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Editorial

Impact of Light on Horticultural Crops

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Light is an essential factor for the growth and quality of horticultural plants and its effects depend upon parameters such as duration, intensity and quality. It is an energy source for photosynthesis as well as a signal triggering plant photomorphogenesis and physiological, biochemical and molecular responses. However, solar light strongly differs between winter and summer conditions, with excess light in open field cultivations imposing severe stress on plants, especially during summer months, while supplementary light sources are implemented in greenhouse crop production to complement natural light when it is insufficient. On the other hand, artificial lighting is used as the sole lighting source in plant factories (PFALs) and nurseries (e.g., healing chambers for grafted seedlings). Technological innovation such as the emergence and growth of light-emitting diodes (LEDs), heating and cooling systems, disinfection materials, and renewable energy sources enabled and facilitated horticultural crop production in closed production systems. In order to enhance sustainability and profitability, light must be studied and efficiently applied within horticultural crop production. The abovementioned novel technologies showcase the critical role of light interacting with plants from the level of seed germination to growth rate, product quality and post-harvest storage. Moreover, from an investor's and producer's point of view, these technologies offer the possibility to reduce electrical consumption, to balance the carbon footprint of fresh products, and ultimately to reduce production costs.

This Special Issue collects recent research findings dealing with a wide range of topics related to light effects on horticultural crops. All contributions are original research articles dealing with a wide range of subjects. These subjects include seed treatment with light and laser to enhance caper germination [1], light quantity and quality effects on the production of grafted and ungrafted vegetable seedlings [2–5], application of light in a greenhouse or a PFAL system to enhance the yield and nutritional value of lettuce varieties [6–8] and watercress [9], light colour impact on Chrysanthemum cuttings' rooting and growth [10], as well as a study of the potential of LEDs in combination with adaptive lighting control protocols and greenhouse-integrated photovoltaics to enable year-round crop cultivation in the Nordics [11].

Caper (*Capparis spinosa* L.) seeds show considerable difficulties in their germination, with light offering the potential to withdraw the dormancy in certain seeds. Foschi et al. [1] analysed the germination response of caper seeds after exposure to light and He-Ne laser. According to their results, the authors concluded that light (they tested white, red, blue, and red + blue wavelengths, and darkness) during the germination process did not provoke a response to caper seeds. Therefore, to save energy, darkness is the logical way for caper germination. On the other hand, irradiation of pre-soaked caper seeds with a He-Ne laser increased their germination percentage but only after application of a gibberellic acid solution.

In the northern hemisphere, solar light reaching inside a greenhouse can be insufficient during the winter months and may result in inferior vegetable seedling quality. Supplemental lighting is a means to encounter this constrain, and light quality can have a significant effect. Yan et al. [2] tested LEDs with different spectral emissions (including white, blue and UV-A) as supplemental lighting options for the production of cucumber (*Cucumis sativus* L. cv. Tianjiao No. 5) seedlings. According to their findings, solar light enhanced the plant height and the hypocotyl length but decreased the leaf area and thickness compared to the supplemental LED combinations. Moreover, the shoot and root fresh weight, and the seedling quality index were enhanced by the white, blue, and UV-A lights, while the white/blue/UV-A combinations led to increased cellulose content and stem firmness. Overall, the white/blue/UV-A combinations led to the development of compact cucumber seedlings with superior mechanical properties, and preferable growth performance. Therefore, this light recipe could be applied to achieve the desired morphological and quality characteristics of cucumber seedlings.

Throughout the world, watermelon (*Citrullus lanatus* L.) is propagated in high percentages through grafting, and seedlings are then subjected to a healing stage where conditions such as light are controlled. Bantis et al. [3] examined the impact of different light qualities (applied at the healing stage) for the field cultivation of grafted watermelon (cv. Celine F1 scion grafted onto *Cucurbita maxima* × *C. moschata* cv. TZ-148 rootstock) transplants. In their contributions, the authors reported that a treatment emitting 88/12% red/blue (12B) light and 12B including 5% far-red (12B + FR) improved the vegetative growth. The latter light treatment also accelerated flowering even compared to 12B which only lacked 5% far-red radiation, an important wavelength related to flowering. Following, these light treatments along with monochromatic red also accelerated the fruit production, which was eventually similar under all light treatments when the rest caught up after a few days. Monochromatic blue had a similar response to the control (fluorescence lamps: FL), showing decreased vegetative growth and slower flowering and fruit production. Fruit morphological and biochemical properties were also not affected by the different light qualities during healing. Overall, red, blue, and far-red wavelengths during the healing of grafted watermelon seedlings improved the growth and accelerated the flowering and fruit production of watermelon crops.

Another important crop which is widely established with the use of grafted seedlings is tomato (*Solanum lycopersicum* L.). In their contribution, Melissas et al. [4] studied the effect of light quality during the healing of grafted tomato (cv. Kabrera F1 scion grafted onto cv. Emperador F1 rootstock) seedlings, on seedling adaptation to transplant shock. Monochromatic blue light reaffirmed its inhibitory effect on plant growth by showing poor results both before and after the seedlings were transplanted in pots. Similar but less pronounced effects were reported for monochromatic red light. The control (FL) treatment also decelerated the seedling's growth due to inferior spectral distribution compared to light recipes containing proper red–blue amounts and wavelengths. On the other hand, light treatments including large amounts of red and 11–24% blue (i.e., 88/12% red–blue, 76/24% red–blue, and white with 71/18/11% red–green–blue) enhanced the seedling quality before and after transplanting in pots. This is also supported by the greater antioxidant activity and overall adaptation to transplant shock. Finally, the white treatment is preferable to achieve better light conditions for the human eye.

In another contribution involving grafted tomato (*Lycopersicon esculentum* Mill.) transplants, Zheng et al. [5] compared different photon flux densities during the healing of grafted seedlings, as well as broad-spectrum light qualities for the production of scions (Cv. Dongfeng No. 1) and rootstock (cv. Zhezhan No. 1), and during the post-grafting stage. The authors examined the growth and energy-use efficiency under the abovementioned treatments. During the experiment, the LEDs showed a 110% greater electrical energy saving compared to FL lights. The addition of red light to white LEDs enhances the dry matter accumulation and improves plant compactness and leaf thickness. However, red light should be added with caution since excessive amounts may lead to negative responses on seedling quality and could possibly increase the operation costs. Nevertheless, a higher photon flux density during healing improved the seedling growth and quality without increasing the energy consumption. Overall, a red/blue ratio of 1.2 and red/far-red ratio of 16, and a photon flux density of 150 μmol m^{-2} s^{-1} were suggested for the production of grafted tomato transplants, taking into account both the seedling quality and the energy consumption.

Ultraviolet (UV) radiation is known to affect the yield and quality of red lettuce (*Lactuca sativa* L.). In their contribution, Lycoskoufis et al. [6] aimed to enhance red lettuce (var. Redino Lollo rosso) yield and quality through a UV management system in a greenhouse. Specifically, the authors created a new cultivation system by combining polyethene film, which blocks UV radiation in a greenhouse (UV-block), and supplemental UV light, and compared with a UV-open greenhouse. It was reported that the latter showed decreased red lettuce growth (i.e., head weight) and quality (i.e., total phenols, flavonoids, and antioxidant capacity) compared to UV-block greenhouse including supplemental UV light.

Even in the Mediterranean region, climatic conditions and especially light quantity during winter are suboptimal for the efficient production of leafy vegetables. Nowadays, PFALs offer the option to cultivate such products all year round while maintaining crop yield and quality regardless of outside conditions. Voutsinos et al. [7] evaluated the commercial benefits arising from the cultivation of butterhead lettuce (*Lactuca sativa* L. cv. Glory) using only artificial lighting indoors compared to a glasshouse in the Mediterranean region during wintertime. High light intensity (310 μmol m^{-2} s^{-1}) in the vertical facility resulted in greater photosynthetic capacity, biomass accumulation, and quality characteristics. Only in the vertical farming system, nitrate content was within the limits set for the human consumption of 100 g of fresh lettuce regardless of light intensity.

In another study involving "Elizium" romaine lettuce (*Lactuca sativa* L. var. longifolia), Matysiak et al. [8] analysed the impact of the light quality of the crops using two different nutrient solutions in a controlled environment. The authors reported that a RGB 70/18/12% combination enhanced the leaf biomass and inhibited the accumulation of potassium and magnesium, while showing low nitrogen balance index and high flavonol index. A 25% increase of mineral concentration in the nutrient solution (EC 2.0 mS m^{-2} s^{-1}) negatively affected the food quality displayed by the nitrogen balance index, flavonol index, nitrate content, and tipburn.

PFALs can also be the production centre of less pronounced and less studied leafy vegetables such as watercress (*Nasturtium officinale* L.). In their contribution, Lam et al. [9] determined the optimal photoperiod and light intensity for the production of watercress with a view to increase its plant growth and glucosinolate content in a deep flow system. It is suggested that the 20 h photoperiod and 160 μmol m^{-2} s^{-1} light intensity promotes the plant growth and glucosinolate content of watercress. The decrease in light intensity and increase in the photoperiod led to a gradual decrease in net photosynthesis and stomatal conductance.

Cuttings of ornamental plant are among the plant materials that can be cultivated in a closed system with controlled conditions. In the case of chrysanthemums (*Chrysanthemum grandiflorum* Ramat./Kitam) cv. "Nova Lime", Schroeter-Zakrzewska and Pradita [10] investigated the rooting in cuttings and the subsequent plant growth as affected by light colour. White and monochromatic blue lights promoted rooting compared to white+blue and red+blue treatments. Blue also enhanced the plant height, while red+blue promoted the leaf number. Overall, the authors concluded that chrysanthemum showing good quality can be cultivated under low light intensity, leading to reduced energy costs.

A valuable aspect characterizing controlled environment agriculture is the potential to grow plants all year round. This is particularly important for regions facing harsh climate conditions for large part of the year such as the Nordics (Sweden, Denmark, Norway, Finland, and Iceland). Velasco [11] analysed the meteorological satellite data of these regions to evaluate the potential of technological advancements to be used for efficient year-round plant production. For that purpose, LEDs, greenhouse-integrated photovoltaics, and adaptive lighting control were jointly studied. It is reported that such a concept is indeed a feasible option even in the climatic conditions of the Nordics. In that region, natural temperatures and daily light integral are only sufficient in the summer months. Greenhouses can be used to extend the growth period further in the spring and autumn months, while transmittance levels of natural light affect the supplementary lighting used for the plants. Among the options tested, LEDs in combination with adaptive lighting control have the potential to save the most energy. In addition, greenhouses with integrated photovoltaics offer the possibility to use the abundant summer sunshine and decrease some electricity during the darker period of the year. Closed production systems provide a stable environment for plant production during the winter months.

This Special Issue provides a fraction of the recent research findings related to light effects on horticultural crops with respect to their yield, nutritional value, physiological responses, and overall production and development. Additional research efforts could be made towards the sustainability of the closed production systems, taking into account running costs for heating and cooling along with lighting. Moreover, large-scale experiments are necessary to evaluate the usefulness of such systems for the year-round production of vegetables compared to the conventional methods applied throughout the world. Finally, several underutilized leafy and fruit crops could be tested under different light configurations with a view to increase their overall production and quality. Furthermore, biodiversity is still an important aspect of plant production, and studying the underlying mechanisms of light on several genotypes is a long-lasting effort.

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