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Genetic study of terminal heat stress in indigenous collections of Indian mustard (*Brassica juncea* L.) germplasm

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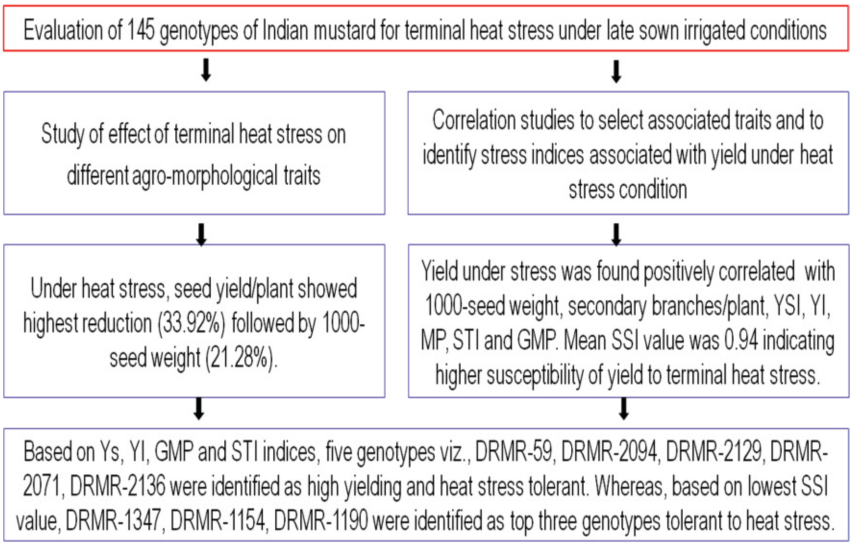
Abstract

Aim: The present study was carried out to evaluate 145 genotypes of Indian mustard for terminal heat stress under late sown irrigated conditions.

Methodology: One hundred and forty five genotypes of Indian mustard were evaluated for terminal heat tolerance, along with six checks in augmented block design. The effect of heat stress was assessed on different agro-morphological traits. Data were recorded on five randomly selected plants for 12 different quantitative traits for each genotype.

Results: Terminal heat stress caused significant reduction in performance of all traits, except oil content and fruiting zone length. Seed yield per plant showed highest reduction (33.92%) followed by 1000-seed weight (21.28%). Thousand-seed weight and secondary branches per plant were found associated with seed yield under late sown conditions. Based on yield under stress, yield index, geometric mean productivity and stress tolerance indices, five lines *viz.,* DRMR-59, DRMR-2094, DRMR-2129, DRMR-2071, DRMR-2136 were identified as high yielding and terminal heat stress tolerant. Whereas, based on heat stress susceptibility index, DRMR-1347, DRMR-1154, DRMR-1190 were top performing lines tolerant to terminal heat stress.



Interpretation: Selection of high yielding lines under stress condition can be done using correlated traits. Yield under stress was found significantly correlated with YSI, YI, MP, STI and GMP suggesting to use these indices for selection of high yielding and heat tolerant lines. However, further re-validation is very much needed for effective use of these indices for selection of heat tolerant lines in Indian mustard.

Key words: *Brassica juncea*, Correlation, Heat stress, Stress susceptibility index

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Introduction

The genus *Brassica* L. belongs to family Brassicaceae (Cruciferae) under the tribe Brassiceae (Rakow 2004). A good number of species (3000 to 4130) and genera (365 to 419) has been reported by different scientists in family Brassicaceae (Warwick *et al.,* 2006). It includes crop Brassicas which are important edible crop speceis used as vegetable, oilseed and condiment crops globally (Singh *et al.,* 2017). In India, rapeseed-mustard stands second after soybean in terms of area (24%) and production (25%) among oilseed crops. *B. juncea* (Indian mustard L.) is holding sizable contribution in terms of area and production of oilseeds and edible oils (Jat *et al.,* 2019). In India, a gradual increase in the production of oilseed brassica was recorded from a mere 0.76 million tonnes (1950–1951) to 9.34 million tonnes (2018-19) (Agriculture Statistics at a Glance, 2019). Because of increasing population, changing food habits and improved purchasing power, the demand of vegetable oils is likely to grow upto 82-102 mt of oilseeds by 2030 from the present level of 33.50 mt during 2019-20. Further, the projected demand for this rapeseed-mustard would be around 16.4-20.5 mt by 2030. Realizing the exploitable yield reservoir by narrowing yield losses due to biotic (disease and insect pest) and abiotic stresses (drought, heat, frost) is one of the strategy to achieve this growing demand (Chauhan *et al.,* 2020).

Increased climate variability and higher mean temperatures across world may likely to cause large negative impacts on crop productivity (Rezaei *et al.,* 2015). Indian mustard is grown under varied agro-ecological conditions as sole-and/or mixed crop in early/timely or late sown situation either rainfed or irrigated (Singh and Bhajan, 2016). The inter-/mixed cropping Indian mustard with wheat as well as late sowing after cotton, rice etc., exposes this crop to high temperature stress during the reproductive stage (Chauhan *et al.,* 2009; Singh and Bhajan, 2016). Hence, heat becomes important limiting factor for late sown mustard crop. Proper crop growth and development depends on normal functioning of various processes such as photosynthesis, respiration, transpiration and dry matter partitioning. These processes work well within an optimal range of temperature (Sánchez *et al.,* 2013; Rezaei *et al.,* 2015).

Indian mustard can tolerate, annual temperature of 6 to 27°C, but it has efficient photosynthetic response at 15–20°C temperature. At this temperature the plant achieve maximum CO_2 exchange range which declines thereafter (Shekhawat *et al.,* 2012). However, high temperature at reproductive stage severly affects the flowering, siliqua formation and seed development which leads to reduced seed yield and forced maturity in Indian mustard (Young *et al.,* 2004; Chauhan *et al.,* 2009). However, breeding for heat tolerance solely based on yield is very difficult due to low heritability of yield under stress condition (Blum 1988, Ludlow and Muchow, 1990). High temperature stress during flowering in mustard causes reduced fertility, flower and fruit abortion with loss in seed yield (Young *et al.,* 2004; Singh *et al.,* 2014). Nuttall *et al.* (1992) reported that flowering duration has a strong influence on seed yield and a rise in 3°C in maximum daily temperature (21-24°C) during flowering caused a decline of 430 kg ha^{-1} in canola seed yields. Many methods and methamatical models like stress susceptibility index (Fischer and Maurer 1978), tolerance Index, mean productivity (Rosielle and Hamblin 1981), stress tolerancc index (Fernandez 1992) and geomatric mean productivity (Kristin *et al.,* 1997) have been proposed and used by researchers in different crops (wheat, barley, bean) to identify promising lines for stress tolerance mainly draught tolerance (Yadav and Bhatnagar, 2001; Reynolds *et al.,* 2007). Heat susceptibility index was used to select heat tolerant genotype in Indian mustard (Chauhan *et al.,* 2009).

In Indian mustard very few studies has been done to assess the effect of terminal heat stress with limited lines (Chauhan *et al.,* 2009, Meena *et al.,* 2013; Rout *et al.,* 2018). Ram *et al.* (2017, 2021) evaluated germplasm lines and breeding materials and studied the effects of heat stress in Indian mustard at seedling stage. In present study, a large set of 145 diverse germplasm lines of Indian mustard of indigenous origin from different regions of India were evaluated. We assessed the effect of terminal heat stress on Indian mustard and compared different stress tolerance Indices to identify promising donors for high thermo-tolerance at terminal stage.

Materials and Methods

Present experiment was conducted at research farm of ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, Rajasthan, (Coordinates: 77°3' E, 27°15' N, altitude:178.37 msl) during Rabi, 2018-19. A total of 145 genotypes of Indian mustard were sown under two environments (E1: timely sown irrigated condition, on 15 October, 2018; E2: late sown irrigated condition, on 22 November, 2018) for thermo-tolerance at terminal stage along with six checks (NPJ112, NRCHB101, CS 56, Pusa Bold, Kranti, PM26). Germplasm for present study were obtained from germplasm unit of ICAR-DRMR, Bharatpur. All genotypes were indigenous collections of Indian origin. Temperature data during the cropping season is presented in Fig. 1. Genotypes were sown in five blocks. Each block consisted of 45 genotypes along with six checks. All Checks were replicated in five blocks. A single row of 3m length of each genotype was grown. Row to spacing was 45 cm and plant to plant spacing was maintained about 10-15 cm.

The crop was raised as per all recommended crop production and protection measures. Data were recorded for 12 different quantitative traits on five randomly selected plants for each genotype (Table 1). ANOVA for different agro-morphological traits was estimated in Augmented Block Design, using SSCNARS website of ICAR (https://sscnars.icar.gov.in/). Aadjusted mean data were used for further analysis. Descriptive statistics and principal component analysis was done using PAST 3.0 software (Hammer *et al.,* 2001). Character association between different traits was estimated based on Pearson's correlation coefficient using SPSS 16.0 software (SPSS 2007). Different stress tolerance indices were estimated using the formula given by different researchers. Stress Susceptibility Index (SSI) was estimated following Fischer and Maurer (1978), Stress Tolerance (TOL) and Mean productivity (MP) were calculated as suggested by Rosielle and Hamblin (1981). Geomatric Mean Productivity (GMP) and Stress Tolerancc Index (STI) were estimated according to formula given by Fernandez (1992). Other indices *viz.,* Yield index (Gavuzzi *et al.,* 1997), Yield reduction ratio (Araghi and Assad, 1998) and yield stability index (Bouslama and Schapaugh,1984) were also calculated. Based on different indices of heat tolerance promising 30 accessions of Indian mustard were identified and Principal coordinate analysis (PCoA) plot of 36 genotypes (30 genoytpes, 06 checks) was constructed using DAR win 6.0 software based on Euclidean genetic distance (Perrier *et al.,* 2006).

Results and Discussion

High temperature, especially terminal heat stress is the second most important stress after drought. It adversely affects growth, development and productivity of crop plants. Late sown crop of Indian mustard faces heat stress at terminal stage hence shows considerable yield reduction (Meena *et al.*, 2013; Rout *et al.*, 2018). Heat stress affects all vegetative and reproductive stages of plants. Plant exhibit various physiological injuries such as scorching of leaves and stems, abscission and senescence of leaves and fruits, which consequently lead to reduced plant

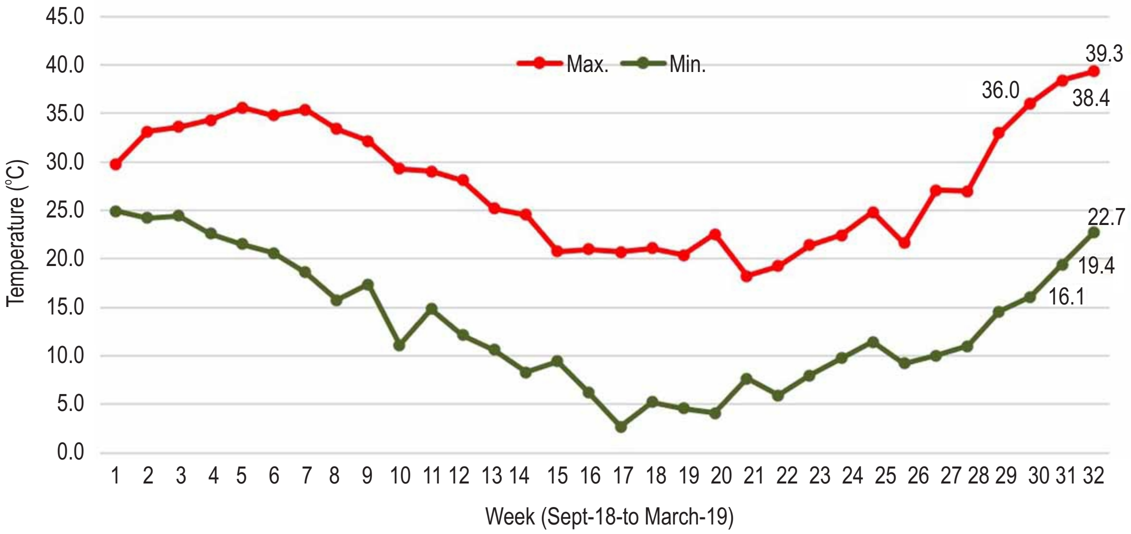

Fig.1: Temperature during the crop growing period from September 2018 to March 2019.

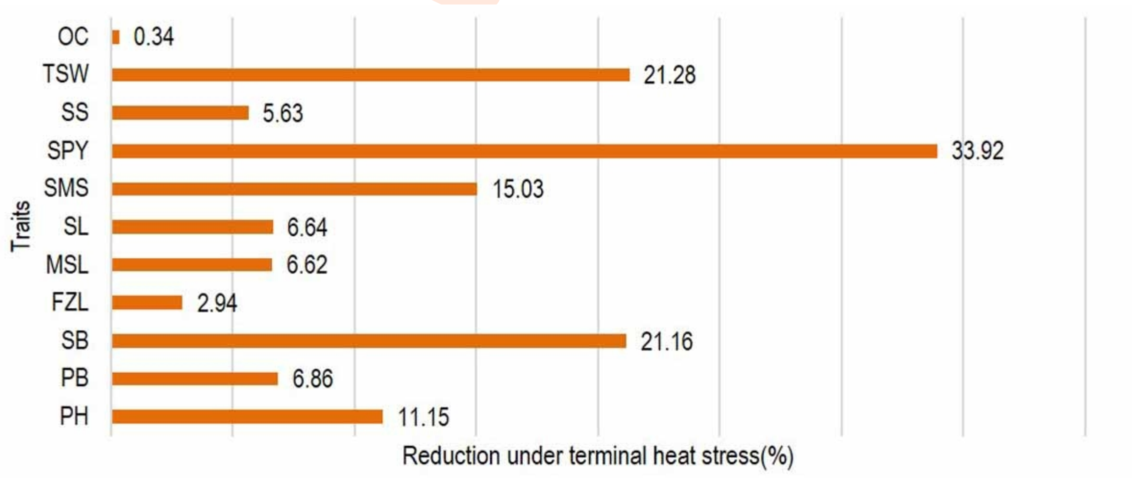

Fig. 2: Effect of heat stress on different yield attributing traits in Indian mustard depicted as per cent reduction.

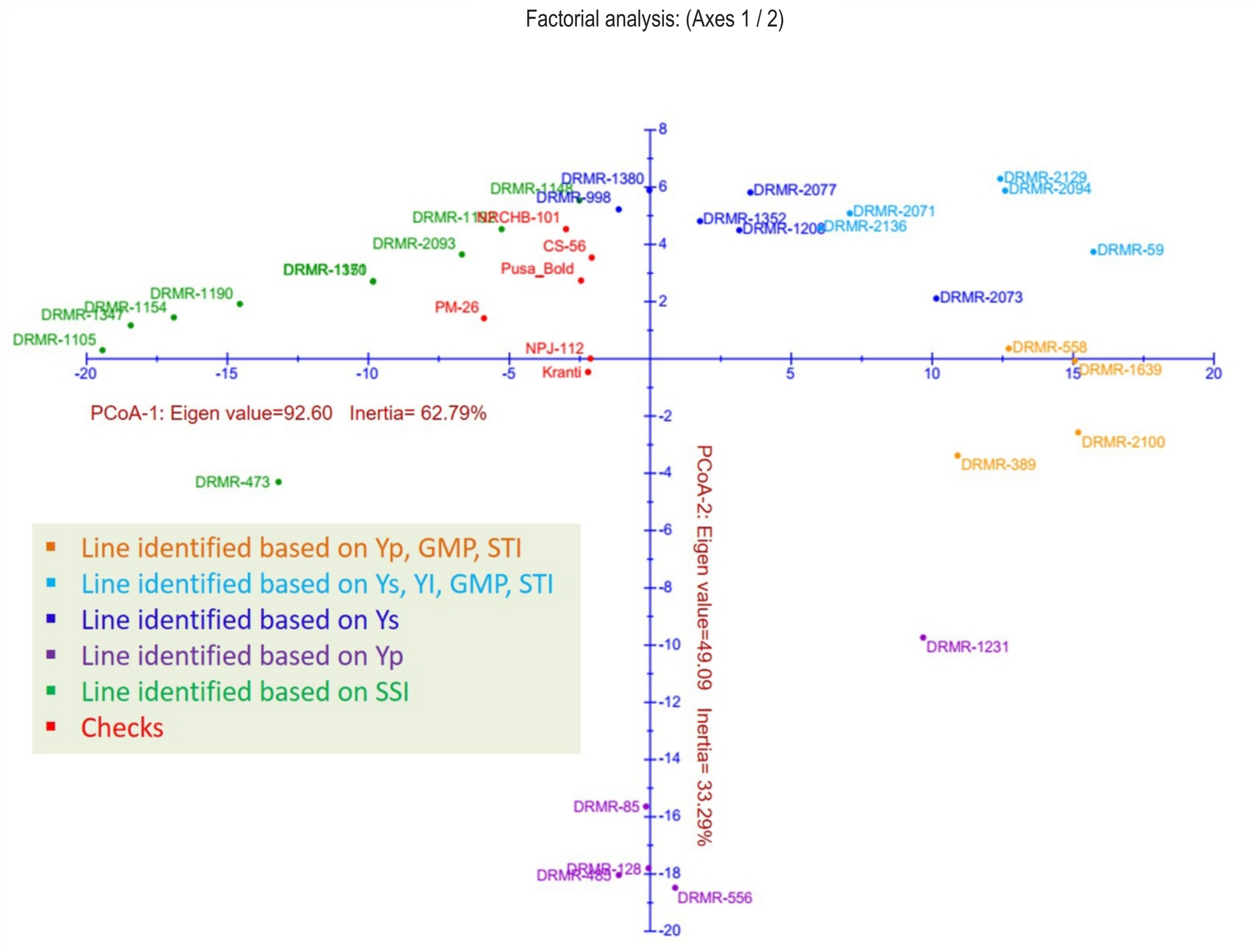

Fig. 3: PCoA plot showing distribution of 30 heat tolerant lines of Indian mustard along first two axes (½).

productivity because of decreased shoot net assimilation rates, and thus the total dry weight (Wahid *et al.*, 2007; Bita and Gerats, 2013). With this backdrop, the present study was carried out with a large set of 145 diverse germplasm lines of Indian mustard to assess the effect of terminal stage heat stress on agromophological trait and to identify suitable donors, based on different stress tolerance indices for their further utilization in the breeding program. Analysis of variance for all the traits revealed significant differences among genotypes of Indian mustard under timely sown and late sown crop. Descriptive statistics for different yield attributing traits is presented in Table 1.

Under timely sown conditions, seed yield/plant varied from 6.7 to 29.2g with a general mean of 18.15 g. 1000-seed weight ranged from 2.3 to 5.9 g whereas oil content varied from 33.6 to 41.2%. Phenotypic coefficient of variation was highest for first basal branching (36.53%) followed by seed yield/plant (26.53%). Ram *et al.* (2017), Prasad *et al.* (2018) and Lakra *et al.* (2020) reported good amount of variability for different yield attributing traits in Indian mustard under non-stress and stress environment. Under late sown conditions, seed yield was drastically reduced as revealed from mean (11.6g) and range (1.7g to 18.2g). Terminal heat caused reduction in seed size which is clearly understood by reduced 1000-seed weight (range: 1.1 to 4.8 g, mean 3.24 g). Heat stress induces change in respiration and photosynthesis, thus leading to a shortened life cycle and diminished plant productivity (Barnabás *et al.*, 2008).

Significant improvement in yield under heat stress conditions depends on many physiological processes and mechanisms that contribute to heat tolerance in the field, such as amendments to photosynthesis, and production of osmolytes and proteins involved in heat stress defense. Therefore, a heat-tolerant variety has higher photosynthetic rates, increased membrane thermostability and heat avoidance (Scafaro *et al.*, 2010; Bita and Gerats, 2013). Descriptive parameters for different stress indices (Table 2) were estimated. Stress susceptibility Index (SSI) varied from 0.09 (DRMR 1347) to 2.07 (DRMR 2003).

Table 1: Descriptive statistics for different yield attributing traits in Indian mustard under non-stress and stress conditions

Parameters	PH	PB	SB	FBB	FZL	MSL	SL	SMS	SPY	SS	TSW	OC
Non-stress condition (Timely sown)												
Min.	167.3	4.6	9.2	12.0	59.1	44.9	3.0	31.4	6.7	9.1	2.3	33.6
Max.	268.2	11.4	24.6	78.6	160.1	100.9	6.6	65.4	29.2	19.8	5.9	41.2
Mean	209.93	6.43	14.84	40.36	113.64	72.34	4.09	47.46	18.15	14.14	4.14	39.00
Sem (±)	1.56	0.09	0.28	1.20	1.35	0.74	0.05	0.57	0.39	0.19	0.06	0.12
SD (±)	19.12	1.11	3.47	14.74	16.59	9.12	0.60	6.99	4.82	2.30	0.76	1.48
PCV (%)	9.11	17.20	23.38	36.53	14.60	12.61	14.68	14.73	26.53	16.23	18.27	3.80
CD (5%)	25.35	1.02	5.57	12.64	18.26	14.24	0.69	11.49	5.78	3.49	1.25	1.98
Stress condition (Late sown)												
Min.	127.0	4.0	5.9	12.5	57.2	41.4	2.2	25.7	1.7	8.0	1.1	31.9
Max.	220.0	9.9	21.8	76.7	138.7	90.1	5.7	63.8	18.2	18.7	4.8	40.9
Mean	185.72	5.86	11.10	38.99	109.19	66.75	3.76	39.80	11.58	13.01	3.24	38.81
SEm (±)	1.30	0.07	0.25	0.92	1.15	0.61	0.05	0.56	0.23	0.18	0.06	0.11
SD (±)	16.03	0.81	3.03	11.36	14.19	7.51	0.57	6.94	2.87	2.20	0.77	1.30
PCV (%)	8.63	13.87	27.31	29.15	12.99	11.25	15.26	17.43	24.79	16.95	23.66	3.35
CD (5%)	15.11	0.99	4.22	10.02	20.34	9.03	0.75	8.76	3.23	2.62	0.58	2.03

PH: Plant height (cm); PB: Primary branches/plant (No.); SB: Secondary branches/plant (No.); FBB: First basal branching (cm); FZL: Fruiting zone length (cm); MSL: Main shoot length (cm); SL: Siliqua length (cm); SMS: Siliqua on main shoot (No.); SPY: Seed yield/plant (g); SS: Seeds/siliqua (No.); TSW: 1000-seed weight (g); OC: Oil content (%). CD(5%)is for comparison between check and genotype

Table 2: Descriptive statistics for different stress indices in Indian mustard

Parameters	Ys	Yp	YSI	YI	TOL	MP	Yrr	SSI	STI	GMP
Min.	1.7	6.7	0.25	0.15	0.33	4.21	0.03	0.09	0.03	3.37
Max.	18.2	29.2	0.97	1.57	18.33	22.37	0.75	2.07	1.43	21.76
Mean	11.58	18.15	0.66	1.00	6.58	14.87	0.34	0.94	0.65	14.37
Sem (±)	0.23	0.39	0.01	0.02	0.36	0.27	0.01	0.04	0.02	0.26
SD (±)	2.87	4.81	0.17	0.25	4.39	3.30	0.17	0.46	0.27	3.14
PCV (%)	24.79	26.51	25.11	24.76	66.71	22.19	48.91	48.77	41.59	21.87

Yp: Yield under timely sown conditions; Ys: Yield under stress condition (late sown); YSI: Yield stability index; YI: Yield index; TOL: Tolerance index; MP: Mean productivity; Yrr: Yield reduction ratio; SSI: Stress susceptibility index; STI: stress tolerance index; GMP: Geometric mean productivity

Mean SSI value was 0.94 indicating higher susceptibility of yield to terminal heat stress. STI varied from 0.03 (DRMR 2003) to 1.43 (DRMR 59). The highest and lowest PCV were noticed for Yrr (48.91%) and GMP (21.87%), respectively. Siahsar *et al.* (2010) evaluated 18 lentil lines for drought tolerance and reported highest and the lowest phenotypic coefficient of variation for STI and yield stability index. Correlations between different yield attributing traits was estimated for both environments (timely sown, late sown) and are presented in Table 3.

Under timely sown conditions, seed yield per plant showed significant and positive correlations with plant height, primary branches, secondary branches, fruiting zone length, main shoot length and 1000-seed weight. Whereas, under late sown conditions it showed positive correlation with secondary branches and 1000-seed weight. Ram *et al.* (2017) reported positive association of seed yield per plant with membrane stability index and 1000 seed weight under heat stress conditions. Raza *et al.* (2019) reported positive correlation of yield component with morphological characters studied. Lakra *et al.* (2020) reported that yield per plot showed positive and significant correlation with days to 50% flowering, days to maturity, siliquae/ plant, siliqua length and seeds/silique. Similarly other workers (Singh *et al.,* 2016; Chaurasiya *et al.,* 2019) reported association of seed yield with different component traits. However, under stress conditions 1000-seed weight and number of secondary branches could be used for selection of heat tolerant lines in mustard.

During the cropping season, highest temperature up to 39.3°C was recorded at crop maturity stage. Hence, the impact of terminal heat was assessed on different yield attributing traits (Fig. 2). Terminal heat stress caused significant reduction in performance of all traits, except oil content and fruiting zone

Table 3: Correlation coeffecient between different yield attributing traits under non-stress (timely sown) and stress conditions (late sown) in Indian mustard

Trait	PH	PB	SB	FBB	FZL	MSL	SL	SMS	SPY	SS	TSW
PH	-	0.179*	0.271**	0.404**	0.767**	0.192*	-0.003	0.314**	0.272**	-0.021	-0.211**
PB	0.141	-	0.779**	-0.212**	0.157	0.203*	0.097	0.151	0.338**	0.252**	0.031
SB	0.293**	0.457**	-	-0.202*	0.195*	0.241**	0.115	0.246**	0.401**	0.077	0.032
FBB	0.221**	-0.166*	-0.162*	-	0.554**	-0.103	-0.089	0.091	-0.08	-.168*	-0.13
FZL	0.712**	0.14	0.026	0.366**	-	0.058	-0.046	0.291**	0.178*	0.011	-0.249**
MSL	0.046	-0.124	-0.127	-0.034	-0.058	-	0.141	0.607**	0.262**	-0.206*	0.228**
SL	-0.077	-0.147	-0.224**	-0.065	-0.021	0.201*	-	-0.002	0.004	0.028	0.078
SMS	0.126	-0.079	0.037	0.027	0.061	0.503**	0.086	-	0.086	-0.077	-0.094
SPY	0.142	0.149	0.227**	-0.127	0.083	-0.015	0.016	0.103	-	0.008	0.173*
SS	-0.026	0.115	0.211**	-0.146	-0.089	-0.08	-0.028	0.057	0.095	-	-0.153
TSW	0.160*	0.128	0.146	-0.115	-0.076	0.240**	0.174*	0.176*	0.161*	-0.202*	-

*p<0.05; **p<0.01 Note: Correlations in upper diagonal are under non-stress condition (timely sown) and correlations in lower diagonal are under stress condition (late sown)

Table 4: Correlation coefficients between different indices of stress tolerance in Indian mustard

Indices	Yp	YSI	YI	TOL	MP	Yrr	SSI	STI	GMP
Ys	0.439**	0.492**	1.000**	-0.173*	0.755**	-0.492**	-0.491**	0.835**	0.853**
Yp		-0.526**	0.439**	0.809**	0.920**	0.526**	0.528**	0.836**	0.842**
YSI			0.492**	-0.898**	-0.170*	-1.000**	-1.000**	-0.042	-0.016
YI				-0.173*	0.755**	-0.492**	-0.491**	0.835**	0.852**
TOL					0.515**	0.898**	0.899**	0.371**	0.365**
MP						0.170*	0.171*	0.974**	0.985**
Yrr							1.000**	0.042	0.016
SSI								0.043	0.017
STI									0.987**

$^*p$<0.05; $^{**}p$<0.01

length. Seed yield per plant showed highest reduction (33.92%) followed by 1000-seed weight (21.28%) and secondary branches per plant (21.16%), while its effect on oil content was least (0.34% reduction). Reduction in seed yield during heat stress was associated with flower abortion, male sterility, short flowering duration, reduced seed size,reduction in number of secondary branches and other yield contributing traits (Nuttall *et al.*, 1992, Young *et al.,* 2004; Wassmann *et al.,* 2009) (Fig. 2), which plays important role in seed yield. High temperature from February to March forced the plant to mature fast, and hence resulted into small seed size (Meena *et al.,* 2013; Rout *et al.,* 2018). Likewise, seed yield, seed number and seed quality (protein and oil content) reduced in many crops by heat stress, with increasing temperatures during flowering and seed development (Porter and Semenov, 2005; Mahmood *et al.,* 2010).

High temperature negatively affect various physiological processes including photosynthesis, metabolism, lipid and hormonal signaling. However, plant growth and development is affected due to reduced stability of various proteins, membranes and cytoskeleton structures which results into considerable yield loss (Bita and Gerats, 2013). Chauhan *et al.* (2009) studied 18 advanced breeding lines and 4 varieties of Indian mustard under terminal heat stress and reported reduction ranging from 22.2% for seeds per siliqua to 69.2% for seed yield per plant. Meena *et al.* (2013) investigated 22 genotypes of Indian mustard under normal and late sown conditions. They reported that genotypes BPR 538-10 showed terminal heat tolerance for biological yield/plant, seed yield/plant. Breeding for stress tolerance requires efficient screening procedures, identification of key traits in diverse tolerant lines and understanding of their inheritance and molecular genetics (Bita and Gerats, 2013).Therefore, a plant breeder's main aim remains to develop an effective set of thermotolerance markers/indices for heat tolerance. Study of plant phenology in response to heat stress could be an effective approach for this purpose (Wahid *et al.,* 2007).

One of the important phenological trait is plant maturity, as early maturity under high temperatures was found correlated with smaller yield losses in many crops (Adams *et al.,* 2001). Likewise, in mustard early maturing short duration varieties gives more yield than late maturing under late sown conditions. Apart from morphological traits, many physiological assays including chlorophyll accumulation, membrane stability, relative water

Table 5: Principal Component Analysis of Ys, Yp and stress tolerance indices

Indices	PC 1	PC 2	PC 3
Ys	0.195	0.588	-0.143
Yp	0.654	-0.077	-0.163
YSI	-0.011	0.033	-0.266
YI	0.017	0.051	-0.014
TOL	0.459	-0.665	-0.028
MP	0.425	0.256	-0.156
Yrr	0.011	-0.033	0.266
SSI	0.029	-0.090	0.731
STI	0.032	0.030	0.128
GMP	0.375	0.356	0.485
Eigenvalue	53.89	17.90	0.03
Variance (%)	75.03	24.92	0.04
Cumulative variance(%)	75.03	99.95	99.99

content have been used to characterize genetic variability in Brassica and other species (Selvaraj *et al.,* 2011; Ram *et al.,* 2017; Ram *et al.,* 2021) under heat stress. Hence, to determine the most reliable heat tolerance criteria, the correlations between Yp, Ys and indices of stress tolerance were estimated (Table 4). Yield under stress condition (Ys) showed significant positive correlations with potential yield (Yp), suggesting that a high potential yield under optimum condition does necessarily result in improved yield under stress condition. Further, Ys is also positively correlated with YSI, YI, MP, STI and GMP while it showed significant negative correlations with TOL, Yrr and SSI. Similar association of Ys with YI, MP, STI, GMP, TOL and SSI was reported in lentil and rapeseed (Siahsar *et al*., 2010; Rad and Abbasian, 2011). Hence, these indices can be used to identify suitable genotypes for heat stress tolerance. SSI has been widely used by other researchers to select stress tolerant genotype (Fischer and Maurer, 1978; Winter *et al*., 1988; Golabadi et al., 2006). Vallejio and Kelly (1998) reported that there are chances of selecting low yielding cultivars with a small yield differential if TOL is used alone for selecting cultivars with resistance to stress, hence Yadav and Bhatnagar (2001) suggested the use of SSI in combination with yield under stress. Gavuzzi *et al.* (1993) employed these two parameters (SSI, Ys) to identify genotypes with superior drought adaptation in trials conducted in several locations of Western Iran. Rad and Abbasian (2011) evaluated different indices for selection of drought tolerant genotypes in 23 rapeseed line and reported that YI, STI, GMP were better predictors of Yp and Ys than TOL, SSI and YSI.

In the present study, principal component analysis was done using stress indices (Table 5). First three components explained 99.99% of the variance. PC-I showed eigen value of 53.89 (75.03% variance) and showed significant positive correlations with Ys, Yp, MP, GMP, STI and TOL followed by PC-II (eigen value= 17.90, variance=24.92%) which had significant positive correlation with Ys, YSI, YI and negative correlation with SSI, Yrr and TOL. Thus, PC-I is marked as stress tolerant and high yielding axis, while PC-II can be assumed as stress tolerant axis with poor yield. Zare (2012) did PCA and found that MP,GMP, STI had significant corrrelations with PC-I, hence they used them for selecting tolerant Iranian barley genotypes with high yield potential. A principal coordinate analysis (PCoA) plot (Fig. 3) was constructed for clustering of selected genotypes based on indices. Clustering of genotypes reflected their performances based on different selection indices.

A significant positive correlation was found between MP, GMP, STI with seed yield under both stress and non-stress conditions. Hence, based on Ys, Yp, YI, STI, GMP (high) and SSI (low) top ten best performing genotypes were identified (Table 6). Based on Ys, YI, GMP and STI indices, five genotypes *viz.,* DRMR59, DRMR-2094, DRMR-2129, DRMR-2071, DRMR-2136 were identified as high yielding and heat stress tolerant lines. Based onYp, GMP, STI indices four best performing lines (DRMR-2100, DRMR-1639, DRMR-389, DRMR-558) were identified. Whereas, based on SSI, DRMR-1347, DRMR-1154, DRMR-1190 were top three genotypes tolerant to terminal heat stress but poor

Table 6: Best performing genotypes of Indian mustard identified based on different indices

Genotypes	Ys (g)	Genotypes	Yp (g)	Genotypes	YI	Genotypes	GMP	STI	Genotypes	SSI
DRMR-2129	18.16	DRMR-2100	29.2	DRMR-2129	1.57	DRMR-59	21.76	1.43	DRMR-1347	0.09
DRMR-2094	17.96	DRMR-1231	28.5	DRMR-2094	1.55	DRMR-2129	21.37	1.38	DRMR-1154	0.12
DRMR-59	17.19	DRMR-1639	28.3	DRMR-59	1.48	DRMR-2094	21.34	1.37	DRMR-1190	0.17
DRMR-2071	16.96	DRMR-556	28.3	DRMR-2071	1.46	DRMR-1639	20.81	1.31	DRMR-473	0.21
DRMR-2077	16.96	DRMR-59	27.6	DRMR-2077	1.46	DRMR-2100	20.31	1.25	DRMR-1105	0.25
DRMR-1380	16.56	DRMR-128	27.6	DRMR-1380	1.43	DRMR-558	20.26	1.24	DRMR-1192	0.26
DRMR-2136	16.56	DRMR-389	27.2	DRMR-2136	1.43	DRMR-2073	19.91	1.20	DRMR-1148	0.26
DRMR-1208	16.16	DRMR-485	27.0	DRMR-1208	1.39	DRMR-2071	19.64	1.16	DRMR-1171	0.29
DRMR-1352	16.16	DRMR-558	27.0	DRMR-1352	1.39	DRMR-2136	19.24	1.12	DRMR-1350	0.29
DRMR-998	16.01	DRMR-85	27.0	DRMR-998	1.38	DRMR-389	18.92	1.08	DRMR-2093	0.31
NRCHB-101	15.32	Kranti	19.4	NRCHB-101	1.32	CS-56	16.54	0.83	NRCHB-101	0.37

Ck: Best check; Ys: Yield under stress condition (late sown); YI: Yield index; GMP: Geometric mean productivity index; SSI: Stress susceptibility index; STI: Stress tolerance index yielder. Genotype DRMR-59 was identified promising for heat tolerance based on five indices (Ys, Yp, YI, GMP, STI). Heat susceptibility index also known as Stress Susceptibility Index has been used to select heat tolerant genotype in Indian mustard (Chauhan *et al.,* 2009). Many researchers concluded that stress indices, which have significant positive correlations with seed yield under stress were found most suitable for selection of resistant/tolerant lines (Fernandez 1992; Dadbakhsh 2011;Zare 2012). However, most of them reported MP, GMP, STI and TOL as suitable indices.

In conclusion, the findings of this study showed that terminal heat stress caused significant reduction in seed yield/plant. Further to select high yielding lines under stress condition correlated traits like 1000-seed weight and secondary branches per plant should be used. Yield under stress was found positively correlated with YSI, YI, MP, STI and negatively correlated with SSI, hence these indices were used for selecting promising lines for heat tolerance in Indian mustard. However, further re-validation is needed for effective use of these indices for selection of heat tolerant lines in Indian mustard.

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Add-on Information

Authors' contribution: H.K. Sharma: Design and conducting of experiment, Data analysis, Manuscript writing, editing, revisions; **V.V. Singh:** Design of experiment, Manuscript proof reading, editing and guidance; **A. Kumar:** Assistance in conducting of experiment ; **H.S. Meena:** Assistance in manuscript writing and editing; **B.L. Meena:** Assistance in revisions; **P. Sharma:** Assisted in manuscript editing; **P.K. Rai:** Provided resources and guidance.

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