Field evaluation of sensitivity of wheat to high temperature stress near flowering and early grain set

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Abstract

A field study was undertaken at the Waite campus, Adelaide in 2009 to assess the effect of heat stress on four wheat genotypes. Wheat plants were exposed to heat at the green anther stage [Zadoks growth stage (ZGS) 57-59; H_1] and at 7-10 days after anthesis (ZGS 73-75; H_2). The heat treatment was applied on a single day in a purpose-built (1.5 x 0.5 m) transparent heat chamber. The temperature inside the chamber was increased gradually as a step function to a maximum of 35^{0}C, which was maintained for 3 h. Thereafter the temperature was allowed to decrease steadily down to the ambient temperature. This one-day heat event caused a significant decrease in individual grain mass (IGM), grain set and grain yield. As compared to the unheated control, exposure to H_1 and H_2 decreased grain yields by 18 and 19% in Excalibur, by 19 and 22% in Krichauff, by 21 and 26% in Gladius and by 35 and 30% in Janz. There was a strong correlation between wheat grain yield and IGM at maturity (r = 0.70). As compared to the unheated control, heat stress caused only a small reduction in grain set in the floret *a* (0.3%) and *b* (2.3%) but there was a significant reduction in grain set in florets *c* (16.5%) and *d* (41.4%). The results clearly indicate that a single day heat-stress event during the reproductive development of wheat can cause a significant reduction in grain yield.

Key Words

Wheat, heat stress, genotype

Introduction

Previous research has shown that exposure of wheat (*Triticum aestivum* L.) to heat stress (35~40^{0}C) during early reproductive development can damage fertilization, reduce grain filling, IGM and grain yield (Stone and Nicolas 1995; Wollenweber et al. 2003). Many important physiological and biochemical processes in wheat are impaired by heat stress (Wahid et al. 2007). Photosynthesis is among the most sensitive of the processes affected by high temperature in wheat. The grain-filling rate in cereals is dependent on two main carbon resources: current assimilates from photosynthesis and water-soluble carbohydrates (WSC) transported to the grain from leaves, stem and ear (Yang and Zhang 2006). van Herwaarden et al. (1998) showed that if WSC storage was high then the adverse effects of terminal drought and heat could be offset by increased remobilization. Therefore, high WSC concentration is considered to be a potentially useful trait for improving grain weight and yield in water-limited wheat production environments (Foulkes et al. 2007). The ongoing debate on global warming and the succession of years with above-average temperatures in Australia have increased concerns about the impact of heat stress on crop yields, including wheat yield. Farmers and scientists have raised questions about the impact of brief heat-stress events on crop yield, their potential interaction with soil water and whether they will become more common in the future.

Almost all previous research on heat stress has been undertaken under controlled-environment conditions. The response of crop plants to heat stress under controlled environment conditions could be quite different from that in the field due to much greater soil volume available for root exploration. There is an urgent need to develop an efficient methodology to simulate heat-stress events in the field so their effects on crop growth and yield can be examined. Therefore, the present research programme was undertaken with the aims of (i) developing a methodology to impose heat-stress conditions in the field to identify heat tolerant genotypes, (ii) identifying the impact of short-term heat-stress events on floret sterility, grain-fill pattern and yield.

Methods

Four wheat genotypes (Excalibur, Krichauff, Gladius and Janz) were sown in the field at the Waite campus

of the University of Adelaide on June 24, 2009 and harvested on November 19, 2009. The site has a warm summer and cool winter and the area receives 533 mm total annual rainfall, about 77% of which occurs from April to October. Mean minimum and maximum temperatures during the wheat (June to November) season in 2009 were 11.2 and 20.5^{0}C, respectively. The study was laid out in a split-plot design with four replications having four wheat genotypes in the main plots and heat-stress treatments in the sub plots. Wheat genotypes were exposed to a single-day heat event at two different stages, viz. green anther stage [Zadoks growth stage-(ZGS) 57-59; H_1], and 7-10 days after anthesis (ZGS 73-75; H_2) and some plots were maintained as unheated controls. Heat stress (35^{0}C max; day) was applied using purpose-built (1.5 x 0.5 m) transparent heat chambers which were placed over the crop rows. Four chambers were used each day on the same genotype. Each chamber was heated by a single heater connected to a power generator. Temperature and relative humidity inside the chambers were monitored with Tinytag loggers placed at canopy height. The temperature inside the chamber was increased gradually as a step function to a maximum of 35^{0}C, which was maintained for 3 h. Thereafter the temperature was allowed to decrease steadily down to the ambient temperature. At the end of the day, the heat chambers were removed. Each plot was 1.5 x 0.5 m^2 with three rows of each genotype. Two crop rows in each plot were heated as per the treatments. Supplementary N (62 kg/ha) and P (20 kg/ha) fertilisers were applied as urea and diammonium phosphate (DAP) in three equal instalments 30, 45 and 60 days after seeding. One manual weeding was done at maximum tillering stage to control weeds. The experiment was sprayed with a fungicide to control rust infestation during heading. Phenological development of the crop was monitored on tagged plants using the Zadoks Decimal Code (Zadoks et al. 1974). Three primary spikes were harvested from each plot to study the grain-growth pattern; harvests occurred at 7 days interval, starting at 7 DAA and concluding at 35 DAA. A total of twelve grains per spike were removed from the florets *a* and *b* (see below) of the central three spikelets. Before weighing, grain samples were oven-dried at 80^{0}C for 48 h. At maturity three primary tagged spikes per plot were sampled for sterility mapping. Grains were removed from all florets of a spikelet individually. The two basal left and right florets were labelled as *a* and *b* and distal two florets labelled as *c* and *d* respectively. For yield estimation, wheat was harvested by cutting a 0.125 m^2 portion in the middle of each plot. Data on the grain-growth study, sterility mapping, WSC (not reported), leaf senescence pattern (not reported), yield and yield contributing characters were collected and analysis of variance (ANOVA) performed by using GenStat.

Results

Grain growth pattern

There was no detectable influence of heat stress on individual grain mass (IGM) until 14 DAA (Fig. 1). Thereafter, the heat treatments tended to reduce grain growth rate and final individual grain mass (IGM) compared to the unheated control.

The impact of heat stress on IGM was very similar for plants exposed to heat at the green anther stage (H_1) or at 7 to 10 DAA (H2). There was no significant difference in the IGM between the heat treatments and the unheated control until 28 DAA in Excalibur and 35 DAA in Krichauff whereas in Gladius and Janz, heat-stressed plants had significantly lower IGM from 21 DAA. Finally, IGM at maturity of all the cultivars was reduced by heat-stress events applied near flowering, which is consistent with previous reports (Tashiro and Wardlaw 1989; Randall and Moss 1990). Compared to the unheated control, reduction rate in IGM by heat stress in Janz was higher than the other genotypes, followed by Gladius. The decrease in grain mass in heat-treated plants was caused by lower rate of grain filling which could be related to lower stem reserves and rapid senescence of flag leaf (data not presented). The stress may affect cell division in the early stages of grain growth and this can also limit grain size.

Sterility mapping

On an average, as compared to the unheated control, heat stress caused only a small reduction in grain set in florets *a* (0.3%) and *b* (2.3%) but there was a significant reduction in grain set in florets *c* (16.5%) and *d* (41.4%). In wheat, grain set starts from the middle of a spike and progresses towards the apex and also the base of the spike (Mishra and Mohapatra 1987). Sterility mapping showed that grain set in florets *c* and *d* was reduced in the heat-treated plants. As compared to the unheated control, the maximum reductions of grain set were recorded in Janz at H_1 (30.2% in florets *c* and 56.7% in florets *d*) (Table 1). In the case of the H_2 heat treatment, the highest percentage of floret sterility (58.1%) was also observed in florets *d* of Janz. Stone and Nicolas (1995) stated that floret or grain abortion was generally avoided by starting heat treatment no earlier than 10 DAA. This increase in spikelet sterility in wheat could be related to reduced pollen viability by heat stress or inadequate supply of assimilates during grain filling. All varieties selected for this study are mid-maturity types, therefore a small difference in flowering time is unlikely to explain large differences between them in sensitivity to heat stress.

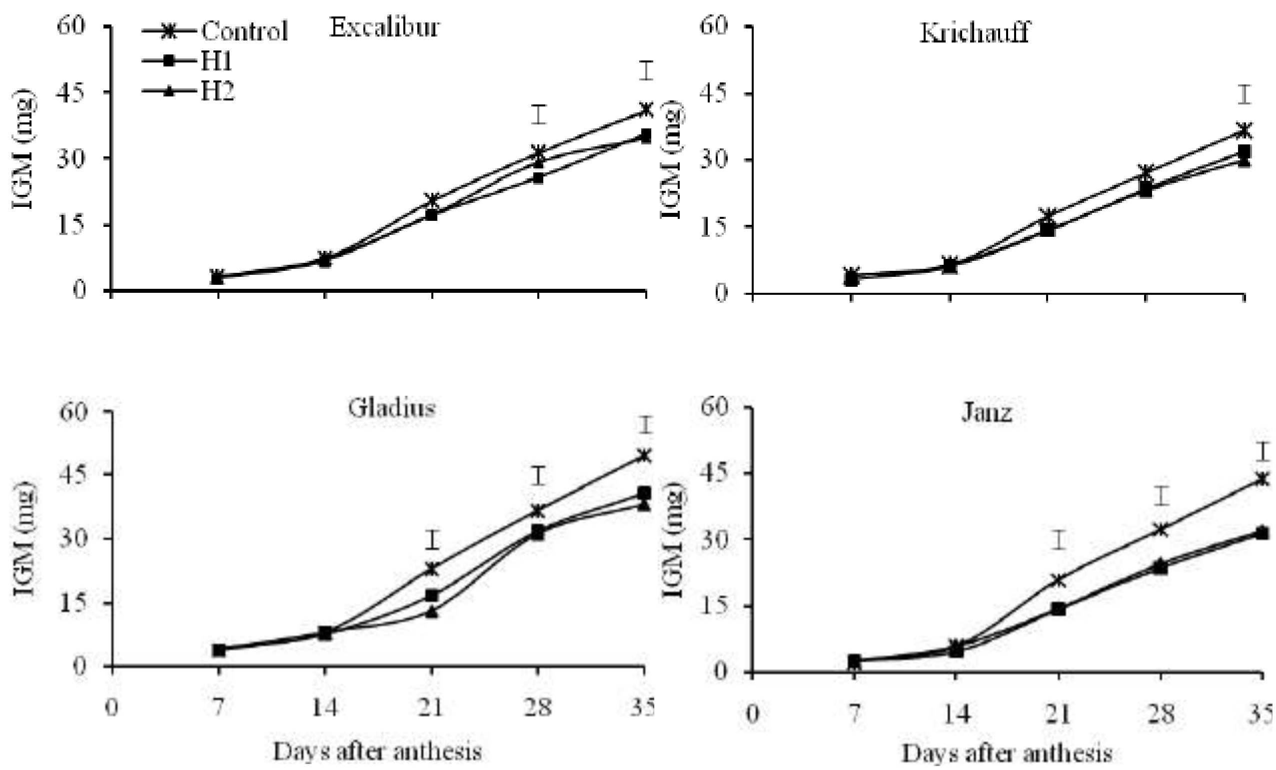

Figure 1. Interaction effects of genotype and heat shock on the grain growth of wheat. Error bar represents the LSD value (*P = 0.05*).

Table 1. Effect of heat stress at either ZGS 57-59 (H_1) or ZGS 73-75 (H_2) on percentage reduction in grain set in different florets of the main stem ear, compared to unheated control.

% Reduction in grain set in different florets

		H_1				H_2		
Genotype	Floret *a*	Floret *b*	Floret *c*	Floret *d*	Floret *a*	Floret *b*	Floret *c*	Floret *d*
Excalibur	0.5	4.9	24.0	34.9	0.5	1.2	16.2	45.6
Gladius	0	0	14.8	42.9	0	3.6	18.2	30.4
Janz	0.5	6.5	30.2	56.7	1.3	1.9	8.0	58.1
Krichauff	0	0	12.5	41.7	0	0.5	9.4	19.7

Grain yield

The one-day heat event caused a significant decrease in IGM at maturity, grain set and grain yield of wheat. Compared to the unheated control, exposure to H_1 and H_2 decreased grain yields by 18 and 19% in Excalibur, by 19 and 22% in Krichauff, by 21 and 26% in Gladius and by 35 and 30% in Janz (Fig. 2).

Superior heat tolerance of Excalibur is consistent with a previous report of Ristic et al. (2008).There was a significant positive correlation (r = 0.70) between wheat grain yield and IGM at maturity indicating IGM was a strong contributor to grain yield (Fig. 3) which is in agreement with the findings of Tyagi et al. (2003). IGM of all four genotypes decreased in response to heat treatments. The greatest reduction (22%) of IGM was in Janz. Wollenweber et al. (2003) reported that individual grain weight declined by 45% with heat stress applied at anthesis. A lack of significant correlation between grain yield and percentage fertile *a* florets (r = 0.14) and fertile *b* florets (r = 0.10) could indicate greater tolerance to heat stress than later-order florets. By contrast, there was strong positive correlation between grain yield and percentage fertile *c* and *d* florets (r = 0.37 and 0.55 in the florets *c* and *d*, respectively). These observations indicated that the reduction in grain set due to heat stress in the florets *c* and *d* contributed to yield reduction in all the cultivars. Future research on selection of lines with superior heat tolerance should focus on IGM and sterility of florets *c* and *d*.

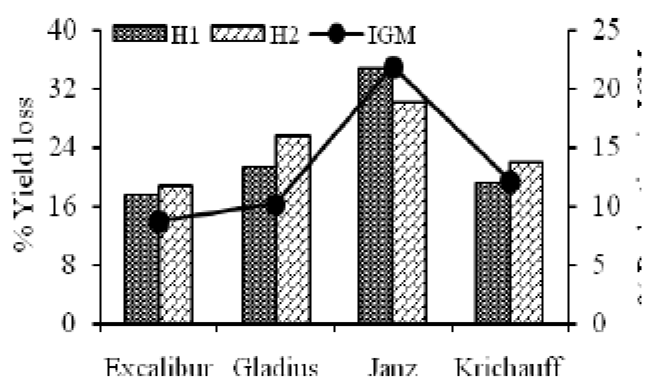

Figure 2. Effect of heat stress on percentage reduction in grain yield and IGM (average of H_1 and H_2) as compared to unheated control.

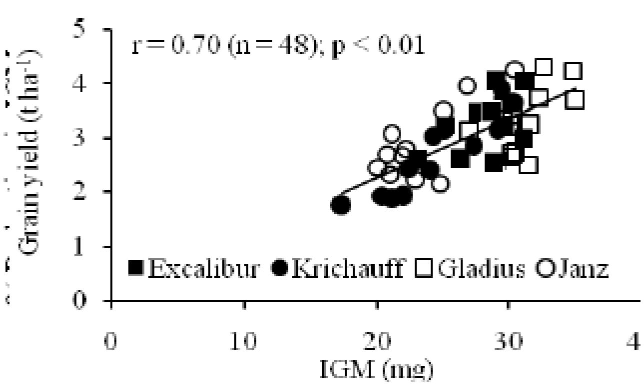

Figure 3. Relationship between grain yield and individual grain mass (IGM) in wheat.

Conclusions

The results of the study showed that the bread wheat genotypes Excalibur and Krichauff had a better ability to tolerate heat stress than Gladius and that Janz was the most sensitive variety. A single day heat-stress event during the reproductive development of wheat can cause a significant reduction in grain yield due to reduction in IGM and grain set in florets *c* and *d*. The methodology developed here can be used under field conditions to impose heat stress and identify heat tolerant genotypes.

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