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Research Article

Screening for heat tolerant genotypes in bread wheat (*T. aestivum* L.) using stress tolerance indices

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Abstract

Heat is a major stress that severely affects wheat productivity. The objective of the current study was estimating the effect of heat stress during the grain-filling stage for screening heat tolerant wheat genotypes by measuring six stress tolerance indices for grain yield and also measured the % of decline on other important traits. A set of 190 wheat genotypes along with four local checks were evaluated in two separate experiments, one under normal condition (timely sown) and the other under heat stress condition (late sown) in augmented block design at the research farm of Department of Genetics and Plant Breeding, C.C.S. University, Meerut (U.P) during rabi season of 2014-2015. The calculation of % declines revealed that there was a significant decline in the performance of traits under heat stress environment (late sown) in comparison to a normal environment (timely sown). Three traits, namely grain yield/plant, biological yield/plant and grain weight/ spike showed 57.15 %, 53.66 % and 47.73 % decline, respectively under heat stress environment indicating that above mentioned three traits are highly affected by heat stress. To evaluate the susceptible and tolerant genotypes for grain yield under heat stress environment, six stress tolerance indices *viz.* heat susceptibility index (HSI), mean productivity (MP), tolerance (TOL), stress tolerance index (STI), trait stability index (TSI) and trait index (TI) were calculated based on the grain yield under normal (timely sown) and stress (late sown) environments. The results of correlation between stress tolerance indices and grain yield in normal environment showed a significant positive relationship with MP (0.822**), STI (0.568**), TSI (0.316**), HSI (0.314**), TI (0.188*) and TOL (0.084). However, in stress environment, grain yield showed a significant positive correlation with TI (1.000**), STI (0.907**), MP (0.713**) and TOL (0.129) and negative correlation with HSI (-0.860**) and TSI (-0.808**). Based on the correlation analysis, we have selected four stress indices *viz.* HSI (heat susceptibility index), MP (mean productivity), STI (stress tolerance index) and TI (trait index) for their use in the selection of heat tolerant wheat genotypes. The results indicated that 9 genotypes (G51, G64, G71, G114, G119, G134, G139, G148 and G150) were heat tolerant and 12 genotypes (G1, G3, G7, G27, G38, G40, G77, G107, G136, G160, G171 and G187) were highly heat susceptible. The genotype G77 was the most heat sensitive genotype while genotype G119 and G139 showed a high yield under heat stress environment. Therefore, genotypes G119 and G139 were identified as a suitable genotype under late sowing environment and can be recommended for heat stress environment. Further, these two genotypes may be also employed in breeding programs aimed for developing heat tolerant varieties of wheat.

Keyword

Wheat, Heat tolerance indices, Heat stress and % decline.

INTRODUCTION

Wheat (*Triticum aestivum L.*) is the most important cereal crop after maize and rice in the world. It occupies 17% of crop acreage worldwide, feeding about 40% of the world population with a share of more than 20% of total food calories and protein in human nutrition (Gupta *et al,* 2008). FAO estimated that the world would require additional 198 million tons of wheat by 2050 (Sharma *et al,* 2015) and the future demand can be accomplished only if the global wheat production would increase by 2.5% per annum. The average annual increase in temperature due to global warming is responsible for reduced water availability in agriculture practices. Higher mean temperature and climate variability are severely affecting crop productivity across the globe. In these circumstances, there is a continuous need for developing heat tolerant genotypes of wheat. Heat stress is a major challenge for wheat productivity. During heat stress, the elevated temperature (30-35 ^{0}C) above the optimum temperature negatively affect the morphological and physiological trait in wheat plant and also responsible for the decrease in the time of heading, grain set and maturity with altered crop season that ultimately reduce the total grain yield in wheat (Hossain *et al.* 2012, Porter, 2005, Gupta *et al*, 2013). In India, heat stress during the grain filling drastically reduces the wheat production in most of the wheat growing regions (Reynolds *et al*. 1994). Any delay in wheat sowing beyond the third week of November has been reported to result in a yield loss of 35-45 kg/ha per day. A total loss of up to 10 mt. per annum has been reported because of late sowing of the crop. High temperatures during the later phases of wheat development and particularly since the beginning of the heading and after anthesis (terminal or late heat stress) are thus considered as an important factor limiting wheat productivity.

The currently available popular wheat varieties grown in the Indo-Gangetic plains are largely sensitive to heat stress. Therefore, there is a need to develop wheat varieties that have the ability to withstand high temperatures during the reproductive and grain filling phases of the crop leading to enhanced productivity under high temperature stress. Screening and evaluation for genotypes with increased heat tolerance in wheat are one of the most vital objectives in the wheat improvement programme.

The major objective of the present study was to screen 190 wheat genotypes along with four checks for identification heat tolerant genotypes in wheat by exploring various stress tolerance indices for grain yield and % of decline for other important traits. The identified heat tolerant wheat genotypes may be further utilized for developing heat tolerant, high yielding and widely adapted varieties suitable for cultivation under late planting conditions.

MATERIAL AND METHODS

One hundred ninety wheat genotypes along with four checks were evaluated in simple augmented block design experiment under normal (timely sown) and heat stress environments (late sown) at the research farm of Department of Genetics and Plant Breeding, Chaudhary Charan Singh University, Meerut during the rabi season of 2014-2015. In the experiment, row -to-row and plant-to-plant distance were kept at 25 cm and 10 cm respectively. The standard agronomic practices were used in each experiment to raise good quality crops. The phenotypic data were recorded on five randomly selected plants of each line for 15 quantitative characters *viz,* days to heading, days to anthesis, days to maturity, grain filling duration, canopy temperature depression, chlorophyll content, plant height (cm), grain weight per spike (gm), grain number per spike, 1000- grain weight (gm), grain yield per plant (gm), tiller number per plant, biological yield per plant (gm), grain protein content (GPC) and grain carotenoids content. For each trait, mean performance (value) of each genotype was derived from the data recorded on 5 plants, these mean values were used to calculate the following parameters of heat sensitivity (stress indices) of genotypes.

(i) Heat susceptibility index (HSI): HSI for each genotype was calculated using the following formula (Fischer and Maurer, 1978).

$$\textbf{HSI} = \frac{1-(\boldsymbol{X}stress/\boldsymbol{X}normal)}{1-\left(\overline{X}\, stress/\overline{X}\, \boldsymbol{normal}\right)}$$

$$\textbf{D} \text{ (Stress intensity)} = 1-(\overline{X}\, stress/\overline{X}\, normal)$$

Where,

X_{stress} represents the yield of individual genotypes under late sown environment.

X_{normal} represents the yield of individual genotypes under timely sown environment.

$\overline{X}_{stress}$ represents the mean of the yield of all genotypes under late sown environment.

$\overline{X}_{normal}$ represents the mean of the yield of all genotypes under timely sown environment.

The lower value of HSI for a genotype indicates heat stress tolerance and the higher values indicates heat stress susceptibility by a genotype (Reynolds *et al.* 1994).

(ii) Mean productivity (MP): MP for each genotype was calculated using the following formula (Hossain *et al*,1990).

$$\textbf{MP} = \frac{(\boldsymbol{X}\, normal+\boldsymbol{X}\, stress)}{\mathbf{2}}$$

Higher value of MP is the indicator of genotypes having superior performance under both the normal and heat stress environments (Hossain *et al.* 1990 ; Mardeh *et al*. 2006).

(iii) Tolerance (TOL): Tolerance for each genotype was calculated using the following formula (Hossain *et al.*1990).

$$\textbf{TOL} = X_{normal} - X_{stress}$$

The negative (lowest) value of TOL indicates higher tolerance of a genotype to heat stress (Hossain *et al.* 1990).

(iv) Stress tolerance index (STI): STI for each genotype was calculated using the following formula (Fernandez 1992).

$$\textbf{STI} = \frac{(X\ normal \times X\ stress)}{(\bar{X}\ normal)^2}$$

Maximum STI value is the better indicator of the superior performance of genotype under both the normal and heat stress environment (Fernandez 1992, Mardeh *et al.* 2006).

(v) Trait stability index (TSI): Trait stability index (TSI) for each genotype was calculated using the following formula given by Bouslama and Schapaugh (1984).

$$\textbf{TSI} = X_{normal} / X_{stress}$$

Maximum TSI values are the better indication of the superior performance of genotypes under heat stress environment (Bouslama and Schapaugh 1984).

(vi) Trait index (TI): Trait index for each genotype was calculated using the following formula (Gavuzzi *et al.* 1997; Lin *et al.*1986).

$$\textbf{TI} = \frac{(X\ stress)}{(\bar{X}\ stress)}$$

The higher TI value for a genotype corresponds to higher heat stress tolerance (Gavuzzi *et al.*1997).

% Decline: % of decline was calculated using the formula

% of decline = (X Normal – X Stress) / X Normal x100

Where,
X represents the mean of phenotypic traits.

RESULTS AND DISCUSSION

The effect of heat stress on growth and development of wheat genotypes was clearly illustrated by the calculation of % decline (**Table 1**). The reduction in mean values of phenological traits involving yield and yield contributing traits under heat stress environment suggested that increased temperature leads to rapid completion of wheat life cycle resulting in poor expression of yield contributing traits and consequently lowers the grain yield.

The data presented in **Table 1** revealed that three traits, grain yield/plant (57.15 %), biological yield/plant (53.66 %) and grain weight/ spike (47.73 %) had a larger decline in the mean value under heat stress environment

Table1. Value of % decline for fifteen quantitative traits of 194 bread wheat genotypes (including 04 checks) under heat stress environment.

Trait	Mean values under Normal	Mean values under Heat stress	Decline in %
Days to heading	84.64	65.20	22.97
Days to anthesis	92.69	72.05	22.27
Days to maturity	124.95	97.93	21.63
Grain filling duration	32.26	25.87	19.79
Canopy temperature depression	4.12	5.20	-26.09
Chlorophyll content	40.34	46.22	-14.55
Tillers /plant	7.62	5.63	26.09
Plant height	90.04	71.51	20.59
Biological yield / plant	158.18	73.31	53.66
Grain weight / spike	2.02	1.06	47.73
Grain number / spike	53.19	39.17	26.35
Grain yield / plant	12.40	5.31	57.15
1000- grain weight	37.35	26.22	29.80
Grain protein content	13.13	13.96	-6.28
Beta -carotene content	5.58	6.36	-13.93

(late sowing) in comparison with the normal environment (timely sowing). A similar decline in mean values of various traits in wheat under heat stress was reported in earlier studies **(**Kirby 1967, Darwinkel *et al.* 1977, Al-Khatib and Paulsen 1984, Jain *et al.* 1992, Kumar *et al.* 1994, Calenderini *et al.* 1999, Wardlaw 2002, Shazad *et al.* 2002, Shahid *et al.* 2005, Irfaq *et al.* 2005, Okuyama *et al.* 2005, Thakur *et al.2020*)**.**

However, among all the 15 traits studied, the canopy temperature depression (-26.09), chlorophyll content (-14.55), beta-carotene (-13.93) and grain protein content (-6.28), showed the negative value of % decline with high heritability in mean value (**Table 1**). The negative value of perc ent decline in canopy temperature depression, chlorophyll content, beta-carotene and grain protein content suggesting that these traits are less affected by heat stress and may be used as important morpho-physiological traits for screening heat stress tolerance in wheat.

Heat tolerance is the adaptability of plant for their growth and development without compromising the yield under increased temperature environment. Heat stress is characterized by an increase in average temperature during anthesis and grain filling period that leads to forced maturity. The rapid completion of the life cycle is one of the major constraints of wheat production in arid and semiarid regions of the world. To study heat tolerance and susceptibility in wheat genotypes, we used six stress indices i.e. heat susceptibility index, mean productivity, tolerance, stress tolerance index, trait stability index and trait index. All these indices were calculated on the basis of the mean of grain yield of the genotypes under normal (timely sowing)and heat stress environments (late sowing). Among these, we selected four major indices that showed a higher degree of correlation with grain yield under heat stress environment, i.e. trait index, stress tolerance index, mean productivity and heat susceptibility index. With these stress indices, we evaluated 194 genotypes (including 04 checks) with the help of their correlation studies with grain yield under heat stress environment **(Table 2)**.

On the basis correlation study, we have achieved the following result under normal and stress environments shown in **Table 2**. A study of grain yield per plant in normal environment revealed a significant and positive correlation with MP (0.822), STI (0.568), TSI (0.316), HSI (0.314), GY/P (0.187) and tolerance (0.084), furthermore, no negative correlation was found in the normal environment except with a less significant result intolerance (0.084). While in the stress environment study, we found both positive and negative significant correlations. In a positive correlation, a highly significant result of GY/P in stress environment occurred with TI (1.000), STI (0.907), MP (0.713), tolerance (0.129) and significant negative correlation between SI (-0.860) and TSI (-0.808). Previously, the same patterns of correlation and selection criteria for heat tolerance in durum wheat were observed by Talebi *et al.* (2008).

Table 2. Correlation between yield in normal and heat stress environment with heat tolerance indices for 194 (including 04 checks) bread wheat genotypes along with four checks

Character	Grain yield (Normal)	Grain yield (Stress)	Trait Index	Trait Stability Index	Stress Tolerance Index	Tolerance	Mean Productivity	Heat Susceptibility Index
GY/P (Normal)	1.000	0.187*	0.188*	0.316**	0.568**	0.084	0.822**	0.314**
GY/P (Stress)		1.000	1.000**	-0.808**	0.907**	0.129	0.713**	-0.860**
Trait Index			1.000	-0.807**	0.907**	0.129	0.714**	-0.860**
Trait Stability Index				1.000	-0.552**	-0.066	-0.243**	0.915**
Stress Tolerance Index					1.000	0.140	0.931**	-0.574**
Tolerance						1.000	0.135	-0.089
Mean Productivity							1.000	-0.274**
Heat Susceptibility Index								1.000

***= significant at 0.05 probability level, **= significant at 0.01 probability level**

In the present study, out of the 190 genotypes and 04 checks only 12 genotypes (G1, G3, G7, G27, G38, G40, G77, G107, G136, G160, G171 and G187) were found highly heat susceptible and the genotype no. 77 was the most susceptible genotype as it had the lowest value of grain yield under heat stress environment. However, 9 genotypes (G51, G64, G71, G114, G119, G134, G139, G148 and G150) were heat tolerant and among them, genotype G119 and G139 showed high yield under heat stress environment **(Table 3)**. These analyses were based on the study of certain stress indices, such as HSI, MP, STI and TI. From the above analysis, it may be concluded that most of the wheat genotypes are largely susceptible to heat stress and only a smaller fraction of genotypes in the germplasm show tolerance to heat stress. Our study is in conformity with previously reported Okechukwu *et al.* 2016, Khan *et al.* 2014 and Khajuria *et al.*2016 for the evaluation of heat tolerant genotypes.

Table 3 Heat susceptible and heat tolerant wheat genotypes each with four heat susceptible indices in normal and heat stress environments.

Heat susceptible genotypes	Grain yield (Normal)	Grain yield (Stress)	HSI	MP	TOL	STI	TSI	TI
1	12.30	2.50	1.39	7.41	7.30	0.21	4.94	0.48
3	12.45	2.81	1.36	7.64	6.39	0.24	4.44	0.54
7	12.31	2.65	1.38	7.48	7.42	0.22	4.67	0.51
27	11.47	3.44	1.22	7.46	7.26	0.27	3.33	0.66
38	12.21	2.95	1.33	7.58	6.94	0.25	4.17	0.57
40	11.53	2.85	1.32	7.19	8.20	0.22	4.07	0.55
77*	10.21	2.33	1.34	6.27	7.55	0.16	4.30	0.45
107	11.73	3.43	1.24	7.58	6.98	0.27	3.42	0.66
136	10.31	3.72	1.12	7.02	8.34	0.26	2.77	0.71
160	10.70	3.19	1.23	6.95	7.85	0.23	3.35	0.61
171	12.07	3.03	1.31	7.55	8.66	0.25	4.02	0.58
187	9.18	3.41	1.10	6.29	7.48	0.21	2.69	0.65
Heat tolerant genotypes	**Grain yield (Normal)**	**Grain yield (Stress)**	**HSI**	**MP**	**TOL**	**STI**	**TSI**	**TI**
51	12.70	7.97	0.65	10.34	8.71	0.69	1.60	1.53
64	13.54	7.49	0.78	10.52	8.07	0.69	1.81	1.44
71	13.22	7.48	0.76	10.35	9.48	0.67	1.77	1.44
114	15.13	7.72	0.86	11.43	7.17	0.79	1.96	1.48
119*	13.11	8.82	0.57	10.97	7.76	0.78	1.49	1.69
134	13.94	7.90	0.76	10.92	8.38	0.75	1.76	1.52
139*	12.10	8.78	0.48	10.44	7.63	0.72	1.38	1.69
148	13.43	8.07	0.70	10.75	8.30	0.74	1.67	1.55
150	15.82	8.15	0.85	11.98	7.22	0.87	1.94	1.56

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