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The response of sunflower to acute disturbance in water availability

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ABSTRACT

The influence of disturbance in water availability to electron flow in photosystem II was studied in five cultivars of sunflower. The results showed unaffected optimal quantum yield of photosystem II in the plants exposed to limited water supply, indicating the short-term tolerance of photosynthetic processes to acute water deficiency. Effective quantum yield of photosystem II was affected by interruption of water flow through the plants. Cultivar Labud exhibited the greatest sensitivity to water deficiency.

Key words: quantum yield of photosystem II, sunflower, water deficiency

IZVLEČEK

ODZIV SONČNIC NA AKUTNO POMANJKANJE VODE

Pri petih kultivarjih sončnic smo preučevali vpliv omejene preskrbe z vodo na pretok elektronov v fotosistemu II. Prekinitev vodnega toka skozi rastlino ni vplivala na optimalno fotokemično učinkovitost fotosistema II, kar kaže na odpornost procesa fotosinteze na akutno zmanjšano preskrbljenost rastlin z vodo. Dejanska fotokemična učinkovitost fotosistema II se ob akutni motnji preskrbe z vodo zmanjša. Odziv kultivarja Labud kaže največjo občutljivost.

Ključne besede: fotokemična učinkovitost fotosistema II, omejena preskrba z vodo, sončnica

1 INTRODUCTION

In natural environment plants are subjected to several stresses that adversely influence growth, metabolism, and yield. Biotic (insects, bacteria, fungi, and viruses) and

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abiotic (light, temperature, water availability, nutrients, and soil structure) factors affect the growth of higher plants. Among these, drought is a major abiotic factor that limits agricultural crop production (Reddy et al., 2004). Further fluctuations of precipitation distribution caused by global warming, might increase the risk that plants are repeatedly exposed to drought. Almost all plant species exhibit water stress tolerance but the ability varies among species and even cultivars. Stress caused by drought does not occur abruptly, but develops slowly and increases in intensity by the time of duration in contrast to majority of other stress factors (Larcher, 2003).

Photosynthesis in higher plants is known to decrease with the relative water content (RWC) and leaf water potential decreases (Lawlor and Cornic, 2002). Drought mainly limits photosynthesis through stomatal closure and through metabolic impairment (Tezara et al., 1999; Lawson et al., 2003). Drought stress can affect growth of plant organs, resulting in the alteration of the morphological features of the plants (French and Turner, 1991).

Plants have different life strategies to cope drought stress, like drought avoidance and drought tolerance. The ability of plants to delay harmful decrease in the water potential of the protoplasm is considered as avoidance of desiccation. Desiccation tolerance means that plants have ability to maintain their normal functions even at low tissue water potentials. A wide diversity of drought tolerance mechanisms; both morphological and physiological have been developed in plants (Blum, 1996).

Fluorescence measurements as a nonintrusive method allows the rapid assessment of quantum yield of electron flow through photosystem (PS) II. The method has been widely used for detecting water stress in plants (Reddy et al., 2004). In the present research we tested the response of five cultivars of sunflower grown in the field to acute disturbance in water availability using measurements of chlorophyll fluorescence.

2 MATERIAL AND METHODS

Plant material: Sunflower (*Helianthus annuus* L.) has a long and varied history as an economic plant, but the time and place of its first cultivation is uncertain. Sunflower was developed first as an important commercial oilseed crop in the former Soviet Union. The oil has found widespread acceptance as a high quality, edible oil throughout much of the world (Schneider et al., 1981). Sunflower is an anisohydric plant that means that leaf water potential markedly decreases due to evapotranspiration during the day and that it is lower in droughted comparing to watered plants (Tardieu et al., 1996; Tardieu et al., 1998).

Sunflower grew on experimental field of the Biotechnical faculty, University of Ljubljana, (320 m above sea level, 46°35'N, 14°55'E). Experiment was performed in three replicates on the middle heavy soil, with uniform texture (PGI) and good structure.

Fluorescence measurements were conducted on July 30th, 2004 and August 13rd, 2004. Measurements in July were carried out on intact leaves. Measurements in August were done on intact and detached first fully developed leaves. Disturbance in water availability was achieved by detaching the leaves and thus interrupting water flow through the plant. The petioles of the first set of detached leaves were put in water, while the second leaves gradually dried out. Intact leaves were used as a control. Measurements were carried out after four hours after detaching the leaves.

The optimal and effective quantum yield of PSII were measured using the fluorometer OS-500 (Opti-Science, USA). At the ambient temperature nearly all of the fluorescence derives from PSII (Björkman and Demmig-Adams, 1995). The basic fluorescence parameters measured are F_o , F_m and F . When all reaction centres are open F_o can be observed, and F_m is found when all centres are closed. F_v is variable fluorescence ($F_v = F_m - F_o$). Optimal quantum yield expressed as F_v/F_m , is a measure of the efficiency of energy conversion in PSII. F_v/F_m is 0.8–0.83 for a variety of dark-adapted plants (Björkman and Demmig-Adams, 1995). Any deviation from optimal value indicates that a certain plant is exposed to stress (Schreiber et al., 1995). The effective quantum yield of PSII $(F_m' - F)/F_m' = \Delta F/F_m'$ gives the actual efficiency of energy conversion in PSII (Björkman and Demmig-Adams, 1995). F_m' is maximal fluorescence of an illuminated sample and F is steady state fluorescence (Schreiber et al., 1995). Before measuring optimal quantum yield, leaves were kept in dark for 15 min at ambient temperature. Fluorescence was excited with a saturating beam of “white light” (PPFD = 8 000 $\mu\text{mol m}^{-2} \text{s}^{-1}$, 0.8 s). The effective quantum yield was measured under saturating irradiance at the prevailing ambient temperature by providing a saturating pulse of “white light” (PPFD = 9 000 $\mu\text{mol m}^{-2} \text{s}^{-1}$, 0.8 s) using a standard 60° angle clip.

Statistical analyses: Measurements were carried out on 5 to 10 parallel samples. The significance of differences between treatments was tested by ANOVA (Statgraphics Version 4, Statistical Graphics Corp.). The significance was calculated at $p = 0.05$. Columns in the figures sharing the same letter are not statistically different.

3 RESULTS AND DISCUSSION

Optimal quantum yield of all cultivars, measured in July was around 0.8 (Fig. 1). Results showed that sunflowers were in good physiological state. Any decrease in optimal quantum yield directly decreases the flux of electrons out of PSII and consequently lowers the rates of ATP and NADPH₂ formation and that, in turn, slows the enzymatic conversion of CO₂ into organic carbon (Schofield et al., 1995). The values of effective quantum yield were around 0.4 for all cultivars (Fig. 2). Even though effective quantum yield was much lower comparing optimal quantum yield, the changes in reaction centre were reversible, since F_v/F_m was close to 0.8. The second set of measurements was done in August. Optimal quantum yield of control leaves was close to 0.8, while values from the leaves with acute limited supply of water were mainly lower. However, except in cultivar Labud, they were still above 0.7 (Fig. 3). The maintenance of F_v/F_m at high values demonstrated the resistance of the photosynthetic processes to water deficit, as it has been already reported for sunflower (Panković et al., 1999) and some other species (Jiménez et al., 1999; Chaves et al., 2002). Loosing of water in sunflowers was possibly the result of morphological characteristic of epidermis and cuticle. Cornic and Briantis (1991) made conclusion based on chlorophyll *a* fluorescence, that the potential rate of electron transport in tylakoids was maintained even at low relative water content. The F_v/F_m was significantly lower in leaves exposed to limited supply of water comparing to the control in cultivar 1200K and Labud. This suggested that the photosynthetic activity decreased by injury of electronic transfer in PSII. The decrease of F_v/F_m after severe water stress was recently reported by Miyashita et al. (2004). Boyer (1971) reported that after the decrease of leaf water potential below critical level, the recovery of photosynthesis and transpiration in sunflower was incomplete. Havaux et al. (1988) claimed that alterations in chlorophyll fluorescence in leaves subjected to rapid dehydration may provide a useful method of screening genotypes for drought resistance in wheat. In four hours effective quantum yield significantly decreased in detached leaves (Fig. 4). The values were the lowest in cultivar 1200K and Labud,

corresponding to the results of optimal quantum yield. Foyer and Noctor (2000) stated that drought stress inhibited photosynthetic activity in tissues due to the imbalance between light capture and its utilization. Down regulation of PSII activity, causing an imbalance between generation and utilization of electrons, apparently resulting in changes in quantum yield (Reddy et al., 2004). On the other hand, results from Conroy et al. (1986) suggest that the primary effect of water stress on photosynthesis is *via* increased stomatal resistance rather upon primary photochemical events. However, Jefferies (1992) studies on potato have demonstrated that photosynthetic capacity is reduced by water stress.

4 CONCLUSIONS

We can confirm that chlorophyll fluorescence measurement is a suitable tool of studying changes in the photosynthetic capacity of the plants exposed to limited supply of water. Cultivars responded differently to disturbance in water availability. Further analyses and more measurements are needed to be able to range cultivars of sunflowers according to their different sensitivity to acute limitation of water supply.

5 ACKNOWLEDGEMENT

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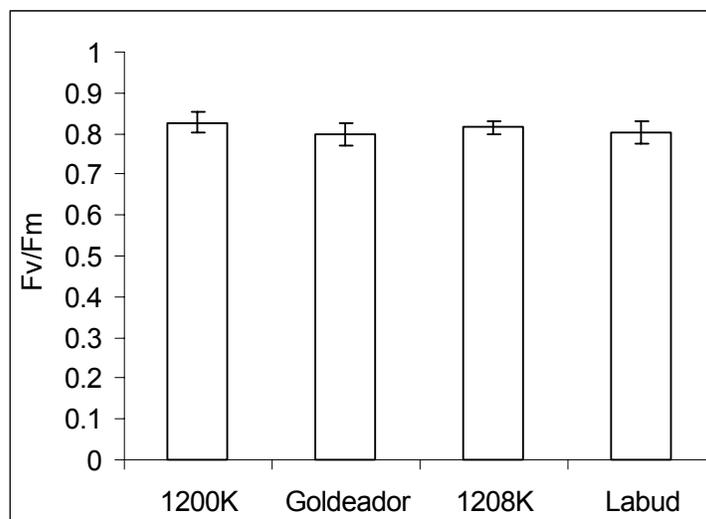


Figure 1: Optimal quantum yield (F_v/F_m) of photosystem II in four cultivars of sunflower measured in July 2004 ($p = 0.05$, $N = 5-10$).

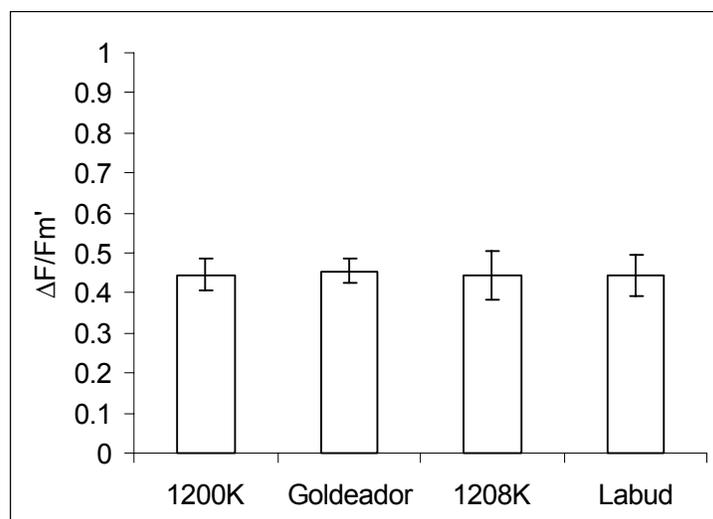


Figure 2: Effective quantum yield ($\Delta F/F_m'$) of photosystem II in four cultivars of sunflower measured in July 2004 ($p = 0.05$, $N = 5-10$).

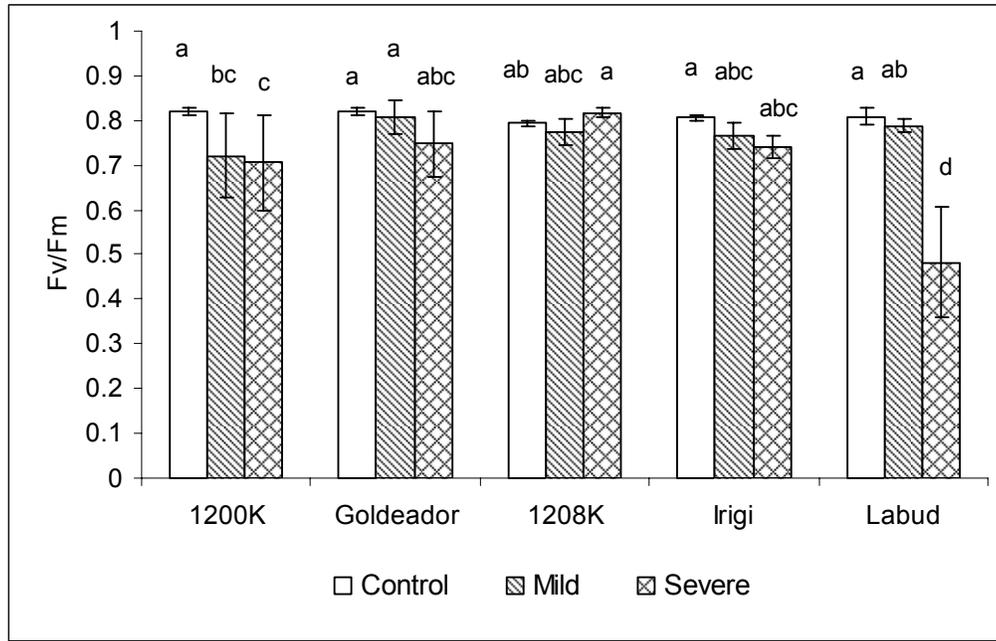


Figure 3: Optimal quantum yield (Fv/Fm) of photosystem II in five cultivars of sunflower measured in August 2004. “Control” stands for intact leaves, “Mild” stands for the detached leaves, which were put in water, while “Severe” stands for leaves that gradually dried out. Columns sharing the same letter are not statistically different (p = 0.05, N = 5-10).

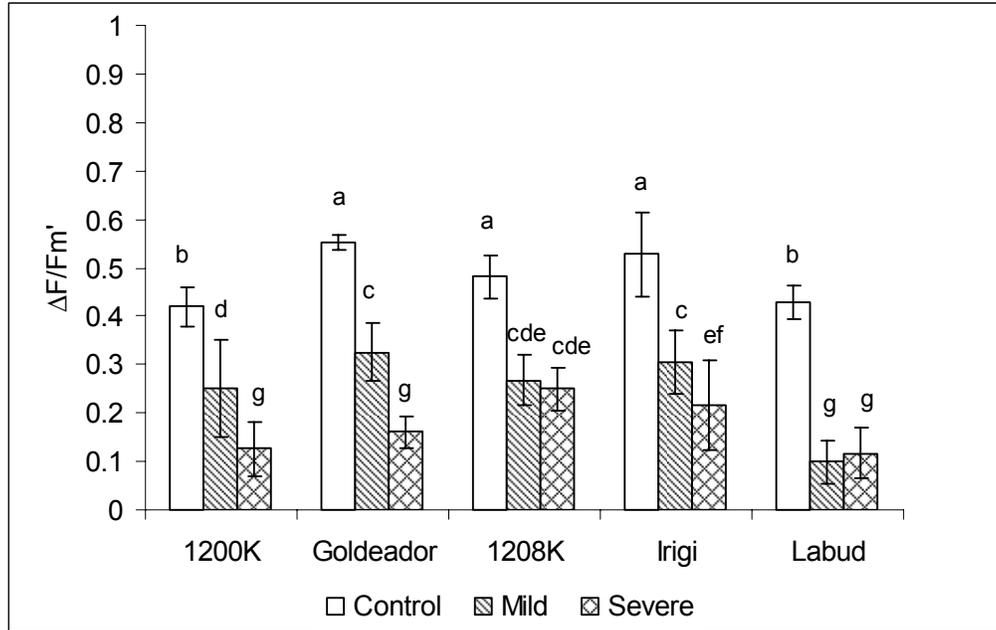


Figure 4: Effective quantum yield (ΔF/Fm') of photosystem II in five cultivars of sunflower measured in August 2004. “Control” stands for intact leaves, “Mild” stands for the detached leaves, which were put in water, while “Severe” stands for leaves that gradually dried out. Columns sharing the same letter are not statistically different (p = 0.05, N = 5-10).