

sustaining ABA-associated developmental progression (Sun et al., 2024). Mechanistically, blue or red light combined with sucrose promotes detached ripening by increasing ABI4 expression, decreasing SnRK2.6 expression, and suppressing AUX/IAA11 and ARF6, consistent with activation of ABA signaling alongside inhibition of auxin signaling (Jiang et al., 2023).

This hormonal crosstalk extends to direct control of sugar transport and signaling outputs. ABA regulates sugar accumulation through the FaRIPK1-FaTCP7-FaSTP13/FaSPT module, in which ABA-enhanced FaRIPK1 interaction with FaTCP7 relieves repression of sugar transporter genes and thereby promotes soluble sugar accumulation during ripening. Light and ABA also converge, but not identically, on downstream ripening regulators: both induce FaMYB10 and enhance anthocyanin accumulation, yet their effects are additive rather than strictly linear, indicating partly independent pathways that intersect at common transcriptional targets controlling fruit maturation and quality formation.

7 Case Studies: Application of Light Management Technologies in Strawberry Production

7.1 LED spectrum optimization for improving strawberry sugar content and fruit quality

Case studies of LED spectrum optimization show that spectral composition can be used to target both sugar accumulation and visual fruit quality in greenhouse strawberries. In a four-cultivar greenhouse experiment, blue, red, and red/blue supplemental lighting all increased early fruit yield in most cultivars, while supplemental light also raised total soluble solids and anthocyanin concentration, indicating that spectrum selection can simultaneously improve sweetness-related and pigmentation traits (Roosta et al., 2024). A complementary preharvest study found that red LED supplementation produced the highest productivity and selectively enhanced anthocyanin accumulation, whereas blue and green light preferentially increased other primary and secondary metabolites, showing that different spectra shift fruit quality in different biochemical directions (Lauria et al., 2023).

Recent synthesis studies suggest that the most effective strategy is not a fixed wavelength but a phase-specific spectral program matched to crop development. Red-blue combinations are reported to improve photosynthetic efficiency and accelerate fruit maturation when applied at moderate photon flux and long daily duration, while dynamic spectral adjustment across vegetative growth, flowering, and maturation is proposed to better coordinate yield formation with sugar and anthocyanin accumulation (Wang et al., 2025). More broadly, controlled-environment evidence indicates that manipulating light intensity and spectral composition can substantially modify strawberry secondary metabolism and fruit antioxidant properties, although blue-light effects remain less consistent across studies than responses to mixed or red-dominant spectra (Figure 2) (Warner et al., 2021).

7.2 Supplemental lighting in greenhouse strawberry production under low-light conditions

Under winter and spring greenhouse conditions, supplemental lighting consistently improves strawberry growth and fruit quality when natural radiation is inadequate. A commercial greenhouse study using an hourly light integral strategy showed that supplemental LEDs increased daily light integral to about 10 mol m⁻² d⁻¹, raised canopy temperature by 1 °C-2 °C, and improved net photosynthetic rate, fruit yield per plant, soluble solids, and sugar-acid ratio, demonstrating that real-time light compensation can directly enhance both productivity and eating quality (Yang et al., 2024). Similar benefits were observed in a subtropical forcing system, where daytime LED lighting further improved dry matter accumulation and yield during cloudy winter periods, although the yield advantage became limited in spring when solar radiation was already high (Nakayama and Nakazawa, 2023).

Case studies also show that supplemental lighting is most effective when integrated with other greenhouse controls. In autumn-to-spring production, the combination of elevated CO₂ and LED supplemental light increased photosynthetic capacity, biomass, and yield, while also improving fruit soluble sugar content and reducing titratable acidity across the growth cycle (Qiu et al., 2023). Under full and deficit irrigation, supplemental lighting likewise increased fruit polyphenols early in the season and total sugar, glucose, and fructose later in the season, indicating that added light can stabilize or improve fruit quality even when water management differs (Xu et al., 2023).