

In basil, the use of LED lighting has shown superior performance compared to fluorescent tubes. In a study testing four LED spectral profiles, including combinations of red, far-red, blue, green and UV, both cultivars displayed significantly greater total biomass and phenolic content under LED treatments, compared to fluorescent control (Bantis et al., 2016). A more recent study found that combinational red, blue and far-red LEDs further elevated biomass and phenolic production relative to white LEDs (Rahman et al., 2021).

Tomato research indicates that even short LED light supplementation during night periods of red/blue/far-red spectrum can enhance yield nutritional quality (Arif et al., 2024). In cucumber (*Cucumis sativus* L.), nutrient film technique (NFT) trials comparing LED-only lighting with combined HPS+LED and HPS-only treatments found the highest yields and chlorophyll content under LED-only conditions. Enhanced gas exchange and PSII efficiency in LED-only compartments further supported fruit yield improvements (Gajc-Wolska et al., 2021). Additionally, cucumber seedlings grown under red/blue LEDs developed stronger root systems and higher biomass accumulation than controls.

Microgreens, due to their short growth cycle and high nutritional density, are particularly sensitive to light conditions. Both the spectral composition and intensity of artificial lighting significantly influence their morphological development, pigment accumulation and nutrient content. Optimizing parameters such as the blue:red light ratio and total photon flux density can modulate key traits including shoot elongation, biomass production and the synthesis of bioactive compounds (Zhang et al., 2020; Partap et al., 2023). In a hydroponic study, increasing the proportion of blue light from 0% to 100% consistently reduced shoot elongation in mustard (*Brassica juncea* L.) and kale microgreens, while simultaneously enhancing the accumulation of macro and micronutrients (Brazaitytė et al., 2021).

Collectively, these studies illustrate a consistent trend: LED lighting enhances both productivity and functional quality across a range of hydroponic crops. Crop-specific ‘lighting recipes’, including tailored red:blue ratios, supplemental periods and dynamic light profiles, enable optimization of distinct outcomes such as yield, antioxidant capacity, and nutrient accumulation. This supports the concept of precision lighting in hydroponic horticulture to meet both agronomic and nutritional goals.

3.3 Practical implications of artificial light strategies in hydroponics

The evidence reviewed across multiple hydroponic crops highlights the central role of light spectrum and intensity as modulators of both productivity and nutritional quality. LEDs (owing to their customizable spectra, energy efficiency, and minimal heat output) consistently outperform traditional lighting systems such as HPS and fluorescent lamps in both yield optimization and enhancement of phytochemical profiles. These advantages are particularly evident in leafy greens and microgreens, where short cycles allow rapid phenotypic responses to spectral adjustments.

Species-specific outcomes underline the necessity of tailored “light recipes.” For instance, lettuce benefits from moderate red:blue ratios (e.g., 3:1) for biomass and phenolic accumulation (Dannehl et al., 2021), while basil and tomato exhibit improved functional traits under red and far-red enriched environments (Bantis et al., 2016; Arif et al., 2024). Microgreens, by contrast, respond to blue-dominant spectra with reduced elongation and elevated nutrient density, although responses vary significantly between cultivars (Zhang et al., 2020).

From an agronomic perspective, these findings support a paradigm shift toward dynamic lighting strategies in commercial hydroponic systems. Implementing crop and stage specific light profiles (potentially using programmable LED arrays and sensor-integrated control) could enhance both resource use efficiency and final product quality. This precision lighting approach aligns with broader goals of sustainable intensification in controlled-environment agriculture (Stanghellini and Katzin, 2024).