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Effective selection criteria for assessing yield of wheat (*Triticum aestivum*) under early and late heat stresses in irrigated environment of South-East Asian conditions

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ABSTRACT

The study was conducted for 2 winter seasons during 2004–05 and 2005–06 at Indian Agricultural Research Institute, New Delhi using 9 wheat (*Triticum aestivum* L. emend. Fiori & Paol.) genotypes ('HD 2923', 'RS 911', 'HD 2944', 'HD 2950', 'HD 2936', 'RS 937', 'PBW 343', 'HD 2851' and 'HDR 77') and 3 sowing dates (15 October, 15 November and 15 December) to assess the relative efficiency of different selection parameters. Grain yield was significantly correlated with biomass (0.8067), grains/m^2 (0.5387), spikes/m^2 (0.6618), grain growth rate (0.9133), biomass growth rate (0.7736) and harvest index (0.9309). The results suggest that these traits can be utilized as selection criteria for early and late heat stress. Among the different stress parameters, stress tolerance index (r= 0.7303) followed by stress susceptibility index (r= 0.8393) was found to be the best parameter to distinguish the genotypes performing well under both the stresses and non-stress environments.

Key words: Wheat, Heat stress, Stress tolerance index, Stress susceptibility index

Wheat (*Triticum aestivum* L. emend. Fiori & Paol.) is best adopted to cool growing conditions. However this is being increasingly grown in South-East Asia including India, Pakistan, Bangladesh and Nepal where the ambient temperatures exceed the optimum temperature. Therefore heat stress is one of the major constraints of wheat production in many areas of the world. Heat stress at late growth stages is a problem in 40% of wheat areas in the temperate environments (Reynolds *et al.* 2001).

Studies conducted under controlled environments have revealed that long hours of exposure to moderately high temperature as well as short exposure to very high temperature reduces wheat yield. Gradual rise in daily maximum temperature inflicts relatively less damage in comparison to the severe damage caused by sudden temperature build up. Such situations arise under Indian wheat growing environments due to the proximity to the desert and delayed planting.

Wheat grain yield is the product of two major yield components, the number of grains/m^2 and individual grain weight. When the crop is exposed to high temperature before anthesis, reduction in grains occurs via reduction in spike/m^2 and grains/spike (Shipler and Blum 1991). The reduction in grain weight results from reduction in the grain filling duration and rate (Shipler and Blum 1991). The uniqueness of wheat growing environments in India necessitates the search of selection criteria that might be associated with yield under such environments and accelerate developing heat tolerant wheat cultivars. Therefore, this study was conducted to assess the relative efficiency of different selection criteria to distinguish genotypes performing well under stress and non-stress temperature conditions.

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MATERIALS AND METHODS

Nine wheat genotypes including 8 bread wheat lines, viz 'HD 2923', 'RS 911', 'HD 2944', 'HD 2950', 'RS 937', 'PBW 343', 'HD 2851', 'HD 2936' and 'HDR 77' were selected for the present study. The experiment was conducted for 2 seasons (2004-05 and 2005-06) at Experiment Station, Indian Agricultural Research Institute, New Delhi (28°38' N and 77°12' E, 293 m ASL). Three sowing dates; early, optimum and late (15 October, 15 November and 15 December, respectively) were used during the two seasons. Early sowing subjects wheat to heat stress during the early growth stages of the crop, which affects the establishment of the crop and the development of tillers and spikelets. This permits differentiation of genotypes according to their reaction to the early heat stress. The late sowing allows the crop to grow and mature under high temperature and the response of different genotypes to late heat stress can be assessed. Normal cultural practices were followed to raise the experiments. Irrigation was given as per the schedule to avoid any water stress. The experiment was arranged in a randomized complete block design with three replications.

Data on yield and other yield related parameters were subjected to stress related parameters, viz mean productivity (MP), geometric mean productivity (GMP), tolerance (TOL), stress susceptibility index (SSI) and stress tolerance index (STI). The performance of test material under normal (November sowing) conducive to high productivity and stress environments (October and December planting), were taken into account, to work out the stress tolerance parameters. The correlation of yield under normal (Yn) and stress (Ys) environments with stress tolerance parameters were worked out. Different stress tolerance attributes were calculated as:

Stress intensity (SI) = 1- Ys/Yn

Ys = Mean yield in stress environments

Yn = Mean yield in optimum environment

Mean Productivity (MP) = (Ys+Yn)/2 (Rosielle and Hamblin 1981)

Tolerance (TOL) = Yn-Ys (Rosielle and Hamblin 1981)

Stress susceptibility index (SSI) = 1-{Ys/Yn}/SI

Geometric mean productivity (GMP) = Ys × Yn

Stress tolerance index (SSI) = Yn × Ys /Yn^2

RESULTS AND DISCUSSION

Weekly minimum, maximum and mean temperatures during the two cropping seasons are given in the Fig 1. The temperature in the second season was 2-5 °C higher than the first season. This clearly affected grain yield and other related traits. Grain yield in the second season was reduced (by 22.35 %) compared with the first season and is in agreement with Fischer and Maurer (1978), who reported that a 1° C rise in temperature reduced the grain yield by about 4%. In the first season, a reduction of 14.07% was found in the grain yield of early sowing compared to optimum sowing (Table 1). Grain yield along with days to heading, days to anthesis, days to maturity, grain filling duration, biomass, spikes/m^2, grains/spike, harvest index, grain growth rate, grains/ m^2 and thousand grain weight were all reduced in different degree by the early and late sowing. The effect of late heat stress was clearly reflected in the great reduction in almost all the traits measured (Table 1). Grain yield, biomass, grains/m^2, grain growth rate, spikes/m^2, biomass growth rate and vegetative growth rate were more sensitive to heat. A reduction of 22.35% was found in grain yield of the late sowing compared to the optimum sowing. Similar reduction was also found in case of biomass, grains/m^2, grain growth rate and biomass growth rate. Reduction in harvest index, spikes/m^2, thousand grain weight, days to maturity, grain filling duration were significant. During the second season the grain yield in the early heat stress and late heat stress was reduced to 13% and 19%, respectively as compared to the optimum sowing conditions (Table 1). This was due to the fact that the grain yield of the optimum sowing condition in the second season was reduced by 19% as compared to the first season. Significant reduction in the days to heading, days to anthesis, spikes/m^2, biomass, biomass growth rate and thousand grain weights were observed in early sowing of the second season. On the other hand, harvest index, grain growth rate did not record drastic reduction in the early and late heat stress experiments. With the late sowing, all the traits measured showed reduction as compared to the optimum sowing. Across the two seasons, biomass, grains/ m^2, grain growth rate, biomass growth rate and days to heading were more sensitive to heat stress during the early stages of the growth. High temperature late in the season was more detrimental to most of the traits during the two seasons. Biomass, grains/m^2, grain growth rate, days to maturity, grain filling duration and days to heading were negatively affected during both the seasons. Limitation in the source to meet the demand of high sink might have been important besides the big reduction in the grain filling duration especially when compared with that of the early sowing.

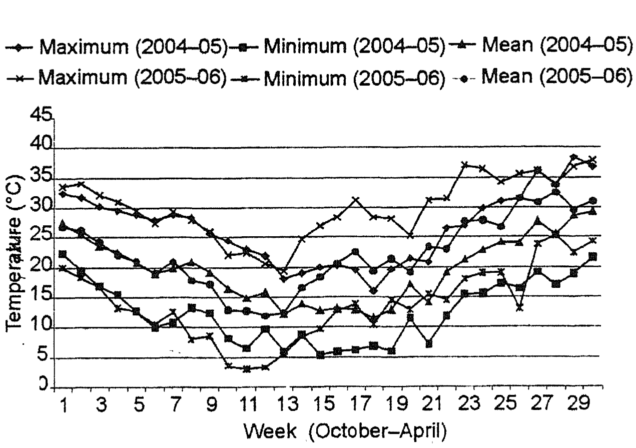

Fig 1 Weekly maximum, minimum and mean temperature during the crop growth years (2004-05 and 2005-06)

Simple correlation was computed between grain yield and other traits of nine genotypes for each of the sowing dates across the two seasons (Table 2). Grain yield was significantly correlated with grain growth duration, biomass, spikes/m^2, harvest index, grain growth rate, biomass growth rate and grains/m^2 across all the three sowing dates during both the seasons. However, the magnitude of the correlations varied with the different dates of sowing. Days to heading, days to anthesis, grains/spike were showing significant correlation with the grain yield only in the early sown and optimum sowing conditions, but not in the late sowing. Thousand grain weights showed significant positive correlation only for the optimum and late sowing conditions. The above results suggests that traits like grain growth duration, biomass, spikes/m^2, harvest index, grain growth rate, biomass growth rate and grains/m^2 are important traits under both early as well as late heat stresses in wheat. The importance of biomass and spikes/m^2 confirmed the earlier reports under similar conditions (Reynolds *et al.* 1998).

Data on stress tolerance parameters are presented in the Table 3. The correlation coefficients of normal season and the stress seasons (early and late) yield with mean productivity (MP), tolerance (TOL), stress susceptibility index (SSI) and stress tolerance index (STI) are given in the Table 4. Based

Table 1 Response of grain yield and other traits of nine wheat genotypes to different dates of sowing

Traits	First season (2004 –05)					Second season (2005–06)				
	Sowing dates			Per cent reduction over optimum		Sowing dates			Per cent reduction over optimum	
	Early	Optimum	Late	Early	Late	Early	Optimum	Late	Early	Late
Grain yield (kg/ha)	3175	3695	2869	14.07	22.35	2613	3016	2445	13.36	18.93
Days to heading	66	85	64	22.10	24.70	76	86	69	11.62	19.76
Days to anthesis	73	94	70	22.34	25.53	80	90	75	11.11	16.66
Days to maturity	126	135	115	6.66	14.81	120	133	107	9.02	19.54
Grain filling duration	34	39	31	12.82	20.51	33	36	30	8.33	16.66
Biomass (kg/ha)	8965	10089	7653	11.14	24.14	6936	7799	6639	11.06	14.87
Spikes/m²	496	521	465	4.79	10.74	426	496	368	14.11	25.80
Grains/spike	47	48	42	2.08	12.50	44	46	41	4.34	10.86
Harvest index (%)	36.2	37.3	34.9	2.94	6.43	37.0	36.8	36.1	2.71	1.90
Grain growth rate (kg/ha/day)	93.2	110.3	83.6	14.23	24.20	70.3	83.6	80.3	1.99	3.94
Biomass growth rate (kg/ha/day)	94.6	114.6	84.0	17.45	26.70	71.3	84.9	75.9	16.01	10.60
Grains/m²	11059	13169	8936	16.02	32.14	9976	10456	8436	4.59	19.31
Thousand grain weight	34.6	39.2	34.3	11.73	12.50	31.6	35.4	30.9	10.73	12.71

Table 2 Correlation coefficients of grain yield and its heat stress intensity (HSI) of nine genotypes with different traits and their HSI

Traits	Grain yield (kg/ha)		
	Early sowing	Optimum sowing	Late sowing
Days to heading	0.6297**	0.5877*	0.3698
Days to anthesis	0.5217*	0.5868*	0.3699
Days to maturity	0.3778	0.2336	0.2236
Grain growth duration	0.6867**	0.5955*	0.5639*
Biomass	0.8067**	0.7192**	0.7456**
Spikes/m²	0.6618**	0.6532**	0.5619*
Grains/spike	0.5387*	0.5632*	0.3623
Harvest index	0.9309***	0.8996**	0.6699**
Grain growth rate	0.9133***	0.9169***	0.8963**
Biomass growth rate	0.7788**	0.6599**	0.8688**
Grains/m²	0.7736**	0.7997**	0.8523**
Thousand grain weight	0.4833	0.7699**	0.6632**

*, **, ***Significant at 0.05, 0.01 and 0.001 levels, respectively

on the mean productivity and geometric mean productivity, genotypes HD 2944, HD 2950, PBW 343 are found to be the best followed by HDR 77 and HD 2936. The mean productivity had very high correlation with normal season and stress season (early and late heat) grain yield. Rosielle and Hamblin (1981) showed that under most yield trials, the correlations between mean productivity and grain yield are positive. Thus the higher mean productivity increases the grain yield and selection based on the MP increases the average performance under both the normal and stress conditions. Similar findings were reported by Golabadi *et al.* 2006. A larger value of TOL represents the relatively more sensitive to stress. Tolerance had high positive correlation with grain yield under optimum conditions, but had negative correlation in stress environments. Therefore, it can not serve as the best selection parameters for the selection of genotypes under normal and stress environments. The smaller the value of SSI, greater is the stress tolerance. The lowest SSI was observed in genotype HD 2923 followed by RS 911, HD 2944, HD 2936, HD 2950 and PBW 343. All these genotypes had higher value of the mean productivity. SSI had high

Table 3 Grain yield per plant and estimates of stress parameters of different genotypes of wheat over different environments

Genotype	Mean productivity		Geometric mean productivity		Tolerance		Stress susceptibility index		Stress tolerance index	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
'HD 2923'	3.127	2.713	4.79	3.70	3.34	3.07	0.266	1.110	4.79	3.70
'RS 911'	3.029	2.533	4.08	3.22	3.10	2.73	0.351	0.816	4.08	3.20
'HD 2944'	2.800	3.233	5.41	5.36	3.42	3.58	0.471	0.850	5.41	5.36
'HD 2950'	2.786	3.400	4.52	5.86	1.33	1.75	0.496	0.693	4.52	5.86
'HD 2936'	2.580	3.600	3.87	6.51	2.98	4.12	0.400	1.056	3.87	6.46
'RS 937'	2.733	3.021	1.33	4.45	2.05	3.21	0.560	0.420	1.80	4.45
'PBW 343'	2.880	3.041	6.59	4.52	1.99	1.31	0.460	0.570	6.51	4.52
'HD 2851'	2.880	3.125	1.70	4.72	3.92	3.28	1.120	0.370	1.70	4.66
'HDR 77'	3.480	2.850	5.99	4.04	3.93	3.09	0.730	0.626	5.99	4.03

Table 4 Correlation coefficient of normal and stress environment grain yield with stress tolerance parameters

Stress tolerance parameters	Grain yield (under normal environment)	Grain yield (kg/ha)	
		Under early heat Stress	Under terminal heat Stress
Stress tolerance	–0.8806**	0.7303**	0.5000*
Stress susceptibility index	0.8869**	0.8393**	0.5301*
Geometric mean productivity	0.6669*	0.6394*	0.6308*
Mean productivity	0.8889**	0.8877**	0.7407**
Stress tolerance index	0.9926**	0.9724**	0.8924**

*, **Significant at 0.05 and 0.01 levels, respectively

positive correlation with grain yield under optimum and stress environments. The results of the present study are in agreement with those of Kirigwi *et. al.* (2004) who reported that selection under optimum condition enables the identification of lines with responsiveness to optimum environment, while selecting under stress environment identifies high yielding lines carrying traits for performance under stress conditions. Therefore, stress susceptibility index can serve as an indication for selecting genotypes with higher yield and higher tolerance to thermal stress. The higher the value of stress tolerance index of a genotype better is the stress tolerance. The genotypes 'HD 2944', 'HD 2950', 'PBW 343' and 'HDR 77' had higher MP, GMP, SSI and STI. Therefore, STI can be utilized for the selection of genotypes with high yield and higher tolerance to heat stress. The STI had high positive correlation with the grain yield under normal and both the stress conditions. The correlation coefficients are useful in finding degree of association with the yield and yield contributing traits. Therefore, it can be concluded that on the basis of the results the stress tolerance index is the best parameter to assess the genotype for high performance in the stress and non-stress conditions. Grain yield under stress (early and later heat) and optimum conditions can be improved by improving traits like grains/m^2, spikes/m^2, biomass, harvest index, grain growth rate and biomass growth rate.

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