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Trait association analysis under abiotic stresses in Indian mustard (*Brassica juncea* L. Czern. & Coss.): Unraveling relationships and significance

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Abstract

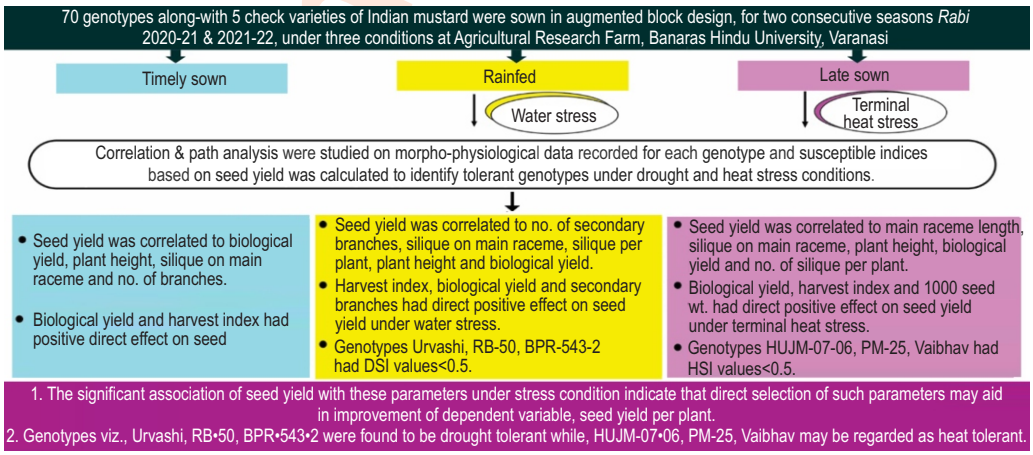
Aim: The present study was conducted to estimate the character association among yield and its associated traits and identify tolerant genotypes of Indian mustard under abiotic stress condition.

Methodology: 70 genotypes and 5 check varieties of Indian mustard, *viz.*, RH-749, NRCHB-101, RH-406, Giriraj, and Kranti were sown in augmented block design, for two consecutive seasons during *Rabi* 2020-21 and 2021-22, under three conditions, *viz.*, timely sown, drought and late sown (terminal heat stress) at Agricultural Research Farm, Banaras Hindu University, Varanasi. The morphological and physiological data were observed to determine the traits associated with seed yield under abiotic stress condition. The heat susceptibility index (HSI) and drought susceptibility index (DSI) were calculated based on seed yield to categorize genotypes according to their response under stress condition.

Results: Plant height, biological yield, secondary branches, number of silique on main raceme and silique per plant showed significant positive correlation with seed yield per plant under all three conditions, and the highest positive direct effect on seed yield/plant under all three conditions as per path analysis was exhibited by biological yield and harvest index. Genotypes *viz.*, HUJM-07-06, PM-25 and Vaibhav were found to be most heat tolerant whereas Urvashi, RB-50 and BPR-543-2 were found to be most drought tolerant.

Interpretation: It can be interpreted that direct selection for such traits may aid in improving seed yield per plant under stress condition and thus, be used in breeding programs to select genotypes suitable under stress environment.

Key words: Drought, Indian mustard, Path coefficient analysis, Susceptible indices, Terminal heat stress



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Introduction

Indian mustard [*Brassica juncea* L., AABB genome, 2n=36] is an amphidiploid species developed naturally by crossing *B. campestris* (2n=20) and *B. nigra* (2n=16) (Nagaharu, 1935), a popular Rabi season oilseed crop, belonging to family Brassicaceae. The area, production and productivity of rapeseed-mustard in India during 2022-23 was 9.8 Mha, 14.8 MT and 1500 kg ha^{-1}, respectively (Kumar *et al*., 2025), despite this, the Indian Government had to import 15 Mt of edible oil to meet the current demand. Several biotic and abiotic factors, notably drought and heat, are hampering the productivity of Indian mustard as a result of emerging climate change. Drought causes about 17-94% annual yield loss in Indian mustard (Srivastava *et al.,* 2021). Drought stress elevates the solute concentration in the root zone of the plant, causing an osmotic flow of water out of the plant cells. This decreases the cell's water potential and disturbs the physiological activities (Dogra *et al.,* 2018), which consequently have a significant influence on source and sink`s storage potential (Chauhan *et al.,* 2007; Sinaki *et al.,* 2007) and cause a decrease in seeds per pod, seed weight, oil content and total productivity in Brassica (Sandhu *et al.,* 2021).

Flowering is the most vulnerable stage to any stress because it is vulnerable to the formation of pollen, anthesis and fertilization, which reduces the crop yield (Hall and Rao, 1992). Additionally, elevated temperatures alter the thylakoid membrane's structural arrangement and physio-chemical characteristics, which can have a direct or indirect impact on the rate of photosynthesis in plants (Subrahamanyam and Rathore, 1994). Sharma and Sardana (2016) found a 53.10% loss in yield and a 6.97% reduction in oil content due to high temperature stress. Due to late harvest of paddy crops, adverse impacts of heat stress are consistently seen in mustard in Eastern Uttar Pradesh (Srivastava and Srivastava, 2020). Delayed sowing reduces the amount of dry matter accumulation, shortens the vegetative period, and lowers the potential genetic yield. Heat blast from high temperatures during pod development also lowers the test weight. According to Tiwari *et al.* (2022), crop yield decreases by 17% for rise in every 1°C in the mean temperature of planting season. Poor plant stand and consequent seedling mortality are probable in the crop if the mean surface temperature rises above 32°C. Heat susceptibility index (HSI) and Drought susceptibility index (DSI) values aid in characterizing the relative tolerance of genotypes against heat and drought stress, respectively. The speculation is aimed at reducing yield losses relative to standard environmental conditions (Singh *et al.,* 2022). Using tolerant genotypes to alleviate the effect of stress is the best way to achieve a sustainable seed yield under stress conditions, for which selection for the traits associated with yield under stress condition (Sharma *et al.,* 2022) is important.

Susceptibility index is a quantitative trait that identifies the genotypes performing better under stress. The genotypes with a lower susceptibility index value can be used as a tolerant donor parent to transfer the desired characteristics into new variety, for development of resilient varieties. These varieties show reduced risk of crop failure amidst global temperatures, heat waves, or prolonged dry periods, ensuring stable yields. They often exhibit traits like better water use efficiency, enhanced photosynthesis under stress, and improved nutrient uptake, contributing to sustained productivity even in adverse conditions. It plays a wide role in crop improvement in this era of climate change as it helps maintain stable productivity and thus, secure global food nutrition.

Materials and Methods

An experiment was performed in a completely randomized augmented block design, in the Research Farm at Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, during the consecutive Rabi seasons of 2020-21 and 2021-22. The experimental field comprised of 3 trials (timely sown, drought sown and late sown), each consisting of 5 blocks. In the year 2020-2021, sowing for timely sown and drought condition was done on 23rd October and late sown trial was sown on 17th November, while, in the year 2021-22, the timely, drought and late sown trials were sown on 11th November, 10th November and 6th December, respectively. Each of the three sets consisted 70 genotypes of Indian mustard along with 5 check varieties, *viz.,* RH-749, NRCHB-101, RH-406, Giriraj and Kranti. Each plot consisted of five rows of 3m length each, spaced 30 cm apart with plant-to-plant distance of 15cm, with each block having all checks randomized and replicated. The meteorological data at BHU, Varanasi for the years 2020-21 and 2021-22 is presented in Fig. 1. From the graph, it is apparent that the crop, being grown in *Rabi* season, receives very less rainfall that creates a drought condition frequently. And pod development stage that generally coincides with the month of March in the Varanasi region experiences extreme high temperature, thereby, causing terminal heat stress conditions in Indian mustard genotypes.

The character association among the traits was studied using correlation (Searle, 1961) and path coefficient analysis (Dewey and Lu, 1959). The physiological parameters were studied during the flowering stage. The relative water content (RWC) was estimated by the methodology described by Barrs and Weatherly (1962); while Membrane thermo-stability index (MSI) using the method described by Sairam *et al.* (1994). Five plants were randomly selected from each plot, avoiding the border row, to record the data for different morphological characters *viz.,* plant height, number of primary branches, number of secondary branches, main raceme length, number ofsilique on main raceme, number of silique per plant, siliqua length, number of seeds per siliqua, biological yield, test weight, yield per plant and yield per hectare. Days to 50% flowering was recorded on plot basis. To assess the tolerance of various genotypes to heat and drought stress separately, the susceptibility index was calculated by the formula given by Fischer and Maurer (1978). Based on the susceptibility index values, genotypes were classified as follows: tolerant (SI < 0.50), moderately tolerant (SI: 0.50-1.00), susceptible (SI >1.00).

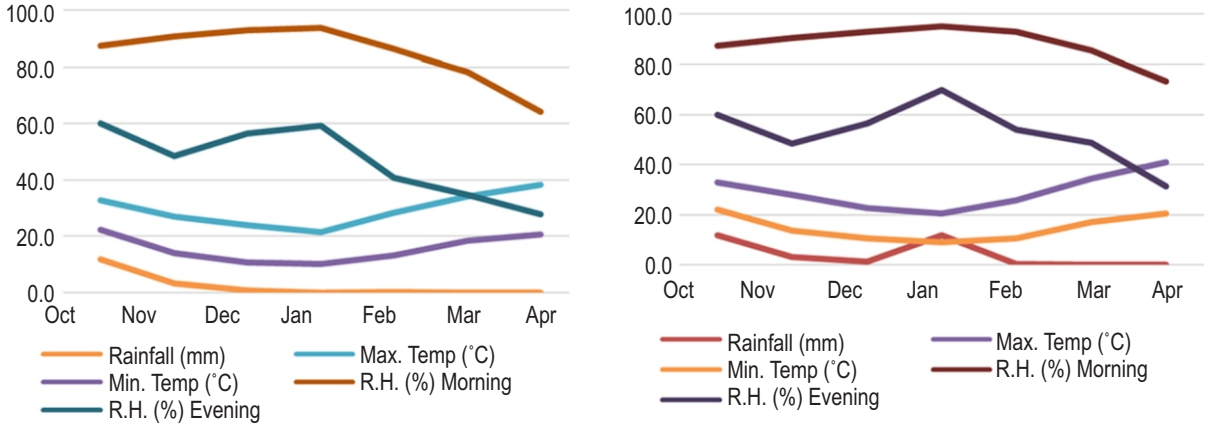

Fig. 1: Weather parameters observed in the Rabi season of years 2020-21 (a) and 2021-22 (b).

Table 1: Pooled phenotypic correlation among traits studied for 75 genotypes of Indian mustard (*Brassica juncea* L.) in timely sown condition for the years Rabi 2020-22

Traits	DTF	MRL	MSI	NPB	NSB	NSR	NSP	PH	RWC	SL	SPS	TGW	Y	HI	BY	EY
DTF	1.00	0.14	-0.11	0.04	0.13	0.16	-0.01	0.01	-0.24*	0.02	0.16	0.09	-0.17	0.35**	-0.11	-0.06
MRL		1.00	-0.13	0.04	-0.30**	0.86**	-0.14	-0.22*	-0.31**	0.78**	0.58**	0.16	-0.20	0.19	-0.21	-0.19
MSI			1.00	-0.06	-0.14	-0.10	-0.16	0.04	0.44**	-0.12	-0.06	0.19	-0.00	0.09	-0.00	0.08
NPB				1.00	0.34**	0.03	0.09	0.23*	0.10	0.05	0.01	-0.01	0.30**	-0.14	0.402**	0.31**
NSB					1.00	-0.35**	0.26**	0.29*	0.13	-0.13	-0.32**	-0.20	0.42**	-0.31**	0.52**	0.40**
NSR						1.00	0.48*	0.39*	-0.35**	0.35**	0.11**	0.13	0.36**	0.28*	0.35**	0.29*
NSP							1.00	0.26*	0.02	-0.05	-0.15	-0.12	0.22*	-0.15	0.30**	0.22
PH								1.00	0.20	0.07	-0.45**	0.11	0.44**	-0.44**	0.68**	0.47**
RWC									1.00	-0.14	-0.31**	-0.01	0.15	-0.18	0.21	0.13
SL										1.00	-0.06	0.05	0.07	0.01	0.05	0.01
SPS											1.00	0.12	-0.42**	0.30*	-0.39**	-0.31
TGW												1.00	0.07	0.14	0.09	0.13
Y													1.00	-0.17	0.77**	0.79**
HI														1.00	-0.38**	0.11
BY															1.00	0.84**
EY																1.00

Where, (DTF)=Days to 50% flowering, (MRL)=main raceme length(cm), (MSI)=Membrane thermo-stability index, (NPB)= number of primary branches, (NSB)=number of secondary branches, (NSR)=number of silique on main raceme, (NSP)=number of silique per plant, (PH)=Plant height(cm), (RWC)=relative water content, (SL)=siliqua length(cm), (SPS)=number of seeds/siliqua, (TGW)=test weight(g), (Y)=seed yield/ hectare(Kg), (HI)=Harvest Index, (BY)=biological yield (g), (EY)= seedyield/plant (g).

Results and Discussion

Seed yield is a complex and polygenic trait, influenced by numerous confounding factors. Direct genotype selection established on yield does not result in superior outcomes because it is influenced by the environment. So, it is vital to employ fundamental biometrical data, such as correlation and path coefficient analysis. The pooled phenotypic correlation among traits studied for 75 genotypes of Indian mustard in timely sown, drought and terminal heat stress condition for the years *Rabi* 2020-22 has been tabulated in Tables 1, 2 and 3 respectively. At phenotypic level, under drought condition, the number of secondary branches, silique on main raceme, total silique, plant height and biological yield showed highly significant positive association with the seed yield per plant and under late sown condition, length of main raceme, no. of silique on main raceme, plant height, biological yield and number of silique/plant exhibited high positive interrelationship with yield per plant. Under drought sown condition, secondary branches showed a highly positive significant correlation with silique per plant, yield per plant, plant height and number of silique on main raceme whereas with plant height, the number of silique per plant and biological

Table 2: Pooled phenotypic correlation among characters studied for 75 genotypes of Indian mustard (*Brassica juncea* L.) under drought condition for the years Rabi 2020-22

Traits	DTF	MRL	MSI	NPB	NSB	NSR	NSP	PH	RWC	SL	SPS	TGW	Y	HI	BY	EY
DTF	1.00	-0.01	-0.10	0.09	0.27*	0.07	0.20	0.25*	-0.09	-0.13	-0.22*	-0.16	-0.07	0.03	0.13	0.08
MRL		1.00	0.06	-0.30	0.03	0.17	0.08	0.32*	-0.00	-0.10	-0.10	0.00	0.15	-0.27*	0.26*	-0.05
MSI			1.00	0.15	0.01	-0.02	-0.06	0.18	0.29**	-0.13	0.02	-0.15	-0.01	0.02	0.02	-0.11
NPB				1.00	0.45*	-0.05	0.38**	0.23	0.13	-0.18	-0.13	-0.10	0.17	-0.02	0.29**	0.15
NSB					1.00	0.25*	0.74**	0.31*	-0.24*	-0.29**	-0.37**	-0.24	0.11	-0.06	0.60**	0.35**
NSR						1.00	0.40**	0.49*	-0.02	-0.07	-0.37**	-0.03	0.08	0.263*	0.38**	0.52**
NSP							1.00	0.36*	-0.13	-0.30**	-0.36**	-0.09	0.11	-0.21	0.71**	0.31**
PH								1.00	0.23*	-0.24*	-0.43**	-0.11	0.20	0.03	0.52**	0.32**
RWC									1.00	0.06	0.12	0.03	0.15	-0.05	0.02	0.17
SL										1.00	0.19	0.18	-0.04	0.40**	-0.34**	0.21
SPS											1.00	0.07	-0.15	-0.18	-0.30	-0.34**
TGW												1.00	0.14	-0.09	-0.02	-0.10
Y													1.00	-0.04	0.28**	0.15
HI														1.00	-0.30**	0.77**
BY															1.00	0.32**
EY																1.00

Table 3: Pooled phenotypic correlation among characters studied for 75 genotypes of Indian mustard (Brassica juncea L.) for terminal heat stress condition for the years Rabi 2020-22

Traits	DTF	MRL	MSI	NPB	NSB	NSR	NSP	PH	RWC	SL	SPS	TGW	Y	HI	BY	EY
DTF	1.00	0.00	0.02	0.23*	0.20	0.26*	0.07	0.27*	0.18	-0.08	0.01	0.16	0.12	-0.12	0.24*	0.21
MRL		1.00	0.02	0.06	0.08	0.54*	0.30**	0.45*	0.10	0.20	-0.20	0.15	0.29**	-0.20	0.43**	0.33**
MSI			1.00	0.14	0.01	0.05	0.02	-0.01	0.41**	0.01	-0.05	-0.04	0.06	0.14	-0.08	0.20
NPB				1.00	0.25*	0.04	0.25*	0.20	0.05	0.09	-0.01	0.05	0.11	-0.20	0.33**	0.14
NSB					1.00	0.21	0.36**	0.37*	0.09	-0.27*	-0.35**	0.14	0.12	-0.07	0.31**	0.20
NSR						1.00	0.48**	0.56**	0.17	-0.01	-0.30**	0.13	0.32**	-0.20	0.46**	0.40**
NSP							1.00	0.36**	-0.09	-0.25*	-0.48**	0.05	0.35**	-0.18	0.58**	0.44*
PH								1.00	0.14	-0.03	-0.40**	0.13	0.32**	-0.14	0.52**	0.46**
RWC									1.00	-0.03	0.05	0.05	0.08	0.13	-0.02	0.12
SL										1.00	0.43**	0.00	0.13	-0.02	0.06	0.07
SPS											1.00	-0.14	-0.28**	0.02	-0.37**	-0.33
TGW												1.00	0.16	0.23*	0.08	0.23
Y													1.00	0.16	0.59**	0.81**
HI														1.00	-0.40**	0.24*
BY															1.00	0.75**
EY																1.00

yield during late sown condition. Under drought condition, the main raceme length exhibited a positive significant association with biological yield and plant height. However, under late condition, it manifested a high positive significant association with number of silique on main raceme, plant height, yield per plant, number of silique per plant and seed yield ha^{-1}. Under drought condition, the number of siliquae on main raceme exhibited a positive significant association with yield per plant, number of silique per plant, biological yield and plant height. However, the trait was positively and significantly correlated to plant height, total silique on each plant, yield per plant, yield ha^{-1} and pollen viability under late sown conditions. The number of silique per plant exhibited positive correlation with traits, *viz.,* plant height and seed yield under drought and biological yield, yield per plant, plant height and yield per ha under late sown condition. Biological yield was significantly correlated to number of silique per plant, number of secondary branches and seed yield; and number of silique on main raceme, yield per plant and main raceme length under drought condition and delayed planting conditions, respectively.

The association of seed yield with one or more of the above traits has also been witnessed by previous workers, (Awasthi *et al.,* 2020 and Kumar *et al.,* 2018). The membrane

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Table 4: Pooled phenotypic direct and indirect effect among the characters studied for 75 genotypes of Indian mustard (*Brassica juncea* L.) at timely sown condition during the years Rabi 2020-22

Traits	DTF	MRL	MSI	NPB	NSB	NSR	NSP	PH	RWC	SL	SPS	TGW	Y	HI	BY
DTF	-0.17	-0.02	0.02	-0.01	-0.02	-0.03	0.00	0.00	0.04	0.00	-0.03	-0.02	0.03	-0.06	0.02
MRL	0.00	-0.09	0.02	-0.08	0.08	-0.08	0.18	0.14	0.01	-0.08	-0.03	-0.08	0.22	-0.10	0.27
MSI	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
NPB	0.00	0.00	0.00	0.05	-0.02	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	-0.01	0.01	-0.02
NSB	0.01	-0.02	-0.01	0.03	0.07	-0.03	0.02	0.02	0.01	-0.01	-0.02	-0.02	0.03	-0.02	0.04
NSR	0.12	0.52	-0.02	0.08	-0.04	0.06	0.11	-0.01	0.00	0.03	0.02	0.07	-0.14	0.03	-0.08
NSP	0.00	0.01	0.00	0.00	-0.01	0.01	-0.03	-0.01	0.00	0.00	0.01	0.00	-0.01	0.01	-0.01
PH	0.00	-0.01	0.00	0.01	0.01	-0.01	0.01	0.03	0.01	0.00	-0.01	0.00	0.01	-0.01	0.02
RWC	0.00	0.02	-0.02	-0.01	-0.01	0.02	-0.00	-0.01	-0.05	0.01	0.02	0.00	-0.01	0.01	-0.01
SL	0.04	0.06	-0.03	0.09	0.05	0.10	-0.10	0.04	-0.01	0.03	0.11	0.10	0.15	0.02	0.09
SPS	-0.02	-0.02	0.03	-0.09	0.03	-0.01	0.14	0.03	0.09	0.21	-0.08	-0.09	0.18	-0.15	0.11
TGW	0.00	0.00	-0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	0.00	0.00	0.00
Y	-0.02	-0.03	-0.00	0.05	0.07	-0.06	0.04	0.07	0.03	0.01	-0.07	0.01	0.17	-0.03	0.13
HI	0.19	0.11	0.05	-0.08	-0.17	0.15	-0.08	-0.24	-0.10	0.01	0.16	0.08	-0.09	0.55	-0.21
BY	-0.10	-0.18	-0.00	0.35	0.45	-0.30	0.26	0.59	0.18	0.04	-0.34	0.08	0.67	-0.33	0.87
EY	-0.06	-0.19	0.08	0.31	0.40	-0.29	0.22	0.00	0.01	0.01	0.03	0.00	-0.01	0.03	0.85
Partial R^2	0.13	0.01	-0.31	0.13	0.79	0.11	0.84	0.01	-0.01	0.03	0.08	0.00	0.13	0.06	0.73

R SQUARE = 0.960 RESIDUAL EFFECT = 0.200

Table 5: Pooled phenotypic direct and indirect effect among the characters studied for 75 genotypes of Indian mustard (Brassica juncea L.) at drought condition for the years Rabi 2020-22

Traits	DTF	MRL	MSI	NPB	NSB	NSR	NSP	PH	RWC	SL	SPS	TGW	Y	HI	BY
DTF	-0.03	0.00	0.02	0.00	-0.01	0.00	-0.01	-0.01	-0.04	0.00	0.01	0.01	0.00	0.00	0.00
MRL	0.00	0.09	0.01	-0.03	0.00	0.02	0.01	0.03	0.00	-0.01	-0.01	0.00	0.01	-0.02	0.02
MSI	0.01	0.00	-0.06	-0.01	-0.00	0.00	0.00	-0.01	0.08	0.01	0.00	0.01	0.00	0.00	0.00
NPB	0.00	-0.01	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
NSB	0.00	0.00	0.01	0.00	0.11	0.00	0.01	0.00	-0.02	0.00	0.00	0.00	0.00	0.00	0.00
NSR	0.00	0.01	0.00	0.00	0.01	0.04	0.02	0.02	0.00	0.00	-0.01	0.00	0.00	0.01	0.01
NSP	0.04	0.02	-0.01	0.07	0.09	0.07	0.18	0.07	0.02	-0.06	-0.07	-0.02	0.02	-0.04	0.13
PH	-0.01	-0.02	-0.01	-0.01	-0.02	-0.03	-0.02	-0.05	-0.01	0.01	0.02	0.01	-0.01	0.00	-0.03
RWC	0.00	0.01	-0.01	-0.00	0.01	0.00	0.00	-0.01	0.12	0.00	0.00	0.00	0.01	0.00	0.00
SL	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	-0.01	0.00	0.03	0.01	0.01	0.00	0.01	-0.01
SPS	-0.01	-0.01	0.00	-0.01	-0.02	-0.02	-0.02	-0.02	0.01	0.01	0.05	0.00	-0.01	-0.01	-0.02
TGW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.04	0.00	0.00	0.00	0.00	0.00
Y	0.00	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.00	-0.01	0.01	0.04	0.00	0.01
HI	0.03	-0.26	0.02	-0.02	-0.06	0.25	-0.20	0.03	-0.04	0.39	-0.17	-0.09	-0.04	0.95	-0.28
BY	0.06	0.12	0.01	0.13	0.25	0.18	0.33	0.24	0.01	-0.16	-0.14	-0.01	0.13	-0.14	0.47
EY	0.08	-0.05	0.11	0.15	0.35	0.52	0.31	0.32	0.17	0.21	-0.34	-0.10	0.15	0.77	0.32
Partial R^2	0.00	-0.01	0.00	0.00	0.00	0.02	0.06	-0.02	0.04	0.01	-0.02	0.00	0.01	0.74	0.15

R SQUARE = 0.949 RESIDUAL EFFECT = 0.226

stability index and relative water content showed a positive significant correlation to each other at phenotypic level under timely, drought and thermo-stress condition, respectively. Increased solute leakage, which results from damaged membrane integrity under stress, is a sign of declining membrane stability and is utilized as an indirect indicator of the ability to withstand heat stress (Wahid *et al.,* 2007). The significantly less RWC values under heat stress and drought stress circumstances suggested poor retention and increased water loss from the leaves at the reproductive stage.

Path coefficient analysis, that divides the total correlation into direct and indirect effects, indicated that under timely sown condition, the highest positive direct effect on yield per plant was manifested by biological yield followed by harvest index, yield ha^{-1} and number of secondary branches (Table 4), under drought

Table 6: Pooled phenotypic direct and indirect effect among the characters studied for 75 genotypes of Indian mustard (*Brassica juncea* L.) at late sown (terminal heat stress) condition for the years Rabi 2020-22

Traits	DTF	MRL	MSI	NPB	NSB	NSR	NSP	PH	RWC	SL	SPS	TGW	Y	HI	BY
DTF	0.10	0.00	0.00	0.02	0.02	0.03	0.01	0.03	0.02	-0.01	0.00	0.01	0.01	-0.01	0.02
MRL	0.00	-0.03	0.00	0.00	0.00	-0.02	-0.01	-0.01	0.00	-0.01	0.01	0.00	-0.01	0.01	-0.01
MSI	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NPB	-0.01	0.00	-0.01	-0.04	-0.01	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.01	-0.01
NSB	-0.01	0.00	0.00	-0.02	-0.06	-0.01	-0.02	-0.02	0.01	0.02	0.02	-0.01	-0.01	0.00	-0.02
NSR	0.02	0.05	0.00	0.00	0.02	0.08	0.04	0.05	0.01	0.00	-0.03	0.01	0.03	-0.02	0.04
NSP	0.00	-0.01	0.00	-0.01	-0.02	-0.02	-0.05	-0.02	0.00	0.01	0.02	0.00	-0.02	0.01	-0.03
PH	0.03	0.04	0.01	0.02	0.04	0.06	0.04	0.10	0.01	0.00	-0.04	0.01	0.03	-0.01	0.05
RWC	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
SL	0.00	-0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	-0.05	-0.02	0.00	-0.01	0.00	0.00
SPS	0.00	-0.01	0.00	0.00	-0.02	-0.01	-0.02	-0.02	0.00	0.02	0.04	-0.01	-0.01	0.00	-0.02
TGW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
Y	0.03	0.07	0.02	0.03	0.03	0.08	0.09	0.08	0.02	0.03	-0.07	0.04	0.25	0.04	0.15
HI	-0.06	-0.11	0.01	-0.11	-0.04	-0.11	-0.10	-0.08	0.07	-0.01	0.01	0.8	0.09	0.55	-0.22
BY	0.21	0.37	-0.06	0.28	0.26	0.39	0.50	0.44	-0.02	0.05	-0.32	0.07	0.50	-0.34	0.85
EY	0.21	0.33	0.20	0.14	0.20	0.40	0.44	0.46	0.12	0.07	-0.33	0.23	0.81	0.24	0.75
Partial R^2	0.02	-0.01	0.08	-0.01	-0.01	0.03	-0.02	0.05	0.01	0.00	-0.02	0.00	0.21	0.13	0.64

R SQUARE = 0.963 RESIDUAL EFFECT = 0.192

condition, by harvest index followed by biological yield, number of silique per plant and main raceme length (Table 5). Whereas, under terminal heat stress condition, biological yield followed by plant height, number of siliquae, main raceme length, harvest index, test weight and days to fifty percent flowering (Table 6). The significant observations were plant height, number of total branches and number of silique per plant showed a positive indirect effect via biological yield on yield per plant under all three sowing conditions. The results were in concordance with the reports of Yadav *et al*. (2023), Dwivedi *et al*. (2023) and Guguloth *et al.* (2024). They emphasized on the indirect selection of plants based on these characters for improvement in yield.

During the timely sown and drought stress condition, silique per plant had an indirect positive effect on harvest index, however, under terminal heat stress condition, the trait had an indirect negative effect on seed yield per plant. Traits, like seeds per siliqua were negatively correlated to seed yield per plant and showed a negative effect on seed yield per plant, so a breeder may use appropriate selection index to improve the yield giving more weightage to seeds per siliqua to simultaneously improve both the parameters. Kaur *et al.* (2009) observed that stress-signal transduction and gene activation are mediated by heat shock proteins (Hsps) in genotypes of *Brassica*. Aneja *et al.* (2015) observed accumulation of *hsp* transcript in stressed plants, but it was absent in control and rehydrated plants of *Brassica juncea*. This indicates that the gene is activated in the presence of drought stress. Arabidopsis Hsp70 gene expression profile research by Wang *et al.* (2004) revealed that these proteins express under the influence of drought and heat. Other heat shock proteins such as, Hsp90, Hsp22, Hsp100, Hsp110, etc., have also been identified in the plants. It has been reported that the ABA1 gene expresses in the presence of both drought and abscisic acid and catalyzes the conversion of zeaxanthin to neoxanthin.

Another gene, ABA4, was found to positively regulate neoxanthin synthase despite not being stimulated by drought. As a result, knocking down either of the genes prevent dehydration-induced accumulation of ABA (North *et al.,* 2007). The NCED (9-cis- epoxycartenoid dioxygenase) genes have been identified as a part of the ABA-specific metabolic pathway, and it has been reported by Iuchi *et al.* (2001) that over-expression of these genes in Arabidopsis increases ABA levels and tolerance to drought stress. Although majority of transcripts gets down-regulated in response to stress, transcripts belonging to the families of heat shock factors (HSFs) were differently up-regulated during high temperature stress and dehydration responsive element-binding (DREB) gets up-regulated by drought stress (Bhardwaj *et al.,* 2015). Depending on heat susceptible index (HSI) values for seed yield per plant, the genotypes HUJM-07-06 (0.47), PM-25 (0.49) and Vaibhav (0.50) were found to be most heat tolerant genotype (Fig. 2). Similarly, based upon drought susceptible index (DSI) for yield per plant, genotypes Urvashi (0.41), RB-50 (0.43) and BPR-543-2 (0.50) were found to be most drought tolerant genotypes (Fig. 3). Sandhu *et al.* (2020) also used HSI values under heat stress to identify potential heat tolerant cultivars and breeding lines. Srivastava *et al.* (2021) studied the influence of drought on yield by formulating DSI for seed yield and the genotype RB-50 with a DSI value of 0.38 was found to be the most tolerant. Sodani *et al.* (2017) concluded that all the attributes declined significantly under stress. However, due to lower yield reduction and tolerance mechanisms, genotypes RB-50 and RGN-48 sustained relatively higher seed yield and oil content in drought situations as

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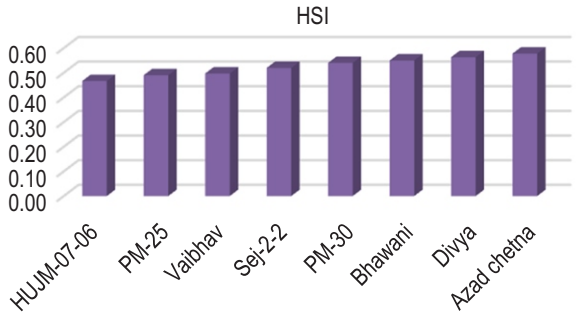

Fig. 2: Heat susceptibility index of some tolerant genotypes.

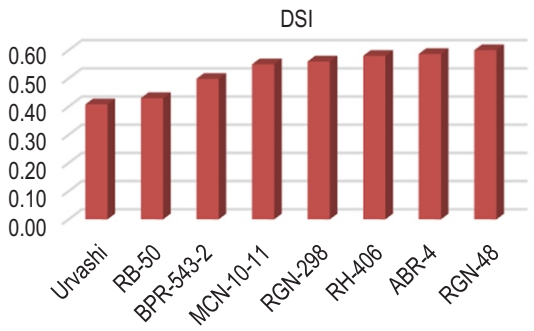

Fig. 3: Drought susceptibility index of some tolerant genotypes under study under study.

compared to normal condition. Pandey *et al*. (2024) found a positive correlation among stress susceptibility index, yield under normal condition and percent yield reduction under stress condition, hence, used it as an indicator to screen genotypes for thermo-tolerance. Similarly, Singh *et al.* (2024) utilized heat susceptible index to distinguish promising genotypes to be employed in further breeding programs for development of heat tolerant mustard varieties and elucidated on developing mapping population using contrasting genotypes to identify candidate genes/QTLs responsible for heat tolerance.

From this study, it can be concluded that the significant correlations between two parameters indicate that there may be a strong association between them, thus, selecting the parameter may aid in improvement of both the characters. Therefore, enhancing yield per plant genetically can be accomplished by rigorously selecting for specific traits., viz., plant height, secondary branches, silique on main raceme, total silique per plant, biological yield and thousand seed weight. Also, biological yield and harvest index showed the maximum positive direct effect under all three conditions on yield per plant so there might indeed be a relation between these traits and yield per plant, and selecting this attribute directly will lead gain in yield per plant in stress conditions. Furthermore, selection of traits such as plant height, number of primary branches and secondary branches, and number of silique on main branch can indirectly improve the seed yield per plant by improving the biological yield. More precisely, the number of secondary branches under drought stress condition and 1000 seed weight under terminal heat stress are some additional important traits for selecting tolerant lines in Indian mustard under stress condition. Genotypes having lowest HSI *viz.,* HUJM-07-06, PM-25 and Vaibhav and lowest DSI *viz.,* Urvashi, RB-50 and BPR-543-2, can be considered as tolerant genotypes and could be used as a donor parent in further breeding programs.

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