Received: 09 Oct 2023 | Revised: 15 Jun 2024 | Accepted: 19 Jun 2024

Electronic Journal of Plant Breeding

Research Article

Morpho-physiological characterization and selection of heat tolerant wheat lines using selection indices

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Abstract
Heat stress is one of the major constraints in wheat production due to its adverse effect on grain yield and component traits. Moreover, it negatively affects the physiological, biochemical and quality traits of wheat. Therefore, selection of heat tolerant wheat lines is one of the major breeding goals for wheat scientist. In present study, 238 recombinant inbred lines were evaluated along with their parents WH 711 × WH 542 under timely and late sown (heat stress) condition. The heat tolerance indices were calculated based on grain yield under normal and stress conditions. The mean grain yield of 238 wheat lines was reduced by 20.54% suggesting critical effect of heat stress on grain yield. The harmonic mean (HM), stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), and mean relative performance (MRP) were correlated significantly and positively with grain yield under stress and normal conditions. Whereas, Tolerance index (TOL) was correlated negatively with grain yield under stress conditions and positively under normal condition. Based on STI, MP, HM, GMP and MRP, wheat lines WL 92, WL 119, WL 114, WL 110, WL 6 were identified as heat tolerant and could be utilized as potential lines for increasing heat stress tolerance of future wheat breeding programs.

Keywords: Bread wheat, heat stress, selection indices, correlation, grain yield

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is a major staple food crop grown widely in diverse ecology of the world (Ullah *et al.,* 2021). It provides 20% of the total food calories and proteins for more than 4.5 billion people in developing countries (Braun *et al.,* 2010). Globally, wheat is cultivated on 220.06 Mha with 763.18 MT of production and 3.47 MT/ha of productivity (FAOSTAT, 2019). In India, it is cultivated on 29.55 Mha area with 101.20 MT production and 3.42 MT/ha of productivity (FAOSTAT, 2019). However, wheat production is greatly affected by heat stress. Wheat is highly sensitive crop to high temperature and with 1° C increase in temperature cause 6 to 27 % decline in world wheat production (Yu *et al.,* 2014; Bergkamp *et al.,* 2018). The optimum temperature for wheat varies between 15 to 20°C during growth stages and from 12 to 22° C during grain filling stage (Shewry, 2009). However, heat stress at anthesis causes pollen sterility due to interruption in reproductive physiology leading to production of underdeveloped embryo and at grain filling stage decrease the grain filling rate which ultimately affect the grain size, grain weight and overall grain yield (Mondal *et al.,* 2013; Ullah *et al.,* 2021). Temperatures more than 22° C from anthesis to grain maturation stages reduce the grain yield due to shorter grain filling duration, reduced leaf photosynthesis and grain sugar metabolism (Dias and Lidon, 2009; Zhang *et al.,* 2018). Moreover, high temperature causes reduced biosynthesis of chlorophyll a and b due to reduced activity of many enzymes such as 5-aminolevulinate dehydratase (Sattar *et al.,* 2020). Therefore, to keep the pace with growing population, it is necessary to increase the wheat production by breeding varieties that can withstand under high temperature without yield penalty (Poudel *et al.,* 2021). Several selection indices like stress susceptibility index (SSI), relative stress index (RSI), stress tolerance (TOL), mean productivity (MP), yield stability index (YSI), harmonic mean (HM), geometric mean productivity (GMP), stress tolerance index (STI) and yield index (YI) have been proposed for the identification of heat tolerant wheat lines by screening the advanced breeding material under normal and stress conditions (Kamrani *et al.,* 2017). Previous studies reported that selection for TOL reduces while for MP increase the grain yield under both normal and heat stress condition (Dodig *et al.,* 2008).

Some multivariate approaches such principal component analysis, factor analysis and cluster analysis have also been employed for the selection of best wheat lines using multiple selection indices (Singh *et al.,* 2018). However, combination of best selection indices might be more useful for the identification and selection of superior wheat lines. Earlier, (Singh *et al.,* 2017) reported that MP, GMP, HM and STI were the most effective indices for the election of better performing wheat cultivars under normal and stress conditions. (Sabouri *et al.,* 2022) introduced a composite selection index (CSI) based on the selection indices correlated significantly with grain yield under both stress and non-stress conditions. Therefore, the present study was planned to evaluate the 238 recombinant inbred lines of wheat along with their parents for stress tolerance and estimating the correlations between selections indices for identifying the better performing wheat lines under heat stress and normal conditions.

MATERIALS AND METHODS

A field investigation was carried out in semi-tropical region of North Western Plain Zone of Indian sub-continent at CCS Haryana Agricultural University, Hisar. The location is geographically located at 29.09°N, 75.43°E and 215.2 m above sea level. The plant genetic material comprised of 238 recombinant inbred lines (RILs) of WH 711 × WH 542 cross (**Table 1**). The two parents differed from each other for grain yield, quality traits and heat stress tolerance with the line WH 711 being heat tolerant. The population was produced by selfing the F_1 plants and advancing the generation from F_2 onwards by self-pollination. The RILs along with their parents were grown in Wheat and Barley Section CCS Haryana Agricultural University, Hisar, during *Rabi* season 2017-2018 under two sowing conditions: November 8, 2017 (timely sown) and December 8, 2017 (late sown). The late sown conditions in wheat coincide with heat stress at reproductive stage (**Fig.1**). The RILs were planted in three rows of 2.5 m length at 20 cm spacing in randomized block design with two replications. The recommended dose of nitrogen, phosphorus, and potassium (60 kg N, 24 kg P_2O_5, and 24 kg K_2O acre^{-1}) was applied. The full dose of phosphorus and potassium were applied as a basal, while the nitrogen was top dressed in two equal halves through urea at first and second irrigations. Observations were recorded for twelve grain yield traits, namely plant height (cm) (PH), number of tillers per meter (NTM), days to heading (DH), spike length (cm) (SL), number of spikelets per spike (NSS), number of grains per spike (NGS), grain weight per spike (g) (GWS), grain yield per meter (g) (GY), biological yield per meter (g) (BY), harvest index (%) (HI),100 grain weight (g) (TGW), days to maturity (DM); three seed quality traits, seed density (g/cc) (SD), grain length (mm) (GL) and grain breadth (mm) (GB); four physiological traits, canopy temperature (CT) measured by hand held infrared thermometer, model AG-42, Tele temp crop Fullerton, chlorophyll-a (Cha), chlorophyll-b (Chb) and carotenoids (Cart) was measured by following the method of (Hiscox and Isrealstam 1979). Analysis of variance of (ANOVA) and association among selection indices and with grain yield under heat stress and normal condition was calculated using statistical software STAR, version 2.0.1. Various heat stress selection indices were calculated using following formulas,

(i) Heat susceptibility Index (HSI)

The heat susceptibility index for each trait was calculated following the method suggested by Fischer and Maurer, (1978):

$$HSI = (1 - Xh/X)/ (1 - Yh/Y)$$

Where,

Xh and X are the phenotypic means for each genotype under heat stress and control conditions respectively, and Yh and Y are the phenotypic means for all genotypes under heat stress and control conditions, respectively.

stress susceptibility index (SSI) (Fischer and Maurer, 1978),

ii) Stress susceptibility index (SSI)

The stress susceptibility index was calculated for each progeny using the formula suggested by Fischer and Maurer (1978):

$$SSI = \frac{1-(Ys|Yp)}{1-(\bar{Y}s|\bar{Y}p)}$$

Where,

Ys = grain yield of genotype under stress condition

Yp = grain yield of genotype under normal condition

$\bar{Y}s$ and $\bar{Y}p$ are the mean yield of all genotypes under stress and normal conditions

(iii) Stress tolerance (TOL)

The stress tolerance was calculated for each progeny using the formula suggested by Rosielle and Hamblin (1981):

$$TOL = Yp-Ys$$

Where,
Yp = grain yield of genotype under normal condition
Ys = grain yield of genotype under stress condition

(iv) Yield index (YI)

The yield index was calculated for each progeny using the formula suggested by Gavuzzi *et al*. (1997):

$$YI = \frac{Ys}{\overline{Ys}}$$

Where,
Ys = grain yield of genotype under stress condition
$\overline{Ys}$ = mean yield of all genotypes under stress condition

(v) Yield stability index (YSI)

The yield stability index was calculated for each progeny using the formula suggested by Bouslama and Schapaugh (1984):

$$YSI = \frac{Ys}{Yp}$$

Where,
Ys = grain yield of genotype under stress condition
Yp = grain yield of genotype under normal condition

(vi) Relative stress index (RSI)

The relative stress index was calculated for each progeny using the formula suggested by Fischer and Wood (1979):

$$RSI = \frac{(Ys|Yp)}{(\overline{Ys}|\overline{Yp})}$$

Where,
Ys = grain yield of genotype under stress condition
Yp = grain yield of genotype under normal condition
$\overline{Ys}$ and $\overline{Yp}$ are the mean yield of all genotypes under stress and normal conditions

(vii) Stress tolerance index (STI)

The stress tolerance index was calculated for each progeny using the formula suggested by Fernandez (1992):

$$STI = \frac{Ys \times Yp}{(\overline{Yp})^2}$$

Where,
Ys = grain yield of genotype under stress condition
Yp = grain yield of genotype under normal condition
$\overline{Yp}$ are the mean yield of all genotypes under normal conditions

(viii) Mean productivity (MP)

The mean productivity was calculated for each progeny using the formula suggested by Rosielle and Hamblin (1981):

$$MP = \frac{Yp+Ys}{2}$$

Where,
Yp = grain yield of genotype under normal condition
Ys = grain yield of genotype under stress condition

(ix) Geometric mean productivity (GMP)

The geometric mean productivity was calculated for each progeny using the formula suggested by Fernandez (1992):

$$GMP = \sqrt{Ys \times Yp}$$

Where,
Ys = grain yield of genotype under stress condition
Yp = grain yield of genotype under normal condition

(x) Harmonic mean (HM)

The harmonic mean was calculated for each progeny using the formula suggested by Bidinger *et al*. (1987):

$$HM = \frac{2(Yp \times Ys)}{(Yp+Ys)}$$

Where,
Yp = grain yield of genotype under normal condition
Ys = grain yield of genotype under stress condition

(xi) Mean relative performance (MRP)

The mean relative performance was calculated for each progeny using the formula suggested by Ramirez and Kelly (1998):

$$MRP = (Ys/\overline{Ys}) + (Yp/\overline{Yp})$$

Where,
Ys = grain yield of genotype under stress condition
Yp = grain yield of genotype under normal condition
$\overline{Ys}$ and $\overline{Yp}$ are the mean yield of all genotypes under stress and normal conditions.

Table 1. Pedigree of parents

Parents	Released year	Pedigree	Features
WH 711	2002	ALD"S/HUAC//HD 2285/3/ Hfw-17	Dwarf (81 cm), shining, amber hard grains and good for chapati making, high yielding, lodging resistant and good quality grain
WH 542	1992	JUPAtECo/BLUEJA//URES	First semi dwarf (90 cm) variety with 1B/1R translocation, high tillering, medium bold, amber, shining, semi-hard grains

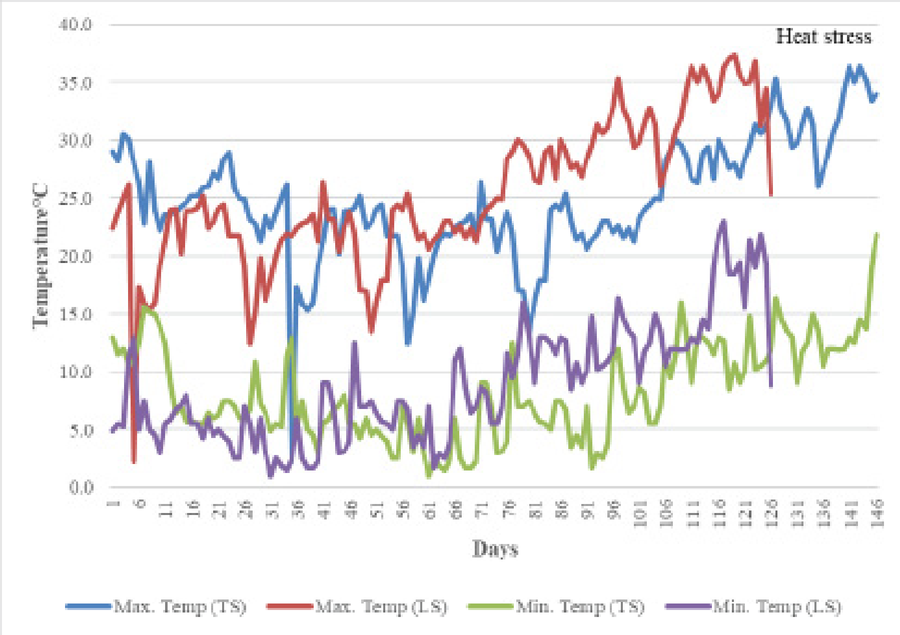

Fig.1. Temperature regime during the study

RESULTS AND DISCUSSION

Impact of heat stress on grain yield, quality and physiological traits: The ANOVA (**Table 2**) revealed significant differences (P < 0.01) for all the studied traits under both normal as well as late sown conditions, indicating varying performance of parents as well as RILs. The coefficient of variance (CV) varied between 2.08% for days to maturity to 26.89% for chlorophyll b under timely sown condition while between 2.03% for days to maturity to 26.70% for grain yield under late sown conditions (**Table 3**). A large amount of phenotypic variation was observed for grain yield, yield component, quality and physiological traits under normal and heat stress conditions indicating varying responses of different genotypes under stress condition. The character wise percent reduction under stress in comparison to normal conditions is given in **Table 3**. Heat stress causes reduction in all the studied traits. The characters namely grain yield per meter (20.54%), grain weight per spike (16.80%), biological yield per meter (12.75%), carotenoids (12.50%), test grain weight (12.46%), grain breadth (12.38%), chlorophyll-a (11.41%), harvest index (9.29%), number of tillers per meter (8.33%) and number of grains per spike (4.14%) showed maximum percent reduction and were found as highly sensitive to heat stress. Wheat genotypes exposed to temperature above ambient enhance the florets sensitivity, reduce the pollen viability, spikelet's fertility, number of grains per spike and ultimately reduces the grain yield (Banyai *et al.,* 2014; Kumar *et al.,* 2014; Kesh *et al.,* 2022a). In addition to grain yield, significant reduction was also reported in yield component traits *i.e.*, grain weight per spike, number of grains per spike, number of tillers per meter, biological yield per meter and chlorophyll content. The reduced chlorophyll content due to high temperature is concomitant with high respiration rate which reduce the grain filling duration and grain yield (Dubey *et al.,* 2020). Previous studies also reported a significant and negative effect of heat stress on grain yield (Pradhan and Prasad, 2015; Schittenhelm *et al.,* 2020; Kesh *et al.,* 2022c), grain filling duration (Vignjevic *et al.,* 2015), chlorophyll content (Liu *et al.,* 2017), number of grains per spike, spike length and biological yield (Rehman *et al.,* 2021, Kesh *et al.,* 2022b).

Selection of elite wheat lines based on correlation coefficient between stress indices and grain yield: The analysis of variance (ANOVA) revealed that the grain yield under normal, heat stress and stress indices showed significantly substantial variance among wheat RILs **(Table 4).** Pair wise coefficients of correlation were measured between grain yield under stress and non-stress conditions and heat tolerance selection indices to identify the most desirable selection criterion (**Table 5**). A positive and significant correlation (P < 0.01) of STI, YI, MP, GMP, HM and MRP with grain yield under normal and stress condition was observed. Meanwhile, TOL demonstrated a positive and significant correlation with Yp and negative and significant with Ys. Likewise, YSI and RSI showed a significantly positive correlation with Ys and non-significant correlation with Yp. The Yp and Ys had a significant correlation (P < 0.01) with STI (r= 0.831; 0.921), YI (r= 0.566; 0.912), MP (r= 0.870; 0.899), GMP (0.839; 0.923), HM (0.806; 0.941), MRP (0.840; 0.923).

Similar findings were also reported by (Dorostkar *et al.,* 2015; Singh *et al.,* 2017) during evaluation of wheat cultivars under normal and stress conditions. A positive and significant correlation between Yp and

https://doi.org/10.37992/2024.1502.056

Table 2. Pooled analysis of variance for different agro-physiological traits under timely and late sown conditions

Source	df	MSS																			
		Condition	DH	CT	Cha	Chb	Cart	DM	PH	NTM	SL	NSS	NGS	GWS	TGW	SD	GL	GB	GY	BY	HI
Total wheat lines	239	TS	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
		LS	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
RILs	237	TS	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
		LS	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Replications	2	TS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
		LS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* Significant at 5 *per cent* and ** Significant at 1 *per cent*, ns non-significant
Sowing conditions: TS- Timely sown, LS- Late sown
Traits: DH-days to heading, CT-canopy temperature, Cha-chlorophyll-a, Chb-chlorophyll-b, Cart-carotenoids, DM-days to maturity, PH-plant height (cm), NTM-number of tillers per meter, SL-spike length (cm), NSS-number of spikelets per spike, NGS-number of grains per spike, GWS-grain weight per spike (g), TGW-100 grain weight (g), SD -seed density (g/cc), GL-grain length (mm), GB-grain breadth (mm), GY-grain yield per meter (g), BY-biological yield per meter (g), HI- harvest index (%).

Table 3. Mean, range, %reduction and CV for different agro-physiological traits under timely (TS) and late sown (LS) conditions

Traits	Mean			Range		CV	
	TS	LS	Reduction	TS	LS	TS	LS
DH	103.08	89.97	13 days	93-115	88-95	4.92	2.45
CT	23.25	28.59	-22.97 %	19.20-25.90	26.20-32.90	6.68	5.71
Cha	1.84	1.63	11.41%	1.17-2.30	1.07-2.26	13.81	15.64
Chb	0.47	0.49	-4.26%	0.20-0.82	0.26-0.86	26.89	24.88
Cart	0.64	0.56	12.50%	0.38-0.79	0.36-0.76	16.47	14.78
DM	144.88	123.36	22 days	140.151	120-127	2.08	2.03
PH	90.17	80.40	10.84%	72.83-109.70	65.03-96.17	8.24	7.48
NTM	142.08	130.24	8.33%	110-160	107-160	8.44	9.65
SL	12.01	11.06	7.91%	9.67-14.87	8.57-13.57	8.82	9.02
NSS	20.48	19.73	3.66%	17-23	17.23	6.22	7.05
NGS	56.72	54.37	4.14%	40-67.80	30.20-68.80	13.17	15.51
GWS	2.56	2.13	16.80%	1.80-2.33	1.13-3.23	14.36	24.94
TGW	3.53	3.09	12.46%	2.51-4.40	2.14-4.29	11.04	16.21
SD	1.38	1.41	-2.17%	0.81-2.37	0.76-3.00	20.94	25.79
GL	6.34	6.13	3.31%	5.28-7.40	5.42-6.82	5.10	4.64
GB	3.07	2.69	12.38%	2.29-3.67	2.13-320	8.54	7.04
GY	232.51	184.75	20.54%	136.85-335.89	102.58-290.31	18.85	26.70
BY	634.65	553.75	12.75%	412.34-798.25	300.51-765.18	15.08	19.55
HI	36.93	33.50	9.29%	21.24-43.35	20.01-43.72	15.87	18.78

Ys was observed indicating that high yielder wheat varieties can be selected based on selection indices under both heat stress and normal conditions. TOL index showed a negative association under stress and a positive association under non-stress conditions with grain yield showing agreement with results those of (Kamrani *et al.,* 2015; Poudel *et al.,* 2021 ; Kalagare *et al.,* 2021) indicating selection of varieties based on TOL will be useful only under normal condition.

Selection of elite wheat lines based on selection indices: During recent past, a number of yield-based stress indices have been used for the estimation of heat tolerance in crop plants. The yield-based indices with their ranks were calculated in present research which can be divided into two groups (**Table 6**). The Ist group includes SSI and TOL, the low value of these indices indicates the high stress tolerance of the wheat line while the IInd group consists of MRP, MP, GMP, STI, HM, YI, YSI and RSI, the higher

Table 4. Analysis of variance for grain yield under normal (Yp), stress (Ys) conditions and heat tolerance indices of wheat RILs.

Source	df	MSS											
		Yp	Ys	SSI	TOL	YI	YSI	RSI	STI	MP	GMP	HM	MRP
Replication	2	18.43	26.37	0.00	0.39	0.00	0.00	0.00	0.00	0.00	56.20	9.47	41.12
RILs	237	5809.24*	7336.14*	2.17*	5746.28*	0.22*	0.09*	0.09*	0.15*	0.29*	5136.10*	5231.98*	5370.95*
Error	474	39.91	22.31	0.00	2.37	0.00	0.00	0.00	0.00	0.00	30.08	29.50	26.77

* Significant at 5 *per cent* and ** Significant at 1 *per cent*, ns non-significant**Yp**: Grain yield of progenies under normal condition, Ys: Grain yield of progenies under stress condition, YSI: Yield stability index, RSI: Relative stress index, SSI: Stress susceptibility index, STI: Stress tolerance index, YI: Yield index, TOL: Tolerance, MP: Mean Productivity, GMP: Geometric mean productivity, HM: Harmonic mean and MRP: Mean relative performance.

Table 5. Correlation coefficients between Yp, Ys and stress indices evaluated under normal and late sown conditions

	Ys	YSI	RSI	SSI	STI	YI	TOL	MP	GMP	HM	MRP
Yp	0.567**	-0.091ns	-0.09ns	0.09 ns	0.831**	0.566**	0.365**	0.870**	0.839**	0.806**	0.840**
Ys		0.761**	0.761**	-0.761**	0.921**	0.912**	-0.560**	0.899**	0.923**	0.941**	0.923**
YSI			0.915**	-0.921**	0.455**	0.761**	-0.950**	0.406**	0.457**	0.502**	0.459**
RSI				-0.814**	0.456**	0.761**	-0.951**	0.407**	0.457**	0.503**	0.459**
SSI					-0.456**	-0.762**	0.950**	-0.407**	-0.458**	-0.503**	-0.460**
STI						0.921**	-0.205**	0.992**	0.995**	0.994**	0.995**
YI							-0.560**	0.899**	0.922**	0.941**	0.923**
TOL								-0.140*	-0.199**	-0.252**	-0.198**
MP									0.998**	0.991**	0.998**
GMP										0.998**	0.999**
HM											0.996**

* Significant at 5 *per cent* and ** Significant at 1 *per cent*, ns non-significant
Yp: Grain yield of progenies under normal condition, Ys: Grain yield of progenies under stress condition, YSI: Yield stability index, RSI: Relative stress index, SSI: Stress susceptibility index, STI: Stress tolerance index, YI: Yield index, TOL: Tolerance, MP: Mean Productivity, GMP: Geometric mean productivity, HM: Harmonic mean and MRP: Mean relative performance.

value of which indicates high stress tolerance. Based on significant correlation of selection indices with grain yield only TOL, MP, GMP, STI, HM, YI were used for the identification of tolerant genotypes. The top 18 lines out of 20 selected best lines namely WL 92, WL 119, WL 114, WL 110, WL 6, WL 56, WL 53, WL 48, WL 52, WL 19, WL 50, WL 66, WL 63, WL 28, WL 82, WL 159, WL 153, WL 5 were found common in five selection indices (STI, MP, GMP, HM and MRP). Likewise, based on YI and TOL 14 common lines namely WL 119, WL 99, WL 43, WL 78, WL 94, WL 62, WL 108, WL 158, WL 90, WL 96, WL 107, WL 155, WL 15, WL 167 were selected (**Table 5**). Further, based on STI, YI, MP, GMP, HM, MRP and TOL, the composite selection index (CSI) was calculated for parents and RILs. The best wheat lines showing maximum value for CSI were WL 92, WL 119, WL 114, WL 110, WL 53, WL 56, WL 6, WL 48, WL 52, WL 19, WL 28, WL 63, WL 66, WL 50, WL 159, WL 82, WL 108, WL 153, WL 5 and WL 78 (**Table 5**). Interestingly, the wheat lines identified based on CSI are in agreement with those identified by STI, MP, GMP, HM and MRP indices. Many early studies also reported that MP, GMP and STI were the most efficient selection indices for choosing the heat tolerant wheat lines under heat stress condition (Singh *et al.,* 2018; Thapa et al., 2020). Similar conclusion based on HM, GMP and STI was drawn based on three years study for selection of drought tolerantwheat genotypes by Kumar *et al.* (2020) and rice genotypes by Sabouri *et al.* (2022).

Heat stress is a major and complex abiotic stress, receiving an increased attention in wheat due to its significant effect on grain yield, particularly at reproductive stage. In the present study, significant reduction in grain yield, its components and physiological traits was observed due to heat stress. However, sufficient variability among the wheat lines were also observed for different agro-physiological traits supporting their adaptation to terminal stress condition. Therefore, selection for tolerant wheat lines would be helpful. Selection indices along with

Table 6. Top 20 elite lines performing better than their parents evaluated under late sown and normal conditions

STI	YI	MP	GMP	HM	MRP	TOL	CSI
WL92 (1.52)	WL119 (1.57)	WL92 (286.32)	WL92 (286.31)	WL92 (286.31)	WL92 (2.78)	WL99 (-60.31)	WL 92 (760.28)
WL119 (1.44)	WL92 (1.54)	WL110 (280.29)	WL119 (279.02)	WL119 (278.80)	WL119 (2.72)	WL94 (-56.03)	WL 119 (743.31)
WL114 (1.41)	WL99 (1.52)	WL119 (279.24)	WL114 (276.14)	WL114 (275.95)	WL114 (2.67)	WL62 (-54.59)	WL 114 (731.41)
WL110 (1.40)	WL53 (1.49)	WL6 (276.83)	WL110 (274.84)	WL56 (271.06)	WL110 (2.66)	WL167 (-53.02)	WL 110 (719.21)
WL6 (1.38)	WL43 (1.49)	WL114 (276.33)	WL6 (273.30)	WL53 (269.93)	WL6 (2.64)	WL158 (-49.63)	WL 53 (718.23)
WL56 (1.37)	WL78 (1.48)	WL56 (273.61)	WL56 (272.33)	WL6 (269.82)	WL53 (2.63)	WL43 (-45.33)	WL 56 (718.06)
WL53 (1.35)	WL94 (1.47)	WL48 (270.26)	WL53 (269.99)	WL110 (269.50)	WL56 (2.63)	WL96 (-40.10)	WL 6 (717.19)
WL48 (1.34)	WL114 (1.44)	WL52 (270.26)	WL48 (268.75)	WL48 (267.25)	WL48 (2.59)	WL78 (-38.45)	WL 48 (708.11)
WL52 (1.33)	WL159 (1.44)	WL53 (270.05)	WL52 (268.50)	WL52 (266.76)	WL52 (2.59)	WL90 (-38.17)	WL 52 (707.02)
WL19 (1.31)	WL62 (1.44)	WL50 (269.45)	WL19 (266.34)	WL19 (264.47)	WL50 (2.57)	WL15 (-35.49)	WL 19 (701.07)
WL50 (1.31)	WL108 (1.43)	WL19 (268.23)	WL50 (266.33)	WL28 (264.33)	WL19 (2.57)	WL31 (-31.54)	WL 28 (700.42)
WL66 (1.31)	WL158 (1.43)	WL64 (267.95)	WL66 (265.84)	WL63 (264.19)	WL66 (2.57)	WL89 (-29.46)	WL 63 (699.67)
WL63 (1.30)	WL90 (1.42)	WL66 (267.89)	WL63 (264.97)	WL66 (263.80)	WL28 (2.56)	WL113 (-25.19)	WL 66 (699.47)
WL28 (1.29)	WL96 (1.41)	WL82 (265.98)	WL28 (264.58)	WL50 (263.26)	WL63 (2.56)	WL119 (-22.15)	WL 50 (699.29)
WL82 (1.27)	WL107 (1.41)	WL63 (265.76)	WL82 (262.22)	WL159 (262.16)	WL159 (2.55)	WL131 (-20.22)	WL 159 (696.98)
WL159 (1.27)	WL155 (1.38)	WL28 (264.82)	WL159 (262.18)	WL82 (258.52)	WL82 (2.53)	WL130 (-19.33)	WL 82 (687.65)
WL153 (1.25)	WL15 (1.38)	WL153 (263.07)	WL153 (260.32)	WL153 (257.59)	WL64 (2.53)	WL107 (-16.81)	WL 108 (685.19)
WL64 (1.24)	WL167 (1.38)	WL159 (262.20)	WL64 (259.19)	WL108 (257.42)	WL153 (2.51)	WL108 (-13.18)	WL 153 (683.84)
WL5 (1.24)	WL135 (1.38)	WL5 (261.02)	WL5 (258.64)	WL5 (256.28)	WL108 (2.51)	WL11 (-13.16)	WL5 (679.92)
WL108 (1.23)	WL140 (1.38)	WL22 (260.73)	WL108 (257.51)	WL32 (255.75)	WL5 (2.50)	WL155 (-12.64)	WL 78 (678.30)
WH 711 (0.83)	WH 711 (1.06)	WH 711 (213.07)	WH 711 (212.35)	WH 711 (211.64)	WH 711 (2.05)	WH 711 (34.79)	WH 711 (560.34)
WH 542 (0.69)	WH 542 (0.94)	WH 542 (194.10)	WH 542 (192.93)	WH 542 (191.77)	WH 542 (1.86)	WH 542 (42.49)	WH 542 (507.95)

multivariate approaches are the effective tools for the selection of superior genotypes under both stress and non-stress conditions. According to the results of correlation STI, YI, MP, GMP, HM, MRP and CSI exhibited a strong correlation with Yp and Ys. Therefore, they appear to be most effective selection criterion for the selection of wheat lines with better yield potential under stress and non-stress conditions. Based on the results of present study, wheat lines WL 92, WL 119, WL 114, WL 110, WL 6, have been identified as heat tolerant lines. These lines could be utilized for future crop improvement programs against heat stress and to explore the physiological and biochemical mechanisms of heat tolerance in wheat.

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