EFFECT OF ELEVATED CO_2 AND HIGH TEMPERATURE ON THE PHOTOSYNTHESIS AND YIELD OF WHEAT

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Introduction

The atmospheric concentration of CO_2 has been steadily increasing for at least 200 years due to human activity. The rate of annual growth is 1.82 ppm (Haszpra 1995). Increased growth CO_2 levels result in higher rates of biomass accumulation and higher yield (Kendall *et al.* 1985, Harnos *et al.* 1998, Bender *et al.* 1999, Bencze *et al.* 2000). High temperature during grain filling reduces yield mass by decreasing the number of grains and grain size (Blumenthal *et al.* 1995, Wheeler *et al.* 1996), but the effects of heat stress can be reduced by elevated CO_2 (Taub *et al.* 2000, Bencze *et al.* 2004). Photosynthesis may be a key factor through which the favourable effects of high CO_2 levels can operate against the damaging effects of high temperature. The aim of this study was to investigate the process of photosynthesis from this point of view.

Materials and methods

Three commonly cultivated winter wheat (*Triticum aestivum* L.) varieties with various agronomic characteristics were chosen for the tests: Mv Martina, Mv Emma and Mv Mezőföld. The experiment was carried out under controlled environmental conditions in Conviron PGV/36 growth chambers in the phytotron. Vernalized seedlings were planted four to a pot (21x21x17 cm) and the pots were placed randomly in the growth chambers and rearranged regularly. The atmospheric CO_2 level in the growth chambers was either ambient (375 $\mu mol*mol^{-1}$) or doubled (750 $\mu mol*mol^{-1}$). The temperature regime changed weekly beginning with a min/max/mean of 10/12/10.7°C during the first week and increasing until it reached 20/24/22.7°C (in the 11^{th} week). In the control and after the heat stress treatment it remained at this level till the end of the experiment. Heat stress began 12 days after the average heading date (Zadoks 59), which was determined separately for each variety and treatment so that the groups should be in the same phenological stage during heat treatment. In the heat stress treatment the temperature was 20/35/25.2°C, the maximum temperature being maintained for 8 hours a day for 15 days. There were at least 7 pots (28 plants) in each treatment. The chlorophyll fluorescence induction parameters of the youngest fully expanded leaves were determined using a pulse amplitude modulated fluorometer (PAM-2000, Walz, Effeltrich, Germany). Measurements on the quantum yield of Photosystem II (ΔF/Fm', Genty et al. 1989) were carried out in the growth chambers in the light. After harvest the following parameters were also determined: aboveground.

DOI: 10.1556/CRC.33.2005.1.95

The bars represent significant differences at the p=0.05 level. HS_1, HS_2 =Start of heat stress at the normal and doubled CO_2 level.

biomass (AGB, g), grain number per plant (GN), thousand kernel weight (TKW, g) and grain yield per plant (GY, g).
Statistical analyses were carried out on the collected data using two-way ANOVA to study the effects of the treatments on the three varieties.

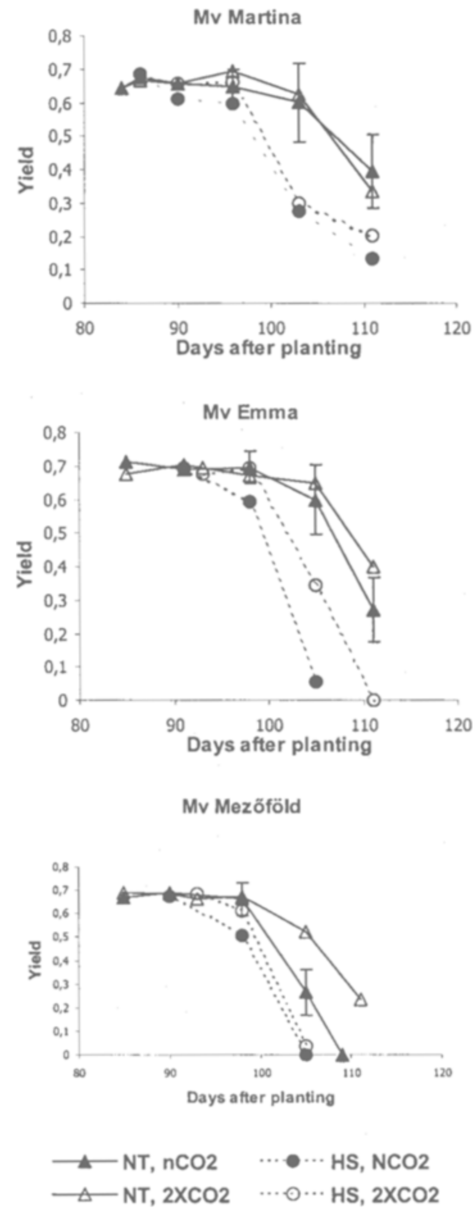


Fig. 1. Effects of elevated CO_2 and heat stress on the quantum yield of PSII.
Abbreviations n =normal, 2X= doubled CO_2, NT=normal temperature, HS=heat stress

Results and discussion

Photosynthesis

There were considerable differences between the varieties in the response to heat stress treatment, but high temperature always accelerated the aging process (Fig. 1). In two of the three varieties plants grown at doubled CO_2 level maintained their photosynthetic activity during grain filling and maturation for a longer period than at the ambient level. The same was true of one variety when the plants were exposed to heat stress. This is in accordance with the findings of Taub *et al.* (2000) who reported that high CO_2 had a positive effect on the heat stress response of some of a wide range of species examined. In the present work both heat stress and elevated CO_2 level were found to affect photosynthesis to a much lesser extent in Mv Martina than in the other two varieties. In this variety a significant increase in the quantum yield at normal temperature due to high CO_2 was only observed on the 91^{st} day after planting. Despite this, and the fact that the difference between the CO_2 treatments was not significant thereafter, the plants matured earlier at doubled CO_2 than at the ambient level in this variety. Although there was a significant difference between the CO_2 treatments on the 91^{st} day in heat-stressed plants, too, this was probably due to the fact that heat stress began later in plants at high CO_2 because of a delay in heading due to CO_2 enrichment.

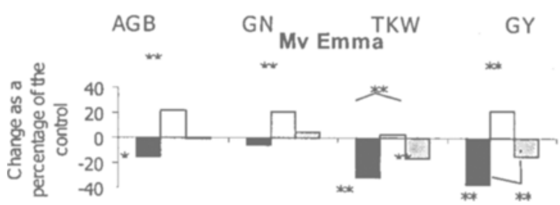
The curves of the quantum yields of Mv Martina plants exposed to heat stress at both CO_2 levels were very similar, suggesting that heat stress had a similar effect on the process of maturation regardless of the CO_2 level in this variety. These plants suffered less damage from heat stress than the other two varieties as they were still alive even 25 days after the start of heat stress. In Mv Emma an elevated CO_2 level enabled the plants to maintain their photosynthetic activity longer at both normal temperature and during and after heat stress. At the ambient CO_2 level, the plants died by the end of the heat shock, while at the doubled level they were able to survive high temperature for a few days. In Mv Mezőföld the control plants (normal CO_2 level and temperature) matured very fast (Fig. 1). CO_2 enrichment retarded this process at normal temperature, but was ineffective in heat-stressed plants, as they did not even survive till the end of the heat shock. Heat stress had the most dramatic effect on photosynthesis at both CO_2 levels in this variety. Heat stress had severe effects: it decreased biomass accumulation and the size of grains, leading to a yield loss of up to 37 % (Fig. 2, black columns). Plants grown at doubled CO_2 level had higher aboveground biomass, number of grains per plant in Mv Martina and Mv Emma, leading to a significantly higher yield (20-22 %, Fig.2, white columns). In Mv Mezőföld there was also a slight, 12 % increase, but this was due to larger grain size. When grown at high CO_2, plants of Mv Martina and Mv Emma tolerated high temperature during grain filling better, as can be seen in Fig. 2 (grey columns). In these varieties elevated CO_2 level was able to counteract heat stress. In plants exposed to high temperature, both the thousand kernel weight and the grain yield were significantly higher at doubled CO_2 than at the ambient level, though the values were still lower compared to the control. In Mv Mezőföld, elevated CO_2 level was unable to compensate for the negative effects of heat stress on the yield due to the low value of thousand kernel weight, although the biomass and grain number were similar to the control values, as in the other varieties.

Conclusions

Result shows that the rate of photosynthesis was extremly sensitive to heat stress. However, when it was maintained longer due to elevated CO_2 level, the plants suffered less damage from heat stress and produced a higher yield than at the ambient level.

Acknowledgements

These trials were conducted within the framework of the research programme "Climate Change-Effect-Response".



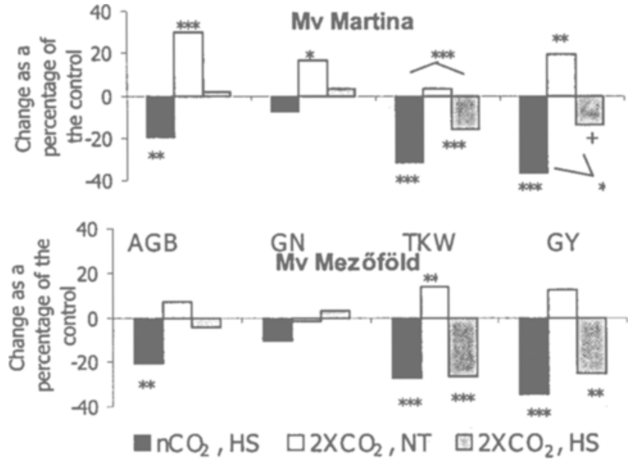


Fig. 2. Effects of CO_2 and heat stress on the aboveground biomass (AGB), grain number (GN), thousand kernel weight (TKW) and grain yield (GY) per plant.
Control values are the results at normal CO_2 (n) and normal temperature (NT). $2XCO_2$= doubled level, HS=heat stress. +, *, **, ***, differences significant at the p=1, 0.5, 0.1 and 0.01 probability levels compared to the control or between the treatments.

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