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Research Article

Photosynthetic Active Pigments Changes in Norway Spruce (*Picea abies*) under the Different Acclimation Irradiation and Elevated CO_2 Content

Miroslav Kvíčala,[1] Eva Lacková,[2] and Lenka Urbancová[2]

[1] *Department of Non-Ferrous Materials, Rafination and Recyclation, VŠB-Technical University of Ostrava (VŠB-TU Ostrava), 17. listopadu 15/2172, 70833 Ostrava, Czech Republic*
[2] *Institute of Environmental Engineering, VŠB-Technical University of Ostrava (VŠB-TU Ostrava), 17. listopadu 15/2172, 70833 Ostrava, Czech Republic*

Correspondence should be addressed to Miroslav Kvíčala; miroslav.kvicala@vsb.cz

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Photosynthetic active pigments content (chlorophylls and carotenoids) in Norway spruce (*Picea abies*) needles was measured by absorption spectroscopy. Norway spruce was exposed to low and high photosynthetic active radiation and ambient and elevated CO_2 concentration. It was investigated that combination of low photosynthetic active radiation and elevated concentration of CO_2 resulted in stimulation of chlorophylls and carotenoids production. Combination of high photosynthetic active radiation and elevated CO_2 concentration led to overall chlorophylls and carotenoids content decrease. Moreover, specific leaf area trend could be used as a potentially reliable indicator of plant stress response.

1. Introduction

Higher plants are permanently stressed by different kinds of natural and artificial factors. These stress factors could be drought, rapid temperature changes, diseases, herbicides, intraspecies and interspecies competition, insect, high salinity, low soil minerals content, and elevated carbon dioxide (CO_2) concentrations. During the last 100 years CO_2 concentration in atmosphere increased dramatically as a result of human activities. Actual CO_2 concentration 350 μmol(CO_2)$\cdot$mol^{-1} is definitely not the fixed value and is going to increase in the future, Busch et al. [1]. It is expected that CO_2 concentration will be two times higher than at the present (King et al. [2]). With respect to this expectation CO_2 concentration influence on photosynthetic apparatus of the higher plants is a subject of interest for modern ecophysiology, Pittermann et al. [3], Gerhart et al. [4], and Whitehead [5].

2. Experimental Methods

One-year-old trees of Norway spruce (*Picea abies*) were used in this study. All plants were grown in soil substrate. Distilled water was used during the whole experiment. All plants were grown in growth chamber HB 1014 (Bio Line, Heraeus, Germany). Light regime in growth chamber was 8 hours of darkness and 16 hours of light. In the growth chamber there were stable conditions (humidity 65% and temperature 20°C). The first group of Norway spruce trees was adapted to high irradiation 1200 μmol$\cdot$m$^{-2}\cdot$s^{-1} and atmospheric CO_2 concentration 350 μmol(CO_2)$\cdot$mol^{-1} for 25 days. Thereafter irradiation remained the same, but CO_2 concentration was increased up to 700 μmol(CO_2)$\cdot$mol^{-1}. These conditions were kept for 11 days. The second group of Norway spruce trees was growing under the low irradiation 100 μmol$\cdot$m$^{-2}\cdot$s^{-1} and atmospheric CO_2 concentration for 25 days. After that irradiation remained the same, but CO_2 concentration

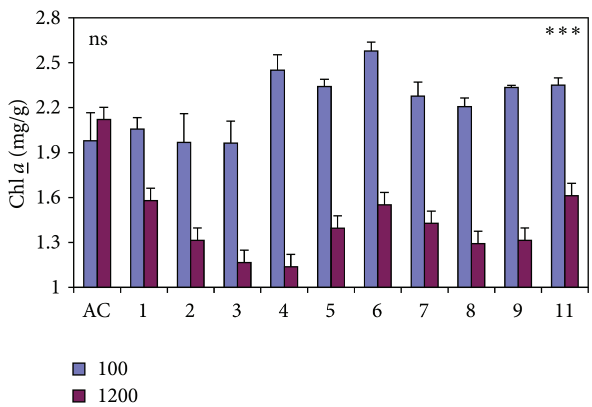

Figure 1: Chl a content in Norway spruce needles associated with dry matter ($mg{\cdot}g^{-1}$). Legend on the right side represents acclimation irradiance 100 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$. AC—ambient concentration of CO_2—350 $\mu mol{\cdot}mol^{-1}$, days 1–11 (elevated concentration of CO_2: 700 $\mu mol{\cdot}mol^{-1}$).

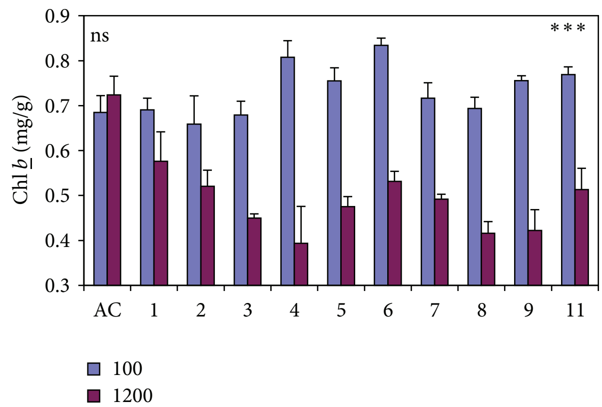

Figure 2: Chl b content in Norway spruce needles associated with dry matter ($mg{\cdot}g^{-1}$). Legend on the right side represents acclimation irradiance 100 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$. AC—ambient concentration of CO_2—350 $\mu mol{\cdot}mol^{-1}$, days 1–11 (elevated concentration of CO_2: 700 $\mu mol{\cdot}mol^{-1}$).

increased up to 700 $\mu mol(CO_2){\cdot}mol^{-1}$. These conditions were kept also for 11 days. The first samples collection was realized the last day before CO_2 concentration was increased. Thereafter, samples were collected every day of experiment (with one exception—day 10th). Samples were taken from four different trees of Norway spruce for every group. Needles were randomly collected from the second whorl. The digital scanner and analytical weighter were used for determination of specific leaf area. Absorption measurements were realized using UV-VIS spectrophotometer (UV/VIS 550, UNICAM, England). Pigments content was calculated according to equations proposed by Lichtenthaler [6] as an average of six samples. All results are demonstrated as an average ± standard deviation (SD).

All data were statistically analyzed using Minitab 15 software. The three significance levels which were used are $\alpha = 0{,}05$ (marked as—$*$), $\alpha = 0{,}01$ ($**$), and $\alpha = 0{,}001$ ($***$). Nonsignificant differences were marked such as ns.

3. Results and Discussion

From the kinetics of chlorophyll a (Chl a) ($mg{\cdot}g^{-1}$) content changes in Norway spruce needles it is clear that different acclimation irradiation (100 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$) and atmospheric concentration 350 $\mu mol(CO_2){\cdot}mol^{-1}$ did not result in significant changes in Chl a content relative to dry matter. In the case of Norway spruce exposed to both acclimation irradiation and elevated CO_2 concentration (700 $\mu mol(CO_2){\cdot}mol^{-1}$) the significant difference in Chl a content which is (31,5%) in favor of lower irradiation was observed, but there is also difference for the same irradiation and different CO_2 concentrations; see Figure 1.

It could be expected that in the case of lower irradiation and increased CO_2 concentration photosynthetic activity is optimized due to the Chl a content increase in reaction centers (RC) of photosystem II (PS II). On the contrary, combination of 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation and elevated CO_2 concentration is a stressful combination that led to decrease of RC PS II photosynthetic activity.

The kinetics of chlorophyll b (Chl b) ($mg{\cdot}g^{-1}$) content in Norway spruce needles is similar to that of Chl a. The combination of 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation and elevated CO_2 concentration resulted in significantly lower value of Chl b compared to the same CO_2 concentration and 100 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation. On the contrary, elevated CO_2 concentration combined with lower irradiation resulted in higher content of Chl b in light harvesting complexes (LHC) of PS II. Generally said, 100 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation is too low for optimal function of Norway spruce photosystem and atmospheric CO_2 concentration; see Figure 2.

The kinetics of carotenoids (Carx+c) ($mg{\cdot}g^{-1}$) content changes in Norway spruce needles demonstrates significant differences in carothenoids content for atmospheric CO_2 concentration. Carx+c reflects protective mechanism of Norway spruce during different irradiation. It could be said that 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation is not a stress factor for Norway spruce, because higher irradiation resulted only in the higher content of Carx+c, but it did not influence chlorophylles content. So the CO_2 assimilation capacity remained stable. Combination of increased irradiation and elevated CO_2 resulted in the significant decrease of Carx+*c* content. This fact could be interpreted as a consequence of photosynthetic apparatus reduction (both Chl a from RC PS II and Chl b from LHC PS II were degradated); see Figure 3.

The kinetics of Chl a/b rate in the Norway spruce needles did not show a significant difference for an atmospheric CO_2 concentration. It could be said that 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation is not high enough to become a stress factor for Norway spruce. Once again, also this rate change may be interpreted as an indicator of the plant irradiation stress. Although Chl a/b rate increased slightly during the experiment, those differences were statistically nonsignificant. However, the

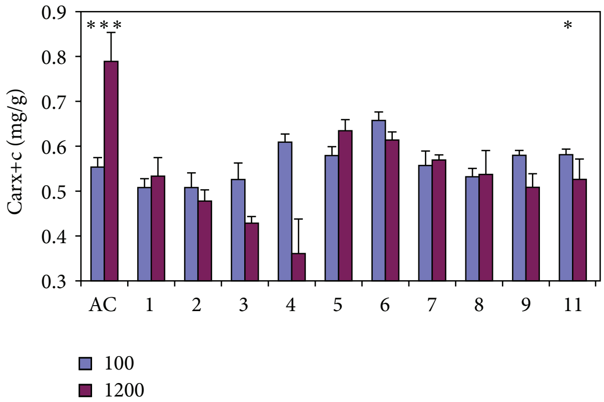

FIGURE 3: Carx+c content in Norway spruce needles associated with dry matter ($mg{\cdot}g^{-1}$). Legend on the right side represents acclimation irradiance 100 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$. AC—ambient concentration of CO_2—350 $\mu mol{\cdot}mol^{-1}$, days 1–11 (elevated concentration of CO_2: 700 $\mu mol{\cdot}mol^{-1}$).

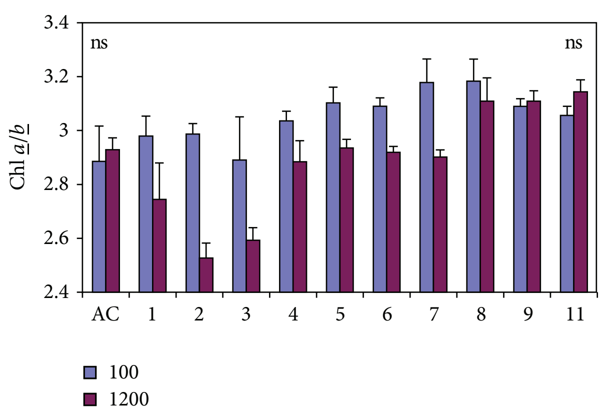

FIGURE 4: Chl a/b content rate in Norway spruce needles. Legend on the right side represents acclimation irradiance 100 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$. AC: ambient concentration of CO_2, days 1–11 (elevated concentration of CO_2: 700 $\mu mol{\cdot}mol^{-1}$).

chlorophylls degradation was parallel process, which was realized in LHC antennas and reaction centers. Slightly increasing Chl a/b rate indicates that light harvesting Chl b is degradated preferably and Chl a degradation is follow-up process; see Figure 4.

Different irradiation and CO_2 concentration resulted in the statistically significant changes in specific leaf area (SLA) of the Norway spruce needles. Meanwhile, combination of the ambient CO_2 concentration and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation led to SLA increase; this fact may be interpreted as a proof of photosynthesis yield optimization. On the contrary, synergistic effect of elevated CO_2 concentration and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation resulted in a significant SLA decrease that could be interpreted as a result of the oversaturated photosystem; see Figure 5.

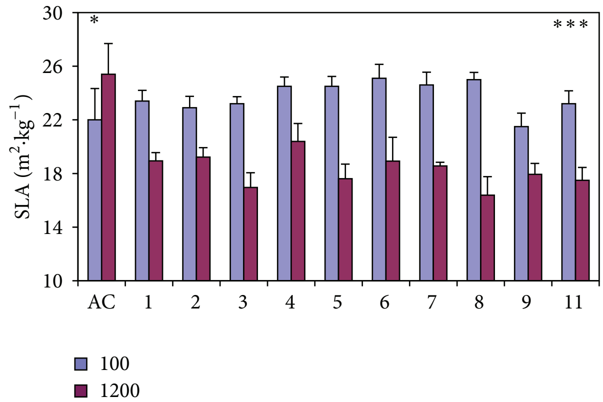

FIGURE 5: Specific leaf area ($m^2{\cdot}kg^{-1}$) of Norway spruce needles. Legend on the right side represents acclimation irradiance 100 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$. AC—ambient concentration of CO_2—350 $\mu mol{\cdot}mol^{-1}$, days 1–11 (elevated concentration of CO_2: 700 $\mu mol{\cdot}mol^{-1}$).

4. Conclusions

This paper deals with photosynthetic active pigments content in the Norway spruce needles under the different irradiation and CO_2 concentration. It was investigated that an acclimation irradiation 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ is not a stress factor for photosynthetic apparatus of the Norway spruce in the case of the atmospheric CO_2 concentration. The difference between 100 and 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation could be balanced by a higher content of protective carotenoids pigments. On the contrary, combination of the 1200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ irradiation and elevated CO_2 concentration resulted in a significant decrease of the Chl a from RC PS II and Chl b from LHC PS II due to the oversaturation of the plant photosynthetic apparatus. It can be said that low irradiation in combination with elevated CO_2 concentration may lead to optimization of the CO_2 assimilation. However, in the case of higher irradiation level and elevated CO_2 concentration, it leads to the photosynthetic depression.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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