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Research Article

Stress response behavior in different wheat species in relation to heat tolerance

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Abstract

Eighty wheat genotypes, twenty each from *Triticum aestivum*, *Triticum durum*, *Triticum dicoccum* and Synthetic *T. aestivum* were evaluated for terminal heat tolerance by normal (non-stress) and late (stress) planting in field in randomized block design with three replications for two crop seasons; 2012-13 and 2013-14. The genotypes differed significantly for grain yield in non-stress and stress conditions. The heat susceptibility and tolerance indices were calculated as Heat Sensitivity Index (HSI) and Heat Response Index (HRI) for grain yield. Genotypes PBW 550, HD 2733, HD 2967, PBW 343 & PBW 373 from *T. aestivum*, WHD 943, WHD 945, WHD 314, WHD 946 & WHD 912 from *T. durum*, DI 26, DI 119, DI 88, DI 52 & DI 61 from *T. dicoccum* and Syn 22, Syn 24, Syn 30, Syn 36, Syn 62 & Syn 25 from Synthetic *T. aestivum* were found heat tolerant on the basis of heat susceptibility index and could be useful as genetic stock to develop wheat heat tolerant varieties in breeding programs. Synthetic *T. aestivum* was found to have lowest HRI followed by *T. durum*, *T. dicoccum* and *T. aestivum* respectively while HSI was lowest in *T. durum*, *T. aestivum*, *T. dicoccum* and Synthetic wheat lines respectively.

Key words: Wheat species, heat sensitivity index, heat response index

1. Introduction

Global warming is predicted to have a general negative effect on plant growth and development. There is a differential effect of climate change both in terms of geographic location and the crops that will likely show the most extreme reductions in yield as a result of expected extreme fluctuations in temperature and global warming in general. High temperature stress has a wide range of effects on plants in terms of physiology, biochemistry and gene regulation pathways. However, strategies exist in crop improvement for heat stress tolerance through generation of new varieties with sustainable yield production (Bita and Gerats, 2013).

Wheat is the most important cereal crops used as staple diet for more than one third of the world population (Abd-El-Haleem *et al.*, 2009). The optimum temperature for growth and yield of wheat is in the range of 18–24 °C and even short periods (5–6 days) of exposure to temperatures of 28–32 °C result in significant decreases in yield of 20 % or more (Stone and Nicolas, 1994). It is estimated that for every 1°C increase in temperature above the optimal growing temperature of 15–20 °C, the duration of grain-filling is reduced by 2.8 days (Streck, 2005). Estimation of heat stress susceptibility indices and ranking of genotypes showed that every genotype possess different degree of tolerance to heat stress. The geometric mean, stress tolerance index (STI) and stress susceptibility index (SSI) was used to evaluate the genotypic performance under heat stress and non-stress conditions. The results indicated that it is possible to identify superior genotypes for heat tolerance based on their stress indices. Moreover, the selected genotypes may be utilized in breeding programme to develop high yielding heat tolerant/resistance cultivars.

2. Materials and Methods

The experimental material consisting of eighty wheat genotypes, twenty each from *Triticum aestivum*, *Triticum durum*, *Triticum dicoccum* and Synthetic *T. aestivum* were grown in randomized block design with three replications for two crop seasons i.e. 2012-13 and 2013-14 and under two conditions; timely sown (second week of November) and late sown (last week of December) at the experimental area of Wheat and Barley section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. Each plot consisted of 2 rows of 1.5 m length with 20 cm inter row and 5 cm intra row spacing. The data of temperature and rainfall during the season was obtained from the observatory, Department of Meterological Science, CCSHAU, Hisar (Table 1).

Table 1. Temperature and rainfall during wheat crop season of 2012-13 and 2013-14

Month	Temperature (°C)				Rainfall (mm)	
	2012-13		2013-14			
	Min	Max	Min	Max	2012-13	2013-14
December	6.0	20.8	7.0	21.8	5.5	0.0
January	4.8	18.4	5.6	18.0	14.4	2.0
February	5.3	21.0	7.6	20.8	0.0	12.5
March	10.3	28.5	12.2	26.3	0.0	47.0
April	15.0	34.1	7.6	24.9	33.3	16.4

Heat susceptibility index for grain yield (HSI): HSI was calculated over stress and non-stress environment. The HSI of individual genotype was calculated by the method suggested by Fischer and Maurer (1978) with the following formula:

HSI for grain yield = 1-(Y/YP)/D.

Where, D = 1- (X/XP), Y and YP is grain yield for individual genotypes under heat stress and normal environment, respectively. X and XP represents mean grain yields of all genotypes under heat stress and normal environment, respectively.

Heat Response Index for grain yield (HRI): The heat tolerance of individual genotype was computed using the formula given by Bidinger *et al.* (1987) as HRI = (Ya- Yest)/SES

Where, Yest and Ya are the estimated yields by regression and actual yields, respectively, and SES is the standard error of the dependent trait, significant positive values of HRI denote heat tolerance, while significant negative values denote heat susceptibility of genotype negative values denote heat susceptibility of genotype.

HSI depends on grain yield of stressed and non-stressed genotypes as well as their overall population mean, whereas HRI not only takes into consideration the grain yield, but also can give an estimate of heat tolerance potential by removing the influence of intervening variables such as heat escape, avoidance and the influence of yield potential by taking into consideration residual variation in multiple regression techniques improvements in yield under heat stress should combine a reasonably high yield potential with a specific plant factor which would buffer yield against severe reduction under heat stress (Jones *et al.*, 1989). Influence of intervening variables were nullified by taking the use of residual values of multiple regression of grain yield under stress condition as dependent traits and high grain yield under timely sown and days to heading under stress environment was taken as intervening variable to remove the effect of high yielding genotype due to earliness.

Statistical Analysis: The statistical analysis was performed by using the softwares, namely, OPSTAT and SPSS 19.

3. Results and discussion

3.1 Variability for morpho-physiological traits

Late sowing caused reduction in all the yield and yield parameters (Table 2) studied in four wheat species cultivars except for biomass/m^2 in *T. durum and* Synthetic *T. aestivum*. Grain weight /spike was observed maximum in *T. aestivum* under both the environments (Table 2). Grain yield and harvest index was maximum in *T. aestivum* and minimum in *T. diccoccum* under both the environments (Table 2). Genetic variation is an essential prerequisite for any crop improvement programme (Ober and Luterbacher, 2002) and wide genotypic variation was shown for yield and yield components in four wheat species under timely and stress conditions (Late sown), in agreement with previously reported results of Singh *et al.* (2008). The heat stress reduces particularly grain yield and its components contribute significantly to low productivity of wheat (Pandey *et al.*, 2014). Sareen *et al.* (2014) reported grain weight per spike and test grain weight as important selection parameter for heat tolerance.

Table 2. Variability for physiological, grain yield & other yield related parameters of wheat species under timely & late sown environment (mean of 2012-13 and 2013-14)

Species	Environment	Days to heading	Days to maturity	No. of grains/ spike	Grain wt. / spike (g)	1000-grain wt. (g)	Biomass (kg) /m2	Grain yield (kg)/ m2	Harvest index
T. aestivum	Timely	109.32±1.08	137.1±0.98	66.3±1.52	2.67±0.25	48.5±0.20	1.39±0.11	0.59±0.03	42.40±2.35
	Late	89.5±0.77	118.9±0.69	63.3±1.07	2.26±0.22	42.8±0.14	1.13±0.08	0.45±0.02	39.80±1.66
T. durum	Timely	95.6±1.84	143.1±1.23	65.7±0.90	2.34±0.17	45.6±0.20	1.10±0.10	0.57±0.03	42.36±3.24
	Late	87.7±1.30	125.9±0.87	63.3±0.64	2.04±0.12	40.8±0.16	1.15±0.08	0.46±0.02	39.69±2.29
T. dicoccum	Timely	100.1±0.92	150.5±1.34	48.1±1.38	1.23±0.31	25.6±0.17	1.19±0.07	0.20±0.08	16.80±1.81
	Late	93.7±0.65	130.1±0.94	45.6±0.98	1.08±0.15	21.4±0.12	1.01±0.05	0.18±0.01	17.82±1.28
Synthetic T. aestivum	Timely	102.6±1.48	154.4±6.03	68.1±1.19	1.58±0.51	29.6±0.20	1.40±0.04	0.33±0.01	23.63±3.73
	Late	95.5±1.05	133.7±4.26	67.2±0.84	1.38±0.43	25.3±0.14	1.60±0.10	0.30±0.03	21.82±2.64

3.2 Analysis of variance

To determine the variation for morpho-physiological traits in wheat species analysis of variance (ANOVA) was calculated. The analysis of variance (ANOVA) for grain yield (kg)/m^2 showed that mean sum of squares in all the four wheat species i.e in *T. aestivum, T. durum, T. dicoccum* and Synthetic *T. aestivum* wheat indicate significant difference at 5% and 1% probability level among genotypes except interaction between G x Y in Synthetic T .aestivum due to year (Y) in *T. aestivum* & *T. dicoccum* interaction between E x Y in *T. aestivum, T. durum.* Interaction between G x E x Y in *T. aestivum, T. dicoccum*, Synthetic *T. aestivum* were found nonsignificant (Table 3).

Table 3. Mean sum of squares for grain yield in wheat species over the years and environments

Grain yield/m^2 (kg)					
Source	DF	*T. aestivum*	*T. durum*	*T. dicoccum*	Syn. *T. aestivum*
Replication	2	47.53**	64.61**	50.74*	24.96*
Genotypes (G)	19	95.06**	29.22**	90.48**	49.92*
Environment (E)	1	303.52**	475.1**	794.73**	443.86**
G x E	19	28.12**	41.56**	61.68**	50.15
Year (Y)	1	105.43**	31.00**	10.10	213.49**
G x Y	19	63.84**	102.74**	41.43	83.62
E x Y	1	183.43**	246.70**	41.86**	774.10**
G x E x Y	19	23.78	38.72	57.08**	17.45
Error	158	2.90	4.54	5.39	109.25
Total	239				

**, **: Significant at 5% and 1% probability level, respectively*

3.3 Stress indices (Heat Susceptibility Index and Heat Response Index)

Based on Heat Susceptibility Index, minimum HSI was found in the genotypes PBW 550 (0.19) in *T. aestivum*; WHD 943 (0.14) in *T. durum*; DI 26 (0.28) in *T. dicoccum* and SYN 67 and SYN 36 (0.44) in Synthetic *T. aestivum* (Table 4). Involvement of these genotypes in crossing programme with that of high yielding may provide desirable segregants under heat stress conditions. The HSI and HRI may be used as an indicator of yield stability and a proxy for heat tolerance.

On the basis of Heat Response Index, minimum HRI in *T. aestivum* was noticed in WH 711 (-0.92) followed by Raj 3765 (-0.53) and HD 2285 (-0.85), and in *T. durum* minimum HRI was found in WHD 950 (-1.52) followed by WHD 912 (-1.48), HD 4725 (-1.17) WHD 314 (-1.17) & HI 2724 (-0.86), and in *T. dicoccum* minimum HRI was found in DI 124 (-1.06), DI 65 (-1.06) and DI 86 (-1.27), while in case of Synthetic *T. aestivum* minimum HRI was found in SYN 24 (-1.79), SYN 30 (-1.39) and SYN 34 (0.62).

Table 4. Heat susceptibility and Heat response index of the genotypes of four wheat species

T. aestivum	HSI	HRI	*T. durum*	HSI	HRI	*T. dicoccum*	HSI	HRI	Synthetic *T. aestivum*	HSI	HRI
DBW 16	0.64	0.04	NIDW 706	0.64	0.17	DI 119	0.34	-0.67	SYN 02	0.54	-0.38
DBW 17	0.54	0.65	HD 4725	0.55	-1.17	DI 124	0.56	-1.06	SYN 04	0.55	0.73
HD 2285	0.66	-0.50	WHD 950	0.53	-1.52	DI 26	0.28	0.03	SYN 05	0.59	0.04
HD 2733	0.25	-0.19	HI 8727	0.48	-0.17	DI 30	0.77	0.85	SYN 07	0.51	-0.18
HD 2987	0.64	-0.44	MACS 3929	0.42	-0.21	DI 43	0.75	2.09	SYN 11	0.54	0.64
HD 2967	0.26	-0.02	WHD 948	0.43	1.28	DI 52	0.42	0.77	SYN 14	0.55	0.04
PBW 343	0.37	0.06	HI 2724	0.50	-0.86	DI 59	1.06	-0.13	SYN 16	0.63	1.61
PBW 373	0.37	0.10	MACS 3828	0.60	0.31	DI 60	0.45	-0.31	SYN 20	0.62	0.77
PBW 550	0.19	1.74	HI 8728	0.44	0.48	DI 61	0.42	0.46	SYN 22	0.50	-0.32
Raj 3765	0.38	-0.53	AKDW 4749	0.43	0.62	DI 62	0.83	0.96	SYN 24	0.45	-1.79
Sonak	0.65	0.75	UPD 94	0.61	0.21	DI 63	0.54	0.77	SYN 25	0.54	0.00
Sonalika	0.70	0.61	RKD 219	0.65	-0.17	DI 65	0.77	-1.06	SYN 27	0.55	0.93
UP 2425	0.46	0.19	WHD 943	0.14	1.31	DI 67	0.50	-0.44	SYN 28	0.53	0.08
WH 1021	0.43	1.18	WHD 946	0.25	1.55	DI 69	0.60	0.72	SYN 30	0.45	-1.39
WH 1105	0.51	-0.23	WHD 948	0.45	1.90	DI 70	0.50	-0.83	SYN 34	0.51	0.62
WH 1123	0.52	-0.29	WHD 953	0.64	0.03	DI 78	0.53	-0.75	SYN 36	0.44	-1.33
WH 1124	0.73	-0.31	WHD 912	0.36	-1.48	DI 84	0.55	-0.23	SYN 38	0.55	0.44
WH 711	0.59	-0.92	WHD 954	0.15	-0.76	DI 86	0.99	-1.27	SYN 40	0.52	0.12
WH 730	0.47	-0.31	WHD 896	0.40	-0.45	DI 87	0.46	0.59	SYN 62	0.50	-0.46
WH 1129	0.42	-1.57	WHD 314	0.22	-1.17	DI 88	0.36	-0.54	SYN 67	0.44	-0.22

**HSI - Heat susceptibility index; HRI - Heat Response index*

In order to exploit heat tolerance in wheat breeding programmes, the information on heat resistance/tolerance potential is required in addition to yield potential. A drought susceptibility index (DSI) suggested by Fischer and Maurer (1978) and drought response index suggested by Bidinger *et al.* (1987) could be employed in the same way for determination of a HSI and a HRI, respectively, of individual genotypes.

Fischer and Maurer (1978) and Langer *et al.* (1979) used stress sensitivity index (SSI) to characterize the yield stability between two environments. Drought and heat tolerance is usually quantified by grain yield under stress conditions. However, selection for yield under stress conditions is complicated by large genotype-environment interaction (Golabadi *et al.*, 2005). Genotypic differences in yield and its components among genotypes for growth under stress conditions, could lead to identify the most tolerant and most sensitive ones (Menshaway *et al.*, 2006). HSI was used to measure terminal heat stress tolerance in term of minimizing the reduction in yield caused by unfavorable vs favorable 84 environments by Verma *et al.* (2006). SSI can be useful indicator for wheat breeding under stress conditions (Sio-Se Mardeh *et al.*, 2006; Dhanda and Munjal, 2012). Genotypic variation under heat stress conditions as evident from late sown environment may be used as a direct screening tool for selecting genotypes having higher yield potential and grain productivity. Results of this study suggest that there is genetic variability among wheat species that can be utilized in breeding wheat for heat tolerance.

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