INTERACTIVE EFFECTS OF ELEVATED CO_2 CONCENTRATION, DROUGHT AND NITROGEN NUTRITION ON YIELD AND GRAIN QUALITY OF WINTER WHEAT

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ABSTRACT

Elevated CO_2 concentration generally leads to increased rates of photosynthesis, increased formation of assimilates and finally to storing them in the grain. Increased storage of starch in the grain, however, leads to an unbalanced proportion to the proteins, and their absolute quantity decreases. This is particularly apparent in the conditions of nitrogen deficiency. Interaction effect of elevated CO_2, nitrogen nutrition and drought are not yet sufficiently described. Within the manipulation experiment in open top chambers (Domanínek near Bystřice nad Pernštejnem) that allow simulation of elevated concentration of CO_2 (expected by the end of this century – 700 μmol mol^{-1}) and simulation of drought periods, the effect of these interactions on biomass production, grain yield, protein content, and other quality parameters of grain was studied. Elevated CO_2 concentration increased production of both aboveground biomass and grain. This stimulatory effect is more pronounced if nitrogen is no limiting factor and also under the effect of drought. Higher effect under drought stress is probably due to increased water efficiency. The results show that the drought and nitrogen deficiency amplified the negative effect of elevated CO_2 concentration on grain quality. Elevated CO_2 concentration leads to a decrease in grain protein content and to reduction of other quality parameters such as Zeleny sedimentation test.

Key words: winter wheat, elevated CO_2 concentration, nitrogen nutrition, drought stress, yield, protein content

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INTRODUCTION

Global concentration of carbon dioxide [CO_2] is rising rapidly since the start of the Industrial Revolution in the second half of the 18th century. Current [CO_2] is at about 392 p.p.m. (parts per million) and the rate of the increase is about 2 p.p.m per year (NOAA, 2012). This [CO_2] is the highest during the last 15-20 million of years (Tripati et al., 2009). Without any effort to mitigate the atmospheric [CO_2] it may reach the level of more than 1 000 p.p.m by 2100 (Sokolov et al., 2009).

Understanding how plants respond and might be adapted to a future increase in [CO_2] will also help us understand how they are currently responding and how they may have adapted to the increase that has already occurred. In the short term C_3 land plants appear to sense and respond directly to rising [CO_2] exclusively through direct effects of increased carboxylation by Rubisco and decreased stomatal opening. These changes, which both increase the efficiency of CO_2 uptake and water use, produce a wide range of secondary responses, most notably large increases in leaf nonstructural carbohydrates, improved plant water status including increased leaf water potential, and in many cases increases in plant carbon to nitrogen ratio (C/N), and decreases in leaf Rubisco activity, stomatal density, and root/shoot mass (Long et al. 2004).

However, this increased potential is rarely realized fully in the long-term, due to down-regulation of photosynthetic capacity (Urban, 2003). Much circumstantial evidence, primarily from studies in enclosed environments, suggests that this down-regulation results from different causes, nutrient deficiency, genetic regulation and inadequate “sink” capacity.

It is obvious that nitrogen nutrition, which is particularly reflected in the amount and activity of enzyme Rubisco, and the water availability for plants, which interacts with the stomatal response to elevated [CO_2] are the main factors that may influence the effect of elevated [CO_2] on productivity and qualitative parameters of field crops.

The main objective of the experiment was to analyze the impacts of expected global change on wheat grain production and quality parameters and to study mutual interactions of several factor simultaneously: elevated [CO_2], drought stress and nitrogen nutrition.

MATERIAL AND METHODS

The experiment was conducted in experimental station Domanínek, near Bystřice nad Pernštejnem in Bohemian-Moravian highlands (Czech Republic, 49°521'N, 16°235'E, altitude 575 m a. s. l.). The soil type is modal cambisol, with geological bedrock weathered gneiss in depth 60-90 cm. Soil texture is sandy loam (45-60% sand and up to 16% clay) and pH(KCl) is between 4-5. This region is characterized as rain-fed area with mean annual precipitation 610 mm and mean annual temperature 7.2 °C. The experiment consists of 24 open-top chambers, which allows manipulation of [CO_2] and precipitation (Fig. 1). Winter wheat variety Bohemia with bread quality A was sown on 10th October 2012 in the chambers with density 4 MGS (millions of germinating seeds). Fumigation with elevated [CO_2] (EC; 700 μmol mol^{-1}) started at the beginning of stem elongation (middle of May) and drought stress induction started at the end of stem elongation (end of May). The plots inside chamber were divided to two subplots and one of them fertilized with calcium nitrate in a dose 200 kg ha^{-1} at the growth stage end of tillering. The second subplot remained unfertilized with nitrogen. Each combination of factors was three times replicated.

The aboveground biomass was harvested manually at full ripening and weighted. This was followed by threshing of grain using a small plot harvester. The cleaned grain was used for analysis of protein content on the elemental analyzer Flash 2000 (Thermo Scientific, USA). Detailed analyses of grain quality (starch content using NIRs method, Zeleny sedimentation test, falling number) were performed in an accredited laboratory (UKZUZ Brno) using certified analytical methods.

Fig. 1 Experimental site with 24 open-top chambers and experimental plots inside chamber

RESULT AND DISCUSSION

The assessment of the effects of elevated [CO_2] in the interaction with the effects of nitrogen nutrition and drought stress revealed similar results for both, aboveground biomass and grain yield. The results indicate that the elevated [CO_2] increases the yield of aboveground biomass and grain yield (Fig. 2). However, this effect is modified by the effect of drought and nitrogen nutrition. Due to drought the grain yield decreases for all treatments, but in case of elevated [CO_2], this decrease is lower, in particular at a sufficient level of nitrogen nutrition. Higher level of nitrogen nutrition in general increases the stimulatory effect of [CO_2] on yield. Nitrogen deficiency is one of the causes of feedback regulation of photosynthesis at elevated [CO_2], becomes the limiting factor, and therefore the effect of increased [CO_2] under these conditions is usually low. Reich et al. (2006) showed in grassland ecosystem that elevated [CO_2] stimulated plant biomass much less under ambient than enriched N supply. Because these limitations to productivity resulting from the insufficient availability of N are widespread in both unmanaged and managed vegetation, they assumed that soil N supply is probably an important constraint on global terrestrial responses to elevated [CO_2]. Higher yield response to elevated [CO_2] in dry conditions is probably due to the influence of [CO_2] on stomatal closure and thereby increasing the water use efficiency. The effect of [CO_2] on reduction in stomatal conductance and decrease in canopy evapotranspiration was reviewed by Leakey et al. (2009).

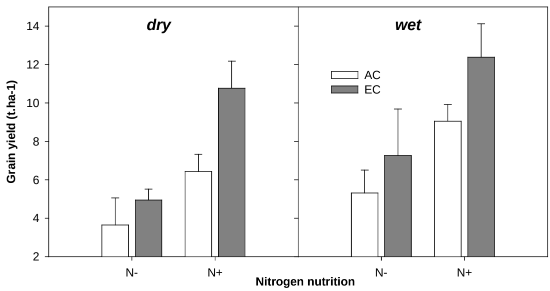

Fig. 2 Effect of CO_2 concentration, nitrogen nutrition and drought stress on grain yield. AC (ambient CO_2 concentration; 385 μmol mol^{-1}), EC (elevated CO_2 concentration; 700 μmol mol^{-1}), N- (unfertilized with nitrogen), N+ (fertilized with nitrogen 200 kg ha^{-1}), wet (ambient precipitation), dry (drought stress). Means (columns) and 95% confidence intervals (error bars) are presented (n=3).

Based on grain analyzes, we found that the elevated [CO_2] generally decreases protein content (Fig. 3). This effect is more pronounced when the plants were subjected to drought stress. Nitrogen nutrition has a typical effect on the grain protein content, i.e. with an increased dose of nitrogen the protein content increases, but it is also apparent interaction with the [CO_2]. At the higher nitrogen dose is the negative impact of [CO_2] on the protein content generally lower. Similar response in protein content was reported by Högy et al. (2009). They found that total grain protein concentration decreased significantly under elevated [CO_2], and protein and amino acid composition were altered. With regard to mixing and rheological properties of the flour, a significant increase in gluten resistance under elevated [CO_2] was observed. Similarly we found decrease in Zeleny sedimentation test (Fig. 4) under elevated [CO_2]. However this effect was observed only if the plants were subjected to drought stress.

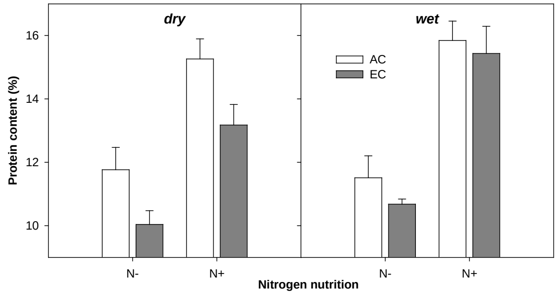

Fig. 3 Effect of CO_2 concentration, nitrogen nutrition and drought stress on protein content in wheat grain. AC (ambient CO_2 concentration; 385 μmol mol^{-1}), EC (elevated CO_2 concentration; 700 μmol mol^{-1}), N- (unfertilized with nitrogen), N+ (fertilized with nitrogen 200 kg ha^{-1}), wet (ambient precipitation), dry (drought stress). Means (columns) and 95% confidence intervals (error bars) are presented (n=3).

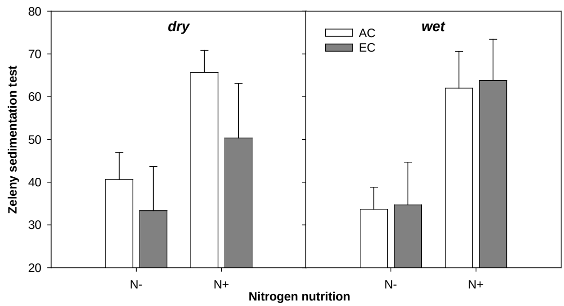

Fig. 4 Effect of CO_2 concentration, nitrogen nutrition and drought stress on Zeleny sedimentation test. AC (ambient CO_2 concentration; 385 μmol mol^{-1}), EC (elevated CO_2 concentration; 700 μmol mol^{-1}), N- (unfertilized with nitrogen), N+ (fertilized with nitrogen 200 kg ha^{-1}), wet (ambient precipitation), dry (drought stress). Means (columns) and 95% confidence intervals (error bars) are presented (n=3).

CONCLUSIONS

Elevated [CO_2] stimulates photosynthesis and, consequently, leads to increased production of aboveground biomass and grain.

This stimulatory effect is more pronounced if nitrogen is no limiting factor and also under the effect of drought. Higher effect under drought stress is probably due to the stomatal response to elevated [CO_2] and increased water efficiency.

Elevated [CO_2] leads to a decrease in grain protein content and to reduction of other quality parameters such as Zeleny sedimentation test. The negative effect on the quality is higher particularly when plants were exposed to drought stress and also under nitrogen deficiency.

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