

Review Article

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Photobiology in Hydroponics: Effects of Artificial Light Quality on Crop Growth, Metabolism and Resilience

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Abstract Hydroponic cultivation has emerged as a highly efficient method for producing high-quality crops in controlled environments, where artificial lighting plays a central role in determining plant performance. This study synthesizes current knowledge on how artificial light spectra (particularly blue, red, green, far-red and UV-A/B) affect plant growth, metabolism and stress resilience in soilless cultivation systems. The review highlights an integrated framework of light quality-metabolism-stress resistance and discusses how spectral composition influences both productivity and functional quality. Red and blue wavelengths, widely used due to their photosynthetic roles, are shown to increase yields by approximately 15%-25% compared with monochromatic or broad-spectrum light. Emerging evidence further emphasizes the functional relevance of green, far-red and ultraviolet light in modulating biomass accumulation, secondary metabolite production and abiotic stress responses. The study underscores the importance of tailoring light quality according to species, growth stage and desired agronomic outcomes, integrating dynamic lighting strategies, crop-specific “light recipes” and AI-assisted control. Understanding and leveraging photobiological responses in hydroponics are essential to achieving sustainable, high-performance food production.

Keywords Hydroponics; Artificial light spectra; Photobiology; LED-based lighting strategies; Dynamic lighting control

1 Introduction

Hydroponic cultivation has gained prominence as a viable and sustainable alternative to traditional soil-based agriculture, offering advantages such as optimized resource use, spatial efficiency and the potential for year-round production under controlled environments (Pomoni et al., 2023; Singh et al., 2024). In such systems, light is not only a vital energy source for photosynthesis but also serves as a primary environmental signal regulating plant growth, morphogenesis, metabolism and stress adaptation (Paradiso and Proietti, 2022).

Unlike field-grown crops that experience fluctuating and often suboptimal light conditions, hydroponic systems provide a unique opportunity to manipulate light quality (spectral composition), intensity and photoperiod with high precision. This capacity for control allows researchers and growers to tailor lighting strategies to the specific physiological needs of crops, potentially enhancing productivity and nutritional value (Olle and Viršile, 2013; Mitchell et al., 2015).

The advent of light-emitting diode (LED) technology has revolutionized artificial lighting in controlled environment agriculture (CEA). LEDs offer the ability to emit narrow wavelength bands with low heat output and high energy efficiency, enabling fine-tuned photobiological responses in plants (Bourget, 2008). Numerous studies have investigated the effects of different light spectra, particularly red and blue light, on plant morphology and photosynthesis, but a comprehensive synthesis focusing on photobiological responses in hydroponically grown crops remains limited.

Furthermore, recent evidence suggests that light quality can modulate the biosynthesis of secondary metabolites such as flavonoids, terpenes and antioxidants (Dou et al., 2017), as well as influence tolerance to abiotic stresses including salinity, drought and thermal fluctuations (Dou et al., 2017; Hasan et al., 2017). These responses are