

results suggest that fruit bagging acts as a localized shading treatment that weakens berry sink activity during early ripening, but its final effect depends on how long light exclusion persists and whether the vine retains sufficient whole-plant carbon supply.

At the metabolic level, altered source-sink balance under bagging likely affects both sugar transport and sink conversion within berry tissues. Post-véraison sunlight studies showed that exocarp sugar transport can directly influence skin pigmentation and that flavonoid gene promoters contain sugar-responsive elements, whereas ABA-treated berries up-regulated beta-fructofuranosidase and sucrose transporter genes that support sucrose cleavage and import during ripening (He et al., 2020). This indicates that bagging-induced reductions in light may suppress not only photosynthate delivery but also sugar-responsive signaling networks that couple carbon status to color and flavor development.

More broadly, grape berries function within a dynamic source-sink system in which environmental constraints reshape carbon partitioning priorities rather than simply reducing total assimilate availability. Grapevines are managed around the ratio of leaf area to fruit mass, and over-cropping can delay ripening, while crop studies under periodic shading show that yield penalties are closely tied to disrupted source:sink carbon partitioning and can be mitigated by strengthening reproductive sinks (Martínez-Lüscher and Kurtural, 2021; Liang et al., 2025). Bagging therefore appears to regulate quality through a combined mechanism of reduced irradiance, modified sink strength, and delayed metabolic transition of the berry into a dominant carbon sink.

5.2 Influence of bagging on hormonal regulation during fruit ripening

Bagging-induced ripening delay is closely linked to hormonal reprogramming, especially the balance between ABA, auxin, and ethylene. In grape, ABA is a major positive regulator of ripening onset and promotes sugar metabolism, cell enlargement, softening, and color development, whereas auxin acts as a repressor of véraison and delays ripening at the transcriptional level. This hormonal opposition provides a mechanistic basis for the lower sugar accumulation, delayed coloration, and slower maturation commonly observed under prolonged bagging.

Direct bagging evidence supports this interpretation. In Cabernet Sauvignon, delayed ripening under sunlight exclusion coincided with up-regulation of auxin-related negative biomarkers such as AUX/IAA and ARF, while bagged strawberry fruit also showed delayed ripening associated with reduced ABA accumulation and induction of an ABA catabolism gene, suggesting that light exclusion can shift hormone balance away from ripening promotion (Sun et al., 2024). Although the strawberry work is not grape, it supports a general mechanism by which reduced light under bagging lowers ABA-driven ripening competence through enhanced ABA turnover.

Hormonal control during bagging is not limited to ABA alone, because grape ripening depends on strong crosstalk among several phytohormones. Reviews of non-climacteric fruit show that ABA, auxin, gibberellins, and ethylene act together during ripening, and grape-specific analyses indicate that light-responsive changes in auxin, cytokinin, ABA, brassinosteroid, salicylic acid, and ethylene signaling all occur after bagging or bag removal. Bagging therefore appears to alter a broader signaling network rather than a single pathway, with the timing of re-exposure to light likely determining whether ripening resumes rapidly or remains delayed.

Experimental hormone treatments in grape clarify the direction of these effects. Exogenous ABA increases endogenous ABA, activates ethylene and auxin signaling-related genes, and improves color, sugar accumulation, and softening, whereas NAA lengthens the growth-to-ripening interval and suppresses normal ripening progression (He et al., 2020). In practical terms, bagging likely delays maturation because light exclusion favors auxin-linked repression and reduces ABA-associated ripening signals, while bag removal reverses part of this shift by restoring the environmental cues that support ABA-mediated onset of ripening.

5.3 Molecular regulation of secondary metabolism under altered light conditions

The strongest molecular effect of bagging is on light-regulated secondary metabolism, especially anthocyanin and flavonol biosynthesis in the berry skin. Sunlight exposure during ripening increases flavonoid accumulation and the expression of biosynthetic genes, whereas cluster bagging in Cabernet Sauvignon caused coordinated changes