Book of Abstracts

1st PhotosynthOS Conference

April 24-25, 2023 Osijek, Croatia

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1st PhotosynthOS Conference

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PhotosynthOS 2023

1st PhotosynthOS Conference

April 24-25, 2023 Osijek, Croatia

Organizers:

Agricultural Institute Osijek, Osijek

Faculty of Humanities and Social Sciences, Josip Juraj Strossmayer University of Osijek

Department of Biology, Josip Juraj Strossmayer University of Osijek

Croatian Society of Plant Biologists, Zagreb

Sponsor:

International Society of Photosynthesis Research

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1st PhotosynthOS Conference program

Monday, April 24, 2023

8:30-9:30 Registration

9:30-10:00 Conference opening

Plenary lecture

10:00-11:00 **Kalaji, H. M., Dąbrowski, P., Sierka E., Piano D., Golonko, P., Mojski, J., Jaszczuk, Z., & Adamski, A.:** An advanced biological feedback system enables plants to regulate their supplemental lighting in greenhouse conditions

11:00-11:15 Coffee break

Oral presentations

11:15-11:30 **Lepeduš, H.**: A brief historical overview and scientific impact of chlorophyll *a* fluorescence measurements in Croatia during first 20 years

11:30-11:45 **Mlinarić, S.**: Loving the curves: discovering the shapes of the OJIP transient

11:45-12:00 **Šimić, D. & Mlinarić, S.**: Chlorophyll *a* fluorescence and beyond: Recent advancements and future prospects

12:00-13:00 *Poster section*

Mlynarikova Vysoka, D., Kovar, M., Živčák, M., Jasenovská, L., Barboričová, M., Filaček, A. & Brestič, M.: Effect of UV-B radiation on primary photosynthetic processes of lettuce plants

Jasenovská, L., Brestič, M., Barboričová, M., Filaček, A. & Živčák, M.: Screening of the effects of monochromatic light in microgreens using analysis of chlorophyll fluorescence kinetics

Tkalec, M., Vitko, S., Talanga Vasari, A., Goreta Ban, S. & Salopek-Sondi, B.: Photosynthetic adaptation of kale to abiotic stresses

Vitko, S., Vuk, T., Bauer, N. & Vidaković-Cifrek, Ž.: Salt and osmotic stress influence photosynthetic performance of *Arabidopsis thaliana* with modified DMS3 expression

Barboričová, M., Filaček, A. & Brestič, M.: Evaluation of the sensitivity of photosynthetic parameters in conditions of drought and high temperature

13:00-14:00 Lunch break

Oral presentations

14:00-14:15 **Galić, V., Ledenčan, T., Jambrović, A., Zdunić, Z., Podnar Žarko, I. & Šimić, D.**: Photosynthetic activity shows different breakpoints in response to increasing temperatures between maize maturity groups

14:15-14:30 **Viljevac Vuletić, M., & Mihaljević, I.**: Application of chlorophyll fluorescence in fruit science

14:30-14:45 **Mahawar, L. & Brestič, M.**: Impact of the foliar application of zinc oxide nanoparticles on photosynthesis and physiology of Raphanus sativus L. under salinity stress

14:45-15:00 **Antunović Dunić, J., Peršić, V., Zellnig, G. & Cesar, V.**: The effect of cadmium on photosynthesis and chloroplast ultrastructure in *Spirodela polyrhiza*: age-related susceptibility

15:00-15:15 **Mazur, M., Vukadinović, L., Jambrović, A. & Galić, V., Šimić, D.**; Unveiling the potential of chlorophyll *a* fluorescence as a highthroughput phenotyping method in maize breeding and research

15:15-15:45 Coffee break

15:45-17:00 Poster section

Filaček, A., Živčák, M. & Barboričová, M.: Non-invasive methods reveals the significance of alternate electron fluxes in photoprotection of different wheat genotypes under nitrogen deficit conditions

Mirosavljević, M., Mikić, S., Kondić-Špika, A., Župunski, V., Ottosen, C-O. & Zhou, R.: The effect of heat stress on chlorophyll fluorescence in Pannonian wheat varieties

Komazec, B., Vidaković-Cifrek, Ž. & Peharec Štefanić, P.: Effect of silver nanoparticles and ions on photosynthetic performance and oxidative stress induction in *Chlorella vulgaris*

Komazec, B. & Peharec Štefanić, P.: Effect of copper oxide nanoparticles and ions on photosynthetic performance and oxidative stress induction in *Chlorella vulgaris*

Košpić, K., Biba, R., Peharec Štefanić, P., Balen, B. & Tkalec, M.: Coating-dependent effects of silver nanoparticles on photosynthetic performance of tobacco seedlings

Lazarević, B.: Chlorophyll fluorescence imaging in assessing crop abiotic stress

Katanić, Z., Mlinarić, S., Duvnjak, J., Šunić, K. & Španić, V.: Effect of drought on photosynthetic performance of wheat during stem elongation stage

19:00 Conference dinner

Tuesday, April 25, 2023

Plenary lecture

9:00-10:00 **Živčák, M., Filaček, A. & Brestič, M.**: Simultaneous measurements of chlorophyll fluorescence to study photosynthetic regulation in plants exposed to environmental stresses

10:00-10:15 Coffee break

PhotosynthOS 2023

Oral presentations

10:15-10:30 **Šunić, K., Katanić, Z. & Španić, V.**: Photosynthetic efficiency of winter wheat (*Triticum aestivum* L.) infected with *Fusarium* head blight in controlled conditions

10:30-10:45 **Peršić, V., Antunović Dunić, J., Drezner, G. & Cesar, V.**: Exploring winter wheat genotypes' response to physiological drought: insights into the photosynthetic performance

10:45-11:00 **Duvnjak, J., Katanić, Z. & Španić, V.**: Different responses of wheat varieties to drought stress assessed by chlorophyll *a* fluorescence

11:00 – 12:00 *Poster section*

Kovar, M., Živčák, M., Mlynarikova Vysoka, D., Jasenovská, L., Barboričová, M., Filaček, A. & Brestič, M.: Photosynthetic responses of a collection of sorghum genotypes to salinity

Melnjak, A., Limón Santana, J. A. & Peršić, V.: Hungry for sulfur: the interplay of photosynthesis, starch, and anthocyanins

Suman, L., Mlinarić, S., Krvavica, M., Krstin, Lj. & Žuna Pfeiffer, T.: Photosynthetic performance of sun and shade leaves in solitary *Sorbus domestica* L. trees

Begović, L., Mlinarić, S., Galić, V., Abičić, A., Lalić, A. & Cesar, V.: Impact of differing weather conditions on photosynthetic performance of three field- grown barley cultivars

Lunch break

An advanced biological feedback system enables plants to regulate their supplemental lighting in greenhouse conditions

Hazem M. Kalaji[1,2]*, Piotr Dąbrowski[3,2], Edyta Sierka[4,2], Dario Piano[1,2], Piotr Golonko[5,2], Jacek Mojski[6,2], Zuzanna Jaszczuk[7,2], Adam Adamski[2]

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Keywords: Artificial intelligence, chlorophyll fluorescence, greenhouse, light, photosynthesis

Abstract:

Photosynthesis and chlorophyll fluorescence (ChFl) have been utilized to detect the effects of various stressors on plants. Initially, practical research using ChFl measurements aimed to understand the response of plants to various biotic and abiotic stressors. Later, it was employed to enhance the growth and yield of plants and eventually to increase food production and promote sustainability in agriculture. Our concept went a step further and found that ChFl measurements can be used to non-invasively monitor photosynthesizing organisms in various ecosystems and identify the type of stress. Recently, using artificial intelligence and machine learning, we have focused on creating a biological feedback system that allows plants to control their growth conditions, such as light quality and intensity.

Simultaneous measurements of chlorophyll fluorescence to study photosynthetic regulation in plants exposed to environmental stresses

Marek Živčák*, Andrej Filaček, Marián Brestič

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Keywords: photosynthesis, chlorophyll fluorescence, absorbance, gas exchange, stress

Abstract:

Chlorophyll fluorescence analysis as an optical method can be efficiently combined with simultaneous measurements of different signals, thus providing qualitatively more robust information about the photosynthetic processes, regulations, limitations, and photoprotective responses. In drought, salinity, and heat stress conditions, we examined various genotypes of wheat (*Triticum* sp.) of different origins and ploidy, including specific photosynthetic mutant lines. The simultaneous gas exchange and chlorophyll fluorescence measurements during light induction revealed the increasing rates of alternative electron flow in stress conditions but with unequal responses in different genotypes. The simultaneous analyses of PSII fluorescence and P700 absorbance were extremely valuable in evaluating the regulation of electron transport at PSII and PSI in stress conditions, with increasing efficiency observed under drought stress while indicating the occurrence of failures in heat or salinity stress conditions in susceptible genotypes. Similarly, combining chlorophyll fluorescence with analysis of electrochromic bandshift (ECS) provided deep insight into the regulatory role of the transthylakoid proton gradient and its link to photosynthetic proton motive force and ATP synthesis. The topic of simultaneous measurements of different signals with chlorophyll fluorescence is still developing regarding field use, higher throughput, and low-cost technological solutions. Supported by the projects VEGA 1-0664-22 and APVV-18-0465.

A brief historical overview and scientific impact of chlorophyll *a* fluorescence measurements in Croatia during first 20 years

Hrvoje Lepeduš*

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Keywords: chlorophyll *a* fluorescence transients, JIP test, photosynthesis, saturating pulse method

Abstract:

The chain of events that enabled introduction of the chlorophyll *a* fluorescence measurement methods in Croatia and its further application in different scientific institutions and academy will be presented here. Also, the major scientific projects in the period from the past 20 years that utilized this method will be listed. The scientific impact of the method was assessed due to list of Doctoral dissertations and Master of Science Thesis that were produced by using chlorophyll *a* fluorescence measurement, beside other employed methods. Numerous scientific articles will be mentioned with aim to discuss scientific impact that was achieved by adoption of chlorophyll *a* fluorescence measurement as very important scientific tool in various scientific topics and collaborations.

Loving the curves: discovering the shapes of the OJIP transient

Selma Mlinarić*

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Keywords: OJIP, L band, K band, H band, G band

Abstract:

After illumination of the dark-adapted photosynthetic sample by saturating light, a sudden increase in chlorophyll fluorescence arises, followed by a slow decrease of the induced fluorescence. The illuminated photosynthetic sample reveals the fast polyphasic rise from O (F_0) to P (F_P), with several steps (J and I) between the initial and maximum fluorescence intensity. The shape of the raw OJIP transient depends on the proper functioning of the PSII acceptor and donor sides of electron transport in PSII, as well as on the efficiency of interactions between photosynthetic units, which determines the possibility of excitation energy transfer between neighboring reaction centers. To compare the samples for specific events in OJ, OI, and IP phases, transients need to be normalized as relative variable fluorescence and to calculate the difference kinetics. This can reveal specific bands (L, K, H, and G), usually hidden between basic steps of the raw or normalized transients. Each particular band could be correlated with the specific event of light-dependent primary photosynthetic reactions allowing detailed insight into adjustments and functionality of photosynthetic samples. Therefore, extracting all possible information contained in the shape of OJIP transients has great potential for fundamental and practical applications that is yet to be fully explored.

Chlorophyll *a* fluorescence and beyond: Recent advancements and future prospects

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Keywords: chlorophyll fluorescence, future prospects, monitoring, climate change

Abstract:

Although there are thousands of articles on chlorophyll fluorescence (ChFl), it is still widely used in plant research and new developments in technology and analysis have improved its usefulness. A few recent advancements include imaging ChF, multispectral ChFl and imaging reflectance, proximal and remote sensing of ChFl, applications in plant breeding and combination with other techniques. In the future, ChlF is expected to play an increasingly important role in precision agriculture, urban farming, forestry management, aquatic, climate change and bioenergy research. Overall, chlorophyll fluorescence remains a significant tool for understanding photosynthesis and its response to environmental stress, the health of plants and ecosystems.

Photosynthetic activity shows different breakpoints in response to increasing temperatures between maize maturity groups

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Keywords: machine learning, heat stress, diurnal changes

Abstract:

Photosynthetic activity in maize is inhibited by excess light and high temperatures. During the growth cycle, both excess light and high temperature occur, especially during the flowering and grain filling, when the plant is most susceptible to stress. We carried out measurements of the dark adapted chlorophyll fluorescence in 48 maize hybrids belonging to different maturity groups. Measurements were taken consecutively from the morning (7:00 AM) to the maximum light intensity and temperature (3:00 PM) over two years, 2020 and 2021. Early maturing hybrids showed later occurrence of photosynthetic activity breakpoint, while the later ones were more efficient during the morning with steep drop in activity after 10:00 AM. Implications of these findings will be discussed.

Application of chlorophyll fluorescence in fruit science

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Keywords: fruit quality, fruit tree, oxidative stress, postharvest quality

Abstract:

The wide range of research on chlorophyll fluorescence (ChlF) demonstrates its usefulness in many plant biology, agronomy, and ecology research areas. Perennial fruit trees are frequently exposed to various biotic and abiotic stresses throughout their lifespan, limiting their crop quality and yield. Fruit trees exhibit more complex photosynthetic reactions to stress than herbaceous, depending on their age, species, and cultivar characteristics. Therefore, ChlF is an excellent research tool for assessing physiological status thus fruit growers can benefit from using chlorophyll fluorescence to improve plant performance, yield, and quality. In addition to investigating oxidative stress, there are varieties of ChlF applications in other aspects of fruit growing, such as assessment of fruit maturation, postharvest quality, preservation of quality during fruit storage, early detection of disease occurrence of stored apple fruits, and so on. We will present the various applications of ChlF mentioned so far through our own published papers and a literature review.

Impact of the foliar application of zinc oxide nanoparticles on photosynthesis and physiology of *Raphanus sativus* L. under salinity stress

Lovely Mahawar*, Marián Brestič

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Keywords: nanoparticles, zinc oxide nanoparticles, salinity stress, *Raphanus sativus*, nanofertilizers

Abstract:

Salinity is one of the major abiotic stresses that threatens global food security by impacting agricultural production. As major crops are glycophytes, the presence of Na^+ and its excessive uptake negatively influence plant growth and physiology. The study aims to assess the effect of foliar zinc oxide nanoparticles (ZnO NPs) on the photosynthetic efficiency and physiology of Raphanus sativus L. subjected to different concentrations of NaCl. Two weeks old radish seedlings were treated with 150 mM NaCl and 300 mM NaCl alone and in supplementation with ZnO NPs (100 ppm) for 10 and 17 days. Under salinity stress, the leaf area, relative water content, and chlorophyll fluorescence of crop reduces, and it accumulates a considerable amount of flavonoids, anthocyanin and proline to adapt towards stressful environment. Foliar application of ZnO NPs improved the growth of stressed plants by enhancing leaf area and chlorophyll fluorescence, improving phenolic contents and plant pigments, and lowering oxidative damage (H_2O_2) and stress indicator (proline). The interactive study on nanoparticles and NaCl concluded that ZnO NPs enhance crop tolerance and reduce the severe effect of stress on plants. The study is beneficial and has immediate agricultural applications to use metal nanoparticles as nanofertilizers for sustainable crop production in changing environments.

The effect of cadmium on photosynthesis and chloroplast ultrastructure in *Spirodela polyrhiza*: age-related susceptibility

Jasenka Antunović Dunić[1]*, Vesna Peršić[1], Günther Zellnig[2], Vera Cesar[1,3]

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Keywords: dose-time-age response, chlorophyll *a* fluorescence, TEM

Abstract:

Short-term assessment of adverse outcomes is essential for plants growing in high-risk environments. This study examines how cadmium affects the photosynthetic apparatus of *Spirodela polyrhiza* fronds, particularly how different plant generations react to cadmium exposure. A four-frond colony of mother, daughter, and granddaughter plants was exposed to increasing cadmium concentrations for 6, 24, and 72 hours. The results revealed that the length of cadmium exposure was the most relevant variable affecting chlorophyll content. Chlorophyll fluorescence measurements showed that cadmium affects various photosynthetic electron transport segments as plants mature. Mother and daughter fronds responded differently in photosynthetic performance, with mother plants having closed and inactive reaction centers, dissipating energy outflux, and inhibited photosynthesis, indicating more damage as the cadmium concentration increased. At the same time, young fronds exposed to cadmium exhibited increased non-reducing reaction centers, thermal phase reduction, and activation of dissipative mechanisms, showing less damage as cadmium concentration increased. Cadmium-induced alterations in the ultrastructure of chloroplasts were visible after 6 hours of exposure, even at the lowest concentrations, with the thylakoid system gradually degrading as duckweed fronds aged. In conclusion, this study demonstrates that cadmium exposure affects mother and daughter fronds differently, with young fronds being more resilient.

Unveiling the potential of chlorophyll *a* fluorescence as a high-throughput phenotyping method in maize breeding and research

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Keywords: abiotic stress, chlorophyll *a* fluorescence, high-throughput phenotyping, JIP-test, maize (*Zea mays* L.)

Abstract:

A method of fast chlorophyll *a* fluorescence transient measuring (OJIP) is a non-invasive and fast method to measure the physiological status of plants which generates considerable amount of data belonging to high-throughput phenotyping methods. In the last few decades, it has been studied for its potential use as a tool for improving crop productivity and stress tolerance. Researchers at the Agricultural Institute Osijek have used chlorophyll *a* fluorescence to study the effects of various environmental factors on maize growth and development, including drought, temperature, salinity and heavy metal toxicity, providing valuable insights into the photosynthetic properties of maize and potential strategies for improving important traits. The JIP-test has been proven to be a useful method for monitoring plant status in relation to stress, but has several limitations. To overcome these issues, a new low-cost proximal sensor device has been developed to analyze multispectral reads in maize under stress conditions representing the first real high-throughput phenotyping research in maize plants in Croatia. However, further research is necessary to fully understand the benefits and applications of this technique.

Photosynthetic efficiency of winter wheat (*Triticum aestivum* L.) infected with Fusarium head blight in controlled conditions

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Keywords: Fusarium head blight, biotic stress, chlorophyll *a* fluorescence, OJIP kinetics, winter wheat

Abstract:

A significant portion of wheat grain yield losses results from different diseases such as Fusarium head blight (FHB). This study aimed to provide information about the photosynthetic performance of winter wheat varieties under FHB infection. Two winter wheat varieties (Vulkan and Golubica) were inoculated with *Fusarium graminearum* and *F. culmorum* at the flowering stage in controlled conditions. Measurements of chlorophyll *a* fluorescence on flag leaves and ears of controlled and inoculated varieties were performed at 1 day post inoculation (dpi), 3 dpi, 7 dpi, and 10 dpi using Plant Efficiency Analyzer. Results showed that the maximum quantum yield of primary photochemistry (TR_0/ABS), specific energy fluxes per active photosystem II (PS II) reaction center (ABS/RC, TR_0/RC, ET_0/RC, DI_0/RC), as well as performance index on absorption basis (PI_{ABS}) were not significantly affected by treatment in flag leaves. However, the photosynthetic efficiency of the ears significantly decreased at 7 dpi in both varieties, where Golubica variety showed no photosynthetic activity at 7 dpi, compared to Vulkan which was photosynthetically active even at 10 dpi. Since this experiment was conducted in controlled conditions, it provides valuable information about FHB-induced early changes in the functioning of the photosynthetic apparatus of resistant and susceptible wheat varieties.

Exploring winter wheat genotypes' response to physiological drought: insights into the photosynthetic performance

Vesna Peršić[1]*, Jasenka Antunović Dunić[1], Georg Drezner[2], Vera Cesar[1,3]

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Keywords: PEG-6000, *Triticum aestivum*, chlorophyll *a* fluorescence

Abstract:

The study aimed to investigate wheat seedlings' response to simulated physiological drought (induced by PEG-6000) and identify elements of the photosynthetic process that best explain variations observed across 18 winter wheat genotypes. The imposed physiological drought mainly affected phenomenological energy fluxes and the efficiency with which electrons were transferred to final Photosystem I (PSI) acceptors. Based on the size of the effect, difference analysis of all genotypes revealed that the chlorophyll fluorescence parameters can be grouped into three categories: (1) photochemical parameters related to the donor and acceptor sides of Photosystem II (PSII); (2) the thermal phase of the photosynthetic process with electron flow around PSI and the chain of electrons between PSII and PSI; and (3) phenomenological energy fluxes per cross-section. Variable fluorescence parameters at K, L, I step, and total performance index (PI_{TOT}) were determined to be the most informative in accounting for the variations in photosynthetic performance across different wheat genotypes. Furthermore, four genotype groups were distinguished based on principal component analysis of wheat seedlings' response to physiological drought. This research shows that different wheat genotypes respond differently to simulated physiological drought, suggesting that these results could have important implications for breeding programs.

Different responses of wheat varieties to drought stress assessed by chlorophyll *a* fluorescence

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Keywords: winter wheat, lack of water, photosynthetic performance

Abstract:

Under changing environmental conditions, the lack of water in the soil results in drought stress, one of the most destructive stress factors for wheat, which represents a significant problem for world food production. Wheat production could be improved by the implementation of more tolerant varieties, that is, genotypes that will retain their green colour longer with prolonged photosynthesis under drought conditions. In this study, chlorophyll *a* fluorescence was measured in the flag leaves and ears of two wheat varieties (Silvija and Bubnjar) after two weeks of provoked drought stress at two intensities (45 and 65% reduction of volumetric soil moisture content) during the anthesis stage. As a result, there were no significant changes in the analysed JIP-test parameters in flag leaves of Silvija, while significant changes in the ears, including a decrease of TR_0/ABS and PI_{ABS} with an increase in DI_0/RC were observed in the ears in drought treatments, compared to control. For Bubnjar no significant decrease in photosynthetic performance was detected in the flag leaves or ears. This indicates differences in the effect of drought on tested varieties. The research needs to be continued in order to assess which variety better tolerates drought stress, relating to other morphological and physiological parameters.

Effect of UV-B radiation on primary photosynthetic processes of lettuce plants

Dominika Mlynarikova Vysoka*, Marek Kovar, Marek Živčák, Lucia Jasenovská, Mária Barboričová, Andrej Filaček, Marián Brestič

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Keywords: lettuce, UV-B, JIP-test, photosynthesis

Abstract:

Ultraviolet radiation is a well-known damaging factor of plant photosynthesis. However, the effects of UV-B radiation on biological processes are highly dependent on plant species, further on the doses of the radiation, and the acclimation level of the plants. The main reason for the harmful effects of UV-B radiation is initiations of photochemical reactions, including production of reactive oxygen species (ROS), which damages biologically active molecules. The objective of this study was to evaluate how UV-B radiation influence the morphology, antioxidative status of cells and photosynthetic behaviour of both green- and red-leaf lettuce plants (*Lactuca sativa* L., cvs. Lento and Rosemary). Biophysical (JIP test), biochemical (contents of MDA, photosynthetic pigments, anthocyanins and polyphenols), physiological and morphological (dry matter, leaf area) measurements were used to analyse the effect of stress acclimation and level of UV-B induced photodamage. The red genotype showed higher resistance to the increasing intensity of UV-B radiation, mainly by maintaining a higher efficiency of primary photosynthetic reactions. This trait significantly corelate with both anthocyanins and polyphenols content, as well as with the activity of antioxidant enzymes. UV-B radiation induced the accumulation of anthocyanins and polyphenols in lettuce leaves.

This work was supported by the projects APVV-18-0465, VEGA-1-0664-22.

Screening of the effects of monochromatic light in microgreens using analysis of chlorophyll fluorescence kinetics

Lucia Jasenovská*, Marián Brestič, Mária Barboričová, Andrej Filaček, Marek Živčák

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Keywords: microgreens, chlorophyll fluorescenc e, light spectra, monochromatic light, LEDs

Abstract:

Cultivation conditions, such as light quality, can influence the content of valuable nutritional elements of microgreens. Our experiments focused on pre-screening the microgreens according to responsiveness to light spectra based on the non-invasive techniques assessing both photochemical and qualitative traits. The present work summarizes the results of analyses of the fast chlorophyll fluorescence kinetics in a collection of microgreens (19 genotypes of 17 species) cultivated in three light environments: control represented by white LEDs with balanced spectral composition, monochromatic blue (470 nm) and red (660 nm) LED lights. In red light, compared to blue light, we observed an increase in PSII antenna size indicated by the ABS/RC parameter, a decrease in the efficiency of electron flow between photosystems (PSII and PSI), and an overall reduction of the pool of electron carriers (Sm). Based on the values of the photochemical performance index (Plabs), we classified the tested genotypes into four groups: non-responsive to spectra (wheatgrass, spinach, pea jumbo, and fava bean), highly responsive to blue spectra (arugula, mung beans, pea, and lettuce), highly responsive to red spectra (watercress, sunflower, lettuce, lentils, kohlrabi, fenugreek, corn, cabbage, and amaranth) and equally responding both to blue and red spectrum (mustard, red radish).

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Photosynthetic adaptation of kale to abiotic stresses

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Keywords: *B. oleracea* var. *acephala*, osmotic stress, heat stress, chlorophyll *a* fluorescence

Abstract:

Brassica vegetables have attracted public and scientific attention because of their richness in "healthy phytochemicals" and their great adaptability to climatic conditions. However, the cultivation of brassicas is becoming increasingly challenging due to the negative impacts of climate change, such as heat stress and decreasing precipitation. In AGROBIOCLIM project we studied the tolerance of 33 kale cultivars (*Brassica oleracea* var. *acephala*) to individual (drought or heat stress) and combined (drought + heat) stress. Based on growth performance and proline content the most tolerant and the most sensitive cultivars were selected to shed light on the mechanisms of their tolerance. Photosynthetic adaptation to stress was studied using chlorophyll *a* fluorescence induction kinetics. After drought stress, both the performance index on absorption basis (PI_{ABS}) and maximum quantum efficiency of photosystem II (F_v/F_m) showed a significant decrease in sensitive cultivars. Reduction in PI_{ABS} was associated with an increase of heat dissipation and a decrease in electron transport flux. Interestingly, combined stress caused less severe effect on photosynthetic apparatus, whereas increased temperature manifested with the least prominent changes. Our research showed that chlorophyll *a* fluorescence could be used as a quick and sensitive method for identifying tolerant cultivars *in vivo*.

Salt and osmotic stress influence photosynthetic performance of *Arabidopsis thaliana* with modified *DMS3* expression

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Keywords: RdDM, stress response, photosynthetic efficiency, OJIP transient

Abstract:

The protein DEFECTIVE IN MERISTEM SILENCING 3 (DMS3) is an essential component of RNA-directed DNA methylation (RdDM) that maintains genome integrity and influences gene expression throughout the plant life cycle. To investigate the role of DMS3 in the stress response of *Arabidopsis thaliana* (L.) Heynh., three lines were used – wild type (wt), line with overexpressed *DMS3* gene (*oeDMS3*), and line with mutated *DMS3* gene (*dms3-1*). Five-day-old seedlings were exposed to 75 mM NaCl or 150 mM mannitol for seven days (from day 6 to day 12). Photosynthetic efficiency was determined using chlorophyll *a* fluorescence induction kinetics followed by the JIP-test. Both wt and *dms3-1* seedlings showed a decrease in the maximum quantum efficiency of photosystem II (F_v/F_m) after salt stress. Moreover, *dms3-1* seedlings also showed decreased F_v/F_m after osmotic stress. Compared with wt, the performance index on absorption basis (PI_{ABS}) and electron transport flux per reaction centre (ET_o/RC) were reduced in *oeDMS3* and *dms3-1* after both salt and osmotic stress. When comparing wt and lines with modified *DMS3* expression, *dms3-1* showed the highest sensitivity of the photosynthetic apparatus. The observed differences suggest an important role of DMS3 and probably RdDM in regulating the photosynthetic response to salt and osmotic stress.

Evaluation of the sensitivity of photosynthetic parameters in conditions of drought and high temperature

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Keywords: wheat, climate change, chlorophyll fluorescence, photosynthesis

Abstract:

Wheat *(Triticum sp.)* is one of the most important staple foods crops and its production and yield can be affected by climate change. The climate change (drought, high temperature) comes along with implications like rise of abiotic and biotic stresses, which negatively affect production of wheat. Drought and high temperature cause multiple negative effects on plants and launches complex stress responses at different levels. The aim of our work was to characterize varietal differences and the sensitivity of photosynthetic parameters from the point of view of evaluating tolerance to drought and high temperature. To evaluate the effect of climatic extremes on photosystem II structure and function and overall photosynthesis, chlorophyll fluorescence (Handy Pea, Hansatech, GB) and gas exchange measurements (Li-cor, Lincoln, NE, USA) were done. Further, the relative water content (RWC), free proline content, and assimilation pigments content were determined. Based on the analysis of the fluorescence parameters, the results showed the influence of the stress factor with a significant decrease in the maximum photochemical yield of the PSII parameter (Fv/Fm), which led to the inhibition of the density of active reaction centres (RC/ABS) and a significant decrease in the total photosynthetic activity (PIabs) in all varieties. It also negatively affected the Wk parameter characterizing the damage to the oxygen-evolving complex. Stomatal closure and the decrease in carbon assimilation influenced stomatal inhibition of photosynthesis.

This work was supported by the projects of the Scientific Grant Agency of Slovak Republic VEGA-1-0664-22 and APVV-18-0465.

Non-invasive methods reveal the significance of alternate electron fluxes in photoprotection of different wheat genotypes under nitrogen deficit conditions

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Keywords: nitrogen, wheat, photosynthesis, photoprotection, phenotyping

Abstract:

Plant growth and the production of cereal crops are primarily driven by photosynthesis. The supply of N to plants greatly influences the health and activity of the photosynthetic machinery in leaves. We performed sophisticated analyses of CO_2 assimilation, PS II, and PS I photochemistry to examine the effects of various nitrogen nutrition at three different leaf positions of two distinct wheat genotypes (cv. Enola and cv. Slomer). We used analyzes of fast chlorophyll fluorescence kinetics (Handy PEA), simultaneous measurement of PSI and PSII activity (Dual-PAM-100) and photosynthesis measurements using the innovative method of fast A/Ci curves were carried out by two IRGAs (Licor-6400XT and Ciras-3). Our results demonstrated the decline in photosynthetic capacity and the modifications of PS II and PS I photochemistry reflected non-stomatal limitations of photosynthesis. Alternative electron flow and photorespiration capability were enhanced in an older genotype Slomer that assimilates CO_2 at a slower rate. Enola, a modern genotype that is highly productive, on the other hand, increased nonphotochemical dissipation and cyclic electron transport in response to decreased photosynthetic activity. Our results demonstrate how crucial alternative electron fluxes are for eliminating the excitation pressure at the PS II acceptor side.

The effect of heat stress on chlorophyll fluorescence in Pannonian wheat varieties

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Keywords: high temperature, photosynthesis, stress, wheat

Abstract:

Winter wheat is sensitive to heat stress, which highlights the need for adaptation to high-temperature events to ensure high and stable yields. This study aimed to investigate the chlorophyll fluorescence response of eight wheat varieties from southeastern Europe to heat stress. Heat stress was applied during anthesis and mid-grain filling at 35/25 °C and 38/28 °C day/night for seven days, respectively. The results showed no significant differences in F_v/F_m values between wheat plants grown under control and heat stress during anthesis on the first, second, fifth, and seventh stress days. This absence of high-temperature effect during anthesis indicates that temperatures of 35/25 °C for seven days are insufficient to differentiate wheat variety reactions based on F_v/F_m measurements. However, when temperatures were increased to 38/28 °C during mid-grain filling, a significant variation in F_v/F_m values among the studied wheat varieties was observed. NS 40S and NS Ilina showed a notably slower reduction in F_v/F_m over time under heat stress treatment at mid-grain filling, exhibiting the highest F_v/F_m values on the seventh day. These varieties can be valuable sources of heat stress tolerance and should be considered for further breeding activities under the conditions of southeastern Europe.

Acknowledgements: This research was supported by Transnational Access EPPN2020 – "Phenotyping of wheat (*Triticum aestivum* L.) response to heat stress at different developmental stages" ID: 170 and the APV long-term project “Winter wheat nitrogen use efficiency improvement in Vojvodina” grant number: 142-451-3152/2022-01/3.

Effect of silver nanoparticles and ions on photosynthetic performance andoxidative stress induction in *Chlorella vulgaris*

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Keywords: AgNPs, chlorophyll fluorescence, cell ultrastructure, ROS, *Chlorella vulgaris*

Abstract:

Silver nanoparticles (AgNP) are commonly used nanomaterials with unique physicochemical properties, but their release into the environment raises concerns about their impact on ecosystems. To evaluate the effect of AgNPs stabilized with CTAB or citrate and silver ions (AgNO3) in *Chlorella vulgaris*, reactive oxygen species (ROS) and lipid peroxidation level were measured after exposure to concentrations that enable 75% cell survival after 72 hours in liquid BBM medium. Furthermore, ultrastructural changes of the cells were analyzed by transmission electron microscopy (TEM). To investigate the effect of the AgNPs and ionic silver on photosynthesis, oxygen evolution and maximum quantum yield of photosystem II (F_V/F_m) were determined. The expression of ribulose bisphosphate carboxylase (Rubisco) and PbsA proteins was analyzed by immunoblotting, since stressful conditions can negatively affect their synthesis. After treatment with AgNP-citrate, AgNP-CTAB and AgNO3, there was a significant increase of ROS and lipid peroxidation level while TEM analysis showed changes in cell wall integrity. Moreover, evolution of oxygen and the F_V/F_m were reduced when compared to the control samples. Differential expression of PbsA and Rubisco was also demonstrated. These results suggest that AgNPs and ionic silver have negative effects on microalgae and their photosynthetic process.

Effect of copper oxide nanoparticles and ions on photosynthetic performanceand oxidative stress induction in *Chlorella vulgaris*

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Keywords: copper nanoparticles, chlorophyll fluorescence, cell ultrastructure, ROS, *Chlorella vulgaris*

Abstract:

Copper nanoparticles have unique properties but raise concerns about their potential impact on aquatic ecosystems. To investigate the effects of CuONP, Cu_2ONP, and copper ions on the freshwater alga *Chlorella vulgaris*, the concentrations enabling 75% cell survival after 72 hoursin liquid BBM medium were used to measure reactive oxygen species (ROS) and lipid peroxidation levels, while ultrastructural changes in the cells were studied by transmission electron microscopy (TEM). The oxygen evolution and maximum quantum yield of photosystem II (F_v/F_m) were measured to evaluate the effects of CuONP, Cu_2ONP, and $CuSO_4$ on photosynthesis, and immunoblotting was performed to analyze the expression of Rubisco and PbsA, two key proteins in photosynthesis. The results indicated a significant increase in ROS and lipid peroxidation levels and changes in cell wall integrity observedafter all treatments. The incorporation of copper into thylakoids after treatment with Cu_2ONPwas confirmed. In addition, oxygen evolution was reduced, F_v/F_m changed after all treatments,while differential expression of PbsA and Rubisco was detected compared to control samples.These results suggest that copper oxide nanoparticles and ionic copper may have deleteriouseffects on microalgae and strongly affect photosynthesis.

Coating-dependent effects of silver nanoparticles on photosynthetic performance of tobacco seedlings

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Keywords: AgNPs, chlorophyll *a* fluorescence, photosynthetic pigments, chloroplast ultrastructure, *Nicotiana tabacum*

Abstract:

Enhanced reactivity and antimicrobial properties of silver nanoparticles (AgNPs) compared to bulk silver have led to their increasing use in various products, including agriculture and food production, posing a threat to the environment and living organisms. Because AgNPs readily transform in the environment, various surface coatings are used to improve their stability, which alters their physicochemical properties and potentially leads to increased toxicity. In this study, the effects of AgNPs stabilised with polyvinylpyrrolidone (AgNP-PVP) and cetyltrimethylammonium bromide (AgNP-CTAB) on photosynthesis were investigated. Three-week-old tobacco seedlings were grown in liquid nutrient medium containing 25, 50, and 100 µM AgNP-PVP or AgNP-CTAB for 7 days. Chlorophyll *a* fluorescence, photosynthetic pigment content, and chloroplast ultrastructure were analysed. Photosynthetic parameters derived from JIP test analysis of fluorescence transients showed decreased photosynthetic performance in plants exposed to AgNP-PVP and AgNP-CTAB compared to the control. This correlated with decreased photosynthetic pigment content as determined by high performance liquid chromatography. Chloroplasts of treated plants exhibited enlarged plastoglobules, a greater amount of starch granules, and thylakoids pressed to the plasma membrane. AgNP-CTAB showed a stronger toxic effect on all parameters studied. Our results suggest that the observed effects of AgNP-PVP and AgNP-CTAB are probably related to their intrinsic properties.

Chlorophyll fluorescence imaging in assessing crop abiotic stress

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Keywords: Abiotic stress, chlorophyll fluorescence imaging, fluorescence heterogeneity, plant phenotyping

Abstract:

Chlorophyll fluorescence imaging is a reliable, nondestructive tool that is ideally suited for plant ecophysiological research to monitor and quantify abiotic stress responses at the leaf or whole plant level. This methodology solves the problem of sample heterogeneity and avoids potential errors that can occur with point measurements. In addition, the integration of chlorophyll fluorescence imaging systems into the plant phenotyping platforms enabled automatic measurements of chlorophyll fluorescence traits on a large number of samples. This has increased the applicability in screening for desirable agronomic traits in various breeding programs. Also, the simultaneous combination of chlorophyll fluorescence measurements with other phenotyping techniques such as multispectral imaging, thermal imaging, 3D scanning, etc., offers new possibilities in plant research and enables detailed study of the temporal and spatial interaction between plant and environment.

Effect of drought on photosynthetic performance of wheat during the stem elongation stage

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Keywords: chlorophyll *a* fluorescence, drought, JIP-test, pigments content, winter wheat

Abstract:

The lack of water in the soil due to the insufficient amount of rainfall during the vegetation season represents a major problem in wheat production with various adverse effects on the wheat plants that can ultimately reflect on the grain yield and quality. Water deficit can occur in different wheat growth stages. Although drought during flowering and grain-filling is considered to be the most problematic, analysis of the response in other growth stages could contribute to a comprehensive understanding of the effects of drought stress on wheat. This study aimed to evaluate the effect of drought (45 and 65% reduction of volumetric soil moisture content) on winter wheat during the stem elongation stage, the most sensitive stage in terms of the total number of spikelets, by analyzing the chlorophyll *a* fluorescence rise kinetics and photosynthetic pigments content. Results indicate that drought in this developmental stage can induce changes in photosynthetic performance and chlorophylls and carotenoids content which are genotype-specific. Among tested varieties (Pepeljuga, Rujana and Anđelka), the variety Pepeljuga was shown to be least affected. The significance of observed differences in the effect of drought during the stem elongation stage for the overall response of these varieties and their agronomical parameters will be further explored.

Photosynthetic responses of a collection of sorghum genotypes to salinity

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Keywords: sorghum, salinity, JIP-test, photosynthesis

Abstract:

Plants cannot move, so they must endure abiotic stresses. The efficiency of photosynthetic machinery under stressful conditions has been identified as a key target for crop improvement. The effect of salinity on primary photochemical reactions in six sweet sorghum genotypes was tested. An increase in salt concentrations significantly induced the accumulation of proline and caused a decline in leaf osmotic potential, which induced an increase in the capacity for osmotic adjustment of cells. Salinity-induced changes in sorghum phenotype were identified at a later stage of the plant's life cycle. Salinity significantly decreased chlorophyll content and photosynthetic efficiency of plants. Increasing salinity led to a higher accumulation of QB-nonreducing PSII reaction centers. K-step in OJIP fluorescence transient was observed for the most sensitive genotypes under the high NaCl concentration. The studied sorghum genotypes responded differently to salinity stress. Thus, the study helps understand the plant tolerance mechanisms of different sweet sorghum genotypes to increasing salinity stress. The study also confirmed that the use of JIP-test is suitable for the identification of sorghum genotypes according to their growth under salinity stress. This work was supported by the projects APVV-18-0465, VEGA-1-0664-22.

Hungry for sulfur: the interplay of photosynthesis, starch, and anthocyanins

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Keywords: *Spirodela polyrhiza*, chlorophyll *a* fluorescence, Photosystem II, electron transport

Abstract:

Sulfur has a vital role as an essential element in various plant components, including the photosynthetic apparatus, electron transport system, coenzymes, and prosthetic groups, and its deficiency can significantly impact the efficiency of photosynthesis. With this in mind, this study aimed to investigate the effects of sulfur deficiency on photosynthetic activity in *Spirodela polyrhiza* and its interplay with chlorophyll degradation, starch buildup, and anthocyanin accumulation. Chlorophyll fluorescence measurement was used to monitor physiological function and the state of Photosystem II (PSII) reaction centers, light-harvesting antenna complexes, and the donor and acceptor sides of PSII. The findings revealed a reduction in electron transport on the acceptor side of PSII by 30% and a decrease in the quantum yield of electron transport flux until PSI end electron acceptors by 58%. At the same time, protective mechanisms were activated to safeguard PSII against photooxidative damage. The growth rate was reduced, and anthocyanin accumulation increased by 224% in sulfur-deficient plants to protect PSII from excessive radiation energy. However, S starvation less affected starch buildup (44% increase) due to the decline in chlorophyll content (33% decrease) and carbon assimilation rate. Overall, these results highlight the importance of sulfur in regulating plant metabolism and growth, maintaining the balance between photosynthesis and secondary metabolite production.

Photosynthetic performance of sun and shade leaves in solitary *Sorbus domestica* L. trees

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Keywords: service tree, solitary trees, extreme temperature

Abstract:

Service tree (*Sorbus domestica* L.) is a wild fruit tree usually used for ornamental purposes, wood and fruit production. Since *Sorbus* trees are unable to stand the competition of other species, they are usually found as solitary trees. As such, they are directly exposed to increased intensity of light and extreme environmental conditions. Measurements were performed in July 2022 in wooded low mountain range in the central part of Croatia at four solitary trees. Chlorophyll *a* fluorescence was measured in the central leaflets of five sun and shade exposed leaves in each tree. Maximum quantum yield of PSII (TR_0/ABS) and quantum yield for electron transport (ET_0/ABS) were lower in sun leaves while the quantum yield for reduction of end electron acceptors at the PSI acceptor side (RE_0/ABS) was lower in shade leaves. While the performance index on absorption basis (PI_{ABS}) was higher in shade leaves, the total performance index (PI_{total}) was shown to be higher in sun leaves. The more negative contribution of driving forces for reduction events of PSI, $\log \delta_{R0}/(1-\delta_{R0})$, in shade leaves was the reason for the opposite difference observed between PI_{ABs} and PI_{total}. Such results suggested that PSI in shade leaves was more prone to photoinhibition than in sun leaves.

Impact of differing weather conditions on photosynthetic performance of three field- grown barley cultivars

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Keywords: *Hordeum vulgare*, photosynthesis, yield, photosystem II, performance index

Abstract:

Meteorological conditions can significantly diverge from mean conditions by the occurrence of extreme weather events such as heavy rainfall and affect crop production. In the present study, we performed the analysis of photosynthetic performance by measuring chlorophyll *a* fluorescence in three spring barley cultivars during two growth seasons, differing in weather conditions, at two growth stages, flowering (May) and grain filling (June). Although the average temperature did not differ between the seasons, unfavorable field conditions in one season were characterized by high amount of rainfall and increased photosynthetic active radiation (PAR) at flowering and grain filling stage what significantly affected yield. Namely, in cv. Astor yield was reduced by approximately 40%, by 45% in cv. Jaran and 54% in cv. Scarlett when compared to the season with average rainfall. Evaluation of the photosynthetic performance of three spring barley cultivars showed that each cultivar employed different strategies in order to adapt and respond to unfavorable field conditions. The increasing number of extremely unfavorable weather conditions in the future are instigating higher interannual yield variability and hence represent a challenge for suitable crop management.

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