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Special issue on Recent advances in photomodulation in higher plants, algae, and bryophytes

EDITORIAL

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Photosynthesis is the green engine that powers life on the Earth, as it is the only biological process that allows plants, algae, cyanobacteria, and anoxygenic photosynthetic bacteria to convert light into chemical energy. Light is not simply the fuel for photosynthesis, indeed light spectra can dramatically influence plant growth and quality *via* the regulation of photosynthesis, photomorphogenesis, and secondary metabolism (Landi *et al.* 2020).

Understanding the intimal mechanisms through which plants respond to light conditions is a frontier research topic for both basic and applicative science. In natural environments, self-shading, shading by surrounding plants, and the presence of clouds are just some events leading to the fluctuation in light perception by plants and other photosynthetic organisms. In those conditions, higher plants, algae, and bryophytes have to promptly respond and adapt their metabolism to such light variation, to perform in a challenging environment. From an applicative point of view, in the last decade lot of research has been done to improve light quality in indoor cultivation and nowadays very efficient and performant light sources are available. For the same reason, the advancement in light technology has generated narrow-band light-emitting diodes which allow deepening the effect of 'quasi-monochromatic' radiation on plant metabolism in terms of morphoanatomical as well as physiochemical photomodulatory effects.

The present special issue includes two review articles and nine research papers dealing with mechanisms related to the photomodulation and photodynamics in higher plants, algae, and bryophytes in both natural as well as artificial conditions.

The literature survey proposed by Sharma *et al.* (2023) depicts the mechanisms of adaptation of both photosystems in conditions of high-light stress, describing the strategies to mitigate the damage by decreasing antennae size, enhancing nonphotochemical quenching through the introduction of mutants, expression of algal proteins to improve photosynthetic rates and engineering ATP synthase. The review by Landi and Guidi (2023) deepens the effect of abiotic stress on photosystem II (PSII) components, with particular emphasis on intrinsic, such as D1 and D2, and extrinsic proteins (*i.e.*, PsbO, PsbP, PsbQ, and PsbR) behavior when plants experience a condition of light stress.

The research by Sunoj *et al.* (2023) reports the effects of chilling on photosynthesis in six tropical tree species growing in the subtropics in China. The authors found that chilling induced stomatal and nonstomatal effects and photoinhibition of PSII, with severe effects in *Ixora chinensis*. Conversely, moderate effects were recorded in *Woodfordia fruticosa*, with negligible reduction of photosynthesis and PSII activity, higher cyclic electron flow, and oxidation state of P_{700}. Studied parameters revealed that coupling between light-dependent and CO_2 assimilation reactions was enhanced under chilling.

Pashkovskiy *et al.* (2023) studied the influence of phytochromes on microRNA expression, phenotype, and photosynthetic activity in *Arabidopsis thaliana phy* mutants under different light regimes. The main findings highlight that the reduced content of photoreceptors in *phy* individuals affects the phytochrome-interacting factors. In plants grown under red (RL) and white light (WL), the phenotype of *phyb* mutant was distorted; however, under blue light (BL) conditions, the *phyb* phenotype was restored. The photosynthetic rates of both the mutants and wild type were higher under BL than under RL and WL. The expression of most studied miRNAs increased in *phyaphyb* mutants under BL conditions, which is probably one of the reasons for the normalization of the phenotype, the increase in PSII activity, and the photosynthetic rate.

Results by Tomar *et al.* (2023) unveil that in *Chlorella vulgaris* and *Scenedesmus acutus* light intensity impacts the toxicity of pyrene (PYR), a 4-ring polycyclic aromatic hydrocarbon. In the presence of PYR, *S. acutus* grew

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well in both low light (LL) and high light (HL) intensity. On the other hand, *C. vulgaris* showed a drastic decrease in growth and photosynthesis under HL conditions due to PYR toxicity. Regulation of photochemical and nonphotochemical quenching was responsible for the survival of *S. acutus* under PYR toxicity in both light regimes. Given the above, *S. acutus* is a more promising candidate for PYR degradation in a range of light conditions.

Pandey *et al.* (2023) investigated the effects of UV-B radiation and chromium in ultrastructure, photosynthetic abilities, and secondary metabolite accumulation in *Adhatoda vasica*, a well-known medicinal plant. As the main findings, a significant reduction in photosynthetic rate, intercellular CO_2 concentration, and stomatal conductance, were observed under all treatments, with maximum amplitude in Cr+UV-B stressed plants. Chlorophyll fluorescence parameters showed variable responses under Cr and Cr+UV-B. Chlorophyll content declined under all treatments whereas Chl *a*/*b* ratio and carotenoid concentration were promoted by UV-B while depressed under Cr and Cr+UV-B. Notably, vasicine (medicinally important secondary metabolite) increased under treatments, mostly in Cr-stressed plants.

In another study dealing with UV-B radiation (Baroniya *et al.* 2023), it has been reported that four soybean varieties (namely PK-1029, PK-472, NRC-7, and Hardee) performed differently and showed a degree of UV-B sensitivity. The significant increase in net photosynthesis was linked to increased stomatal conductance and lower intercellular concentration of CO_2 in UV-excluded plants. The exclusion of solar UV increased seed mass per plant in all soybean varieties as compared to the control growing in ambient UV-B, supporting the fact that ambient UV exclusions boost photosynthetic efficiency and improve the soybean yield. The overall cumulative stress response index of four varieties implies that Hardee and PK-472 were more sensitive whereas NRC-7 and PK-1029 were tolerant to ambient UV radiations.

Laad *et al.* (2023) also investigated the effect on the photosynthetic apparatus exerted by UV-A and UV-B exclusion in soybean, in association with arbuscular mycorrhizal fungi (AMF) inoculation. The plants grown with UV exclusion and inoculated with AMF inoculation (I) had higher contents of photosynthetic pigments, carbonic anhydrase activity, reduced internal CO_2 concentration, enhanced transpiration rate, and stomatal conductance as well as an improved photosynthetic rate over uninoculated plants. Moreover, –UVB+I and –UVAB+I plants exhibited an increased performance index, the activity of the water-splitting complex on the donor side of PSII, and the concentration of active PSII reaction centers per excited cross-section. Overall, UV-excluded and AMF-inoculated plants showed the highest quantum yield of PSII and rate of photosynthesis which consequently increased the yield of soybean.

The research done by Ivanov *et al.* (2023) investigated the changes in photosynthetic activity, as well as the activity of nitrogen-metabolism enzymes, the level of lipid peroxidation, and proline content in *Triticum aestivum* L. plants after their incubation at a low CO_2 concentration. The main results unveil that low CO_2 concentration resulted in a decline of gas-exchange parameters as well as at the maximum and effective quantum photochemical yields. CO_2 deficiency also impacted nitrate reductase activities, but increased the activities of nitrite reductase, glutamine synthetase, and glutamate dehydrogenase, and promoted proline accumulation.

The impact of additional green light and deficit in cryptochrome 1 on photosynthetic activity and pro-/antioxidant balance in *Arabidopsis thaliana hy4* mutant plants was tested by Kreslavski *et al.* (2023). The authors demonstrated that the deficiency of cryptochrome 1 under a red/blue light ratio of 4:1 led to a decrease in the rate of photosynthesis and PSII activity. However, in the presence of additional green light, this difference for photosynthetic parameters either decreased or was absent, likely due to a green-light-promoted decrease in the content of active cryptochromes. Thus, cryptochrome 1 deficit reduces the photosynthetic rate and PSII activity, and antioxidant capacity in *Arabidopsis*. However, additional green light partially removes these effects of cryptochrome 1.

Fujii *et al.* (2023) investigated the variation in leaf mesophyll anatomy of fern species and found that this trait imposes significant effects on leaf gas exchange, light capture, and leaf hydraulic conductance. Using seven fern species, the authors first showed that fern species with a large mesophyll thickness had a high photosynthetic rate related to high light capture, high drought tolerance, and low leaf hydraulic conductance. The chloroplast surface area (S_c) per mesophyll thickness significantly decreased with an increase in mesophyll thickness, which may increase light diffusion and absorption efficiency in each chloroplast. The photosynthetic rate per S_c was almost constant with mesophyll thickness, which suggests that ferns enhance their light capture ability *via* the regulation of chloroplast density.

Overall, the special issue offers fresh insight on photomodulation in plant metabolism, with a particular focus on photosystems and photosynthetic pigments, and photosynthetic apparatus *sensu lato*. The content of the present Special Issue testifies how active is the research on matter and paves the way for new studies aimed at deepening light-driven plant reactions which is a frontier topic of research in plant science from both an ecophysiological and applicative point of view.

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