Journal of Oilseed Brassica, 15 (2) : 163-171, July 2024

Genetic variability and association studies for morpho-physiological traits under timely and late sown conditions in Indian mustard (*Brassica juncea* L)

Raju Ram Choudhary[1]*, Ram Avtar[2], Sohan Lal Kajla[1], Manohar Ram[1], Babulal Dhaka[1], Mukesh Kumar Poonia[3]

[1]*Sri Karan Narendra Agriculture University, Jobner 303329, Jaipur, Rajasthan, India*
[2]*Chaudhary Charan Singh Haryana Agricultural University, Hisar 125004, Haryana, India*
[3]*Swami Keshwanand Rajasthan Agricultural University, Bikaner 334001, Rajasthan, India*
**Corresponding author: rajuramchoudhary33@gmail.com*
(Received: 21 January 2024; Revised: 08 June 2024; Accepted: 10 June 2024)

Abstract

The present study encompassed a total of 154 genotypes, comprising 150 test genotypes and four checks (RH-1566, RH-1499-30, RH-749 and RH-8812) of Indian mustard. The evaluation focused on morpho-physiological traits, encompassing seventeen characters, during the *Rabi* season of 2021-22 at CCS Haryana Agricultural University, Hisar. The analysis of variance revealed highly significant genotypic differences for all the studied traits under timely (TS) and late sown (LS) conditions. Broad-sense heritability was notably high for all the studied traits except days to maturity in TS condition and transpiration rate and number of seeds per siliqua in LS condition. High heritability along with high genetic advance was reported for number of primary branches, number of secondary branches, siliqua length, 1000-seed weight, seed yield, photosynthetic rate, stomatal conductance, total chlorophyll and carotenoid content in both TS and LS conditions. A significant positive correlation between seed yield and number of primary branches, number of secondary branches, siliqua length, number of seeds/siliqua, 1000-seed weight, photosynthetic rate, stomatal conductance, total chlorophyll and carotenoid content indicating a strong association between these factors under both TS and LS conditions. The characters identified above as indirect yield components could be utilized in formulating effective selection strategy for developing high yielding mustard genotypes.

Keywords: *Character association correlation coefficient, heritability, Indian mustard*

Introduction

Indian mustard, scientifically known as *Brassica juncea* (L.) Czern & Coss., dominates the brassica oilseed landscape in India, constituting 90% of the total cultivated area and contributing 92% to the nation's production of brassica oilseeds. With 6.70 million hectares dedicated to its cultivation, India ranks as the world's third-largest producer of brassica oilseeds, contributing 19.76% to the global production. In the 2020–21 period, the global cultivation of brassica oilseeds spanned 34.71 million hectares, yielding 73.21 million tonnes at a productivity rate of 2110 kg/ha (Singh *et al.,* 2022). The genesis of Indian mustard traces back to the emergence of an amphidiploid crop, *B. juncea* (2n = 36, AABB), formed through the crossing of its diploid relatives *B. rapa* (2n = 20, AA) and *B. nigra* (2n = 16, BB) thousands of years ago (Singh *et al.,* 2021). Apart from its role in culinary practices, Indian mustard finds diverse applications in the food and chemical industries. Notably, India has secured its position as the leading global exporter of mustard seed meal, recognized for its nutritional value for poultry animals (Sharma *et al.,* 2022). India faces a significant productivity gap in brassica oilseeds compared to the global average (1520 kg/ha versus 2110 kg/ha). This disparity is attributed to the crop's heightened susceptibility to a range of biotic and abiotic stresses, such as diseases, pests, heat, drought, and cold stress. The prevailing challenges contribute substantially to the notably low productivity. Moreover, the situation is anticipated to deteriorate further in the foreseeable future due to the evolving climatic conditions, as highlighted by Singh *et al*. (2021). To bridge the gap between this productivity, the development of varieties and hybrids with high seed yield and oil content plays a crucial role (Choudhary *et al*., 2020). Despite a century of breeding research on this crop, there is limited information available on the extent of variability and diversity among the numerous varieties. Assessing genetic diversity and variability among these varieties becomes crucial for selecting suitable parents in the context of heterosis and pedigree breeding. With this background in mind, the current investigation was planned to estimate genetic variability and association for morpho-physiological traits in Indian mustard.

Materials and Methods

The experimental material consisted of 154 Indian mustard genotypes, comprising 150 test genotypes and four checks selected from released cultivars, advanced breeding lines, and germplasm lines available in various brassica breeding institutions of India. These 154 genotypes were cultivated in an augmented block design with ten blocks. The checks (RH-1566, RH-1499-30, RH-749, and RH-8812) were replicated 10 times after every 15 genotypes. The entire experiment was conducted during the *Rabi* season of 2021-22 at the Oilseeds Research Farm, CCS Haryana Agricultural University, Hisar. The genotypes were planted in two rows of 4.0 m length with a row-to-row spacing of 45 cm and a plant-to-plant spacing of 15 cm. Throughout the cultivation process, all recommended cultural practices were diligently followed, from sowing to harvesting the crop. Data were collected on 17 traits, including days to 50% flowering (DF), days to maturity (DM), plant height (PH), number of primary branches per plant (NPB), number of secondary branches per plant (NSB), main shoot length (MSL), number of siliquae on the main shoot (NSMS), siliqua length (SL), number of seeds per siliqua (NSS), test weight (TSW), oil content (OC), seed yield per plant (SYP), photosynthetic rate (A), stomatal conductance (Gs), transpiration rate (E), total chlorophyll content (Chl), and carotenoid content (Caro).

Oil content was determined through soxhlet method of oil extraction. Physiological data, including photosynthetic assimilation rate (A), stomatal conductance (Gs), and transpiration rate (E), were gathered using an infrared gas analyzer (CID 301 IRGA, USA). The measurements were taken during the siliqua filling stage, specifically between 11:00 a.m. to 1:00 p.m., capturing the period when flowering concludes and photosynthates transition from source to sink. Three randomly chosen plants from each plot were included in the data collection. Total leaf chlorophyll content (Chl) and carotenoid content (Caro) were determined using the DMSO method for pigment extraction (Hiscox and Israelstam, 1979). The quantification of total chlorophyll and carotenoid content (mg/g) was carried out using Wellburn's equation (Wellburn, 1994). The traits were analyzed by computing mean data, and after this computation, each characteristic underwent the estimation of genotypic correlation coefficients following the method outlined by Al-Jibouri *et al.* (1958). Genetic parameters were then determined in accordance with the approach presented by Singh and Chaudhary (1985). The analysis of variance (ANOVA) was conducted using the augmented design as per Federer (1956), aiming to obtain adjusted trait values for the four checks and the 150 test genotypes. All the statistical analyses were performed using the R statistical software package.

Results and Discussion

Mean performance

In the study, the traits under consideration were analyzed for both timely and late sown conditions. For the trait DF, the mean value demonstrated a substantial increase from 48.4 under timely sown conditions to 68.7 under late sown conditions, reflecting a significant positive shift of 29.5%. Conversely, the trait DM exhibited a notable decrease in mean from 142.9 to 114.0, indicating a reduction of 25.3% under late sown conditions (Table 1). The trait PH also experienced a decline in mean from 209.6 to 191.4, representing a change of -9.5%. Similarly, the traits NPB and NSB displayed reductions of 29.5% and 41.7% in mean values, respectively, under late sown conditions. These findings highlight the varying impacts of sowing timing on different traits, illustrating both positive and negative trends in the studied parameters. Further examination of the remaining traits reveals distinct patterns and trends that contribute to a comprehensive understanding of the influence of sowing timing on agricultural outcomes. The trait MSL exhibited a decrease in mean from 82.0 to 71.0 under late sown conditions, indicating a decline of 15.4%. Additionally, the trait NSMS showed a reduction in mean from 53.3 to 45.3, resulting in a decrease of 17.5%. Similarly, the trait SL experienced a slight decrease in mean from 4.7 to 4.2, reflecting a change of -9.8%. The trait NSS displayed a decrease in mean from 14.1 to 11.9, representing an 18.6% reduction under late sown conditions. Moving on, the trait OC demonstrated a marginal decrease in mean from 39 to 38.5, indicating a slight change of -1.2%. Likewise, the trait TSW exhibited a reduction in mean from 5.6 to 4.6, resulting in a decrease of 21.2%. The trait SYP showed a substantial decrease in mean from 22.7 to 17.6, representing a change of -28.7%. Furthermore, the physiological traits like A (photosynthetic rate) experienced a significant decrease in mean from 17.4 to 8.9 under late sown conditions, signifying a dramatic reduction of 94.8%. The trait Gs (stomatal conductance) demonstrated a complete shift, with a mean change from 0.4 to 0.2, resulting in a 100% decrease. On the other hand, the trait E (transpiration rate) displayed an increase in mean from 3.3 to 7.5, reflecting a positive change of 55.8%. The traits Chl and Caro experienced decreases in mean by -27.1% and -8.5%, respectively. The similar findings were obtained by the Singh *et al.* (2014) where they observed the reduction in mean value of all the studied morphological and physiological traits. Similarly, Kumar *et al.* (2013) observed the significant reduction in chlorophyll and carotenoid content in late sown environment.

Analysis of variance (ANOVA)

The analysis of variance (ANOVA) for physiological and yield component traits under timely sown conditions

Table 1: Mean performance and range of various traits across timely and late sown environments

Trait	Timely sown			Late sown			% Change in mean
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	
DF	48.4	38.8	59.3	68.7	62.2	79.9	+29.5
DM	142.9	133.4	154.4	114.0	103.8	123.3	-25.3
PH	209.6	182.1	232.2	191.4	164.8	211.5	-9.4
NPB	5.4	3.3	8.0	4.2	2.8	7.5	-29.5
NSB	12.0	7.4	22.7	8.5	5.0	17.7	-41.7
MSL	82.0	58.8	99.7	71.0	51.8	90.7	-15.4
NSMS	53.3	38.7	65.5	45.3	33.1	60.9	-17.5
SL	4.6	3.4	6.5	4.2	2.9	5.6	-9.8
NSS	14.1	11.7	16.7	11.9	10.1	14.1	-18.6
OC	39	38.2	40.0	38.5	37.6	39.3	-1.1
TSW	5.6	3.4	8.0	4.6	2.5	7.2	-21.2
SYP	22.7	14.1	32.5	17.6	9.8	27.2	-28.7
A	17.4	11.8	24.4	8.9	2.8	21.5	-94.8
Gs	0.4	0.2	0.7	0.2	0.1	0.5	-100.0
E	3.3	1.3	6.3	7.5	2.7	11.6	+55.7
Chl	1.1	0.8	1.5	0.9	0.5	1.3	-27.1
Caro	2.1	1.5	2.8	2.3	1.2	3.1	-8.5

DF-Days to 50% flowering; DM-Days to maturity; PH-Plant height (cm); NPB-Number of primary branches/plant; NSB-Number of secondary branches/plant; MSL-Main shoot length (cm), NSMS-Number of siliquae on main shoot; SL-Siliqua length (cm); NSS-Number of seeds/siliqua; OC-Oil content (%); TSW-1000-seed weight (g); SYP-Seed yield/plant (g); A–Photosynthetic rate (µmol $CO_2/m^2/s$); Gs – Stomatal conductance ($mmol/m^2/s$); E – Transpiration rate (mmol $H_2O/m^2/s$); Chl – Total chlorophyll content (mg/g); Caro – Carotenoid content (mg/g).

in Indian mustard reveals significant sources of variation (Table 2). The block effect, representing variability between different blocks while ignoring treatments, shows statistically significant differences for all traits, with highly significant values ranging from 24.0 to 127.7, emphasizing the influence of block-related factors on the observed traits. Upon eliminating block effects, the treatment factor displays significant differences across all the traits, indicating the impact of specific treatments.

ANOVA for physiological and yield component traits under late-sown conditions in Indian mustard reveals significant sources of variation (Table 3). Block effects, representing variability between different blocks while ignoring treatments, demonstrate statistically significant differences for all traits. Highly significant values ranging from 25.4 to 248.8 underscore the influence of block-related factors on the observed traits, emphasizing the need to consider and control for these variations in the analysis. Similar pattern of results obtained by the Choudhary *et al.* (2023) during investigation of 12 morphological traits. Upon eliminating block effects, the treatment factor shows significant differences across traits, indicating the impact of specific treatments under late-sown conditions. The treatment: check interaction reveals significant effects for various traits, highlighting the importance of specific treatments in influencing physiological and yield-related characteristics. The residual values, representing unexplained variation, show relatively low values, indicating that the model accounts for a substantial portion of the observed trait variability. This suggests that the factors considered in the analysis, including blocks and treatments, explain a significant proportion of the overall trait variation under late-sown conditions in Indian mustard.

Studies on genetic variability components

In the realm of plant breeding, the foundation for selection and enhancement of desired traits lies in genetic variability. It is crucial to focus on the heritable portion of the total variation for a given trait, as it is the one that contributes to gains in selection. The selection process is more effective when dealing with traits that exhibit higher heritability, making them more responsive to selection pressures. The study involved estimating variability in various morphological and physiological traits across 150 Indian mustard genotypes.

The results, including phenotypic coefficient of variance (PCV), genotypic coefficient of variance (GCV), broad-sense heritability, genetic advance, and genetic advance

Table 2: Analysis of variance for physiological and yield component traits under timely sown environment in Indian mustard

Source	df	A	Car	Chl	DF	DM	E	Gs	MSH	NSMS	NSS	OC	PB	PH	SB	SL	SYP
Block (ignoring treatments)	9	24.0**	0.2**	0.1**	37.1**	38.5**	4.0**	0.1**	70.4**	68.8**	0.9**	0.1*	3.1**	102.5**	17.3**	2.9**	127.7**
Treatment (eliminating blocks)	153	7.3**	0.1**	0.1**	11.3**	11.8*	0.6**	0.1**	37.9**	23.8**	0.7**	0.1**	0.4**	77.9**	5.6**	0.2**	13.6**
Treatment: check	3	40.5**	0.0ns	0.1**	6.8ns	6.8ns	0.8**	0.1*	0.8ns	48.7**	2.9**	0.1*	0.2ns	280.6**	3.6**	1.1**	73.1**
Treatment: test and test vs. check	150	6.6*	0.1**	0.1**	11.4**	11.9*	0.6**	0.1**	38.7**	23.3**	0.7**	0.1**	0.4**	73.9**	5.7**	0.2**	12.4**
Residuals	27	3.0	0.0	0.0	5	5.9	0.1	0.0	13.6	9.8	0.1	0.0	0.1	21.5	0.4	0.1	3.2

**Significant at $P \leq 0.01$ and *Significant at $P \leq 0.05$; DF-Days to 50% flowering; DM-Days to maturity; PH-Plant height (cm); NPB-Number of primary branches/plant; NSB-Number of secondary branches/plant; MSL-Main shoot length (cm), NSMS-Number of siliquae on main shoot; SL-Siliqua length (cm); NSS-Number of seeds/siliqua; OC-Oil content (%); TSW-1000-seed weight (g); SYP-Seed yield/plant (g); A–Photosynthetic rate (µmol $CO^2/m^2/s$); Gs – Stomatal conductance ($mmol/m^2/s$); E – Transpiration rate (mmol $H_2O/m^2/s$); Chl – Total chlorophyll content (mg/g); Caro – Carotenoid content (mg/g).

Table 3: Analysis of variance for physiological and yield component traits under late sown environment in Indian mustard

Source	df	A	Car	Chl	DF	DM	E	Gs	MSH	NSMS	NSS	OC	PB	PH	SB	SL	SYP
Block (ignoring treatments)	9	25.4**	0.2**	0.1**	29.4**	46.2**	10.2**	0.1**	248.8**	93.2**	1.8**	0.1ns	3.1**	204.4**	13.7**	2.6**	134.4**
Treatment (eliminating blocks)	153	9.4**	0.1**	0.1**	6.8**	10.4**	40.1**	0.1**	47.0**	28.3**	0.8**	0.2**	0.4**	73.7**	4.8**	0.2**	11.6**
Treatment: check	3	80.6**	0.6**	0.1**	5.4*	9.6*	70.3**	0.1**	11.3ns	56.2**	4.7**	1.3**	0.1ns	322.4**	32.6**	0.8**	1.9ns
Treatment: test and test vs. check	150	8.0**	0.1**	0.1**	6.8**	10.4**	2.6*	0.1**	47.8**	27.8**	0.7**	0.2**	0.4**	68.7**	4.2**	0.2**	11.8**
Residuals	27	1.3	0.0	0.1	1.7	3.0	1.4	0.0	15.0	10.4	0.2	0.1	0.1	28.2	0.2	0.1	5.3

**Significant at $P \leq 0.01$ and *Significant at $P \leq 0.05$; DF-Days to 50% flowering; DM-Days to maturity; PH-Plant height (cm); NPB-Number of primary branches/plant; NSB-Number of secondary branches/plant; MSL-Main shoot length (cm), NSMS-Number of siliquae on main shoot; SL-Siliqua length (cm); NSS-Number of seeds/siliqua; OC-Oil content (%); TSW-1000-seed weight (g); SYP-Seed yield/plant (g); A–Photosynthetic rate (µmol $CO^2/m^2/s$); Gs – Stomatal conductance ($mmol/m^2/s$); E – Transpiration rate (mmol $H_2O/m^2/s$); Chl – Total chlorophyll content (mg/g); Caro – Carotenoid content (mg/g).

as a percentage of mean, are summarized in Table 4 (TS) and 5 (LS). The coefficients of variation (%), representing the variability relative to the mean, provide insights into the stability and consistency of various traits. Among the parameters, E, Gs and NSB exhibited higher CV (>20%) suggesting greater variability in their measurements under TS environment. This could indicate inherent fluctuations or sensitivity in the measurements of these traits. The traits A, Car, Chl, NPB, SL, SYP and TSW exhibited medium CV (10-20%). Conversely, OC, DF, DM, MSH, NSMS, NSS and PH displays a notably low coefficient (<10%) indicating a more stable and consistent measurement. The higher coefficients for these traits may imply a higher degree of environmental influence or genetic variation. Overall, understanding the coefficients of variation for each trait is crucial in assessing the reliability and robustness of the measurements, providing valuable information for further research and applications in breeding field. Previously, Chaudhary *et al.* (2023) observed the PCV from 3.4% to 19.3% for various morphological traits. Traits A and Gs showed the high CV (>20%) while, traits like E, NSB, SYP and TSW exhibited medium CV (10-20%) under LS condition. Similar results were observed by Singh *et al*. (2022), Kumar *et al.* (2023), Chaudhary *et al*. (2023) and Choudhary *et al*. (2023).

Table 4: Estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (broad sense) and genetic advance (GA) for different morphological and physiological traits under timely sown environment in Indian mustard genotypes

Trait	Coefficient of variation (%)		Heritability	Genetic	Genetic advance
	PCV	GCV	(Broad sense)	advance	(% of mean)
DF	7.4	5.8	61.9	4.6	9.5
DM	2.5	1.9	55.9	4.2	2.9
PH	4.1	3.4	71.1	12.6	6.0
NPB	14.5	13.3	85.0	1.3	25.4
NSB	21.2	20.5	93.4	4.9	40.9
MSL	7.9	6.5	67.9	9.1	11.1
NSMS	9.7	7.7	63.2	6.7	12.6
SL	13.6	12.5	84.9	1.1	23.8
NSS	6.0	5.5	85.0	1.5	10.0
OC	0.8	0.7	69.1	0.4	1.2
TSW	19.8	18.2	84.5	1.9	34.5
SYP	18.9	17.1	82.3	7.3	32.1
A	16.1	12.5	61.0	3.5	20.2
Gs	22.0	19.7	80.3	0.1	36.4
E	27.2	24.9	83.6	1.5	47.0
Chl	11.3	10.4	84.6	0.2	20.7
Caro	11.7	10.9	87.1	0.4	21.0

DF-Days to 50% flowering; DM-Days to maturity; PH-Plant height (cm); NPB-Number of primary branches/plant; NSB-Number of secondary branches/plant; MSL-Main shoot length (cm), NSMS-Number of siliquae on main shoot; SL-Siliqua length (cm); NSS-Number of seeds/siliqua; OC-Oil content (%); TSW-1000-seed weight (g); SYP-Seed yield/plant (g); A–Photosynthetic rate (µmol $CO^2/m^2/s$); Gs – Stomatal conductance ($mmol/m^2/s$); E – Transpiration rate (mmol $H_2O/m^2/s$); Chl – Total chlorophyll content (mg/g); Caro – Carotenoid content (mg/g).

Heritability estimates along with genetic advance would be more useful in predicting yield under phenotypic selection than heritability estimates alone as suggested by Johnson *et al.* (1955). Genetic gain under selection for morphological and physiological traits depends on the extent of genetic advance as per cent of 5% mean. In present study, high heritability along with high genetic advance were reported for NPB, NSB, SL, TSW, SYP, A, Gs, E, Chl and Caro under TS conditions as well as under LS conditions. Therefore, inheritance of these traits might be under the control of additive gene action hence, the improvement of these traits can be made through direct phenotypic selection. Similar findings have been reported by Kumar *et al.* (2023), Chaurasiya *et al*. (2019) and Rout *et al*. (2018) for NSS, SYP, PH, NPB, TSW and HI. The traits DF, DM, PH and OC have high heritability with low genetic advance as per cent of mean in TS as well in LS environment. Such result has also reported by

Table 5: Estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (broad sense) and genetic advance (GA) for different morphological and physiological traits under late sown environment in Indian mustard genotypes

Trait	Coefficient of variation (%)		Heritability	Genetic	Genetic advance
	PCV	GCV	(Broad sense)	advance	(% of mean)
DF	4.2	3.7	79.4	4.7	6.9
DM	3.1	2.8	77.2	5.7	5.0
PH	4.6	3.6	63.6	11.5	6.0
NPB	18.0	17.1	90.2	1.4	33.5
NSB	25.7	24.9	93.9	4.2	49.8
MSL	10.9	9.4	75.1	12.4	16.9
NSMS	12.4	10.2	67.1	7.8	17.2
SL	13.7	12.1	78.3	0.9	22.2
NSS	6.9	5.2	58.1	0.9	8.3
OC	0.9	0.7	66.6	0.4	1.2
TSW	21.2	18.7	77.4	1.5	33.9
SYP	24.0	20.2	70.6	6.1	35.0
A	34.0	31.4	85.2	5.3	59.8
Gs	31.5	28.0	78.8	0.1	51.3
E	23.0	16.3	50.6	1.8	24.0
Chl	14.5	13.3	83.9	0.2	25.2
Caro	12.9	11.5	80.1	0.5	21.3

DF-Days to 50% flowering; DM-Days to maturity; PH-Plant height (cm); NPB-Number of primary branches/plant; NSB-Number of secondary branches/plant; MSL-Main shoot length (cm), NSMS-Number of siliquae on main shoot; SL-Siliqua length (cm); NSS-Number of seeds/siliqua; OC-Oil content (%); TSW-1000-seed weight (g); SYP-Seed yield/plant (g); A–Photosynthetic rate (µmol $CO^2/m^2/s$); Gs – Stomatal conductance ($mmol/m^2/s$); E – Transpiration rate (mmol $H_2O/m^2/s$); Chl – Total chlorophyll content (mg/g); Caro – Carotenoid content (mg/g).

Tripathi *et al.* (2020), Choudhary *et al.* (2023) and Kumar *et al.* (2023).

Correlation analysis

For the effective selection procedure, it is very important to discover the type of relationship between various morphological and physiological traits with seed yield. Correlation analysis was performed to determine the nature of the relationship between various morpho-physiological variables and seed yield (Fig. 1 and 2).

The correlation matrix presented above reveals the relationships between different variables in a structured format. Positive correlations are denoted by values close to 1, while negative correlations are indicated by values close to -1. A correlation coefficient of 1 signifies a perfect positive correlation, while -1 indicates a perfect negative correlation, and 0 implies no correlation. Looking at specific correlations under timely sown conditions, there is a strong positive correlation (0.9) between DF and DM, suggesting a robust relationship between these two variables. Similarly, there is a significant positive correlation between SYP and NPB (0.8), NSB (0.5), SL (0.4), NSS (0.3), TW (0.6), A (0.6), Gs (0.4), Chl (0.6) and Caro (0.3) indicating a strong association between these factors. Previously Choudhary *et al*. (2022), Yadav *et al.* (2023) and Choudhary *et al.* (2023) reported the high correlation between SYP and NPB, SL, NSB, MSL and NSS. On the other hand, there are several non-significant (NS) correlations, suggesting a lack of statistically significant relationships between certain pairs of variables. Interestingly, there is a notable negative correlation (-0.23) between siliquae length and days to flowering, implying an inverse relationship between these two variables. Additionally, the negative correlation (-0.2) between transpiration rate and NPB suggests a tendency for these variables to move in opposite directions. Overall, this correlation matrix provides a useful overview of the interplay between different variables, laying the foundation for deeper investigations into their associations.

The correlation coefficients among various morphological and physiological traits under late sown condition is presented in the correlation matrix (Fig. 2).

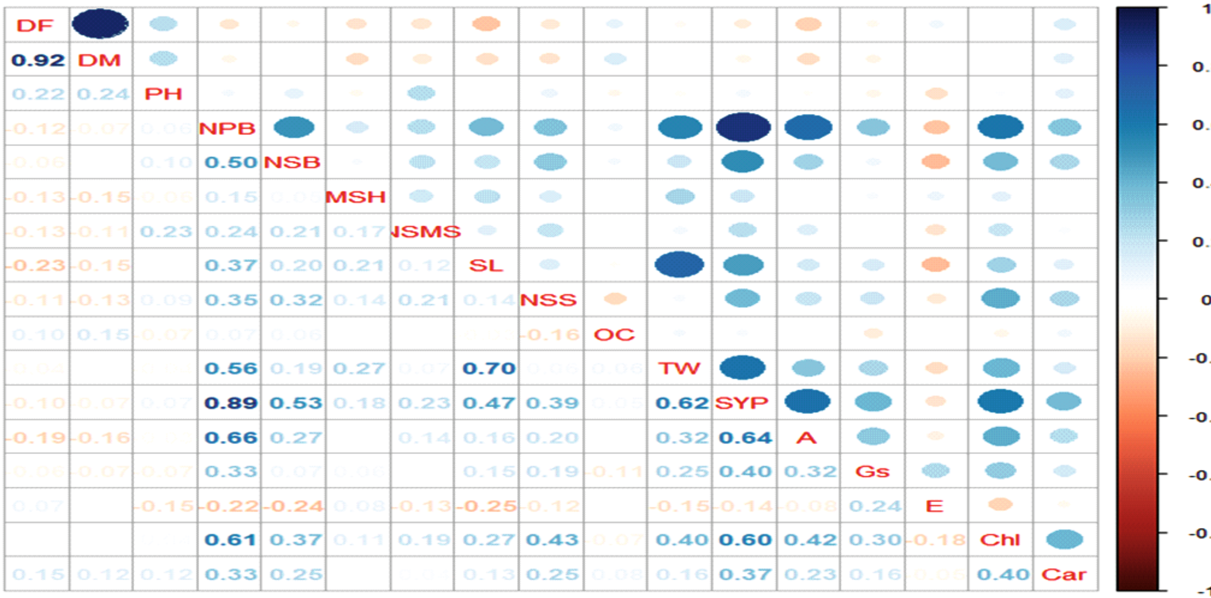

Fig. 1: Correlation coefficient between different morphological and physiological traits under timely sown condition in Indian mustard

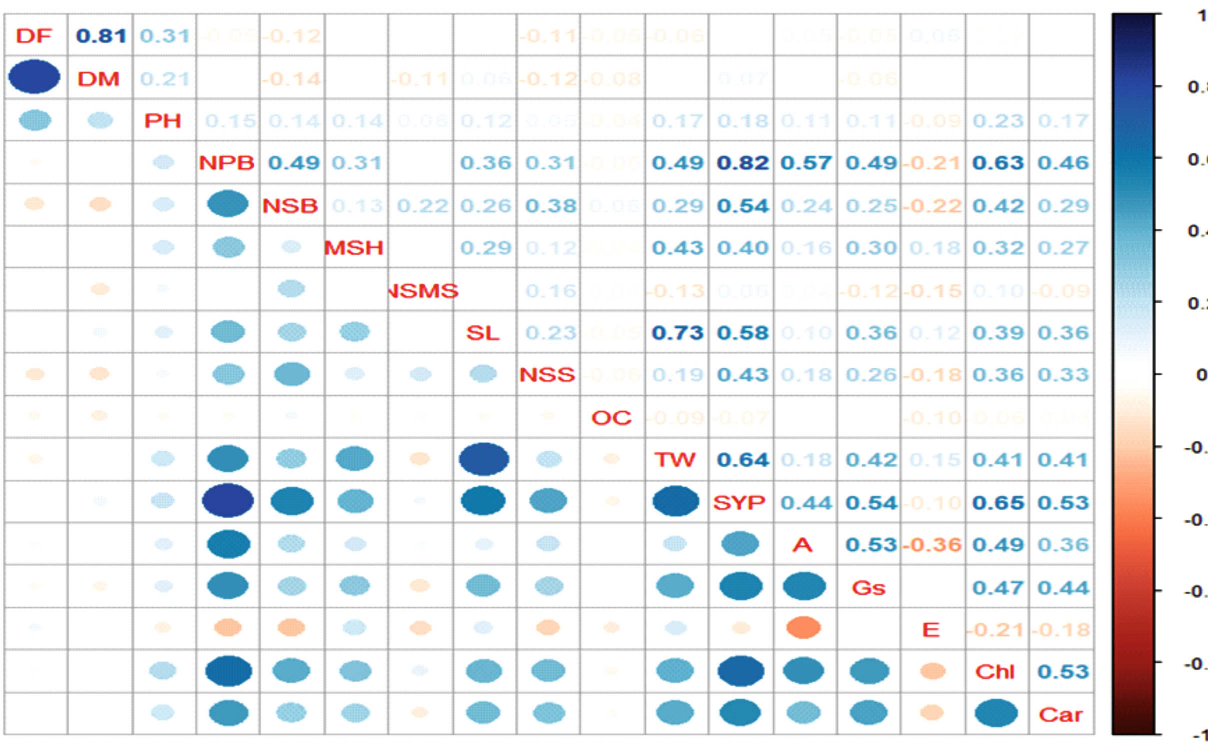

Fig. 2: Correlation coefficient between different morphological and physiological traits under late sown condition in Indian mustard

DF-Days to 50% flowering; DM-Days to maturity; PH-Plant height (cm); NPB-Number of primary branches/plant; NSB-Number of secondary branches/plant; MSL-Main shoot length (cm), NSMS-Number of siliquae on main shoot; SL-Siliqua length (cm); NSS-Number of seeds/siliqua; OC-Oil content (%); TSW-1000-seed weight (g); SYP-Seed yield/plant (g); A–Photosynthetic rate (µmol $CO^2/m^2/s$); Gs – Stomatal conductance (mmol/m^2/s); E – Transpiration rate (mmol $H_2O/m^2/s$); Chl – Total chlorophyll content (mg/g); Caro – Carotenoid content (mg/g).

For instance, a positive and significant correlation was observed between SYP and NPB (0.8), NSB (0.5), MSH (0.4), SL (0.5), NSS (0.4), TW (0.6), A (0.4), Gs (0.5), Chl (0.6) and Caro (0.5). Similar findings were reported by Yadav *et al*. (2023), Choudhary *et al*. (2023) and Srivastava *et al.* (2019). On the other hand, negative correlations were observed between certain traits, such as stomatal conductance (Gs) and transpiration rate (E) with coefficients of -0.3 and -0.2, respectively. The genetic correlations among these traits provide valuable insights into the underlying relationships and potential pleiotropic effects. The positive correlations between days to maturity and plant height suggest that genotypes reaching maturity later tend to have greater plant height. This information is crucial for breeders aiming to optimize the selection process for desired traits. Additionally, the negative correlation between stomatal conductance and transpiration rate suggests a potential trade-off between these two physiological processes.

Conclusion

From the present investigation, it can be concluded that ANOVA results provide valuable insights into the sources of variation for physiological and yield component traits in Indian mustard under late-sown conditions. The high heritability along with high genetic advance were reported for number of primary branches, number of secondary branches, siliqua length, 1000-seed weight, seed yield per plant, photosynthetic rate, stomatal conductance, transpiration rate, total chlorophyll and carotenoid content under timely sown conditions as well as under late sown conditions. The direct selection for these traits will be helpful to increase the productivity of Indian mustard. These findings contribute to a better understanding of the factors influencing crop performance and guide future research and interventions aimed at optimizing agricultural outcomes in this specific environmental context.

References

Al-Jibouri H, Miller PA and Robinson HF. 1958. Genotypic and environmental variances and covariances in an upland cotton cross of inter-specific origin. *Agron J* **50**: 633-636.

Chaudhary B, Lavanya GR, Yadav AP and Prajapat DK. 2023. Estimates of genetic variability, correlation and path analysis in Indian mustard (*B. juncea*). *J Oilseed Brassica* **14**: 170-174.

Chaurasiya JP, Singh M and Tomar P. 2019. Genetic variability, heritability, genetic advance and character association of Indian mustard (*B. juncea*). *J Oilseed Brassica* **10**: 80-86.

Choudhary RR, Avtar R, Singh M, Chaurasia H, Kumari M and Poonia M. 2022. Trait association analysis for yield and its components in Indian mustard (*B. juncea*). *Bio Forum* **14**: 538-542.

Choudhary RR, Avtar R, Singh M and Bishnoi M. 2023. Genetic parameters and correlation studies in Indian mustard (*B. juncea*). *J Oilseed Brassica*. **14**: 68-72.

Choudhary RR, Avtar R, Samita and Kumar D. 2020. Heterosis studies based upon *Mori* CMS system in *Brassica juncea*. *J Oilseed Brassica* **11**: 116-120.

Federer WT. 1956. Augmented (or hoonuiaku) designs. Hawaiian Planters' Record LV **2**: 191-208.

Hiscox JD and Israelstam GF. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Can J Bot* **57**: 1332-1334.

Johnson HW, Robinson HF and Comstock RE. 1955. Estimates of genetic and environmental variability in soybeans. *Agron J* **47**: 314-318.

Kumar S, Bhardwaj R, Jhambhulkar SJ and Rai A. 2023. Assessment of genetic variability, heritability and genetic advance in Indian mustard (*B. juncea*). *J Oilseed Brassica* **14**: 38-43.

Kumar S, Sairam RK and Prabhu KV. 2013. Physiological traits for high temperature stress tolerance in *Brassica juncea*. *Indian J Plant Physiol* **18**: 89-93.

Rout S, Kerkhi SA and Chauhan C. 2018. Character association and path analysis among yield components in Indian musturd (*B. juncea*). *Int J Curr Micro Appl Sci* **7**: 50-55.

Sharma S, Bala M, Kaur G, Tayyab S and Feroz SR. 2022. Chemical composition of oil and cake of *Brassica juncea*: implications on human and animal health. In *The Brassica juncea Genome,* Cham: Springer International Publishing. 29-55.

Singh M, Rathore SS, and Raja P. 2014. Physiological and stress studies of different rapeseed-mustard genotypes under terminal heat stress. *Int J Genet Engin Biotech* **5**: 133-142.

Singh M, Avtar R, Kumar N, Punia R, Lakra N, Kumari N, Bishnoi M, Rohit R, Choudhary RR, Khedwal RS and Meena RK. 2022. Assessment of sclerotinia stem and leaf rot resistance and its association with physical strength attributes in Brassicaceae with special emphasis on *Brassica juncea*. *J Pl Gro Regu* **15**: 1-17.

Singh M, Avtar R, Lakra N, Hooda E, Singh VK, Bishnoi M, Kumari N, Punia R, Kumar N and Choudhary RR. 2021. Genetic and proteomic basis of sclerotinia stem rot resistance in Indian mustard (*B. juncea*). *Gene* **12**: 1784.

Singh RK and Chaudhary BD .1985. Line x Tester analysis. In Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi, India, 215-223.

Singh S, Kumar V, Singh SK and Daneva V. 2022. Genetic variability, interrelation and path analysis for yield and yield characters in Indian mustard (*B. juncea*). *J Oilseed Brassica* **13**: 112-118.

Srivastava SKK and Srivastava A. 2019. Genetic parameters and character association of yield and its attributes in Indian mustard (*B. juncea*). *J Oilseed Brassica* **10**: 140-148.

Tripathi SK, Lallu SKS, Yadav V and Singh M. 2020. Effect of terminal heat stress on variability in physiological traits of Indian mustard (*B. juncea*) due to late sown situation. *Int J Cur Micro Appl Sci* **9**: 1620-1628.

Wellburn AR. 1994. The spectral determination of chlorophylls a and b, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *J Plant Physiol* **144**: 307-313.

Yadav AP, Ram B, Sharma HK, Yadav BS and Yadav M. 2023. Correlation and path analysis in Indian mustard (*B. juncea*) for morpho-physiological traits in early maturing genotypes. *J Oilseed Brassica* **14**: 142-147.