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Study of yield components under heat stress conditions in wheat

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Abstract

High temperature tolerance can be characterised by measuring various plant productivity traits in different developmental stages. The present work investigated the effect of exposure to high temperature (30-35°C) at first node appearance, during early embryo development and in the grain-filling stage on the yield parameters of two winter wheat varieties. Periods of high temperature had diverse effects on wheat plants in different phenophases. The greatest differences between the various developmental stages were found for grain number, grain yield and thousand-kernel weight. Heat stress was demonstrated to have the least effect on total grain number and number of grains per spikelet on the main spike during the grain-filling period. The most pronounced reductions in the traits examined were detected when heat stress was applied during the early embryo development stage.

Keywords

Global warming, high temperature, *Triticum aestivum*, yield parameter

Introduction

An increase in productivity under heat stress conditions will require the development and selection of wheat cultivars tolerant to high temperatures. Heat stress may cause considerable damage to both the length of vegetation period and yield components, but the extent of the damage is greatly influenced by the development stage in which the plants are subjected to high temperatures.

The temperature is of key importance for plant development, influencing the rate of tillering, the appearance of the nodes, flowering and even grain filling. Each phenophase has a specific temperature range within which it takes place normally to the benefit of the whole plant. If temperature conditions are unfavourable, the physiological processes may be defective, with negative consequences for both vegetative and generative developmental processes. Individual winter wheat genotypes respond differently to the exposure to high temperature in various developmental stages.

Satisfactory tillering is critical for the development of a normal stand. The rate of tillering is greatly dependent on temperature, though it also depends in part on genetic factors. The appearance of the first node is influenced to the greatest extent by temperature and nutrient and water supplies. Very high temperatures, especially when accompanied by water deficit, may accelerate first node appearance excessively, resulting in stunted stems. Exposing cereals to extreme temperatures during flowering may have a damaging effect on fertilisation and grain development, leading to lower yields (PORTER 2005). In response to higher temperatures flowering and ripening are accelerated, with a significant reduction in the number of days to the boot stage, heading, flowering and maturity (RAHMAN et al. 2009). Heat stress at the beginning of flowering or during spikelet development reduces the number of potential grains. The weight of mature grains was found to be most sensitive to heat stress occurring early in the grain-filling period, becoming progressively less sensitive in later stages (STONE and NICOLAS 1995a). Stress may also be critical when it occurs during grain filling, as it may result not only in a reduction in the extent of grain filling (WARDLAW and MONCUR 1995), but also in more rapid cell death and in the earlier occurrence of harvest ripeness.

Research on the effects of exposure to heat stress in different phenophases is of outstanding importance, as the increasingly frequent occurrence of periods with extreme weather conditions means that wheat fields in Hungary may be affected not only in very early stages of development but also after heading. Heat stress may thus be decisive not only for grain filling, but also for the success of fertilisation and grain formation. One of the main aims of the present work was thus to determine the effects of high temperature during various phenophases on the yield potential of wheat.

Material and Methods

Three heat stress studies were carried out under controlled conditions in a climatic chamber on two winter wheat varieties, i.e. 'Plainsman V' (USA) and 'Mv Magma' (H), which have widely different genetic backgrounds. The plants were exposed to heat stress at a different stage of development: (i) at shooting in the 8th week; (ii) at early grain development, i.e. 6 days after heading; (iii) at grain-filling, i.e. 12 days after heading. An untreated control was included at each phenophase.

The germinated seeds were vernalised in peat pots for 45 days at 4°C with low light intensity and short daylength. The plants were then grown at controlled temperature with daily watering and a twice-weekly supply of nutrients (Volldünger Solution, Linz, Austria) in tap-water until the start of the stress treatment. High temperature was applied for 15 days under the conditions described in *Table 1* (TISCHNER et al. 1997).

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Table 1: **Conditions applied in the heat stress experiments at three developmental stages**

Treatment	Control			Heat stress		
Growth stage[1]	SH	EG	GF	SH	EG	GF
Day/night temp.	17/13°C	19/25°C	24/20°C	30/20°C	35/20°C	35/20°C
Growing/stress conditions	Phytotron	Greenhouse[2]	Phytotron	Phytotron light intensity: 350 µmol m^{-2} s^{-1}		

[1] SH, shooting (Zadoks 32); EG: early grain development (Zadoks 71-73); GF, grain filling (Zadoks 75) (TOTTMAN and MAKEPEACE 1979)

[2] Plants heading at approximately the same time were transferred to the phytotron for heat treatment on the 6th day after heading and then returned to the greenhouse for further growth

When harvest maturity was reached, the grain yield, biomass, thousand-kernel weight, grain number and harvest index were recorded for control and heat-stressed plants. Two-factorial analysis of variance was used with replications for the statistical evaluation of the data (KUTI et al. 2008).

Results and Discussion

The response of winter wheat to high temperatures is influenced to a decisive extent not only by the intensity and duration of the heat stress but also by the developmental stage of the plants. High temperature during the most sensitive phenophases (first node appearance, early embryo development and grain filling) had very different effects on the wheat yields (*Table 2*).

The biomass of the varieties decreased in response to stress in all three phenophases. Biomass of 'Mv Magma' decreased to a greater extent than that of 'Plainsman V' when heat stress was applied in the shooting stage. The greatest reduction of harvest index (HI) was observed for both varieties when stress occurred in the early stage of embryo development. Heat stress during grain filling had little effect on HI of 'Mv Magma'; HI was affected to the greatest extent by heat stress at first node appearance. Contrary, in 'Plainsman V' heat stress had the least effect in this stage.

The smallest change in the number of grains was recorded when heat stress was applied 12 days after heading; the greatest change after heat stress at early embryo development (*Table 2*). 'Mv Magma' was most sensitive, i.e. greatest reduction in grain number, at shooting, 'Plainsman V' during early embryo development. Heat stress at grain-filling had neither an effect on grain number nor on the number of kernels per spikelet of the main spike, as the final grain number had already been determined by this stage. In 'Mv Magma' heat stress during early embryo development caused no reduction in the number of kernels per spikelet. For both varieties the greatest reduction was caused by heat stress at first node appearance.

The smallest decrease in 1000 kernel weight (TKW) was recorded at the shooting stage, the largest in response to heat stress during grain filling. TKW of 'Plainsman V' decreased to a lesser extent than that of 'Mv Magma' when stressed both at shooting and at early embryo development. The greatest loss of grain yield was observed after heat stress during early embryo development. The smallest loss was observed for 'Mv Magma' when the treatment was applied during grain filling and by 'Plainsman V' after heat stress at first node appearance (*Table 2*). KAUR and BEHL (2010) reported that heat-sensitive and -tolerant genotypes are more sensitive in the booting stage than after flowering (based on grain yield and grain weight per spike) when exposed to temperatures of 31-34°C. While STONE and NICOLAS (1995b) found no reduction in grain weight when heat stress was applied more than 8 days after flowering, MOHAMMADI et al. (2004) detected reductions in grain and spike weight in response to heat stress applied even 10 days after heading. These results differ from the present findings in that considerable reductions in grain weight were observed for 'Plainsman V' after heat stress at both 6 and 12 days after heading. MOHAMMADI et al. (2004) also found no change in grain number, which was confirmed in the present work.

All in all it can be stated that 'Plainsman V' was more tolerant to heat stress in the shooting stage, while 'Mv Magma' was more tolerant during grain filling. Heat stress during early embryo development had a strongly negative effect on both varieties.

Table 2: **Changes in yield parameters in response to heat stress at shooting, early embryo development and grain filling**

Parameters[1]		BIOM		HI		GRAIN		TKW		YLD		KEPS	
Treatment		C[2]	H	C	H	C	H	C	H	C	H	C	H
SH[3]	Pla[4]	7.4	6.7	36.1	34.6	102.4	95.4	26.7	24.4	2.8	2.3	2.3	1.64*
	Mag	7.2	4.8*	40.7	28.2*	113.8	60.2*	26.7	22.9*	2.9	1.4*	2.2	0.92*
EG	Pla	6.3	4.6*	53.2	43.8*	123.2	78.0*	27.4	26.2	3.4	2.1*	3.2	2.33*
	Mag	10.5	7.6*	52.5	38.7*	146.7	107.5*	37.7	28.9*	5.5	2.9*	2.0	1.79
GF	Pla	5.7	4.5*	44.8	34.4*	111.1	85.8	23.9	18.9*	2.6	1.5*	2.7	2.69
	Mag	6.6	4.9*	42.1	45.0	92.1	93.5	30.2	23.6*	2.8	2.2	2.4	2.34
$LSD_{5\%}$		1.1		5.0		29.2		3.8		0.6		0.4	

[1] BIOM, biomass; HI, harvest index; GRAIN, number of grains; TKW, 1000 kernel weight; YLD, grain yield; KEPS, number of kernels per spikelet of the main spike

[2] C, control; H, heat stress

[3] abbreviations see *Table 1*

[4] Pla, Plainsman V; Mag, Mv Magma

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