ANALYSIS OF THE QUALITY OF WHEAT VARIETIES AT EXTREMELY HIGH TEMPERATURES

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Abstract: Nowadays the abiotic stress factor that causes the greatest problems for crop production is extremely high temperature. The aim of the research was to determine the heat tolerance of various wheat varieties and to measure changes in their quality in two phases of development (shooting and grain filling) under controlled phytotronic conditions. Changes in the yield quantity, the grain diameter, the protein content and the ratio of protein components were examined in plants exposed to extremely high temperatures. It could be seen from the results that in the earlier developmental phase the varieties were much more sensitive to heat stress than in the adult stage. Heat stress during grain filling led to a significant reduction in yield parameters. Decreasing values of UPP% (unextractable polymeric protein) and the Glu/Gli (glutenin to gliadin) ratio generally indicate a deterioration in quality despite the increase in the protein content. The plants suffered heat shock when treated at 41°C.

Keywords: winter wheat, heat stress, grain yield, protein content, glutenin/gliadin ratio

Introduction

High temperature is one of the most important abiotic environmental factors during grain filling and may influence both the quantity and quality of the yield. High temperature after anthesis causes a reduction in grain filling (Wardlaw and Moncur, 1995; Veisz et al., 2008), more rapid apoptosis and the earlier attainment of harvest maturity (Altenbach et al., 2003). The severe yield losses are caused by a reduction in the starch content, which makes up more than 65% of the dry weight of cereals (Barnabás et al., 2008; Rakszegi et al., 2006; Yan et al., 2008). Reductions in grain weight in response to stress in the early phases of grain filling could be due to a lower number of endosperm cells (Nicolas et al., 1985), while a decrease in starch synthesis during the later phases of grain filling could be caused by limited supplies of grain assimilates (Blum, 1998) or by direct effects on the process of synthesis in the grain (Yang et al., 2004). High temperature stress has a greater influence on starch accumulation in the middle phase of grain filling than in the early phase (Yan et al., 2008). Starch accumulation was found to be coordinated with the sucrose content of the grain and with the activity of the enzymes sucrose synthase, AGPP (adenosine diphosphate glucose pyrophosphorylase), SSS (soluble starch synthase) and SBE (starch branching synthase), suggesting that low sucrose supplies and a drop in the activity of the enzymes involved in starch synthesis are responsible for the decline in starch accumulation. The accumulation of proteins also undergoes a change in response to heat stress. The accumulation of proteins active in biosynthesis and the metabolism shifts in favour of storage proteins and of those involved in defence against biotic and abiotic stress factors. Specific protein responses depend on whether high temperature is experienced during the early or middle phase of grain filling (Hurkman et al., 2009). It has been proved that the protein content of grains exposed to heat stress after anthesis rose significantly in response to the stress (Balla and Veisz, 2007; Labuschange et al., 2008, in press). A reduction in the glutenin/gliadin ratio has a negative effect on flour quality, despite the increase in protein content (Bencze et al., 2004). High temperature is capable of causing substantial changes in the accumulation level of gluten proteins

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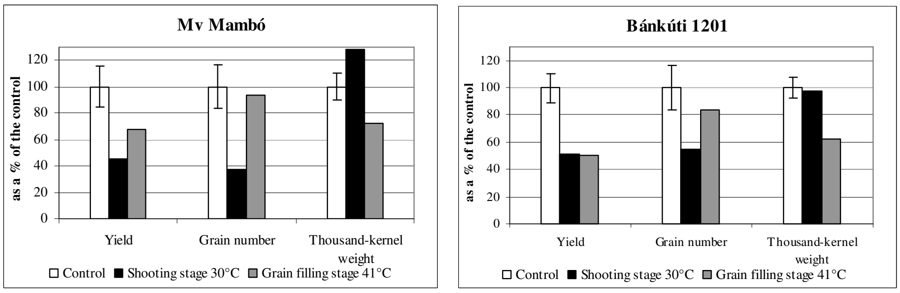
during grain filling. Grains exposed to stress exhibited reductions in thousand-kernel weight, diameter and starch content in response to the treatment (Labuschange et al., 2008, in press). The data indicate that reduced grain yield and grain number may be caused not only by post-anthesis stress but also by pre-anthesis stress. The most sensitive phase proved to be stem elongation, while booting and anthesis were moderately sensitive, and the phase between heading and anthesis was the least sensitive (Ugarte et al., 2007). The present paper discusses the response of the yield to heat stress in two different developmental stages in wheat varieties with different levels of heat tolerance.

Materials and methods

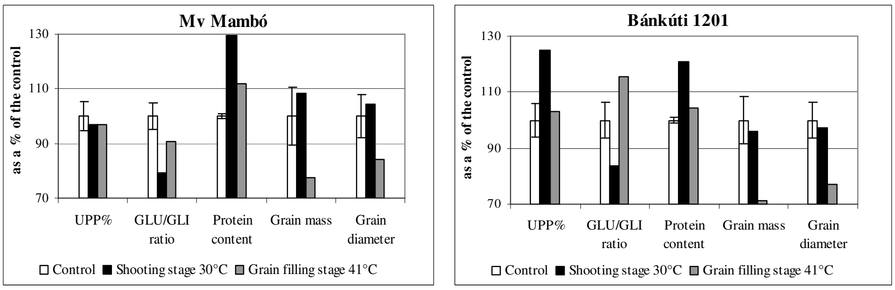
The heat stress studies were carried out under controlled conditions in a climatic chamber on two winter wheat varieties (Mv Mambó and Bánkúti 1201) in early and late stages of development (at shooting in the 8th week, and 12 days after heading). High temperature treatment was applied for 15 days. In the control treatment the plants were kept at day/night temperatures of 17/13°C in the shooting stage and 24/20°C in the adult stage, while in the stress treatments the temperature was raised to 30/20°C in the case of young plants and to 41/20°C for the adult plants (Tischner et al., 1997) The grain number per plant, grain yield and thousand-kernel weight were recorded after harvest. The protein content was determined using a Kjeltec Auto Sampler System 1035 Analyser (with a factor of N × 5.8). The weight and diameter of the grains were measured with a Single Kernel Characterization System 4100. The total glutenin, gliadin contents of the samples were determined using the SE/HPLC technique according to the modified method of Batey et al. (1991). The unextractable polymeric protein fraction (UPP %) was determined using the method of Gupta and MacRitchie (1993). Two-factorial analysis of variance was used for the statistical evaluation of the data (Kuti et al., 1998).

Results and discussion

High temperature caused the greatest changes in the grain yield, grain number and thousand-kernel weight. Stress caused more drastic reductions in young plants (e.g. grain yield decreased by 49–55%, grain number by 46–63%) than in older plants (e.g. grain yield decreased by 32–49%, grain number by 6–17%). Heat stress at shooting led to significant reductions in yield and grain number in both varieties (Figs. 1–2). Fifteen days of heat stress during grain filling caused a significant decline in both grain weight and grain diameter in Mv Mambó and Bánkúti 1201 compared with the control (Figs. 3–4). In young plants the two varieties responded differently, with a slight increase in grain weight and diameter for Mv Mambó and a slight reduction for Bánkúti 1201 compared with the control. An analysis of grain quality revealed that in both phenophases there was a significant increase in grain protein content in both varieties (Figs. 3–4). The greatest change was caused by heat stress to young plants, which could be attributed to a drastic decline in the yield per plant and the grain number as a consequence of forced heading. The varieties responded differently to extremely high temperature (41°C) during grain filling, with a greater increase in protein content in Mv Mambó and a smaller rise in Bánkúti 1201. The relative increase in protein content after heat stress at a late stage of development could be attributed to a reduction in grain weight and grain diameter and to a drastic decline in the starch content (Barnabás et al., 2008; Yan et al., 2008). However, the rise in the grain protein content in heat-stressed plants did not lead to an improvement in grain quality, as quality analysis indicated the unfavourable composition of the gluten proteins. There were exceptions, such as the increase in the unextractable polymeric protein content (UPP %) and the Glu/Gli ratio in Bánkúti 1201. A serious decline in the UPP % is associated with poorer breadmaking quality, despite the higher protein content caused by heat stress. In most cases a reduction in the glutenin/gliadin ratio is indicative of quality deterioration. There was a drastic (significant) reduction in the glutenin/gliadin ratio in Mv Mambó in both young and older plants, suggesting poorer quality, but the old Hungarian variety Bánkúti 1201 proved to be much more resistant. This variety only exhibited greater sensitivity to the 30°C stress at the shooting stage (lower Glu/Gli ratio, but higher UPP %).



Figures 1-2. Changes in grain yield, grain number and thousand-kernel weight in response to heat stress



Figures 3-4. Changes in UPP % (unextractable polymeric protein), Glu/Gli (glutenin/gliadin) ratio, protein content, grain mass and grain diameter in response to heat stress

Conclusions

The results proved that high temperature had a substantial effect on the final grain yield and breadmaking quality when applied not only during grain filling, but also at shooting. The drastic rise in the protein content in response to the treatments was not associated with an improvement in yield quality, due to the unfavourable gluten protein composition (reduction in Glu/Gli ratio or UPP%). The rise in the relative protein content when high temperature was applied during the grain filling phase could be explained by reductions in the thousand-kernel weight (28–37%), the grain mass (22–29%) and the grain diameter (16–23%), while in the shooting stage it could be attributed

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mainly to the drastic decline in the grain number and yield per plant (with a significant increase in the thousand-kernel weight), probably due to a reduction in spikelet differentiation, caused by the incorporation of protein rather than starch (Barnabás et al., 2008; Yan et al., 2008).

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