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***Full Length Article***

# Differential Response of Wheat Cultivars to Terminal Heat Stress

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## Abstract

Heat stress negatively influences the chlorophyll and grain filling processes in plants. Genotypes showing stay green character and better grain filling under heat stress are better able to cope with the heat stress. This study was aimed at knowing the mechanisms of heat resistance, during reproductive stages (booting stage, heading stage, anthesis stage and post anthesis stage) by monitoring the stay green character, water use efficiency, grain filling rate, grain filling duration, grain yield and harvest index of different wheat cultivars. For this experiment, seeds of wheat cultivars Chakwal-50, C-591, BARS-2009, Dharabi-2011, Sehr-2006, Shafaq-2006, Uqab-2000, Lasani-2008, Faisalabad-2008 and Mairaj-2008 were sown in 10 kg soil filled pots on November 25, 2011. The heat stress was applied at each respective reproductive stage, which continued till maturity. The heat stress was imposed separately at booting, heading, anthesis and post anthesis stages by placing pots in glass canopies with temperature of 4-5°C above than the ambient until maturity. Controlled pots were maintained under well watered conditions at ambient temperature. Heat stress at all the stages drastically reduced the performance of all tested wheat cultivars; severity being higher at booting and heading stages than anthesis and grain filling stages. Cultivar Mairaj-2008 stayed green and took more duration for grain filling, which resulted in the maintenance of grain weight and grain number per spike under stress conditions thus showing more grain yield and water use efficiency. In heat sensitive cultivars (BARS-2009, Shafaq-2006), the imposition of heat increased the grain filling rate with a substantial decrease in grain filling duration. Thus, stay green character and grain filling rate and duration under heat stress may be considered as selection criteria for developing new wheat cultivars for heat resistance during reproductive stages. © 2013 Friends Science Publishers

**Keywords:** Heat stress; Stay green; Grain filling; Wheat

## Introduction

Climate change is severely affecting cereal production across the world (Qin *et al.*, 2002), through increase in $CO_2$ concentration and temperature, resulting in heat stress (Farooq *et al.*, 2011). Climate model predicts that temperature will increase by 1.8-5.8°C at the end of this century (IPCC, 2007) and terminal heat stress will increase in wheat growing regions in near future (Mitra and Bhatia, 2008; Semenov, 2009).

Heat stress is more detrimental especially when it occurs at reproductive and grain filling stages (Hays *et al.*, 2007; Farooq *et al.*, 2011). Heat stress affects photosynthetic capacity of plants (Wahid *et al.*, 2007), causes metabolic limitations (Farooq *et al.*, 2011), promotes the production of oxidative reactive species (Wang *et al.*, 2011), reduces pollen tube development and causes pollen mortality (Saini *et al.*, 2010), encourages ethylene production thus increasing grain abortion (Hays *et al.*, 2007) and causes oxidative damage to the chloroplast resulting in minimum grain yield (Farooq *et al.*, 2011).

The leaf senescence rate is important component of stay-green (Harris *et al.*, 2007). Heat stress at reproductive stages causes the leaf senescence and thus progressive loss of leaf area especially during reproductive development (Nooden, 1988). Elevated temperature at reproductive stage further triggers the senescence-related metabolic changes in wheat (Paulsen, 1994). Heat stress accelerates leaf senescence, inhibits biosynthesis of chlorophyll (Tewari and Tripathy, 1998) and accelerates the breakage of thylakoid components (Harding *et al.*, 1990).

Heat stress also disturbs the grain filling in plants through reducing grain weight and grain number (Wollenweber *et al.*, 2003; Schapendonk *et al.*, 2007), resulting in less grain yield (Mullarkey and Jones, 2000; Tewolde *et al.*, 2006). For example, increase of just 1◦C temperature above 15–20°C at grain filling stage can reduce grain weight by 1.5 mg per day (Streck, 2005). Although elevated temperatures promote the growth (Kase and Catsky, 1984), it reduces the phenological duration of various crop stages, which is not compensated by the enhanced growth rate (Wardlaw and Moncur, 1995; Zahedi and Jenner, 2003). Limited grain yield due to heat stress at reproductive stages may be attributed to minimum time duration for resource capture (Wheeler *et al.*, 1996a, b). Heat stress shortens the grain filling duration but accelerates the grain filling rate (Dias and Lidon, 2009). For instance, an increase of 5°C in temperature above 20°C shortened the

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grain filling duration by twelve days in wheat with increase in grain filling rate (Yin *et al.,* 2009).

Various plant species have evolved different mechanisms to cope with heat stress. These mechanisms includes rolling, shedding and thickening of leaves (Wahid *et al.,* 2007), reduction in leaf size and duration of growth, transpirational cooling and other adjustments in morphology (Wahid *et al.,* 2007). Maintenance of stay green character during heat stress is also considered a best indicator of heat tolerance (Fokar *et al.,* 1998), while stay green genotypes are better able to maintain grain filling in elevated temperatures (Farooq *et al.,* 2011), because rate of senescence is low in stay green genotypes and so grain filling is less affected by elevated temperature.

However, maintenance of grain weight during heat stress is also an indication of heat tolerance during grain filling period (Tyagi *et al.,* 2003; Singha *et al.,* 2006). High potential grain weight in heat stress may also be a better criterion for selection of cultivars for heat tolerance (Dias and Lidon, 2009). Halford (2009) opinioned that for better adaptation of crop varieties in climate change conditions, it is necessary to identify the mechanism of heat tolerance and crop responses to elevated temperature.

Although screening for heat resistance in wheat considering different traits has been done in the past but limited work is done to screen wheat cultivars for heat resistance at reproductive stage on the basis of their stay green character and grain filling rate. The objective of this study was to screen wheat cultivars for terminal heat resistance on the basis of their stay green character, grain filling and water use efficiency.

## Materials and Methods

The experiment was conducted in soil-filled pots placed in the glasshouse facility of University of Agriculture, Faisalabad (latitude 31°N, longitude 73°E and altitude 184.4 masl), Pakistan during 2011-2012. Seed of wheat cultivar Mairaj-2008 were obtained from Regional Research Institute Bahawalpur. Seeds of wheat cultivars C-591, Uqab-2000, BARS-2009, Dharabi-2011 and Chakwal-50 were obtained from Barani Agricultural Institute Chakwal. Seeds of wheat cultivars like Sehr-2006, Shafaq-2006, Fsd-2008 and Lasani-2008 were obtained from Wheat Research Institute, AARI, Faisalabad, Pakistan. Individual pot was weighted and the pots were filled with 10 kg soil. Experimental soil was sandy loam in soil texture and possessed following properties (pH= 8.1; EC= 0.33 dS $m^{-1}$; Organic matter= 0.95%; Total nitrogen= 0.060%; Available phosphorous= 4.9 ppm; Exchangeable potassium= 167 ppm)

Experiment was laid down in Completely Randomized Design in factorial arrangement with three replications. Crop was sown in soil-filled pots on 25 November, 2011. Initially, 10 seeds were sown in each pot, which were thinned to six plants per pot after complete emergence. Fertilizers were applied at 0.5-0.45-0.38 N-P-K g/pot using urea (46% N), diammonium phosphate (DAP) (18%N, 46% $P_2O_5$) and sulfate of potash (50% $K_2O$) as sources of fertilizer. Whole of the phosphorous, potassium and nitrogen was applied as basal dose.

The heat stress was imposed at booting stage, heading stage, anthesis stage and post anthesis stages by placing pots in glass canopies with temperature of 4-5°C above than the ambient until maturity. Controlled pots were maintained under well watered conditions at ambient temperature. Weather data during the experimentation is given in Table 1.

Plant height of all plants from each pot was taken at maturity and averaged. Five spikes were selected at random from each pot and their length was measured with a ruler and averaged. Chlorophyll content was measured with the help of chlorophyll meter (CCM 200 plus). Clamped the meter over leafy tissue, and receive an indexed chlorophyll content reading (-9.9 to 199.9) in less than 2 sec. Three spikes were randomly taken from each pot after the start of anthesis with 7 days interval to record grain filling rate. The grains from all the three spikes were isolated and were oven dried. Then the grain filling rate (GFR) was calculated from the following formula.

$$GFR= (W_2 - W_1) / (t_2 - t_1)$$

Where, $W_1$ and $W_2$ are total dry weight of spikes at the first and second harvests, while $t_1$ and $t_2$ are the first and second intervals (in days) at which dry matter was measured.

Number of days from heading to physiological maturity was taken as grain filling duration. Grains from the same five spikes were threshed manually and counted separately. A sub-sample of 100-grains was taken from each pot then weighted on an electric balance and 100-grains weight was calculated. The crop was harvested, sundried for a week and total wheat biomass of sun-dried samples was recorded for each treatment by using an electric balance. The crop was threshed manually. Grain weight for each treatment was recorded by using an electric spring balance in grams. Harvest index was calculated as the ratio of grain yield to total (above ground) biological yield**.** Water use efficiency (WUE) was calculated as the ratio between grain yield harvested and water used (Viets, 1962). Transpiration efficiency was calculated as the ratio between biological yield harvested and water used.

Data collected on all parameters was analyzed statistically by using MSTAT-C software on computer (Crop and Soil Sciences Department of Michigan University, USA). Least significance difference (LSD) test at 5% probability level was applied to compare the treatments means (Steel *et al.,* 1996).

## Results

Analysis of variance indicated that heat stress at different reproductive phases significantly affected all the agronomic, physiological and yield traits of all wheat cultivars. Similarly, different reproductive stages significantly differed in the all the studied traits when heat stress was imposed (Table 2). However, the interaction of different reproductive stages with the wheat cultivars was non-significant in all the studied parameters (Table 2). Data regarding growth and yield attributes are given in Table 3. Maximum plant height was observed in Uqab-2000 followed by Dharabi-2012, Sehr-2006 and C-591, while it was minimum in Lasani-2008 followed by BARS-2009 and Shafaq-2006. Maximum spike length was observed in Sher-2006 while it was the lowest in C-591. Maximum chlorophyll content index was observed in Mairaj-2008 followed by C-591 and Chakwal-50 while it was the minimum in BARS-2009. A highest grain filling rate was recorded in Uqab-2000 and BARS-2009, while it was the lowest in Lasanai-2008 followed by C-591. Grain filling duration was longer in Mairaj-2008, Chakwal-50, Faisalabd-2008 and Lasani-2008, while it was shorter in BARS-2009 and Shafaq-2006. Grains per spike were highest in Mairaj-2008 and Sehr-2006, while the lowest in BARS-2009. A maximum grain weight was recorded in Mairaj-2008 while it was the lowest in Shafaq-2006 (Table 3). Biological yield and transpiration rate were highest in Dharabi-2011 but the lowest in Mairaj-2008. Maximum grain yield, water use efficiency and harvest index were noted in Mairaj-2008 followed by Chakwal-50 while these were the minimum ones in Shafaq-2006.

## Discussion

In this study heat stress applied at all reproductive stages negatively influenced the agronomic, physiological and yield related traits in all cultivars than control (well watered + ambient temperature). Heat stress at booting and heading stages markedly affected all the parameters than heat stress at anthesis and grain filling stages. The possible reason for a greater yield decline at booting and heading stage may be prolonged exposure of wheat cultivars to heat stress. Wheat cultivars suffered less yield decline when heat stress was imposed at anthesis and grain filling stages due to brief exposure to heat stress.

Poor performance of wheat cultivars in heat stress conditions at reproductive stages may be due to increased production of oxidative reactive species (Wang *et al.*, 2011), reduced pollen tube development and more pollen mortality (Saini *et al.*, 2010), thereby leading to enhanced grain abortion (Hays *et al.*, 2007), reduced grain weight and grain number (Wollenweber *et al.*, 2003; Schapendonk *et al.*, 2007). Minimum grain yield in wheat cultivars due to heat stress at reproductive stages may be due to least duration for resource utilization during grain filling (Dias and Lidon, 2009; Yin *et al.*, 2009).

Maximum grain yield, water use efficiency and harvest index was observed in Mairaj-2008. This improvement in yield related parameters in this wheat cultivar may be attributed to its stay green character and better grain filling in heat stress conditions. Genotypes which possess stay-green character are considered best regarding their grain filling in elevated temperature (Farooq *et al.*, 2011). In a study, Kumar *et al.* (2010) reported that stay green or delayed senescence plays a crucial role in grain development in wheat when assimilates are limited, and stay green cultivars are well adapted to heat-stressed conditions.

Poor grain filling and less grain yield in heat sensitive cultivars viz. BARS-2009 and Shafaq-2006 may be due to rapid leaf senescence in such genotypes. Elevated temperature at reproductive stage accelerates the senescence-related metabolic changes in wheat (Paulsen,

**Table 1:** Weather data during the wheat season 2011-2012

| | Maximum temperature (°C) | Minimum temperature (°C) | Relative humidity (%) | Rainfall (mm) | Sunshine hours |
|---|---|---|---|---|---|
| November | 27.6 | 13.3 | 61.2 | 0.00 | 8.5 |
| December | 20.9 | 4.2 | 59.1 | 0.00 | 6.9 |
| January | 17.3 | 3.2 | 69.6 | 3.80 | 7.2 |
| February | 18.4 | 4.6 | 62.1 | 8.00 | 7.3 |
| March | 25.9 | 11.7 | 58.2 | 1.50 | 8.3 |
| April | 32.7 | 18.0 | 59.1 | 10.50 | 9.2 |

Source: Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan

**Table 2:** Analysis of variance for the effect of terminal heat stress on agronomic, yield-related and physiological traits of different wheat cultivars

| SOV | DF | Mean sum of squares | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PH (cm) | SL (cm) | CCI | GFR (g $day^{-1}$) | GFD (days) | GPS | 100-GW (g) | BY (g/pot) | GY (g/pot) | HI (%) | WUE (kg $m^{-3}$) | TE (g $kg^{-1}$) |
| Varieties (V) | 9 | 185.34 ** | 6.22 ** | 58.86 ** | 0.001 * | 8.50 ** | 67.21 ** | 4.85 ** | 106.20 ** | 73.71 ** | 543.41 ** | 0.028 ** | 0.044 ** |
| Heat stress (H) | 4 | 410.57 ** | 8.51 ** | 72.77 ** | 0.005 ** | 273.68 ** | 381.71 ** | 12.49 ** | 619.96 ** | 226.82 ** | 918.66 ** | 0.056 ** | 0.054 ** |
| V × H | 36 | 29.93 | 1.02 | 14.42 | 0.001 | 1.59 | 24.79 | 0.83 | 23.54 | 6.64 | 40.36 | 0.002 | 0.010 |
| Error | 100 | 31.15 | 0.77 | 10.69 | 0.001 | 1.96 | 26.34 | 1.20 | 16.53 | 7.00 | 39.91 | 0.003 | 0.007 |
| Total | 149 | | | | | | | | | | | | |

SOV = Source of variation; DF = Degree of freedom; ** = Significant at p 0.01; PH= Plant height; SL= Spike length; CCI = Chlorophyll content index; GFR= Grain filling rate; GFD= Grain filling duration; GPS= Grains per spike; 100-GW= 100-Grain weight; BY= Biological yield; GY= Grain yield; HI= Harvest index; WUE= Water use efficiency; TE= Transpiration efficiency

**Table 3:** Effect of terminal he stress on agronomic, yield-related and physiological traits of different wheat cultivars

| Treatments | PH (cm) | SL (cm) | CCI | GFR (g $day^{-1}$) | GFD (days) | GPS | 100-GW (g) | BY (g/pot) | GY (g/pot) | HI (%) | WUE (kg $m^{-3}$) | TE (g $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wheat cultivars | | | | | | | | | | | | |
| Mairaj-2008 | 76.1 bc | 10.93 ab | 27.33 a | 0.12 ab | 29.1 a | 21.28 a | 3.71 a | 32.05 f | 9.7 a | 28.88 a | 0.19 a | 0.66 f |
| C-591 | 80.0 ab | 8.51 e | 25.89 ab | 0.08 c | 27.9 bc | 17.83 abc | 2.27 cd | 33.00 ef | 3.6 d | 10.92 d | 0.07 d | 0.68 ef |
| Chakwal-50 | 76.7 bc | 10.23 d | 24.98 abc | 0.11 b | 29.3 a | 19.62 ab | 3.02 abc | 34.48 def | 8.8 ab | 19.34 bc | 0.17 ab | 0.71 c-f |
| Dharabi-2011 | 82.4 a | 10.85 a-d | 23.19 cd | 0.12 ab | 28.4 abc | 19.85 ab | 2.82 bcd | 41.01 a | 7.3 bc | 18.60 bc | 0.15 bc | 0.84 a |
| Sehr-2006 | 81.3 a | 11.15 a | 25.10 abc | 0.12 ab | 29.3 a | 21.07 a | 3.48 ab | 37.51 bc | 7.9 abc | 19.16 bc | 0.17 ab | 0.77 bc |
| BARS-2009 | 74.6 c | 10.43 bcd | 20.31 e | 0.13 a | 27.5 c | 14.38 c | 3.57 ab | 35.48 b-e | 6.1 c | 16.38 c | 0.12 c | 0.73 b-e |
| Uqab-2000 | 83.5 a | 10.85 a-d | 23.37 cd | 0.13 a | 28.9 ab | 16.77 bc | 3.30 ab | 38.33 ab | 6.9 bc | 17.87 c | 0.14 bc | 0.78 ab |
| Fsd-2008 | 76.4 bc | 10.90abc | 23.91 bcd | 0.12 ab | 29.3 a | 19.65 ab | 3.31 ab | 37.19 bcd | 7.1 bc | 22.63 b | 0.13 bc | 0.76 bcd |
| Lasani-2008 | 73.9 c | 10.28 cd | 24.62 bc | 0.07 c | 29.3 a | 18.62 ab | 3.58 ab | 36.74 bcd | 8.6 ab | 22.77 b | 0.14 bc | 0.75 bcd |
| Shafaq-2006 | 74.9 c | 10.26 cd | 22.12 de | 0.12 ab | 27.6 c | 20.24 ab | 2.05 d | 34.68 c-f | 2.7 d | 7.56 d | 0.05 d | 0.71 def |
| *LSD Value* | 4.04 | 0.64 | 2.37 | 0.02 | 1.02 | 3.72 | 0.80 | 2.95 | 1.92 | 4.58 | 0.03 | 0.05 |
| Stage of heat stress | | | | | | | | | | | | |
| Control | 82.1 a | 11.08 a | 26.49 a | 0.13 a | 31.5 a | 23.17 a | 4.04 a | 43.01 a | 10.1 a | 23.05 a | 0.15 a | 0.78 a |
| Booting stage | 72.1 c | 10.02 c | 22.29 c | 0.09 b | 23.5 d | 14.89 c | 2.26 c | 30.93 d | 3.2 d | 10.50 c | 0.07 c | 0.68 c |
| Heading stage | 77.6 b | 10.37 bc | 23.30 bc | 0.10 b | 28.9 c | 16.08 bc | 2.89 b | 33.30 c | 5.0 c | 14.87 b | 0.11 b | 0.71 bc |
| Anthesis stage | 79.7 ab | 10.71 ab | 24.32 b | 0.12 ab | 29.8 b | 18.67 b | 3.17 b | 36.42 b | 7.5 b | 20.64 a | 0.16 a | 0.77 a |
| Grain filling stage | 78.3 b | 10.03 c | 24.01 b | 0.12 ab | 29.6 bc | 21.83 a | 3.20 b | 36.58 b | 8.4 b | 22.98 a | 0.17 a | 0.75 ab |
| *LSD Value* | 2.86 | 0.45 | 1.68 | 0.01 | 0.72 | 2.63 | 0.56 | 2.08 | 1.36 | 3.24 | 0.02 | 0.04 |

Means sharing the same case letter for main effects do not differ significantly at $p < 0.05$; PH= Plant height; SL= Spike length; CCI = Chlorophyll content index; GFR= Grain filling rate; GFD= Grain filling duration; GPS= Grains per spike; 100-GW= 100-Grain weight; BY= Biological yield; GY= Grain yield; HI= Harvest index; WUE= Water use efficiency; TE= Transpiration efficiency

1994). Moreover, heat stress inhibits biosynthesis of chlorophyll (Tewari and Tripathy, 1998), with increase in leaf senescence. Grain weight and grains per spike were also highest in heat resistant cultivar i.e. Mairaj-2008. Maintenance of grain weight during heat stress is also an indication of heat tolerance during grain filling period (Tyagi *et al.,* 2003; Singha *et al.,* 2006) and high potential grain weight in heat stress may be important criteria for selection of cultivars for heat tolerance (Dias and Lidon, 2009).

In conclusion, heat stress at reproductive stages in all wheat cultivars drastically affected agronomic, physiological and yield related traits; severity being higher at booting and heading stage than anthesis and grain filling stage. As a whole, heat stress at booting, heading, anthesis and post anthesis stages caused a yield reduction of 41.4-88.4%, 22.1-66.8, 8.4-48, 7-31.1%, respectively than control (well watered + ambient temperature). Better grain filling and stay green character resulted in increased grain weight, grain per spike and grain yield of wheat cultivar Mairaj-2008. Retention of leaf chlorophyll for longer times emerged as important criterion of heat tolerance, which can be potentially used in breeding programs.

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