

output even when light intensity is adequate (Park et al., 2023). This interaction between light duration and growth is reinforced by recent synthesis work showing that PPFD and photoperiod act synergistically in controlled production, although cultivar-specific sensitivity remains an important constraint on universal lighting prescriptions (Wang et al., 2025).

Photoperiodic regulation also acts through flowering and vegetative signaling pathways that differ among strawberry types and developmental stages. In seasonal flowering cultivars, long days induce FaCO responses yet can delay flowering through repression pathways involving FaTFL1, while FaSOC1 functions as a strong repressor of flowering and promoter of vegetative growth (Muñoz-Avila et al., 2022). After floral initiation, photoperiod continues to shape reproductive progression: in ‘Akihime’, long-day treatment delayed the first inflorescence but increased flower number in the secondary inflorescence and accelerated later fruit maturation, showing that post-flowering photoperiod can redistribute reproductive timing rather than simply promote or inhibit it (Ren et al., 2024).

2.3 Regulation of light quality on plant morphology and physiological responses

Light quality regulates strawberry morphology and physiology by altering chlorophyll formation, stomatal behavior, photochemistry, and downstream metabolic programming. Under different LED spectra, strawberry leaves showed significant changes in chlorophyll content, minimal fluorescence, and net photosynthetic rate, and transcriptomic analysis linked these responses to pathways related to photosynthesis, carbon fixation, chlorophyll metabolism, and hormone biosynthesis (Li et al., 2024). Spectral composition also affected propagation-stage morphology: adding green or far-red light to red-blue backgrounds increased shoot multiplication and plant height, while green light enhanced chlorophyll biosynthesis and far-red stimulated photomorphogenesis-related gene expression (Li et al., 2025).

Different wavebands, however, do not contribute equally to photosynthetic efficiency, and narrow spectra can produce contrasting physiological outcomes. White supplemental light supported higher photosynthesis after prolonged exposure, whereas monochromatic red and blue reduced maximal photosynthetic rate and increased superoxide formation, suggesting that broader spectra better sustain leaf function over time (Lauria et al., 2023). At the leaf level, blue and green light increased intercellular CO₂ concentration and transpiration through stronger stomatal opening, while red light more strongly promoted photochemical reactions and CO₂ fixation, indicating that balanced spectral combinations are more effective than single wavelengths for coordinating morphology with carbon assimilation.

3 Mechanisms of Light Regulation on Strawberry Fruit Quality Formation

3.1 Regulation of light environment on fruit growth and development

Light regulates strawberry fruit growth and development by controlling both whole-plant carbon supply and ripening-related signaling. When light intensity is reduced, strawberry plants show lower photosynthetic rate, stomatal conductance, sugar accumulation, and fruit yield, indicating that insufficient irradiance restricts assimilate production needed for fruit expansion and maturation (Choi, 2021). In contrast, supplemental LED lighting in commercial systems generally increases yield and can accelerate maturation-related changes in fruit quality, showing that managed light environments can shift fruit development toward earlier and more productive harvests (Figure 1) (Tang et al., 2023; Pérez-Romero et al., 2024).

Beyond total irradiance, spectral composition shapes developmental timing and fruit formation through photoreceptor-mediated pathways. Additional far-red light accelerates flower and fruit formation and increases soluble sugar, whereas low red:blue ratios alter metabolite composition without strongly changing fruit set, suggesting that developmental and quality responses can be partially uncoupled (Li et al., 2025). At the molecular level, light signaling also acts as a brake-or-release system during ripening, because COP1 suppresses fruit quality formation by destabilizing HY5-, RIF-, and MYB10-dependent downstream regulators, while light relieves this repression and promotes visible changes in fruit color and shape (Bi et al., 2025).