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Association Analysis among Morpho-physiological Traits of Indian Mustard [*Brassica juncea* (L.) Czern. & Coss.] Lines under Rainfed and Irrigated Conditions

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ABSTRACT

This study was conducted during *rabi* season (November, 2023–March, 2024) at the Agricultural Research Farm, Institute of Agricultural Sciences, BHU, Varanasi, Uttar Pradesh, India to assess the influence of key traits on seed yield in fourteen mustard genotypes grown under rainfed and irrigated conditions. Indian mustard [*Brassica juncea* (L.) Czern. & Coss.], a major oilseed crop, faced significant yield challenges in India due to climate change and water scarcity, which intensified biotic and abiotic stresses. Nineteen phenological, morphological, and physiological traits were analysed for correlation and path coefficients to identify those contributing most to seed yield plant^{-1}. Under rainfed conditions, the highest positive correlations with seed yield plant^{-1} were observed for chlorophyll content (0.533P, 0.992G), the number of primary branches (0.600P, 0.983G), main raceme length (0.540P, 0.943G), number of siliquae plant^{-1} (0.669P. 0.902G), plant height (0.615P, 0.883G), number of siliquae on main raceme (0.523P, 0.720G), and test weight (0.554P, 0.920G). In irrigated conditions, traits like number of secondary branches (0.609P, 0.699G), main raceme length (0.422P, 0.936G), chlorophyll content (0.583P, 0.760G), yield ha^{-1} (0.617P, 0.717G), siliquae plant^{-1} (0.580P, 0.655G), and plant height (0.470P, 0.543G) showed strong correlations with seed yield. Path analysis revealed biological yield and harvest index exhibited the highest positive direct effects on seed yield in both conditions highlighting their importance for direct selection. Therefore, these characters should be considered to improve the seed yield plant^{-1} in rainfed and irrigated conditions.

KEYWORDS: Correlation, Indian mustard, irrigated, path coefficient, rainfed

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1. INTRODUCTION

Indian mustard [*Brassica juncea* (L.) Czern. & Coss.], an autotetraploid crop (2n=36, AABB genome) originated in Central Asia (Afghanistan and its contiguous regions) with Asia Minor, central/western China, and eastern India as secondary centers of diversity (Yang et al., 2018; Kang et al., 2021; Paritosh et al., 2021). India's edible oil sector ranks as the fourth largest globally, following the USA, China, and Brazil, with rapeseed-mustard accounting for 27.8% of its total share (Singh et al., 2017; Bhanu et al., 2019). Nearly half of the needs of vegetable oil are being met through imports (Vaid and Kaur, 2023), and 60% of investments in agricultural commodities are allocated solely to importing vegetable oils. In rapeseed-mustard, biotic stress cause 30–40% yield losses (Sharma et al., 2023), in which different diseases like *Alternaria* blight, *Sclerotinia* stem rot poses a serious threat (Mahapatra and Das, 2016; Khan et al., 2021).

Among abiotic stresses, moisture stress can be considered a significant challenge as it is interconnected with other stresses such as heat and salinity, amplifying their effects (Angon et al., 2022; Dos Santos et al., 2022; Hussain et al., 2022). It is expected that water demand for crop production and consumption as well will increase by 2050 (Mancosu et al., 2015; Pastor et al., 2019), but the availability is likely to drop by 50% (Gupta et al., 2020) and there is a high chance of an increase in the severity and frequency of moisture stress in this climate change era as predicted by many climate models (Aroca, 2012; Gao et al., 2018). Varanasi region of Uttar Pradesh with 80% of rainfall happening from June–October, receives an average rainfall of 890 mm, 78.74 mm, and 32.09 mm during the *kharif*, *rabi*, and *zaid* seasons respectively (Mishra et al., 2015). With a large proportion of rainfall occurring during June–September, the month of October receives about 5% of rainfall, and only 8% of the rain occurs in the remaining seven months from November to May (Anonymous, 2023). The annual rainfall of Varanasi belt varies from 680 mm to 1500 mm with an average 1100 mm which is predicted to decrease in upcoming years (Adinehvand and Singh, 2021) which is supported by historical data analysis from 1971–2010 (Bhatla et al., 2016) and trend analysis from 1998–2018 in Ganga riverfronts concluded that the average annual rainfall amount decreased from 1165 mm to 928 mm (a decrease of 237 mm), with a significant effect of evapotranspiration and drier climatic condition (Raju et al., 2024). *Brassica* sp. crops are more prone to drought as most of the area comes under arid and semi-arid zones in India (Niwas and Khichar, 2016). As a *rabi* season crop, Indian mustard must complete its whole life cycle by utilizing stored moisture and winter rains. Because of this uncertainty involved, the crop is prone to drought stress during multiple growth stages, especially at later stages when stored moisture gets depleted. Even though the consequences of drought depend on genotype, intensity, and severity of stress (Raza et al., 2017; Singh and Singh, 2018), the reproductive stage is the most sensitive stage to water stress as pollen development and fertilization are highly affected finally decreasing dry matter and seed yield (Rani et al., 2024). So, developing tolerant lines is a pressing requirement of today's world (Fita et al., 2015). To carry out the selection of genotypes for rainfed and irrigated conditions, one should know the trait on which we must focus. In line with this, the present study focused on correlation and path analysis in order to identify the most contributing traits.

2. MATERIALS AND METHODS

This study was conducted during the rabi season (November, 2023–March, 2024) at the Agricultural Research Farm, Institute of Agricultural Sciences, BHU, Varanasi, Uttar Pradesh, with latitude 25°15'13.8"N and longitude 82°59'05.5"E in which fourteen lines were sown as per randomized block design with three replications under two conditions, viz. rainfed and irrigated. Each plot consisted of five rows of 5 m length with a spacing of 30×10 cm^2. Both conditions were given, one irrigation at the time of sowing and no irrigation was given for rainfed plots later, whereas one supplemental irrigation 35 days after sowing was provided for irrigated plots. All other recommended package of practices were followed. Five plants from each plot were selected randomly and observations were taken on 19 different phenological, morphological, and physiological parameters which included days to 50% flowering, days to maturity, relative water content (RWC), membrane thermostability index (MSI), pollen viability (%), chlorophyll content, plant height (cm), number of primary branches, number of secondary branches, length of the main raceme (cm), number of siliquae on the main raceme, number of siliquae $plant^{-1}$, siliqua length (cm), seeds $siliqua^{-1}$, seed yield $plant^{-1}$ (g), biological yield $plant^{-1}$ (g), harvest index, test weight (g), and yield ha^{-1} (kg ha^{-1}). Relative water content was estimated by using the method given by Barrs and Weatherly, 1962. At the flowering stage, mature anthers were collected from each genotype on the day of stigma exertion between 8.30 AM to 9:30 AM. The anthers of each genotype were crushed, smeared, and stained in freshly prepared 1% aceto-carmine solution in separate slides. The slides were kept for 5–10 min at room temperature. Later, they were examined under a light microscope. Fertile pollens as they're fully developed, and round, were observed as deep staining structures, and sterile ones remain unstained and shrivelled. The number of fertile (FP) and sterile pollens (SP) in different microscopic fields was counted and the pollen viability was calculated by using the formula: $PV(\%)=(FP/FP+SP)\times100$. The membrane thermo-stability Index (MSI) was determined by the method described by Sairam (1994). The chlorophyll content present in the leaves was estimated by SPAD 502

Chlorophyll Meter during the flowering stage when the sun was overhead from the second or third fully opened leaf from the top avoiding the mid-rib. The mean value of these five readings was considered as SPAD value. The observation of the remaining morphological traits was taken at the time of harvesting from 5 randomly selected plants. The border effect was removed by taking observations on middle plants in a row.

3. RESULTS AND DISCUSSION

3.1. Correlation studies

The analyses under rainfed conditions showed a significant correlation between various traits considered which was presented in the form of Pearson correlation coefficients in Table 1. Among phenological traits, days to 50% flowering was significantly correlated to days to maturity (0.430P, 0.990G), although its correlation with seed yield plant^{-1} was non-significant. The findings of Lodhi et al. (2014) were similar to this. Days to maturity exhibited a significant negative association with the number of secondary branches (-0.436P, -0.664G). When it comes to physiological traits, the chlorophyll content during flowering exhibited a very strong significant correlation with seed yield plant^{-1} (0.992G) at the genotypic level and moderately strong at the phenotypic level (0.533P) similar to the findings of Choudhary et al. (2024). Also, it exhibited a very strong association at the genotypic level with primary branches (0.519P, 0.944G), number of seeds siliqua^{-1}(0.314P, 0.884G), siliquae on main raceme (0.884G), main raceme length (0.310P, 0.771G), number of siliquae plant^{-1} (0.313P, 0.763G), plant height (0.376P, 0.689G), and test weight (0.903G). Out of all morphological traits, a significant positive correlation of seed yield plant^{-1} was noted with the number of primary branches (0.600P, 0.983G), main raceme length (0.540P, 0.943G), number of siliquae plant^{-1} (0.669P. 0.902G), test weight (0.554P, 0.92G), plant height (0.615P, 0.883G), siliquae on main raceme (0.523P, 0.720G), siliqua length (0.442P, 0.667G), seeds siliqua^{-1} (0.450P, 0.564G), and biological yield (0.590P, 0.602G). This was in accordance with the study of Singh et al., (2015) which showed a significant correlation of seed yield plant^{-1} with plant height, primary branches plant^{-1}, main shoot length, siliqua length, seeds siliqua^{-1}, and biological yield under rainfed conditions. The same characters were studied under normal irrigated conditions as well and the correlation coefficients were presented in Table 2. Days to 50% flowering was significantly correlated to days to maturity (0.447P, 0.636G), and pollen viability (0.312P, 0.578G), but no significant association was present with seed yield plant^{-1}

Table 1: Phenotypic (P) and Genotypic (G) correlation coefficients of 19 traits of Indian mustard under rainfed conditions

Traits		DTF	DTM	RWC	MSI	CC	PV	PH	NPB	NSB	MRL
DTF	P	1**	0.430**	-0.181	0.028	-0.099	0.24	0.076	-0.174	-0.278	0.079
	G	1**	0.990**	-0.129	0.101	-0.461	0.389	0.017	-0.237	-0.31	0.06
DTM	P		1**	0.046	0.046	-0.257	0.486**	0.036	-0.059	-0.436**	0.079
	G		1**	0.091	-0.035	0.052	0.765**	0.274	-0.261	-0.664**	0.031
RWC	P			1**	0.05	0.175	-0.019	0.151	0.173	0.336*	0.363*
	G			1**	-0.024	0.625*	0.321	0.099	-0.007	0.427	0.521
MSI	P				1**	-0.041	0.298	0.032	0.035	-0.173	0.133
	G				1**	0.034	0.519	-0.475	-0.262	-0.243	0.477
CC	P					1**	0.144	0.376*	0.519**	0.307*	0.310*
	G					1**	0.004	0.689**	0.944**	0.585*	0.771**
PV	P						1**	0.109	0.054	-0.509**	0.123
	G						1**	0.196	-0.021	-0.687**	0.5075
PH	P							1**	0.647**	0.01	0.407**
	G							1**	0.998**	0.197	0.861**
NPB	P								1**	0.316*	0.435**
	G								1**	0.52	0.789**
NSB	P									1**	0.221
	G									1**	0.389
MRL	P										1**
	G										1**

Table 1: Continue...

Traits		NSM	NSP	SL	SPS	BY	HI	TGW	SYPP	YPH
DTF	P	-.19	.224	.53	-.281	.6	.73	.67	.96	.157
	G	-.82	.31	.71	-.425	-.32	.173	.51	.86	.172
DTM	P	-.44	.283	.94	-.181	.76	.1	-.14	.64	.129
	G	.66	.291	-.14	-.8	-.25	.31	-.78	.189	.33
RWC	P	.18	.192	.453**	.185	-.23	.498**	.441**	.265	.394**
	G	.364	.358	.712**	.214	-.176	.65*	.717**	.42	.537*
MSI	P	.127	.4	.9	.161	-.89	.86	.15	.74	.11
	G	.39	.143	.337	.177	-.45	.468	-.26	.2	.95
CC	P	.267	.313*	.336*	.314*	.28	.87	.16	.533**	.46**
	G	.884**	.763**	.625*	.884**	.592*	.375	.93**	.992**	.747**
PV	P	.14	.68	-.29	-.34	-.174	.293	-.117	.11	.127
	G	-.57	.69	-.14	.199	-.321	.68*	-.5	.183	.155
PH	P	.33	.316*	.24	.272	.395**	.32	.291	.615**	.186
	G	.835**	.615*	.491	.368	.611*	.185	.531	.883**	.27
NPB	P	.267	.237	.371*	.333*	.432**	-.15	.32	.6**	.22
	G	.534*	.584*	.445	.48	.555*	.315	.328	.983**	.366
NSB	P	.117	.328*	.51**	.199	.178	.17	.46**	.376*	.341*
	G	.218	.42	.645*	.199	.23	.141	.646*	.419	.396
MRL	P	.184	.448**	.55**	.376*	.9	.425**	.47**	.54**	.275
	G	.558*	.756**	.785**	.835**	.9	.951**	.672**	.943**	.585*
NSM	P	1**	.531**	.119	.228	.519**	-.168	.454**	.523**	.241
	G	1**	.741**	.493	.433	.781**	-.22	.995**	.72**	.429
NSP	P		1**	.561**	.284	.43**	.77	.495**	.669**	.668**
	G		1**	.713**	.632*	.637*	.133	.992**	.92**	.864**
SL	P			1**	.326*	.79	.252	.32*	.442**	.413**
	G			1**	.673**	.93	.492	.756**	.667**	.634*
SPS	P				1**	.245	.83	.258	.45**	.34
	G				1**	.296	.16	.222	.564*	.476
BY	P					1**	-.683**	.334*	.59**	.314*
	G					1**	-.593*	.643*	.62*	.473
HI	P						1**	.83	.155	.22
	G						1**	.127	.286	.189
TGW	P							1**	.554**	.487**
	G							1**	.92**	.92**
SYPP	P								1**	.644**
	G								1**	.792**
YPH	P									1**
	G									1**

*Significant at (*p*=0.0.5); **at (*p*=0.0.5); DTF: Days to 5% flowering; DTM: Days to maturity; RWC: Relative water content; MSI: Membrane stability index; CC: Chlorophyll content at flowering stage; PV: Pollen viability; PH: Plant heightcm; NPB: The number of primary branches; NSB: The number of secondary branches; MRL: Main raceme lengthcm; NSM: The number of siliquae on main raceme; NSP: No. of siliquae plant^{-1}; SL: Siliqua lengthcm; SPS: Seeds siliqua^{-1}; BY: Biological yield plant^{-1} g; SYPP: Seed yield plant^{-1} g; HI: Harvest index; TW: Test weightg; YPH: Seed yield ha^{-1} kg ha^{-1}.

similar to what was found in rainfed conditions. Bind et al. (2014) also reported a positive correlation between days to 50% flowering and days to maturity. The studies conducted by Shrivastava et al. (2023), and Yadav et al. (2023) also identified absence of significant association of seed yield plant^{-1} with days to 50% flowering.

The trait days to maturity was correlated significantly although negatively to seed yield plant^{-1} (0.421P, -0.556G). Akkenapally and Chetariya, (2022) also reported a similar negative correlation between these two traits. Among physiological characters, seed yield plant^{-1} was associated significantly with chlorophyll content (0.583P, 0.760G) and membrane thermo-stability index (0.409P, 0.749G), and the genotypic correlation was found to be very strong compared to phenotypic coefficients. Choudhary et al. (2024) also reported a significant positive correlation between chlorophyll content and seed yield plant^{-1}. It exhibited a significant positive association with main raceme length (0.422P, 0.936G), siliqua length (0.523P, 0.806G), biological yield (0.619P, 0.691G), number of secondary branches (0.609P, 0.699G), number of siliquae plant^{-1} (0.580P, 0.655G), number of siliquae on main raceme (0.503P, 0.563G), seeds siliqua^{-1}(0.380P, 0.666G) and plant height (0.470P, 0.543G) as well. The results were similar to those of studies done by Chaurasiya et al. (2019). Ray et al. (2023) also reported positive association of seed yield with plant height and number of primary branches. Yadav et al. (2023) and Choudhary et al. (2023) reported the high correlation of seed yield per plant with siliqua length, number of primary branches and number of secondary branches.

3.2 Path co-efficient analysis

Path analysis was performed on the data to split the correlation coefficient into direct and indirect effects, which thereby helped to identify which traits directly influenced the dependent trait (Dewey and Lu, 1959). Table 3 gives the values of direct and indirect effects for rainfed conditions. Maximum positive direct effects towards seed yield plant^{-1} were observed for biological yield (0.555P, 0.880G), harvest index (0.384P, 0.709G), and yield ha^{-1} (0.214P, 0.532G) which showed the necessity of these traits to be included under direct selection for rainfed conditions. The findings of Singh et al. (2022) also reported high direct effects from biological yield and harvest index. The next highest positive direct effects of different traits were moderate by plant height (0.237P, 0.230G); and low by main raceme length (0.190P, 0.126G) which indicated that these traits should also be kept in mind while doing selection. Although the genotypic direct effect of relative water content was negative and low (-0.165G), it was counteracted by moderate and

Table 2: Phenotypic (P) and Genotypic (G) correlation coefficients of 19 traits of Indian mustard under irrigated conditions

Traits		DTF	DTM	RWC	MSI	CC	PV	PH	NPB	NSB	MRL
DTF	P	1**	0.447**	0.332*	-0.011	-0.257	0.312*	0.007	-0.289	-0.266	0.198
	G	1**	0.636*	0.506	0.142	-0.403	0.578*	0.069	-0.375	-0.377	0.18
DTM	P		1**	0.033	-0.345*	-0.357*	0.297	-0.077	-0.038	-0.404**	-0.089
	G		1**	0.161	-0.578*	-0.685**	0.306	-0.104	-0.089	-0.777**	-0.325
RWC	P			1**	-0.006	0.285	-0.039	-0.066	-0.045	0.202	0.318*
	G			1**	0.041	0.791**	0.113	-0.203	0.074	0.357	0.694**
MSI	P				1**	-0.034	0.184	0.293	-0.360*	0.209	0.312*
	G				1**	0.581*	0.207	0.434	-0.579*	0.415	0.477
CC	P					1**	0.007	0.205	0.199	0.425**	0.256
	G					1**	0.028	0.403	0.147	0.599*	0.967**
PV	P						1**	0.309*	-0.063	-0.526**	0.209
	G						1**	0.545*	0.148	-0.803**	0.303
PH	P							1**	0.031	0.006	0.319*
	G							1**	-0.283	-0.073	0.934**
NPB	P								1**	-0.016	-0.273
	G								1**	-0.238	-0.189
NSB	P									1**	0.186
	G									1**	0.145
MRL	P										1**
	G										1**

Table 2: Continue...

Traits		NSM	NSP	SL	SPS	BY	HI	TGW	SYPP	YPH
DTF	P	-0.284	0.232	-0.205	-0.052	-0.203	-0.013	0.23	-0.216	0.103
	G	-0.444	0.447	-0.063	0.137	-0.289	0.144	0.506	-0.185	0.295
DTM	P	-0.591**	-0.275	-0.403**	-0.122	-0.331*	-0.062	-0.051	-0.421**	-0.314*
	G	-0.791**	-0.419	-0.567*	-0.257	-0.563*	0.027	-0.211	-0.556*	-0.493
RWC	P	-0.073	0.449**	0.104	0.431**	-0.042	0.358*	0.447**	0.296	0.568**
	G	-0.184	0.534*	0.496	0.667**	-0.095	0.624*	0.672**	0.344	0.803**
MSI	P	0.3	0.426**	0.495**	0.415**	0.133	0.256	0.381*	0.409**	0.345*
	G	0.762**	0.748**	0.855**	0.595*	0.371	0.413	0.288	0.749**	0.461
CC	P	0.395**	0.357*	0.409**	0.248	0.27	0.318*	0.175	0.583**	0.491**
	G	0.545*	0.620*	0.820**	0.991**	0.487	0.329	0.54	0.760**	0.939**
PV	P	-0.074	0.161	-0.036	-0.046	-0.061	-0.123	0.029	-0.182	0.104
	G	-0.061	0.198	0.149	0.173	-0.14	-0.149	0.148	-0.22	0.063
PH	P	0.274	0.345*	0.232	0.121	0.363*	0.032	0.199	0.470**	0.225
	G	0.523	0.425	0.384	-0.03	0.545*	-0.039	0.225	0.543*	0.358
NPB	P	0.025	-0.144	-0.206	0.069	-0.032	-0.087	-0.094	-0.152	-0.171
	G	0.221	-0.308	-0.535*	-0.084	0.159	-0.506	-0.094	-0.277	-0.196
NSB	P	0.309*	0.443**	0.368*	0.274	0.358*	0.242	0.18	0.609**	0.443**
	G	0.461	0.57*	0.571*	0.504	0.373	0.457	0.275	0.699**	0.629*
MRL	P	0.224	0.321*	0.351*	0.253	0.256	0.114	0.346*	0.422**	0.399**
	G	0.466	0.670**	0.590*	0.880**	0.369	0.669**	0.724**	0.936**	0.870**
NSM	P	1**	0.287	0.282	0.035	0.414**	0.015	0.320*	0.503**	0.286
	G	1**	0.414	0.565*	0.248	0.543*	0.033	0.644*	0.563*	0.329
NSP	P		1**	0.482**	0.253	0.470**	0.074	0.481**	0.580**	0.732**
	G		1**	0.656*	0.670**	0.44	0.3	0.656*	0.655*	0.918**
SL	P			1**	0.107	0.163	0.351*	0.294	0.523**	0.399**
	G			1**	0.561*	0.158	0.804**	0.364	0.806**	0.868**
SPS	P				1**	-0.031	0.427**	0.191	0.380*	0.286
	G				1**	0.304	0.421	0.13	0.666**	0.519
BY	P					1**	-0.538**	0.156	0.619www*	0.335*
	G					1**	-0.427	0.239	0.691**	0.442
HI	P						1.00**	0.237	0.312*	0.268
	G						1**	0.3305	0.357	0.364
TGW	P							1.00**	0.372*	0.472**
	G							1**	0.46	0.725**
SYPP	P								1**	0.617**
	G								1**	0.717**
YPH	P									1**
	G									1**

*Significant at (*p*=0.0.5); **at (*p*=0.0.5)

high indirect effects through yield ha^{-1} (0.286G) and harvest index (0.430G), respectively. Yadav et al. (2023) also reported a negative genotypic direct effect from relative water content. The number of siliquae plant^{-1} had negative direct effects both at the genotypic and phenotypic levels (-0.111P, -0.279G) even though the correlation with the dependant trait was positive and significant, similar to what found by Srivastava and Srivastava, (2019). This showed that the indirect effects were the cause of the correlation. Other high positive indirect effects observed were: Chlorophyll content via biological yield (0.155P, 0.521G), yield ha^{-1} (0.087P, 0.398G), and harvest index (0.024P, 0.267G); the number of primary branches via biological yield (0.240P, 0.488G), and harvest index (0.00P, 0.488G); the number of secondary branches via yield ha^{-1} (0.073P, 0.211G); main raceme length via harvest index (0.123P, 0.276G), and yield

Table 3: Phenotypic (P) and Genotypic (G) direct (diagonal) and indirect effects of 19 traits of Indian mustard under rainfed conditions

Traits		DTF	DTM	RWC	MSI	CC	PV	PH	NPB	NSB	MRL
DTF	P	0.084	0.022	0.005	0.001	-0.004	0.032	0.018	0.008	-0.077	0.015
	G	-0.161	-0.047	0.02	0.006	0.054	-0.021	0.004	0	0.044	0.008
DTM	P	0.036	0.052	-0.001	0.001	-0.011	0.066	0.009	0.003	-0.121	0.015
	G	-0.165	-0.046	-0.014	-0.002	-0.006	-0.043	0.063	0.001	0.094	0.004
RWC	P	-0.015	0.002	-0.031	0.001	0.008	-0.003	0.036	-0.008	0.093	0.07
	G	0.021	-0.004	-0.154	-0.001	-0.073	-0.018	0.023	0	-0.06	0.066
MSI	P	0.002	0.002	-0.001	0.021	-0.002	0.04	0.008	-0.002	-0.048	0.025
	G	-0.016	0.002	0.004	0.062	-0.004	-0.029	-0.109	0.001	0.034	0.06
CC	P	-0.008	-0.013	-0.005	-0.001	0.044	0.019	0.089	-0.024	0.085	0.059
	G	0.074	-0.002	-0.096	0.002	-0.117	0	0.158	-0.002	-0.083	0.097
PV	P	0.02	0.025	0	0.006	0.006	0.135	0.026	-0.002	-0.141	0.023
	G	-0.062	-0.035	-0.049	0.032	0	-0.056	0.045	0	0.097	0.064
PH	P	0.006	0.002	-0.004	0.001	0.017	0.015	0.237	-0.03	0.003	0.077
	G	-0.003	-0.013	-0.015	-0.029	-0.081	-0.011	0.23	-0.002	-0.028	0.109
NPB	P	-0.014	-0.003	-0.005	0.001	0.023	0.007	0.153	-0.047	0.087	0.083
	G	0.038	0.012	0.001	-0.016	-0.111	0.001	0.243	-0.002	-0.073	0.099
NSB	P	-0.023	-0.023	-0.01	-0.004	0.014	-0.069	0.002	-0.015	0.277	0.042
	G	0.05	0.03	-0.066	-0.015	-0.069	0.038	0.045	-0.001	-0.141	0.049
MRL	P	0.007	0.004	-0.011	0.003	0.014	0.017	0.096	-0.02	0.061	0.19
	G	-0.01	-0.001	-0.08	0.029	-0.09	-0.028	0.198	-0.002	-0.055	0.126
NSM	P	-0.009	-0.002	-0.003	0.003	0.012	0.002	0.072	-0.013	0.032	0.035
	G	0.013	-0.003	-0.056	0.002	-0.104	0.003	0.192	-0.001	-0.031	0.07
NSP	P	0.019	0.015	-0.006	0	0.014	0.009	0.075	-0.011	0.09	0.085
	G	-0.048	-0.013	-0.055	0.009	-0.089	-0.004	0.141	-0.001	-0.059	0.095
SL	P	0.004	0.005	-0.014	0	0.015	-0.004	0.057	-0.018	0.141	0.105
	G	-0.011	0.001	-0.11	0.021	-0.073	0.008	0.113	-0.001	-0.091	0.099
SPS	P	-0.023	-0.009	-0.005	0.003	0.014	-0.005	0.064	-0.016	0.055	0.072
	G	0.068	0.004	-0.033	0.011	-0.104	-0.012	0.085	-0.001	-0.028	0.105
BY	P	0	0.004	0.006	-0.002	0.012	-0.024	0.094	-0.02	0.049	0.002
	G	0.005	0.001	0.027	-0.028	-0.069	0.018	0.14	-0.001	-0.029	0.001
HI	P	0.006	0	-0.015	0.002	0.004	0.04	0.007	0	0.03	0.082
	G	-0.028	-0.014	-0.093	0.029	-0.044	-0.034	0.043	-0.001	-0.02	0.12
TW	P	0.006	-0.001	-0.013	0.003	0.007	-0.016	0.069	-0.014	0.112	0.078
	G	-0.008	0.004	-0.11	-0.002	-0.106	0.003	0.122	-0.001	-0.091	0.085
YPH	P	0.013	0.007	-0.012	0.002	0.018	0.017	0.044	-0.01	0.094	0.052
	G	-0.028	-0.015	-0.083	0.006	-0.088	-0.009	0.062	-0.001	-0.056	0.074

Table 3: Continue...

Traits		NSM	NSP	SL	SPS	BY	HI	TW	YPH	r
DTF	P	-0.017	-0.025	-0.001	-0.023	0.003	0.022	-0.001	0.033	0.096
	G	-0.003	-0.084	0.016	0.064	-0.028	0.123	0	0.092	0.086
DTM	P	-0.007	-0.031	-0.002	-0.015	0.042	0.002	0	0.027	0.064
	G	0.002	-0.081	-0.003	0.012	-0.022	0.221	0	0.176	0.189
RWC	P	0.017	-0.021	-0.009	0.015	-0.113	0.145	-0.006	0.084	0.265
	G	0.013	-0.1	0.162	-0.032	-0.155	0.43	0	0.286	0.402
MSI	P	0.019	0	0	0.013	-0.05	0.025	-0.002	0.022	0.074
	G	0.001	-0.04	0.077	-0.027	-0.396	0.333	0	0.05	0.002
CC	P	0.041	-0.035	-0.007	0.026	0.155	0.024	-0.002	0.087	0.533**
	G	0.031	-0.213	0.142	-0.134	0.521	0.267	0	0.398	0.992**
PV	P	0.002	-0.007	0.001	-0.003	-0.097	0.085	0.001	0.027	0.11
	G	-0.002	-0.019	-0.032	-0.03	-0.283	0.432	0	0.083	0.183
PH	P	0.046	-0.035	-0.005	0.023	0.219	0.009	-0.004	0.04	0.615**
	G	0.029	-0.172	0.112	-0.056	0.538	0.131	0	0.144	0.883**
NPB	P	0.041	-0.026	-0.008	0.028	0.24	0	-0.005	0.047	0.600**
	G	0.019	-0.163	0.101	-0.073	0.488	0.223	0	0.195	0.983**
NSB	P	0.018	-0.036	-0.01	0.017	0.099	0.031	-0.006	0.073	0.376*
	G	0.008	-0.117	0.147	-0.03	0.179	0.1	0	0.211	0.419
MRL	P	0.028	-0.05	-0.011	0.031	0.005	0.123	-0.006	0.059	0.540**
	G	0.019	-0.211	0.179	-0.126	0.008	0.676	0	0.312	0.943**
NSM	P	0.153	-0.059	-0.002	0.019	0.288	-0.049	-0.007	0.051	0.523**
	G	0.035	-0.207	0.112	-0.065	0.687	-0.156	-0.001	0.228	0.720**
NSP	P	0.081	-0.111	-0.012	0.024	0.238	0.022	-0.008	0.142	0.669**
	G	0.026	-0.279	0.162	-0.096	0.56	0.095	-0.001	0.46	0.902**
SL	P	0.018	-0.062	-0.02	0.027	0.044	0.059	-0.005	0.088	0.442**
	G	0.017	-0.199	0.228	-0.102	0.081	0.349	0	0.337	0.667**
SPS	P	0.035	-0.032	-0.007	0.083	0.136	0.024	-0.004	0.065	0.450**
	G	0.015	-0.176	0.153	-0.151	0.261	0.113	0	0.253	0.564*
BY	P	0.079	-0.048	-0.002	0.02	0.555	-0.199	-0.005	0.067	0.590**
	G	0.027	-0.178	0.021	-0.045	0.88	-0.422	0	0.252	0.602*
HI	P	-0.026	-0.009	-0.004	0.007	-0.383	0.384	-0.001	0.044	0.155
	G	-0.008	-0.037	0.112	-0.024	-0.524	0.709	0	0.101	0.286
TW	P	0.069	-0.055	-0.007	0.021	0.185	0.019	-0.015	0.104	0.554**
	G	0.038	-0.288	0.172	-0.034	0.566	0.09	-0.001	0.48	0.92**
YPH	P	0.037	-0.074	-0.008	0.025	0.174	0.059	-0.007	0.214	0.644**
	G	0.015	-0.241	0.144	-0.072	0.416	0.134	-0.001	0.532	0.792**

Residual effect: 0.092(P), 0.037(G) *Significant at (p=0.05); ** at (p=0.01); r: Correlation coefficient

ha^{-1} (0.059P, 0.312G); the number of siliquae on main raceme via biological yield (0.288P, 0.687G), and yield ha^{-1} (0.051P, 0.228G); test weight via biological yield (0.174P, 0.416G), and yield ha^{-1} (0.214P, 0.532G). The differences in direct effects at genotypic and phenotypic levels as seen in the number of secondary branches (0.277P, -0.141G), siliqua length (-0.020P, 0.228G), and other traits indicated the environmental influence on the expression. Kumar et al. (2016) also reported differences in genotypic and phenotypic direct effects in plant height, days to 50% flowering, primary branches plant^{-1}, secondary branches plant^{-1}, test weight, siliqua plant^{-1}, and number of seeds siliqua^{-1}. These results highlighted the inclusion of biological yield, harvest index, and yield ha^{-1} while developing selection criteria for rainfed scenarios.

Important to note was even though the direct effect of the harvest index was highly positive. The correlation was not significant which was due to the counterbalance of direct effects by negative indirect effects from biological yield. So, a compromise has to be made between biological yield and harvest index. Similarly, the results of the analyses of normal conditions were presented as direct and indirect effects in the

Table 4: Phenotypic (P) and Genotypic (G) direct (diagonal) and indirect effects of 19 traits of Indian mustard under irrigated conditions

Traits		DTF	DTM	RWC	MSI	CC	PV	PH	NPB	NSB	MRL
DTF	P	-0.012	0.065	0.057	-0.002	-0.058	-0.065	0.002	0.031	-0.018	-0.007
	G	0.246	-0.545	-0.094	0	0.139	0.074	-0.023	-0.067	0.176	0.057
DTM	P	-0.005	0.145	0.006	-0.065	-0.081	-0.062	-0.018	0.004	-0.028	0.003
	G	0.157	-0.857	-0.03	-0.001	0.236	0.039	0.034	-0.016	0.362	-0.102
RWC	P	-0.004	0.005	0.172	-0.001	0.065	0.008	-0.015	0.005	0.014	-0.011
	G	0.124	-0.138	-0.187	0	-0.273	0.014	0.066	0.013	-0.166	0.218
MSI	P	0	-0.05	-0.001	0.189	-0.008	-0.038	0.068	0.039	0.014	-0.011
	G	0.035	0.495	-0.008	0.001	-0.2	0.026	-0.141	-0.103	-0.193	0.15
CC	P	0.003	-0.052	0.049	-0.006	0.227	-0.001	0.047	-0.021	0.029	-0.009
	G	-0.099	0.587	-0.148	0.001	-0.345	0.004	-0.131	0.026	-0.279	0.367
PV	P	-0.004	0.043	-0.007	0.035	0.002	-0.207	0.071	0.007	-0.036	-0.007
	G	0.142	-0.262	-0.021	0	-0.01	0.127	-0.177	0.026	0.374	0.095
PH	P	-0.001	-0.011	-0.011	0.055	0.046	-0.064	0.231	-0.003	0	-0.011
	G	0.017	0.089	0.038	0	-0.139	0.069	-0.324	-0.05	0.034	0.294
NPB	P	0.003	-0.005	-0.008	-0.068	0.045	0.013	0.007	-0.107	-0.001	0.009
	G	-0.092	0.076	-0.014	-0.001	-0.051	0.019	0.092	0.178	0.111	-0.06
NSB	P	0.003	-0.059	0.035	0.039	0.096	0.109	0.001	0.002	0.068	-0.006
	G	-0.093	0.666	-0.067	0	-0.207	-0.102	0.024	-0.042	-0.465	0.046
MRL	P	-0.002	-0.013	0.055	0.059	0.058	-0.043	0.074	0.029	0.013	-0.035
	G	0.044	0.279	-0.13	0	-0.402	0.038	-0.303	-0.034	-0.067	0.315
NSM	P	0.003	-0.086	-0.012	0.057	0.09	0.015	0.063	-0.003	0.021	-0.008
	G	-0.109	0.678	0.034	0.001	-0.188	-0.008	-0.17	0.039	-0.214	0.147
NSP	P	-0.003	-0.04	0.077	0.081	0.081	-0.033	0.08	0.015	0.03	-0.011
	G	0.11	0.359	-0.1	0.001	-0.214	0.025	-0.138	-0.055	-0.265	0.211
SL	P	0.002	-0.059	0.018	0.094	0.093	0.007	0.054	0.022	0.025	-0.012
	G	-0.016	0.486	-0.093	0.001	-0.283	0.019	-0.125	-0.095	-0.266	0.186
SPS	P	0.001	-0.018	0.074	0.079	0.056	0.009	0.028	-0.007	0.019	-0.009
	G	0.034	0.22	-0.125	0	-0.356	0.022	0.009	-0.015	-0.235	0.277
BY	P	0.002	-0.048	-0.007	0.025	0.061	0.013	0.083	0.003	0.024	-0.009
	G	-0.071	0.482	0.018	0	-0.168	-0.018	-0.177	0.028	-0.174	0.116
HI	P	0	-0.01	0.064	0.048	0.071	0.025	0.007	0.008	0.017	-0.004
	G	0.035	-0.023	-0.116	0	-0.113	-0.019	0.013	-0.09	-0.212	0.21
TW	P	-0.003	-0.007	0.077	0.072	0.04	-0.006	0.046	0.01	0.012	-0.012
	G	0.125	0.181	-0.125	0	-0.177	0.019	-0.073	-0.017	-0.128	0.228
YPH	P	-0.001	-0.046	0.098	0.065	0.111	-0.022	0.052	0.018	0.03	-0.014
	G	0.073	0.423	-0.15	0	-0.324	0.008	-0.116	-0.035	-0.293	0.274

Table 4: Continue...

Traits		NSM	NSP	SL	SPS	BY	HI	TW	YPH	r
DTF	P	-0.038	-0.029	-0.025	-0.005	-0.105	-0.002	-0.018	0.012	-0.216
	G	0.215	-0.042	0.006	-0.011	-0.504	0.233	-0.009	-0.036	-0.185
DTM	P	-0.079	0.034	-0.049	-0.011	-0.171	-0.011	0.004	-0.038	-0.421**
	G	0.384	0.039	0.055	0.021	-0.986	0.044	0.004	0.061	-0.556*
RWC	P	-0.01	-0.055	0.013	0.038	-0.022	0.061	-0.034	0.069	0.296
	G	0.089	-0.05	-0.048	-0.054	-0.167	0.913	-0.012	-0.099	0.344
MSI	P	0.04	-0.052	0.06	0.036	0.069	0.042	-0.029	0.042	0.409**
	G	-0.37	-0.07	-0.083	-0.048	0.65	0.67	-0.005	-0.057	0.749**
CC	P	0.053	-0.044	0.05	0.022	0.139	0.052	-0.013	0.06	0.583**
	G	-0.265	-0.058	-0.08	-0.083	0.853	0.534	-0.009	-0.115	0.760**
PV	P	-0.01	-0.02	-0.004	-0.004	-0.031	-0.02	-0.002	0.013	-0.182
	G	0.029	-0.019	-0.014	-0.014	-0.246	-0.242	-0.003	-0.008	-0.22
PH	P	0.036	-0.042	0.028	0.011	0.187	0.005	-0.015	0.027	0.470**
	G	-0.254	-0.04	-0.037	0.002	0.955	-0.063	-0.004	-0.044	0.543*
NPB	P	0.003	0.018	-0.025	0.006	-0.017	-0.012	0.007	-0.021	-0.152
	G	-0.108	0.029	0.052	0.007	0.278	-0.821	0.002	0.024	-0.277
NSB	P	0.041	-0.055	0.045	0.024	0.184	0.04	-0.014	0.054	0.609**
	G	-0.224	-0.053	-0.056	-0.041	0.654	0.741	-0.005	-0.077	0.699**
MRL	P	0.03	-0.04	0.043	0.022	0.132	0.019	-0.027	0.048	0.422**
	G	-0.226	-0.063	-0.058	-0.071	0.647	0.986	-0.013	-0.107	0.936**
NSM	P	0.133	-0.035	0.034	0.003	0.214	0.003	-0.025	0.035	0.503**
	G	-0.486	-0.039	-0.055	-0.02	0.952	0.053	-0.012	-0.04	0.563*
NSP	P	0.038	-0.123	0.059	0.022	0.242	0.012	-0.037	0.089	0.580**
	G	-0.201	-0.093	-0.064	-0.054	0.771	0.487	-0.012	-0.113	0.655*
SL	P	0.038	-0.059	0.122	0.009	0.084	0.059	-0.023	0.048	0.523**
	G	-0.275	-0.061	-0.098	-0.045	0.277	0.957	-0.007	-0.107	0.806**
SPS	P	0.005	-0.032	0.013	0.089	-0.016	0.069	-0.015	0.035	0.380*
	G	-0.121	-0.063	-0.055	-0.08	0.533	0.684	-0.002	-0.064	0.666**
BY	P	0.055	-0.058	0.02	-0.003	0.515	-0.088	-0.012	0.041	0.619**
	G	-0.264	-0.041	-0.015	-0.024	0.952	-0.694	-0.004	-0.054	0.691**
HI	P	0.002	-0.009	0.044	0.037	-0.279	0.273	-0.022	0.033	0.312*
	G	-0.016	-0.028	-0.078	-0.034	-0.748	0.926	-0.006	-0.045	0.357
TW	P	0.043	-0.059	0.036	0.017	0.08	0.046	-0.077	0.057	0.372*
	G	-0.313	-0.061	-0.035	-0.01	0.419	0.537	-0.018	-0.089	0.46
YPH	P	0.038	-0.09	0.049	0.025	0.173	0.044	-0.036	0.121	0.617**
	G	-0.16	-0.086	-0.085	-0.042	0.775	0.591	-0.013	-0.123	0.717**

Residual effect: 0.099(P), 0.048(G) *Significant at (p=0.05); ** at (p=0.01); r: Correlation coefficient

form of Table 4. Biological yield (0.515P, 0.952G) showed maximum positive direct effects at both genotypic and phenotypic levels whereas harvest index (0.273P, 0.926G) only at genotypic level. Ray et al. (2019) also reported high positive direct effects from biological yield and harvest index at both genotypic and phenotypic levels. Days to maturity (0.145P, -0.857G), chlorophyll content (0.227P, -0.345G), plant height (0.231P, -0.324G), number of secondary branches (0.068P, -0.465G), number of siliquae on main raceme (0.133P, -0.486G) exhibited high negative direct effects at genotypic level but positive direct effects at phenotypic level. Studies by Srivastava and Srivastava, (2019) also highlighted differences in the direct effects of the number of secondary branches and the number of siliquae on the main raceme similar to the present study. Although the direct effect of chlorophyll content (-0.345G) was highly negative, it was counteracted by high indirect effects through biological yield (0.853G), and harvest index (0.534G) which resulted in a very strong correlation (0.749G). Similar results were shown by the number of secondary branches too. The siliquae on the main raceme exhibited almost comparable positive significant association with our dependant trait seed yield plant^{-1} under both conditions. The highest indirect effects were noted through biological yield under both conditions which were in accordance with the studies of Devi et al. (2017). A very strong correlation (0.936G) at genotypic level between seed yield plant^{-1} and main raceme length was due to high indirect effects by harvest index (0.986G), and biological yield (0.647G), besides its direct effect (0.315G). The direct effect of the number of siliquae plant^{-1} was negative (-0.123P, -0.093G) but a strong correlation (0.580P, 0.655G) was observed due to indirect contributions from biological yield (0.242P, 0.771G), and harvest index (0.012P, 0.487G). A high indirect effect from biological yield (0.957G) resulted in a very strong correlation (0.806G) between siliqua length and seed yield plant^{-1} as its direct effect was negligible and negative (-0.098G) at the genotypic level. Seeds siliqua^{-1} also behaved in a similar fashion. Ray et al. (2019) and Singh et al. (2015) also reported a positive correlation of harvest index with seed yield plant^{-1} with strong direct effects.

4. CONCLUSION

Traits chlorophyll content, plant height, number of primary branches, main raceme length, siliquae plant^{-1}, and test weight were essential for rainfed conditions, while for irrigated conditions, traits like chlorophyll content, number of secondary branches, plant height, main raceme length, siliquae plant^{-1}, and yield ha^{-1} were important to improve seed yield plant^{-1}. Both biological yield and harvest index had the highest positive effects, suggesting that direct selection for these traits was beneficial, with compromises when used together.

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