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Optimized light management in horticulture

Boosting photosynthesis for improved efficiency in lettuce crop production

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Light provides power to plants photosynthesis. Although coming as a free source from the sun, optimal illumination of greenhouse crops is often constrained by the compromises that controlled environment agriculture requires, e.g., when shading systems are used to avoid excessive temperatures to build up in the growing compartments, or when the greenhouse structural components or cladding materials significantly reduce transmissivity. Accordingly, the efficient use of light in greenhouses has been a key target for horticultural research in the last decades, allowing for instance to improve both the light extinction coefficient (e.g., the amount of light that is intercepted by the crop rather than reaching the soil), as well as the light use efficiency (e.g., the crop capacity to transform light into photosynthetic gains).[1] Achievements include the use of diffusive light covers (transforming direct solar radiation into diffuse light that more easily reaches shaded leaves of the crop fostering photosynthetic gains), as well as crop management practices that dynamically optimize leaf area across the cycle through changes in plant spacing and leaf distribution. Furthermore, supplementary lighting technologies (that have recently moved from traditional fixtures – e.g., fluorescent, high-pressure sodium, metal halide and incandescent lamps – to more efficient LED systems), are often integrated in greenhouse farms, since they allows for fine-tuning the light intrinsic properties (e.g., spectral composition, intensity and photoperiod), in order to meet crop requirements and therefore maximize yields or qualitative performances. Indeed, all these strategies come with an economic cost for the grower, and this is further exacerbated in the booming sector of vertical farms, where plants are grown on multiple layers into sealed and opaque environments and radiation is fully sourced from artificial lighting.[2] Lettuce (*Lactuca sativa* L.) stands amongst the most studied crops for its response to light, also thanks to its intrinsic properties (including its small size, short cycle, high harvest index and easy photoperiod management) that make it an optimal candidate for vertical farming systems. Thanks to the opportunities offered by LED fixtures, research recently allowed to identify the functional components for optimizing plants growth performances altogether with their efficiency in the use of resources. Primarily, combined red (600-700 nm) and blue (400-500 nm) light, which correspond to the chlorophylls' absorption peaks, have been recognized as the wavebands most contributing to photosynthesis. While the role of blue can be generally linked to increased transpiration (thanks to blue light receptors phototropins that regulate stomatal guard cells opening), and dwarfing effects on plants, the red component was shown to foster photosynthesis and resource-use following an optimum function, with benefits maximized in lettuce when the red portion was about three-folds higher than the blue radiation.[3] Although at higher energetic costs (due to the lower efficacy in converting electricity into light), LED lamps featuring a white spectrum (390-700 nm) have generally lower costs, and may also ease crop management (e.g. in terms of visual detection of stress symptoms),[4] without negatively affecting yield. Besides, the crucial role of other spectral components has also emerged, with green light (500-600 nm) being reflected by the canopy and therefore favoring a deeper light distribution that fosters CO_2 assimilation in lower leaves, as well as resulting in cascade mechanisms that enables developmental adaptation and physiological gains.[5] Far-red light (700-750 nm), abundant in sunlight, but often disregarded when referring to photosynthetically active radiation (PAR, 400-700 nm), was recently shown to interact with shorter wavelengths to increase crop photosynthesis.[6] Beyond PAR, also UV (100-400 nm) light (whose potentialities toward pest and disease disinfection are well documented), may foster secondary metabolites accumulation (including anthocyanin and ascorbic acid contents) in lettuce, while also increasing photosynthetic rates and therefore biomass production.[7] Overall, it emerges how optimized light management becomes fundamental for securing crop yield, while cost-effective light supply enabling to preserve revenues is a key research goal. Toward these priorities, passive strategies to improve light spectral composition and intensity in greenhouses are gaining application. In this issue of *Nature Food*, Shen et al. elaborates on possible applications of a spectral-shifting and unidirectional light-extracting photonic thin film, toward the improvement of greenhouse lettuce cultivation.[8] The research, building on a viable integration of horticulture, plant physiology and engineering, paves the way for substantial innovation in greenhouse technology, providing cost-effective strategies for improving the red light fraction, resulting in a substantial (up to +22%) increase of lettuce yield. The viability of the film (expressed as the overall external quantum efficiency in the forward direction) is ensured by the achievement of three key processes, namely keeping internal quantum efficiency close to unity, the unidirectional extraction of photons toward plants, and the minimized attenuation of internally generated photons. Accordingly, the film features a micro-dome array on the top surface that while increasing the exposed surface, also grants a narrow angular distribution of the internal light reflection. Besides, the film also allow for increasing the red light portion without detrimental effects on the overall transmissivity, also at latitudes where the solar angle varies dramatically across days or seasons. The film adoption resulted in larger leaf growth in lettuce plants, which consistently increased radiation capture and therefore their biomass gains. The technology, here tested at lab scale integrating the film under artificial lighting fixtures or in small domes in a greenhouse environment, will benefit from further substantiation in commercial environments, where its full agronomic and economic impacts may become even more evident.

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Competing interests

The authors declares no competing interests.