RESEARCH ARTICLE

PHENOTYPIC EVALUATION OF SPRING WHEAT IN TWO DIFFERENT ENVIRONMENTS

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Abstract: Wheat is one of the most important crop and primary sources of calories for millions of people world-wide. World nutrition mostly depends on wheat and its products. Different climatic and other environmental changes accentuate the requirement for breeding strategies that deliver both an extensively increase in yield potential and resilience to dangerous weather events such as frost, heat waves, and drought. Heat stress around sensitive stages of wheat development has been identified as a possible threat to wheat production in different countries including India. In the present study, we phenotypically evaluated 324 SWRS (spring wheat reference set) wheat genotypes in two different environments. We used different parameters for selection of heat tolerance genotypes like, ANOVA, CV (%), % Decline, Heat susceptibility indices (MP, STI, TI, TSI, TOL, HSI), heritability and correlation for all the 11 quantitative traits and Shannon-Weaver Index (H) was used for two qualitative traits like, leaf glaucousness and leaf rolling.

Keywords: Wheat, Abiotic stress, High temperature, Genetic improvement

INTRODUCTION

The hexaploid wheat (*Triticum aestivum* L. em Thell.), often described as bread wheat or common wheat, world nutrition mostly depends on wheat and its products (Agrawal and Gupta, 2006). It is the most important food crop and covers more cultivated land at the global level than any other crop (Iqbal *et al*. 2017) and it is cultivated over a wide range of climatic and soil conditions. The global warming, characterized by changing local weather patterns and increasing the frequency of extreme events, poses a major challenge to plant breeders in increasing yield potential (Semenov *et al*. 2014). Heat stress is defined as the increase in temperature above a critical threshold for a period of time sufficient to cause irreversible damage to plant growth and development (negative impacts on crop yields, including reducing leaf photosynthesis and enhancing leaf senescence rates, etc.) (Bita, 2013). In the case of wheat, both long hours of exposure to moderately high temperatures (22 to 28 °C) and short exposures to very high temperatures (> 30 °C) affect crop development and reduce grain yield (Stone and Nicolas, 1995; Souza and Pimentel, 2013). Much of this reduction is due to losses in primary yield components and industrial quality is also negatively influenced (Yildirim and Bahar, 2010). The negative impact of heat stress on yield has recently been confirmed for actual production conditions at large spatial scales by the interpretation of field trials, statistical analysis of large scale observational data sets and the application of crop models (Asseng and Turner, 2011; Siebert *et al*. 2014). Wheat yields have also increased significantly in the last century, mainly due to genetic improvements, higher fertilization rates and improved pest and diseases management (Semenov *et al*. 2012).

More critically for yield determination, the studies of previous reported indicate effects of decreasing grain number when heat stress occurs before or around anthesis and reduced grain weight when it occurs during grain filling (Gupta *et al*. 2012). Genetic variability of grain yield and its components, as a function of different genotype responses to heat in different stages of wheat development, was reported by Yildirim and Bahar in 2010. According to Reynolds *et al*. (1994), the grain mass is the most important character to confer heat tolerance. On the other hand, Shpiler and Blum (1986) found that, under heat stress, the variation among genotypes for grain yield is due to a larger variation in number of spikelets per spike and number of grains per spikelet. These characters, along with ear length, were appointed by Farooq *et al*. (2011) as essential for the breeder engaged in the selection of heat tolerant genotypes.

In the present study we evaluated the effect of high temperature on grain yield and yield components, as well as to characterize wheat genotypes for heat tolerance at different stages of development. We used 324 SWRS wheat genotypes to identify wheat genotypes that have built in tolerance to terminal heat stress associated with late planting so as to utilize them for development of high yielding, widely adapted and good quality varieties suitable for cultivation under late planting conditions.

MATERIAL AND METHOD

The experimental panel consisted 324 SWRS diverse wheat genotypes, evaluated in two different environments in simple lattice design, with four

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replications, two of each i.e. normal and heat stress environments in the 2014-15. Each genotype was raised in a plot of 3 rows of 1.5 m each with a row to row distance of 0.25 m. Phenotypic data were recorded for the following traits: (i) Days to heading (DTH) (ii) Days to anthesis (DTA) (iii) Days to maturity (DTM) (iv) Grain filling duration (GFD) (v) Leaf glaucousness (vi) Leaf rolling (vii) Canopy temperature depression (CTD) (viii) Chlorophyll content (CC) (ix) Plant height (PH) (x) Grain weight per spike (GW/S) (xi) Grain number per spike (GN/S) (xii) 1000- grain weight (TGW) (xiii) Grain yield (Y/Plot)

Statistical analysis

Data pertaining to the above characters were statistically analyzed over both the environments. The descriptive statistics including mean, range, standard error, Analysis of variance (ANOVA), Coefficient of variation (CV %) and Pearson's correlation coefficients were obtained using SPSS 17.0. and Shannon-Weaver Index (H), % Decline, Heritability and Heat susceptibility indices by using excel.

Following six different heat susceptibility indices were calculated using the data available during the present study.

(i) Heat susceptibility index (HSI)

$HSI = (1 - X_{\text{Heat stress}}/X_{\text{Normal}})/D$ (Fischer and Maurer, 1978).

$$D \text{ (Stress intensity)} = \frac{\overline{X}_{\text{Heat stress}}}{\overline{X}_{\text{Normal}}}$$

Lower values of HSI indicate heat stress tolerance and the higher values indicate heat stress susceptibility by a genotype (Reynolds *et al*.1994, Ayeneh *et al*.2002).

(ii) Mean productivity (MP)

$$MP = \frac{X_{\text{Normal}} + X_{\text{Heat stress}}}{2}$$ (Hossain *et al*. 1990).

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)

$TOL = X_{\text{Normal}} - X_{\text{Heat stress}}$ (Hossain et al. 1990)

The negative values of TOL indicate higher tolerance of a genotype to heat stress (Hossain *et al*.1990).

(iv) Stress tolerance index (STI)

$$STI = \frac{X_{\text{Normal}} \times X_{\text{Heat stress}}}{(\overline{X}_{\text{Normal}})^2}$$ (Fernandez, 1992).

Maximum STI values are the best indication of the superior performance of genotypes under heat stress environment (Fernandez, 1992 and Mardeh *et al*. 2006).

(v)Trait index (TI)

$$TI = \frac{X_{\text{Heat stress}}}{\overline{X}_{\text{Heat stress}}}$$ (Gavuzzi *et al*. 1997)

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

(vi)Trait stability index (TSI)

$$TSI = \frac{X_{\text{Heat stress}}}{\overline{X}_{\text{Heat stress}}}$$ (Bouslama and Schapaugh, 1984)

Maximum TSI values are the better indication of the superior performance of genotypes under heat stress environment.

(X = represents the value of phenotypic trait, $X_{\text{Heat stress}}$ represents the phenotypic value of a trait in the heat stress environment, X_{Normal} represent the phenotypic value of a trait in normal environment, $\overline{X}_{\text{Heat stress}}$ represent the average value of a phenotypic trait over all the genotypes in heat stress environment, $\overline{X}_{\text{Normal}}$ represents the average value of a phenotypic trait over all the genotypes in normal environment)

RESULT AND DISCUSSION

ANOVA showed significant differences among the wheat genotypes for all the 11 quantitative traits except the chlorophyll content, which was dropped from further analysis during the present study (Table 1). The Shannon Weaver index (H) analyses for two qualitative traits, like leaf rolling and leaf glaucousness, showed a wide variation for leaf rolling but the variation for leaf glaucousness was relatively very low (Table 2). This suggested that the material chosen for the present study has significant genetic divers for different traits and may be utilized for identification of terminal heat tolerant genotypes (Tables 1 and 2). The two environments used to evaluate the SWRS had significant differences suggesting the suitability of the chosen environments for the study of heat stress on the performance of SWRS genotypes. The genotype-by-environment interactions were also significant for all the quantitative traits except the CTD and CC, suggesting that heat stress due to late sown conditions had an impact on the expression of most of the studied traits during the present study. These results are also suggested in previous studies in wheat (Bayoumi *et* al. (2008).

Variability and Heritability

The values of range, over all means and the Shannon Weaver index (H) for the two qualitative traits of SWRS genotypes under normal and heat stress environments are presented in Table 2. For the same set of genotypes, the values of ranges and overall means and CV (%) for the 10 quantitative traits except CC under normal and heat stress environments are presented in Table 3. Wide range was observed for all the traits under both the environments suggesting that the significant variability for all the traits among the SWRS genotypes confirming the above results of the analysis of variance. The genetic variations indicate that, SWRS germplasm may be used for further improvement of wheat breeding programme for different traits.

The CV (%) was high for CTD, GW/S, GN/S and Y/Plot. For the remaining traits, the CV (%) was moderate to low. This suggested that the genotypes comprising SWRS have more variability for CTD, GW/S, GN/S and Y/Plot relative to the remaining six traits. Similar results were reported in an earlier study in wheat (Hossain, 1990). It may further be noted that heat stress had an effect on the variability of different traits in SWRS genotypes. The variability for six traits including DTH, DTA, and DTM, GFD, CTD and TGW was reduced under heat stress. However, the variability for some other traits such as PH, GN/S and Y/Plot had increased under heat stress; these traits also exhibited relatively higher decline in their mean values in heat stress environment. This may evince that the response of individual traits to heat stress was not uniform across all the wheat genotypes and the changes in the magnitude of the expression of different traits of individual genotypes differed under heat stress environment.

The heritability for DTH and DTA was high under both the environments. Heritability for DTM, GFD, TGW, and GN/S and GW/S was low to moderate under normal condition and the heritability for these traits showed an increasing trend under heat stress environment and ranged from moderate to high. The heritability for GFD and Y/Plot was moderate under heat stress environment (Table 4). This lead to suggest that the similar response was not elicited by different traits in response to heat stress environment, although in past several studies a decline in heritability has been reported under the stress environments (Frey 1964; Roy and Murty 1970; Paliwal *et al.* 2012). The moderate heritability of GFD and Y/Plot, two very important traits, suggest that progress for improvement of these traits through selection will be relatively slow compared to other traits like DTH and DTA, which have high heritability. The CTD which has been suggested as important traits for breeding for heat tolerance in wheat surprisingly had a very low heritability during the present study. This put forward an idea that CTD may not be utilized as a useful trait for selection for improved tolerance to heat stress. This observation is contrary to the several earlier studies advocating the use of CTD in breeding for heat tolerance in wheat (Philippe *et al.* 2012, Kumar *et al.* 2013).

Effect of Heat Stress on Phenotypic Performance

The severity of heat stress on the growth and development of the wheat genotypes in the several studies is clearly visible by 6.78% (TGW) to 47.96% (Y/Plot) decline in the mean values of different traits in heat stress environment (Table 5). Similar decline in mean values of various traits under heat stress has also been reported in earlier studies in wheat, Irfaq *et al*. 2005, Okuyama *et al.* 2005). The reduction in mean values of yield and its contributing traits as well as other related phonological traits suggested that the heat stress leads to rapid completion of the life cycle of the wheat, which contributes to the poor expression of yield contributing traits and eventually to lower grain yield under heat stress.

Among all the traits, minimum declines in the mean value of grain weight under heat stress are in agreement with an earlier report (Irfaq *et* al. 2005). However, the maximum decline in Y/Plot under heat stress is not surprising, since Y/Plot is the overall outcome of the interplay of all the traits each of which is adversely affected to various degrees by the heat stress environment. Interestingly, the mean CTD under heat stress was higher than under normal sown conditions. This suggested that the wheat genotypes used during the present study have the ability to maintain cool canopy under the heat stress. However, due to a very low heritability of CTD, selection of heat tolerant genotypes in SWRS is not likely to be successful. The values of mean leaf rolling and leaf glaucousness were also higher under the heat stress (Table 2), suggesting their possible contribution to the tolerance to heat stress.

Effective Selection Criteria for Assessing Heat Stress Tolerance

The significant G×E interactions result due to the changes in the magnitude of yield differences among genotypes in diverse environments or due to change in the relative ranking of the genotypes as also reported by Fernandez,1992. In the past several selection criteria have been proposed to select genotypes based on their performance in stress and normal environments (Barakat *et al*. 2011). The selection of genotypes was based on grouping of genotypes for yield under a normal and stress environments. First group: genotypes express uniform superiority in both stress and normal environments; second group: genotypes perform favorably in normal environment; group three: genotype yield relatively higher only in stress environments; and group four: genotypes uniformly perform poorly in both stress and normal environments. Here, we have evaluated six different stress tolerance indices for their relative ability to identify wheat genotypes that give high yield under normal and heat stress environments.

For all the six heat susceptibility indices, a range of values were observed for the genotypes (Table 5), these values were from low to high and for two out of six indices (tolerance and heat susceptibility index), the values ranged from negative and low to positive and high with mean values ranging accordingly (Table 5). The correlations of five of six heat susceptibility indices (except heat susceptibility index) with the grain yield (under heat stress environment) were positive and varied from as low as 0.16 (involving Tolerance) to as high as 1.00

(involving trait Index) (Table 6). The correlation involving heat susceptibility index was moderate and negative (-0.47), though significant. Three indices, which had the highest correlation with grain yield in heat stress environment included TI (r=1.00), followed by STI (r=0.91) and MP (r=0.87) (Table 6). The higher the values of these three indices, showed that higher the tolerance level of the genotype to the stress. Based on each of the three indices, we selected five genotypes, which had highest values of indices and then compared their grain yield in heat stress and normal environments. It is interesting to note that each of the five sets of genotypes selected following the three stress susceptibility indices belonged to the 10 highest yielding genotypes in the heat stress environment. This may evince us that these three indices may be successfully utilized for the selection of genotypes exhibiting higher tolerance to terminal heat stress with a high degree of reliability.

Table 1. ANOVA for 11 quantitative traits of SWRS genotypes under normal and heat stress environments.

Source	Df	DTH	DTA	DTM	GFD	CTD	CC	TGW	GN/S	GW/S	PH	Y/PLOT
Environment	1	80731.66**	80677.94**	118772.90**	3884.19**	1.146	36.399	192.91*	33430.52**	37.914	184176.84**	18.91**
Replication	1	12.66	1.474	76.141	56.424	131.03**	183.52*	70.466	824.467	0.314	540.13*	0.002
Genotype	323	412.35**	422.37**	308.02**	81.25**	13.80**	28.916	106.20**	652.14**	0.78**	952.17**	0.07**
Genotype × environment	310	69.20**	62.09**	71.16**	53.75**	9.051	31.238	113.98**	377.89**	0.31**	298.05**	0.01**
Error	626	35.596	31.54	52.09	35.303	9.265	34.935	43.054	177.66**	0.096	110.627	0.012

df=degrees of freedom, DTH=days to heading, DTA=days to anthesis,DTM=days to maturity,GFD=grain filling duration,CTD=canopy temperature depression, CC=chlorophyll content,TGW=1000- grain weight, GN/S=grain number per spike, GW/S=grain weight per spike, PH=plant height, Y/PLO=yeild per plot.*Significant at 0.05%; and **Significant at 0.01%

Table 2. Values of Range, Mean and Shannon Weaver index (H) for two qualitative traits in both the environment

Traits	Environment	Range	Mean	Shannon Weaver index (H)
1. Leaf rolling	N	0-3	0.36	1.4
	HS	0-3	0.37	1.6
2.Leafglaucousness	N	0-9	2.41	0.013
	HS	0-10	3.33	0.014

N= normal environment, HS=heat stress environment

Table 3. Values of Range, Mean, CV (%) and Decline (%) for 10 quantitative traits in both the environments.

Traits	Treatment*	Range	Mean	% Decline	CV%
1.DTH	N	85.5-131	103.02	15.82	11.69
	HS	76-110.5	86.72		10.65
2. DTA	N	89-138	109.5	15.4	11.17
	HS	80.5-117	92.64		10.16
3. DTM	N	131-172	141.63	14.3	7.7
	HS	112-148	121.37		7.01
4. GFD	N	16-49.5	32.14	10.58	17.22
	HS	14-43	28.74		15.9
5. CTD	N	0.33-8.23	3.97	-4.03	48.6
	HS	0.2-8.87	4.13		31.38
6. PH	N	61.17-152.5	111.69	22.28	15.43
	HS	42.33-132.17	86.81		17.16
7. GW/S	N	0.33-3.95	1.64	26.22	35.21

	HS	0.2-2.56	1.21		41.67
8. GNPS	N	8.2-100	40.04	20.5	35.08
	HS	5.5-64.30	31.83		41.4
9. TGW	N	18.68-50	41.17	6.78	18.26
	HS	14.54-46.79	38.38		17.09
10. Y/PLOT	N	0.73-9	4.9	47.96	38.15
	HS	0.27-5.47	2.55		41.68

N = normal environment, HS = heat stress environment

Table 4. Estimates the heritability for 10 different traits in both the environments.

Traits	N	HS
1.DTH	0.83	0.7
2.DTA	0.77	0.84
3.DTM	0.52	0.76
4.GFD	0.31	0.33
5.CTD	0.73	0.02
6.PH	0.91	0.55
7.GNPS	0.32	0.86
8.GW/S	0.56	0.84
9.TGW	0.17	0.59
10.Y/PLOT	0.64	0.47

N= normal environment, HS=heat stress

Table 5. Range and Mean values for six heat susceptibility indices for grain yield

Heat susceptibility Indices	Range	Mean
1.Mean productivity	0.73-6.4	3.73
2.Tolerance	-1.33-5.73	2.46
3.Stress tolerance index	0.02-1.5	0.59
4.Trait index	0.1-2.14	1
5.Trait stability index	0.14-1.54	0.53
6.Heat susceptibility index	-1.71-1.89	0.93

Table 6. The estimates of correlation coefficients between grain yield in both the environments and six heat susceptibility indices.

Heat susceptibility index	Correlation coefficient
1. Mean productivity	0.87**
2. Tolerance	0.16**
3. Stress tolerance index	0.91**
4. Trait index	1.00**
5.Trait stability index	0.43**
6. Heat susceptibility index	-0.47**

*Significant at 0.05%; and **Significant at 0.01%, N=normal, HS=heat stressed

Table 7. Grain yield of five wheat genotypes each with highest values of three heat susceptibility indices in normal and heat stress environments.

Name of genotypes	Grain yield per hectare (t/ha)		HSI
	N	HS	
(a) Mean productivity			
MINO	7.67	4.67	6.17
MILAN/KAUZ	8.2	4.27	6.23
ATTILA/BAV92	8.67	4.13	6.4
TRIPLE DIRK	8.33	3.87	6.1
YAR/AE.SQUARROSA(783)	8.67	3.67	6.17
(b) Stress tolerance index			
BJY/COC//PRL/BOW	7.4	4.87	1.5
MINO	7.67	4.67	1.49
MILAN/KAUZ	8.2	4.27	1.45
ATTILA/BAV92	8.67	4.13	1.49
TRIPLE DIRK	8.33	3.87	1.34
(c) Trait index			
BJY/COC//PRL/BOW	7.4	4.87	1.91
MINO	7.67	4.67	1.83
MILAN/KAUZ	8.2	4.27	1.67
SCA/AE.SQ.(518)/3/URES	7.67	4.2	1.65
ATTILA/BAV92	8.67	4.13	1.62

CONCLUSION

Heat stress reduces wheat grain yield and also reduced the values of yield related traits like grains per spike, 1000 grain weight, etc. The genotypes contrast in the developmental stage at which they are more tolerant to heat stress. The response of individual traits to heat stress was not uniform across all the wheat genotypes.

Future line of work

The identified heat tolerant genotypes in the present study may be useful for the development of heat tolerance wheat varieties in the wheat breeding program.

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