The selection criteria to be adopted is decided by the correlation studies of yield and its component characters. The formula of calculation of the genotypic and phenotypic

coefficients of correlation were used as suggested by Al-Jibouri et al. [4]. The data available to the plant breeder immensely helps in estimating the degree of association between two or more plant characteristics in a particular crop (Table 1a and 1b).

The concept of correlation originally was presented and elaborated by Fisher [5] and Wright [6]. Dewey and Lu [7] recognized the nature of population under consideration as the magnitude of correlation coefficient. In the present investigation, the association study was taken up amongst F_1's and F_2's derived from half diallel design. In general, the magnitude of phenotypic correlation is in same direction but lower in revealing the pleiotropic effects rather than linkage for these association.

3.2 Genotypic Correlation Coefficient

Seed yield per plant exhibited positive highly significant association at genotypic level with biological yield per plant (0.977), seeds per siliqua (0.396), days to reproductive maturity (0.366), plant height (0.361), siliqua length (0.346), days to 50% flowering (0.345), total siliqua (0.287), siliqua on main axis (0.220) and harvest index (0.243). Positively significant correlation with number of secondary branches (0.181) and non-significant positive correlation with number of primary branches (0.064), 1000 seed weight (0.036) and main axis height (0.030). Significant negative correlation with oil content (-0.206) and non-significant negative correlation with leaf area index (-0.120) and chlorophyll content (-0.106) in F_1's.

Seed yield per plant exhibited positive highly significant association at genotypic level with biological yield per plant (0.815), chlorophyll content (0.427), total siliqua (0.323) and plant height (0.224). Positively significant correlation with 1000 seed weight (0.177) and non-significant correlation with harvest index (0.160), oil content (0.113), days to reproductive maturity (0.036), number of primary branches (0.034) and main axis height (0.031). Non-significant and negative correlation with leaf area index (-0.103), siliqua length (-0.030), seeds per siliqua (-0.025), siliqua on main axis (-0.008), number of secondary branches (-0.006) and days to 50% flowering (-0.003) in F_2's.

3.3 Phenotypic Correlation Coefficient

Seed yield per plant exhibited positive highly significant association at phenotypic level with biological yield per plant (0.957), seeds per siliqua (0.315), plant height (0.299), total siliqua (0.284), days to 50% flowering (0.232) and days to reproductive maturity (0.229). Positively significant correlation with siliqua length (0.216), harvest index (0.205) and number of secondary branches (0.181). Non-significant positive correlation with siliqua on main axis (0.137), number of primary branches (0.062), main axis height (0.037) and 1000 seed weight (0.034). Significant negative correlation with oil content (-0.173) and non-significant negative correlation with leaf area index (-0.109) and chlorophyll content (-0.097) in F_1's.

Seed yield per plant exhibited positive highly significant association at phenotypic level with biological yield per plant (0.780), chlorophyll content (0.364) and total siliqua (0.308). Positively significant correlation with plant height (0.186) and non-significant positive correlation with 1000 seed weight (0.155), harvest index (0.124), oil content (0.106), number of primary branches (0.038), days to reproductive maturity (0.019), siliqua length (0.016), main axis height (0.008) and siliqua on main axis (0.007). Non-significant and negative correlation with leaf area index (-0.099), seeds per siliqua (-0.026), days to 50% flowering (-0.024) and number of secondary branches (-0.001) in F_2's.

3.4 Path Coefficient Analysis

Path analysis partitions the correlation coefficient into direct and indirect effects of component characters (independent variables) on yield (dependent variable). It gives the understanding of cause-and-effect relationship between different character combinations (Table 2a and 2b). Path coefficient analysis was proposed by Wright [6] and later more lucidly explained by Dewey and Lu [7].

3.5 Genotypic Path Coefficient

In F_1's highest positive direct effect on seed yield per plant was exerted by biological yield per plant (0.8617) followed by harvest index (0.2212), siliqua length (0.1834), days to 50% flowering (0.1436), plant height (0.0493), main axis height (0.0258)' while highest negative direct effect on seed yield/plant was exerted by number of secondary branches (-0.1828) followed by chlorophyll content (-0.1342), days to reproductive maturity (-0.0817), leaf area index (-0.709) and 1000 seed weight (-0.0587). In this generation, high indirect positive effect on seed

yield per plant at genotypic level was exhibited by days to 50% flowering via days to reproductive maturity (0.1450), biological yield per plant (0.0496); chlorophyll content via number of secondary branches (0.0803), number of primary branches per plant (0.0640); number of secondary branches via chlorophyll content (0.1094), harvest index (0.0502); siliqua length via number of siliquae per plant (0.1002), seeds per siliqua (0.0985), number of primary branches (0.0601); biological yield per plant via number of seeds per siliqua (0.3994), days to reproductive maturity (0.3133), days to 50% flowering (0.2977), siliqua length (0.2910), plant height (0.2800), number of siliquae per plant (0.2759), number of siliqua on main axis (0.2284), number of secondary branches per plant (0.2125), number of primary branches per plant (0.0959), harvest index (0.0799); harvest index via chlorophyll content (0.0800), 1000 seed weight (0.0522). While, high indirect negative impact on seed yield per plant at genotypic level was exhibited by chlorophyll content via harvest index (-0.0485); number of secondary branches via number of siliquae per plant (-0.1158), length of main axis (-0.0919), number of siliquae on main axis (-0.0900), siliqua length (-0.0875), number of seeds per siliqua (-0.0591); siliqua length via days to reproductive maturity (-0.0599), days to 50% flowering (-0.0513); biological yield per plant via oil content (-0.1803), chlorophyll content (-0.1439), leaf area index (-0.1420); Harvest index via seeds per siliqua (-0.0789), number of secondary branches (-0.0607). In the F_1's generation genotypic estimate of residual effect was 0.0080. Similar finding were reported by Shekhawat et al. [8], Ray et al. [9] and Tripathi et al. [10].

In F_2's highest positive direct effect on seed yield per plant was exerted by biological yield per plant (0.7557) followed by chlorophyll content (0.3502), plant height (0.3995), number of secondary branches (0.2904) and total siliqua (0.0789), while highest negative direct effect on seed yield per plant was exerted by siliqua length (-0.2290) followed by harvest index (-0.1184), days to 50% flowering (-0.1000), main axis height (-0.0841), oil content (-0.0699), siliqua on main axis (-0.0504), number of primary branches (-0.0337), 1000 seed weight (-0.0334). In this generation, high indirect positive effect on seed yield per plant at genotypic level was exhibited by plant height via siliqua length (0.2120), number of primary branches per plant (0.1286), days to 50% flowering (0.1250), harvest index (0.1246), days to reproductive maturity (0.1087), chlorophyll content (0.0852), oil content (0.0789); chlorophyll content via harvest index (0.1281), days to 50% flowering (0.1063), days to reproductive maturity (0.1045), oil content (0.0781), plant height (0.0747); number of secondary branches via number of seeds per siliqua (0.0625); siliqua length via main axis height (0.0614); biological yield per plant via number of siliquae per plant (0.2229), number of primary branches per plant (0.1813), 1000-seed weight (0.1489), chlorophyll content (0.1300), oil content (0.1002), length of main axis (0.0898), days to 50% flowering (0.0838), plant height (0.0833); While, high indirect negative impact on seed yield per plant at genotypic level was exhibited by days to 50% flowering via days to reproductive maturity (-0.943); plant height via number of secondary branches per plant (-0.1788), number of seeds per siliqua (-0.0809); chlorophyll content via number of primary branches per plant (-0.0672), leaf area index (-0.0576); number of secondary branches via plant height (-0.1300), days to 50% flowering (-0.0581), number of primary branches (-0.0625); siliqua length via oil content (-0.0914), days to 50% flowering (-0.0754); harvest index (-0.1035), number of secondary branches (-0.0825); harvest index via leaf area index (-0.0598). In the F_2's generation genotypic estimate of residual effect was 0.0158. Overall, highly positive direct effect in both F_1's and F_2's generation for plant height, total siliquae per plant and biological yield per plant, while highly negative direct effect in both F_1's and F_2's generation for days to reproductive maturity, number of primary branches, seeds per siliqua, 1000 seed weight and oil content at genotypic level. Similar finding were reported by Tahira et al. [11], Yadav et al. [12] and Lavanya et al. [13].

3.6 Phenotypic Path Coefficient

In F_1's highest positive direct effect on seed yield/plant was exerted by biological yield per plant (0.9585) followed by harvest index (0.1165), plant height (cm) (0.0515), main axis height (0.0391), leaf area index (0.0226) and days to 50% flowering (0.0221), while highest negative direct effect on seed yield per plant was exerted by siliqua on main axis (-0.0479) followed by seeds per siliqua (-0.0369), days to reproductive maturity (-0.0246), number of primary branches (-0.0245), oil content (-0.0220) and number of secondary branches (-0.0209). In this generation, high indirect positive effect on seed yield per plant at phenotypic level was exhibited by days to 50% flowering via days to

Table 1a. Phenotypic (P) and Genotypic (G) correlation coefficient analysis of F_1 for seed yield and its component traits in Indian mustard

Hybrid		DHF	DRM	PH	MAH	LAI	CC	PB	SB	SOMA	TS	SL	S/S	BY	TSW	HI (%)	OC (%)	SY/P (g)
DHF	**GC**	1.000	0.979**	-0.063	0.277**	-0.267**	-0.307**	0.13	0.251**	0.069	0.019	-0.279**	0.094	0.345**	-0.103	0.044	-0.281**	0.345**
	PC	1.000	0.976**	-0.016	0.272**	-0.154	-0.230**	0.102	0.169*	0.068	0.014	-0.132	0.092	0.245**	-0.065	0.056	-0.143	0.232**
DRM	**GC**			-0.055	0.263**	-0.279**	-0.262**	0.129	0.241**	0.064	0.019	-0.326**	0.121	0.364**	-0.142	0.103	-0.300**	0.366**
	PC			-0.010	0.248**	-0.158	-0.195*	0.101	0.151	0.075	0.025	-0.127	0.084	0.238**	-0.087	0.090	-0.130	0.229**
PH	**GC**				0.274**	-0.058	0.003	0.225**	0.207*	0.246**	0.266**	0.236**	0.301**	0.325**	0.018	0.081	0.200*	0.361**
	PC				0.215*	-0.056	-0.009	0.162	0.173*	0.121	0.242**	0.136	0.217*	0.266**	0.018	0.026	0.091	0.299**
MAH	**GC**					-0.073	-0.300**	0.328**	0.503**	0.559**	0.328**	0.009	0.14	0.046	0.111	-0.115	0.148	0.03
	PC					-0.083	-0.223**	0.295**	0.465**	0.424**	0.295**	0.010	0.118	0.046	0.103	-0.112	0.132	0.037
LAI	**GC**						-0.265**	0.137	0.028	0.041	0.059	0.169*	-0.143	-0.165	0.105	0.242**	-0.197*	-0.12
	PC						-0.256**	0.142	0.026	0.006	0.054	0.130	-0.107	-0.159	0.100	0.204*	-0.163	-0.109
CC	**GC**							-0.476**	-0.598**	-0.319**	-0.198*	-0.041	-0.03	-0.167	-0.126	0.362**	0.153	-0.107
	PC							-0.424**	-0.535**	-0.152	-0.199*	-0.056	-0.012	-0.149	-0.108	0.232**	0.145	-0.097
PB	**GC**								0.717**	0.335**	0.497**	0.328**	0.113	0.111	0.062	-0.199*	0.019	0.064
	PC								0.690**	0.228**	0.476**	0.245**	0.103	0.107	0.058	-0.143	0.006	0.062
SB	**GC**									0.492**	0.633**	0.479**	0.323**	0.247**	0.071	-0.275**	-0.007	0.181*
	PC									0.335**	0.612**	0.351**	0.258**	0.243**	0.070	-0.216*	-0.014	0.181*
S0MA	**GC**										0.314**	0.216*	0.262**	0.265**	0.123	-0.172*	0.075	0.220**
	PC										0.204*	0.204*	0.194*	0.197*	0.101	-0.060	0.161	0.137
TS	**GC**											0.546**	0.368**	0.320**	0.014	-0.147	-0.103	0.287**
	PC											0.392**	0.296**	0.308**	0.008	-0.114	-0.089	0.284**
SL	**GC**												0.537**	0.338**	0.125	-0.142	0.017	0.346**
	PC												0.448**	0.247**	0.088	-0.098	0.016	0.216*
S/S	**GC**													0.463**	0.037	-0.357**	0.02	0.396**
	PC													0.388**	0.012	-0.234**	0.006	0.315**
BY	**GC**														0.03	0.093	-0.209*	0.977**
	PC														0.027	0.073	-0.154	0.957**
TSW	**GC**															0.236**	0.272**	0.036
	PC															0.176*	0.234**	0.034
HI (%)	**GC**																0.035	0.243**
	PC																-0.001	0.205*

Hybrid		DHF	DRM	PH	MAH	LAI	CC	PB	SB	SOMA	TS	SL	S/S	BY	TSW	HI (%)	OC (%)	SY/P (g)
OC (%)	GC																	-0.206*
	PC																	-0.173*
SY/P (g)	GC																	1
	PC																	1

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

DFF= days to 50% flowering, DRM= days to reproductive maturity, PH= plant height (cm), MAH= length of main axis (cm), LAI= leaf area index, CC= chlorophyll content, PB= number of primary branches, SB= number of secondary branches, SOMA= siliqua on main axis, TS= number of siliquae per plant, SL= siliqua length, S/S=seeds per siliqua, BY= biological yield per plant, TSW=1000-seed weight, HI=harvest index, OC= oil content, SY/P =seed yield per plant

Table 1b. Phenotypic (P) and Genotypic (G) correlation coefficient analysis of F_2 for seed yield and its component traits in Indian mustard

Hybrid		DHF	DRM	PH	MAH	LAI	CC	PB	SB	SOMA	TS	SL	S/S	BY	TSW	HI (%)	OC (%)	SY/P (g)
DHF	GC	1.000	0.942**	0.313**	0.233**	-0.370**	0.303**	0.081	-0.200*	0.073	-0.116	0.329**	0.270**	0.111	0.239**	-0.136	0.153	-0.003
	PC	1.000	0.779**	0.190*	0.183*	-0.315**	0.228**	0.039	-0.108	0.013	-0.093	0.186*	0.227**	0.092	0.216*	-0.112	0.121	-0.024
DRM	GC			0.272**	0.285**	-0.426**	0.298**	-0.012	-0.042	0.161	-0.036	0.13	0.270**	0.064	0.217*	-0.115	0.119	0.036
	PC			0.181*	0.253**	-0.407**	0.261**	-0.013	-0.052	0.144	-0.039	0.111	0.187*	0.060	0.216*	-0.095	0.102	0.019
PH	GC				-0.066	0.086	0.213*	0.322**	-0.448**	0.048	0.038	0.531**	-0.202*	0.11	0.031	0.312**	0.198*	0.224**
	PC				-0.020	0.077	0.134	0.229**	-0.187*	0.056	0.010	0.083	-0.149	0.073	0.024	0.188*	0.138	0.186*
MAH	GC					-0.189*	0.126	0.262**	0.098	0.446**	-0.024	-0.268**	0.092	0.119	0.149	-0.014	0.031	0.031
	PC					-0.174*	0.111	0.156	0.119	0.329**	-0.027	-0.154	0.048	0.108	0.152	-0.006	0.048	0.008
LAI	GC						-0.164	0.084	-0.086	-0.104	0.127	0.071	-0.105	-0.189*	-0.098	0.505**	-0.112	-0.103
	PC						-0.148	0.033	-0.058	-0.088	0.120	0.029	-0.091	-0.186*	-0.092	0.469**	-0.106	-0.099
CC	GC							-0.192*	-0.068	0.117	0.067	0.011	0.036	0.172*	0.126	0.366**	0.223**	0.427**
	PC							-0.124	-0.068	0.069	0.046	0.026	0.030	0.148	0.095	0.329**	0.196*	0.364**
PB	GC								0.251**	-0.088	-0.388**	0.317**	-0.479**	0.240**	-0.092	0.063	-0.116	0.034
	PC								-0.047	-0.051	-0.180*	0.049	-0.154	0.121	-0.048	0.034	-0.031	0.038
SB	GC									-0.059	0.079	0.071	0.214*	-0.109	-0.025	0.083	0.069	-0.006
	PC									-0.076	0.051	-0.012	0.092	-0.078	-0.038	0.082	0.037	-0.001
S0MA	GC										0.242**	-0.09	0.015	0.035	-0.007	0.013	0.182*	-0.008
	PC										0.182*	-0.119	-0.041	0.031	-0.004	0.000	0.108	0.007
TS	GC											0.251**	0.199*	0.295**	-0.088	-0.044	0.203*	0.323**
	PC											0.100	0.124	0.279**	-0.092	-0.041	0.188*	0.308**
SL	GC												0.210*	-0.05	-0.182*	-0.148	0.399**	-0.03
	PC												0.219*	-0.028	-0.065	-0.045	0.150	0.016

Hybrid		DHF	DRM	PH	MAH	LAI	CC	PB	SB	SOMA	TS	SL	S/S	BY	TSW	HI (%)	OC (%)	SY/P (g)
S/S	**GC**													0.057	0.200*	-0.272**	0.145	-0.025
	PC													0.032	0.157	-0.201*	0.104	-0.026
BY	**GC**														0.197*	-0.137	0.133	0.815**
	PC														0.186*	-0.126	0.126	0.780**
TSW	**GC**															-0.212*	0.011	0.177*
	PC															-0.191*	-0.015	0.155
HI (%)	**GC**																-0.143	0.16
	PC																-0.125	0.124
OC (%)	**GC**																	0.113
	PC																	0.106
SY/P (g)	**GC**																	1
	PC																	1

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

DFF= days to 50% flowering, DRM= days to reproductive maturity, PH= plant height (cm), MAH= length of main axis (cm), LAI= leaf area index, CC= chlorophyll content, PB= number of primary branches, SB= number of secondary branches, SOMA= siliqua on main axis, TS= number of siliquae per plant, SL= siliqua length, S/S=seeds per siliqua, BY= biological yield per plant, TSW=1000-seed weight, HI=harvest index, OC= oil content, SY/P =seed yield per plant

Table 2a. Genotypic (G) and Phenotypic (P) Path coefficient of F_1 for 17 characters in 10x10 Diallel cross in Indian mustard

Hybrid		DHF	DRM	PH	MAH	LAI	CC	PB	SB	SOMA	TS	SL	S/S	BY	TSW	HI	OC	SY/P
DHF	**GP**	**0.1436**	-0.0825	-0.0031	0.0072	0.0189	0.0413	-0.0008	-0.0458	0.0012	0.0003	-0.0513	-0.0006	0.2977	0.0060	0.0098	0.0037	0.345**
	PP	**0.0221**	-0.0240	-0.0008	0.0106	-0.0035	-0.0028	-0.0025	-0.0035	-0.0033	0.0003	-0.0019	-0.0034	0.2346	0.0005	0.0065	0.0032	0.232**
DRM	**GP**	0.1450	**-0.0817**	-0.0027	0.0068	0.0198	0.0352	-0.0008	-0.0441	0.0011	0.0003	-0.0599	-0.0008	0.3133	0.0083	0.0228	0.0040	0.366**
	PP	0.0215	**-0.0246**	-0.0005	0.0097	-0.0036	-0.0023	-0.0025	-0.0032	-0.0036	0.0004	-0.0018	-0.0031	0.2282	0.0006	0.0105	0.0028	0.229**
PH	**GP**	-0.0090	0.0045	**0.0493**	0.0071	0.0041	-0.0004	-0.0014	-0.0379	0.0042	0.0038	0.0433	-0.0020	0.2800	0.0000	0.0179	-0.0026	0.361**
	PP	-0.0004	0.0003	**0.0515**	0.0084	-0.0013	-0.0001	-0.0040	-0.0036	-0.0058	0.0042	0.0020	-0.0080	0.2545	-0.0001	0.0031	-0.0020	0.299**
MAH	**GP**	0.0398	-0.0215	0.0135	**0.0258**	0.0052	0.0402	-0.0021	-0.0919	0.0095	0.0046	0.0016	-0.0009	0.0398	-0.0065	-0.0254	-0.0020	0.030
	PP	0.0060	-0.0061	0.0111	**0.0391**	-0.0019	-0.0027	-0.0072	-0.0097	-0.0203	0.0052	0.0001	-0.0044	0.0440	-0.0007	-0.0130	-0.0029	0.037
LAI	**GP**	-0.0383	0.0228	-0.0029	-0.0019	**-0.0709**	0.0356	-0.0009	-0.0052	0.0007	0.0008	0.0310	0.0010	-0.1420	-0.0061	0.0536	0.0026	-0.120
	PP	-0.0034	0.0039	-0.0029	-0.0032	**0.0226**	-0.0031	-0.0035	-0.0006	-0.0003	0.0010	0.0019	0.0039	-0.1521	-0.0007	0.0238	0.0036	-0.109
CC	**GP**	-0.0441	0.0214	0.0002	-0.0077	0.0188	**-0.1342**	0.0030	0.1094	-0.0054	-0.0028	-0.0075	0.0002	-0.1439	0.0074	0.0800	-0.0020	-0.107
	PP	-0.0051	0.0048	-0.0005	-0.0087	-0.0058	**0.0120**	0.0104	0.0112	0.0073	-0.0035	-0.0008	0.0005	-0.1433	0.0008	0.0270	-0.0032	-0.097
PB	**GP**	0.0186	-0.0105	0.0111	0.0085	-0.0097	0.0640	**-0.0063**	-0.1311	0.0057	0.0070	0.0601	-0.0008	0.0959	-0.0037	-0.0441	-0.0003	0.064
	PP	0.0023	-0.0025	0.0083	0.0116	0.0032	-0.0051	**-0.0245**	-0.0144	-0.0109	0.0083	0.0035	-0.0038	0.1028	-0.0004	-0.0167	-0.0001	0.062
SB	**GP**	0.0360	-0.0197	0.0102	0.0130	-0.0020	0.0803	-0.0045	**-0.1828**	0.0083	0.0090	0.0877	-0.0021	0.2125	-0.0042	-0.0607	0.0001	0.181*

Hybrid		DHF	DRM	PH	MAH	LAI	CC	PB	SB	SOMA	TS	SL	S/S	BY	TSW	HI	OC	SY/P
	PP	0.0037	-0.0037	0.0089	0.0182	0.0006	-0.0064	-0.0169	**-0.0209**	-0.0160	0.0107	0.0051	-0.0095	0.2327	-0.0005	-0.0252	0.0003	0.181*
S0MA	**GP**	0.0099	-0.0052	0.0122	0.0144	-0.0029	0.0428	-0.0021	-0.0900	**0.0169**	0.0044	0.0396	-0.0017	0.2284	-0.0072	-0.0381	-0.0010	0.220**
	PP	0.0015	-0.0019	0.0062	0.0166	0.0001	-0.0018	-0.0056	-0.0070	**-0.0479**	0.0036	0.0030	-0.0071	0.1888	-0.0007	-0.0070	-0.0035	0.137
TS	**GP**	0.0027	-0.0016	0.0131	0.0085	-0.0042	0.0266	-0.0031	-0.1158	0.0053	**0.0142**	0.1002	-0.0024	0.2759	-0.0008	-0.0326	0.0014	0.287**
	PP	0.0003	-0.0006	0.0125	0.0116	0.0012	-0.0024	-0.0117	-0.0128	-0.0097	**0.0175**	0.0057	-0.0109	0.2948	-0.0001	-0.0133	0.0020	0.284**
SL	**GP**	-0.0401	0.0267	0.0117	0.0002	-0.0120	0.0055	-0.0021	-0.0875	0.0037	0.0077	**0.1834**	-0.0036	0.2910	-0.0073	-0.0315	-0.0002	0.346**
	PP	-0.0029	0.0031	0.0070	0.0004	0.0029	-0.0007	-0.0060	-0.0074	-0.0098	0.0069	**0.0145**	-0.0165	0.2365	-0.0006	-0.0114	-0.0004	0.216*
S/S	**GP**	0.0135	-0.0099	0.0149	0.0036	0.0102	0.0040	-0.0007	-0.0591	0.0044	0.0052	0.0985	**-0.0066**	0.3994	-0.0022	-0.0789	-0.0003	0.396**
	PP	0.0020	-0.0021	0.0112	0.0046	-0.0024	-0.0002	-0.0025	-0.0054	-0.0093	0.0052	0.0065	**-0.0369**	0.3721	-0.0001	-0.0273	-0.0001	0.315**
BY	**GP**	0.0496	-0.0297	0.0160	0.0012	0.0117	0.0224	-0.0007	-0.0451	0.0045	0.0045	0.0619	-0.0031	**0.8617**	-0.0017	0.0205	0.0028	0.977**
	PP	0.0054	-0.0059	0.0137	0.0018	-0.0036	-0.0018	-0.0026	-0.0051	-0.0094	0.0054	0.0036	-0.0143	**0.9585**	-0.0002	0.0086	0.0034	0.957**
TSW	**GP**	-0.0148	0.0116	0.0000	0.0029	-0.0074	0.0169	-0.0004	-0.0130	0.0021	0.0002	0.0229	-0.0002	0.0256	**-0.0587**	0.0522	-0.0036	0.036
	PP	-0.0014	0.0021	0.0009	0.0040	0.0023	-0.0013	-0.0014	-0.0015	-0.0048	0.0001	0.0013	-0.0004	0.0259	**-0.0069**	0.0205	-0.0051	0.034
HI	**GP**	0.0064	-0.0084	0.0040	-0.0030	-0.0172	-0.0485	0.0013	0.0502	-0.0029	-0.0021	-0.0261	0.0024	0.0799	-0.0139	**0.2212**	-0.0005	0.243**
	PP	0.0012	-0.0022	0.0014	-0.0044	0.0046	0.0028	0.0035	0.0045	0.0029	-0.0020	-0.0014	0.0086	0.0704	-0.0012	**0.1165**	0.0000	0.205*
OC	**GP**	-0.0403	0.0245	0.0099	0.0038	0.0140	-0.0205	-0.0001	0.0013	0.0013	-0.0015	0.0031	-0.0001	-0.1803	-0.0159	0.0077	**-0.0132**	-0.206*
	PP	-0.0032	0.0032	0.0047	0.0052	-0.0037	0.0017	-0.0001	0.0003	-0.0077	-0.0016	0.0002	-0.0002	-0.1479	-0.0016	-0.0002	**-0.0220**	-0.173*

Bold values shows direct and normal values shows indirect effects

RESIDUAL EFFECT = 0.0080 (Genotypic)

RESIDUAL EFFECT = 0.0576 (phenotypic)

Where,

DFF= days to 50% flowering, DRM= days to reproductive maturity, PH= plant height (cm), MAH= length of main axis (cm), LAI= leaf area index, CC= chlorophyll content, PB= number of primary branches, SB= number of secondary branches, SOMA= siliqua on main axis, TS= number of siliquae per plant, SL= siliqua length, S/S=seeds per siliqua, BY= biological yield per plant, TSW=1000-seed weight, HI=harvest index, OC= oil content, SY/P =seed yield per plant

Table 2b. Genotypic (G) and Phenotypic(P) Path coefficient of F_2 for 17 characters in 10x10 Diallel cross in Indian mustard

Hybrid		DHF	DRM	PH	MAH	LAI	CC	PB	SB	SOMA	TS	SL	S/S	BY	TSW	HI	OC	SY/P
DHF	**GP**	**-0.1000**	-0.0139	0.1250	-0.0196	-0.0299	0.1063	-0.0027	-0.0581	-0.0037	-0.0092	-0.0754	-0.0035	0.0838	-0.0080	0.0161	-0.0107	-0.003
	PP	**-0.1940**	0.0368	0.0232	-0.0137	0.0217	0.0503	-0.0008	-0.0073	-0.0004	-0.0087	0.0097	-0.0038	0.0680	0.0157	-0.0161	-0.0045	-0.024
DRM	**GP**	-0.0943	**-0.0148**	0.1087	-0.0240	-0.0344	0.1045	0.0004	-0.0121	-0.0081	-0.0029	-0.0298	-0.0035	0.0483	-0.0073	0.0137	-0.0083	0.036
	PP	-0.1511	**0.0473**	0.0221	-0.0190	0.0281	0.0574	0.0002	-0.0035	-0.0039	-0.0037	0.0058	-0.0031	0.0442	0.0156	-0.0137	-0.0038	0.019
PH	**GP**	-0.0313	-0.0040	**0.3995**	0.0056	0.0069	0.0747	-0.0108	-0.1300	-0.0024	0.0030	-0.1215	0.0026	0.0833	-0.0011	-0.0369	-0.0138	0.224**
	PP	-0.0369	0.0086	**0.1218**	0.0015	-0.0053	0.0295	-0.0044	-0.0126	-0.0015	0.0009	0.0043	0.0025	0.0539	0.0017	0.0272	-0.0051	0.186*
MAH	**GP**	-0.0233	-0.0042	-0.0265	**-0.0841**	-0.0153	0.0443	-0.0088	0.0285	-0.0225	-0.0019	0.0614	-0.0012	0.0898	-0.0050	0.0017	-0.0022	0.031

Hybrid		DHF	DRM	PH	MAH	LAI	CC	PB	SB	SOMA	TS	SL	S/S	BY	TSW	HI	OC	SY/P
	PP	-0.0355	0.0120	-0.0025	**-0.0750**	0.0120	0.0245	-0.0030	0.0081	-0.0090	-0.0026	-0.0080	-0.0008	0.0798	0.0110	-0.0008	-0.0018	0.008
LAI	**GP**	0.0371	0.0063	0.0342	0.0159	0.0807	-0.0576	-0.0028	-0.0251	0.0052	0.0100	-0.0164	0.0014	-0.1431	0.0033	-0.0598	0.0078	-0.103
	PP	0.0610	-0.0192	0.0093	0.0130	**-0.0691**	-0.0327	-0.0006	-0.0039	0.0024	0.0112	0.0015	0.0015	-0.1384	-0.0067	0.0676	0.0039	-0.099
CC	**GP**	-0.0304	-0.0044	0.0852	-0.0106	-0.0133	**0.3503**	0.0065	-0.0197	-0.0059	0.0053	-0.0026	-0.0005	0.1300	-0.0042	-0.0433	-0.0156	0.427**
	PP	-0.0443	0.0123	0.0163	-0.0084	0.0103	**0.2201**	0.0024	-0.0046	-0.0019	0.0043	0.0014	-0.0005	0.1096	0.0069	0.0475	-0.0073	0.364**
PB	**GP**	-0.0081	0.0002	0.1286	-0.0220	0.0068	-0.0672	**-0.0337**	-0.0625	0.0044	-0.0306	-0.0726	0.0062	0.1813	0.0031	-0.0075	0.0081	0.034
	PP	-0.0077	-0.0006	0.0279	-0.0117	-0.0023	-0.0274	**-0.0192**	-0.0032	0.0014	-0.0169	0.0025	0.0026	0.0901	-0.0035	0.0049	0.0011	0.038
SB	**GP**	0.0200	0.0006	-0.1788	-0.0083	-0.0070	-0.0238	0.0073	**0.2904**	0.0030	0.0063	-0.0163	-0.0028	-0.0825	0.0008	-0.0098	-0.0048	-0.006
	PP	0.0209	-0.0025	-0.0228	-0.0090	0.0040	-0.0149	0.0009	**0.0676**	0.0021	0.0048	-0.0006	-0.0015	-0.0580	-0.0028	0.0118	-0.0014	-0.001
S0MA	**GP**	-0.0073	-0.0024	0.0193	-0.0375	-0.0084	0.0411	0.0030	-0.0172	**-0.0504**	0.0191	0.0207	-0.0002	0.0263	0.0002	-0.0015	-0.0127	-0.008
	PP	-0.0026	0.0068	0.0068	-0.0247	0.0061	0.0152	0.0010	-0.0051	**-0.0274**	0.0171	-0.0062	0.0007	0.0229	-0.0003	0.0001	-0.0040	0.007
TS	**GP**	0.0117	0.0005	0.0151	0.0020	0.0103	0.0233	0.0131	0.0231	-0.0122	**0.0789**	-0.0574	-0.0026	0.2229	0.0030	0.0052	-0.0142	0.323**
	PP	0.0180	-0.0019	0.0012	0.0020	-0.0083	0.0102	0.0035	0.0035	-0.0050	**0.0937**	0.0052	-0.0021	0.2074	-0.0067	-0.0060	-0.0070	0.308**
SL	**GP**	-0.0329	-0.0019	0.2120	0.0226	0.0058	0.0039	-0.0107	0.0207	0.0046	0.0198	**-0.2290**	-0.0027	-0.0375	0.0061	0.0175	-0.0279	-0.030
	PP	-0.0361	0.0052	0.0101	0.0116	-0.0020	0.0057	-0.0009	-0.0008	0.0033	0.0094	**0.0519**	-0.0037	-0.0206	-0.0047	-0.0065	-0.0055	0.016
S/S	**GP**	-0.0270	-0.0040	-0.0809	-0.0077	-0.0085	0.0127	0.0161	0.0621	-0.0008	0.0157	-0.0480	**-0.0129**	0.0429	-0.0067	0.0322	-0.0101	-0.025
	PP	-0.0441	0.0088	-0.0181	-0.0036	0.0063	0.0066	0.0030	0.0062	0.0011	0.0116	0.0113	**-0.0168**	0.0235	0.0114	-0.0291	-0.0038	-0.026
BY	**GP**	-0.0111	-0.0009	0.0441	-0.0100	-0.0153	0.0603	-0.0081	-0.0317	-0.0018	0.0233	0.0114	-0.0007	**0.7557**	-0.0066	0.0162	-0.0093	0.815**
	PP	-0.0178.	0.0028	0.0088	-0.0081	0.0129	0.0325	-0.0023	-0.0053	-0.0008	0.0262	-0.0014	-0.0005	**0.7426**	0.0135	-0.0182	-0.0047	0.780**
TSW	**GP**	-0.0239	-0.0032	0.0126	-0.0126	-0.0079	0.0443	0.0031	-0.0073	0.0003	-0.0070	0.0416	-0.0026	0.1489	**-0.0334**	0.0252	-0.0008	0.177*
	PP	-0.0420	0.0102	0.0029	-0.0114	0.0064	0.0208	0.0009	-0.0026	0.0001	-0.0086	-0.0034	-0.0026	0.1383	**0.0725**	-0.0275	0.0005	0.155
HI	**GP**	0.0136	0.0017	0.1246	0.0012	0.0407	0.1281	-0.0021	0.0240	-0.0007	-0.0035	0.0338	0.0035	-0.1035	0.0071	**-0.1184**	0.0100	0.160
	PP	0.0217	-0.0045	0.0229	0.0004	-0.0324	0.0725	-0.0007	0.0055	0.0000	-0.0039	-0.0023	0.0034	-0.0935	-0.0138	**0.1443**	0.0046	0.124
OC	**GP**	-0.0153	-0.0018	0.0789	-0.0026	-0.0090	0.0781	0.0039	0.0200	-0.0092	0.0160	-0.0914	-0.0019	0.1002	-0.0004	0.0169	**-0.0699**	0.113
	PP	-0.0235	0.0048	0.0168	-0.0036	0.0073	0.0432	0.0006	0.0025	-0.0029	0.0176	0.0078	-0.0017	0.0935	-0.0011	-0.0180	**-0.0369**	0.106

Bold values shows direct and normal values shows indirect effects

RESIDUAL EFFECT = 0.0158 (Genotypic)

RESIDUAL EFFECT = 0.0251 (phenotypic)

Where,

DHF= days to 50% flowering, DRM= days to reproductive maturity, PH= plant height (cm), MAH= length of main axis (cm), LAI= leaf area index, CC= chlorophyll content, PB= number of primary branches, SB= number of secondary branches, SOMA= siliqua on main axis, TS= number of siliquae per plant, SL= siliqua length, S/S=seeds per siliqua, BY= biological yield per plant, TSW=1000-seed weight, HI=harvest index, OC= oil content, SY/P =seed yield per plant

reproductive maturity (0.0215); biological yield per plant via number of siliquae per plant (0.2948), plant height (0.2545), days to 50% flowering (0.2346), number of secondary branches per plant (0.2327), siliqua length (0.2365), days to reproductive maturity (0.2282), number of siliqua on main axis (0.1888), number of primary branches per plant (0.1028); While, high indirect negative impact on seed yield per plant at phenotypic level was exhibited by biological yield per plant via leaf area index (-0.1521), oil content (-0.1479), chlorophyll content (-0.1433); harvest index via seeds per siliqua (-0.0273), number of secondary branches per plant (-0.0252). In the F_1's generation phenotypic estimate of residual effect was 0.0576 Similar finding were reported by Dipti et al. [14], Nur-E-Nabi et al. [15] and Tripathi et al. [10].

In F_2's, highest positive direct effect on seed yield/plant was exerted by biological yield per plant (0.7426) followed by chlorophyll content (0.2201), harvest index (0.1443), plant height (0.1218), total siliqua (0.937), 1000 seed weight (0.0725), number of secondary branches/plant (0.0676), siliqua length (0.0519) and days to maturity (0.0473), while highest negative direct effect on seed yield/plant was exerted by days to 50% flowering (-0.1940) followed by main axis height (-0.0750), leaf area index (-0.0691), oil content % (-0.0369),siliqua on main axis (-0.0274). In this generation, high indirect positive effect on seed yield per plant at phenotypic level was exhibited by days to 50% flowering via chlorophyll content (0.0610); chlorophyll content via harvest index (0.0725), days to reproductive maturity (0.0574), days to 50% flowering (0.0503); biological yield per plant via number of siliquae per plant (0.2074), 1000 seed weight (0.1383), chlorophyll content (0.1096), oil content (0.0935), number of primary branches per plant (0.0901), main axis height (0.0798), days to 50% flowering (0.0680), plant height (0.0539); While, high indirect negative impact on seed yield per plant at phenotypic level was exhibited by days to 50% flowering via days to maturity (-0.1511), chlorophyll content (-0.0443), seed/siliqua (-0.0441), 1000 seed weight (-0.0421); plant height via number of secondary branches (-0.0228); main axis height via siliqua on main axis in (-0.0247); leaf area index via harvest index (-0.0324); chlorophyll content via leaf area index (-0.0327), number of primary branches (-0.0247); biological yield per plant via leaf area index (-0.1384), harvest index (-0.0935) and number of secondary branches (-0.0580); harvest index via seeds per siliqua (-0.0291), 1000 seed weight (-0.0275). In the F_2's generation genotypic estimate of residual effect was 0.0251. Overall, highly positive direct effect in both F_1's and F_2's generation for plant height, total siliquae per plant and biological yield per plant, while highly negative direct effect in both F_1's and F_2's generations for days to reproductive maturity, number of primary branches, seeds per siliqua, 1000 seed weight and oil content at phenotypic level. Similar finding were reported by Singh et al. [16], Rout et al. [17] and Rauf and Rahim [18]. The residual effect determines how the characters account for the variability of the dependent variable i.e. seed yield per plant. The low estimate of residual effect suggests that most of the important traits contributing to yield have been included in the study.

4. CONCLUSION

In this study plant height, total siliquae per plant, and biological yield per plant were found to be the most crucial characters in achieving high seed yield in mustard crop as they showed significant positive correlation at genotypic and phenotypic correlation along with high positive direct effects at both genotypic and phenotypic level on seed yield per plant in F_1's and F_2's generation both. Therefore, we need to consider using these traits as the selection criterion to improve seed yield in mustard crop.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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