

greater fruit size and number, while raising total ellagic acid and ascorbic acid concentrations, showing that reflected PAR can enhance both productivity and bioactive quality traits.

More recent work shows that the effect of mulch-based light management depends on the optical properties of the material used. In greenhouse winter production, white reflective mulch reflected far more PAR than red, olive, or black mulch and supported consistent saleable berry production, suggesting that highly reflective surfaces are useful where ambient light is seasonally limiting. Other light-redistribution materials have also shown strong promise: red light-selective plastic film improved photosynthetic performance, fruit weight, total sugar, and anthocyanin content, while rare-earth photoconversion films increased net CO₂ assimilation, soluble solids, soluble sugar, vitamin C, flavonoids, and yield by modifying spectrum, temperature, and greenhouse light transmission (Peng et al., 2020; Zhao et al., 2025).

6 Molecular and Physiological Mechanisms Underlying Light-Induced Sugar Accumulation

6.1 Regulation of photosynthetic carbon fixation pathways

Light-induced sugar accumulation in strawberry begins with enhanced source activity and more efficient allocation of newly fixed carbon from leaves to fruit. When light intensity declines, strawberry plants show lower photosynthetic rate, stomatal conductance, and sugar accumulation, indicating that reduced carbon fixation at the source directly limits the carbohydrate supply available for developing fruit (Choi, 2021). At the same time, greater daylight integrals increase the rate and amount of photosynthate translocation into individual fruits, showing that stronger leaf assimilation under longer light exposure improves sink loading as well as source production.

The fate of this additional carbon depends on how strawberry leaves partition assimilates between transportable sugars and temporary storage pools. Under high photosynthetic activity, carbon is first allocated to sucrose, but once leaf sucrose concentration exceeds storage capacity, excess carbon is diverted into starch, indicating that starch functions as an overflow product rather than the primary export form (Nakai et al., 2023). More broadly, fruit sugar accumulation depends on coordinated regulation of sugar transporters and metabolic enzymes that govern long-distance translocation, sink unloading, and post-translational control of carbohydrate metabolism, so light-driven increases in fixation must ultimately be coupled to these downstream allocation processes to raise fruit sweetness (Ren et al., 2023).

6.2 Light signaling pathways involved in fruit development

Beyond its role in carbon supply, light also acts as a developmental signal that directly regulates strawberry fruit maturation and sugar-related gene expression. Light-treated fruits accumulate more soluble sugar than dark-treated fruits, and this response is accompanied by stabilization of the ripening regulator FvMYB10, indicating that light promotes sugar accumulation partly through transcriptional and post-translational control during ripening. Blue-light receptors FvCRY1 and FvCRY2 provide a more direct mechanism, because their overexpression increases soluble sugar content and they bind promoters of sugar metabolism genes such as FvSFP9 and FvINV, with blue light enhancing their transcriptional activation capacity (Zhang et al., 2025).

Light signaling in fruit development also includes repressive modules that prevent sugar accumulation when photomorphogenic signaling is attenuated. FvCOP1 acts as a molecular brake by suppressing sugars, anthocyanins, and flavonoids through inhibition of downstream transcriptional activation mediated by FvHY5, FvRIF, and FvMYB10, and by ubiquitinating these regulators to reduce their stability (Bi et al., 2025). Far-red signaling likely contributes as well, because FxAPHY15 is strongly responsive to far-red light and peaks transcriptionally during the fruit turning stage while interacting with PIF3-related regulatory networks, supporting a role for phytochrome-mediated signaling in the transition from vegetative growth to fruit maturation.

6.3 Interaction between light signals and hormonal regulation

Light-induced sugar accumulation is closely integrated with hormone signaling, especially the balance between abscisic acid and auxin during ripening. Fruit grown under light accumulates more ABA than bagged fruit, whereas dark treatment delays sugar accumulation and softening, indicating that light promotes ripening in part by