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PHOTOSYNTHETIC RESPONSES OF BARLEY TO HARMFUL ENVIRONMENT AND EFFICIENCY OF LIGHT CONVERSION

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Summary

In this study we demonstrate how photoadaptation affects the photosynthesis. The strong light during the mid-day depression of photosynthesis caused photoinhibition, measured as a decrease in the ratio of variable to maximum fluorescence. The loss of photosystem II (PSII) electron transfer activity correlated with the decrease in the fluorescence ratio. The constant rate of photoinhibition was directly proportional to photon flux density in all studied light intensities. We discuss the mechanisms of maintenance of high photosynthetic performance.

Key words: photosynthesis, photoinhibition, photochemical PSII efficiency, barley

Introduction

Under natural conditions, photosynthesis is regulated biochemically to maintain a balance between the rates of its component processes and the concentration of metabolites while environment changes (Singsaas et al. 2000). Plants respond to sudden and sustained fluctuations in light quality and quantity, temperature, water and nutrient supply, partly via their chloroplast molecular redox signalling transduction mechanisms that initiate and network to induce marked modulations of chloroplast components, ultimately leading to acclimation of the photosynthetic apparatus allowing plants to coordinate the allocation of resources not only to achieve and maintain optimal rates of photosynthesis, but also and as importantly to function effectively under limiting and excessive light (Anderson et al. 1997; Basu et al 1998). Regulatory mechanisms can respond either to environmental stimuli (exogenous factors) or to biochemical limitations of the mesophyll cells (endogenous factors). Plants must maintain an effective balance between energy supply and energy consumption. Solar energy is trapped by photosystem II (PSII) and photosystem I (PSI) and transformed to chemical energy through photosynthetic electron transport and carbon assimilation which make ATP and carbon skeletons for all other major metabolic processes. Coordinated interactions between light-harvesting, energy conversion, electron transport, proton translocation and carbon fixation are inextricably linked in photosynthesis. Thus, chloroplasts not only are energy transducers for life, but also are primary redox sensors of environmental change that act together with other signal transduction pathways to elicit appropriate physiological and molecular responses (Asada et al. 1998; Matoo et al. 1999).
The objectives of this study is a better understanding the plant tolerance and protective mechanisms in natural environmental conditions via studying the photosynthesis and growth responses of spring barley with different acclimation to light conditions.

Material and methods

The barley plants (cv. Kompakt, Slovakia) were cultivated naturally in 18 kg plastic pots with soil substrate (40 plants per one pot), watered regularly and manured according to growth demands. As soon as the first leaf had emerged the plants were placed under the shields and cultivated for the rest of vegetation period to be acclimated for different light regimes, as follows:
A - control - diurnal incident photosynthetically active radiation (PAR, maximal PPFD level of 1500 $\mu mol.m^{-2}.s^{-1}$)
B - shaded plants - 25 % PAR of the control (PPFD 300-350 $\mu mol.m^{-2}.s^{-1}$)
The diurnal fluctuations of climatic factors were monitored by automatic micro-meteorological station Datalogger LI-1400 (LiCor, Lincoln, Nebraska, USA) with compatible sensors for photosynthetically active radiation (PAR, LI-190SA), global radiation (GR, LI-200SA), air temperature and relative humidity (1400-104) and soil temperature (1400-103) measurements. The leaf and soil water status were measured by HR-33T microvoltmeter and sample chambers C-52 (Wescor, Logan, Utah, USA). During the measuring shaded plants were exposed to diurnal incident radiation and the following photosynthetic characteristics were measured, such as: net CO_2 assimilation rate (A_{CO2}, LI-6200, LiCor, Lincoln, Nebraska, USA) and chlorophyll fluorescence parameters (MINI-PAM, 2030-B leaf clip holder; Waltz, Germany).

Results and discussion

Analysis of primary production processes is of paramount importance to plant cultivation. Primary production ultimately depends on the process of photosynthesis which is a light dependent process. When plants are transferred from a low light intensity to a high light intensity or when radiation is fluctuating, the chloroplasts acclimate to the new light regime (Osmond et al. 1995; Anderson et al. 1997). The different light regimes used in our experiments induced the integral changes of whole plants including leaf and chloroplasts architecture. The leaf photosynthetic activity (A_{CO2}) of shaded variants was significantly

lower in comparison to control plants (17,2 and 4,2 μmol.m^{-2}.s^{-1}, respectively). Exposure to excessive light lead to the photoinhibition of photosynthesis. This phenomenon may resulted from decreased electron transport rate and carbon assimilation (photoinhibitory damage) and/or increases in fluorescence and thermal excitation (photoprotection).
A negative relationship was found between PPFD and Fv/Fm. Extrapolation of the Fv/Fm ratio to 0,8, a value typical for uninhibited plants, indicated empiricaly that plants started to lose PSII function (Oquist et al. 1992; Yin et al. 2000). The 60-min exposure to different light treatment led to decrease in the activity of PSII reaction centre and of maximal photochemical PSII efficiency (Fig. 1). Non-acclimated plants to high light achieved a saturation rate of relative electron transport (ETR) under lower light intensities in relation to sun plants. The determination of Fv/Fm during 1-, 5-, 15- and 30-minute PSII relaxation (Fig. 2) in the dark was associated with mechanisms of dynamic and chronic photoinhibition. The 1-minute dark relaxation of non-acclimated plants after exposure to diurnal incident light leads to fast but not sufficient restoration of RC PSII. The Fv/Fm reached the value of 0,6 which represents 33 % decline in comparison to optimal Fv/Fm. On the other hand, the Fv/Fm decrease in acclimated plants does not practically exceed 10 %.
Photosynthetic apparatus of spring barley is sensitive to diurnal fluctuations of environmental factors, mainly of light which induce moderate stresses in the plants. Their short-term effects expressed in terms of relative air humidity, air and soil temperature was not significant in relation to the parameters of chlorophyll fluorescence under such conditions. Moreover, we demonstrate the activity changes of PSII and consider it as a good indicator of a high light signal. Plant photoprotection and maintenance of high photosynthetic performance are the functions of plant acclimation capacity.

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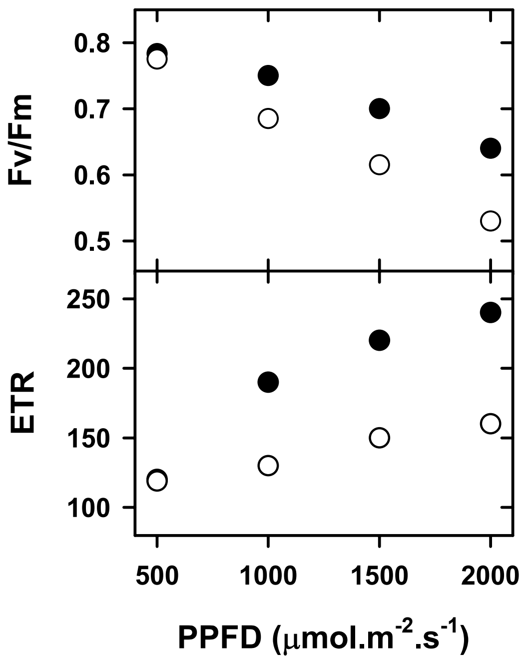

Figure 1: Maximal photochemical PSII efficiency (Fv/Fm) and relative electron transport rate as a function of irradiation. Full symbols – sun plants, empty symbols – shade plants.

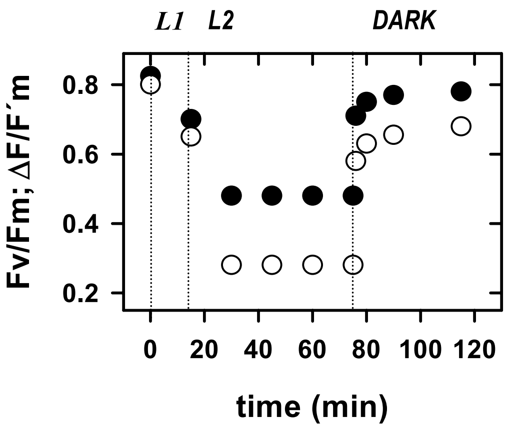

Figure 2: Course of actual photochemical PSII efficiency (ΔF/F´m) during the photoadaptation (50 μmol.m^{-2}.s^{-1}; L1) and photoinhibitory treatment (1000 μmol.m^{-2}.s^{-1}; L2), maximal photochemical PSII efficiency (Fv/Fm) during the dark period.
Full symbols – sun plants, empty symbols – shade plants.