

3.2 Effects of light on sugar accumulation and carbohydrate metabolism

Light promotes sugar accumulation in strawberry fruit at both physiological and molecular levels. Dark-treated fruit fail to accumulate sugars normally, whereas light-treated fruit show increased soluble sugar levels together with stabilization of FvMYB10, indicating that ripening-associated sugar accumulation depends on active light signaling. In greenhouse production, supplemental light increases total sugar, glucose, and fructose concentrations, especially late in the season, confirming that improved carbohydrate status under better light translates into sweeter fruit (Xu et al., 2023).

This regulation is mediated by specific photoreceptors and downstream metabolic genes. Blue-light receptors FvCRY1 and FvCRY2 directly promote anthocyanin and sugar accumulation, and their overexpression increases soluble solids, glucose, and fructose together with higher expression of FvINV and FvSFP9, linking light perception directly to carbohydrate metabolism and transport (Zhang et al., 2025). A parallel negative pathway is mediated by COP1, which represses sugar accumulation by inhibiting HY5-, RIF-, and MYB10-regulated transcriptional activation of downstream biosynthetic genes (Bi et al., 2025).

Spectral quality also changes the balance among carbohydrate-related metabolites. Red-light supplementation alters inositol metabolism and affects compounds such as D-mannose-6-phosphate, sorbitol, and inositol, while transcriptomic enrichment in galactose metabolism suggests that red light reshapes broader carbohydrate networks beyond simple soluble sugar accumulation. Consistent with this, recent review evidence indicates that spectral optimization can balance sucrose-to-hexose partitioning through FaSPS1-related regulation, providing a mechanistic explanation for why different light recipes produce different sweetness outcomes (Wang et al., 2025).

Not all light treatments increase sugars in the same way, and responses can depend on treatment context. In detached fruit, most red-, blue-, and white-light treatments decreased the TSS/TA ratio and the soluble sugar/acid ratio, especially when sucrose was added exogenously, indicating that postharvest or detached-ripening responses can differ from whole-plant preharvest lighting effects (Jiang et al., 2023). Likewise, some commercial greenhouse experiments found that supplemental spectra changed individual sugars by sampling date without altering Brix overall, so sugar regulation by light appears to be dynamic and environment-dependent rather than uniform across all systems (Pérez-Romero et al., 2024; Roosta et al., 2024).

3.3 Light-induced regulation of organic acids, anthocyanins and flavor compounds

Light has especially strong effects on anthocyanin accumulation, which is one of the clearest mechanisms by which it improves strawberry fruit quality. Light is essential for anthocyanin accumulation in ripening fruit, and dual red and blue irradiation appears to optimally activate the flavonoid pathway by co-upregulating structural genes such as CHS, F3H, DFR, and ANS together with regulatory factors including FaMYB10 and FaHY5 (Wang et al., 2025). Blue light tends to induce upstream phenylpropanoid enzymes, whereas red light enhances proanthocyanidin production, showing that different wavebands regulate distinct branches of secondary metabolism rather than producing identical quality responses (Lauria et al., 2023; Wang et al., 2025).

Experimental studies broadly support the quality benefits of preharvest supplemental lighting, although the specific metabolite profile depends on the spectrum. Red light improves productivity and promotes anthocyanin accumulation in fruit, while blue, red, and red/blue combinations also increase anthocyanin concentration across cultivars, indicating that multiple spectra can stimulate pigmentation but with different strengths and accompanying effects on other metabolites (Lauria et al., 2023; Roosta et al., 2024). Under stress conditions, red and blue-red light also raise fruit anthocyanin levels, suggesting that light quality can preserve or enhance color development even when salinity or alkalinity constrains normal metabolism.

Light also regulates acidity and volatile flavor formation, which are critical for perceived eating quality. Supplemental light can increase titratable acids in some greenhouse systems, whereas LED supplementation combined with elevated CO₂ decreases titratable acidity, showing that acid responses are not uniform and depend on the broader production environment (Qiu et al., 2023; Tang et al., 2023). For aroma, red light promotes synthesis of furanones and esters, and blue or red postharvest LED exposure increases key aroma-related volatile esters, supporting a persistent light-triggered effect on flavor chemistry (Farneti et al., 2025; Wang et al., 2025).