

More detailed aroma studies confirm that these effects are selective rather than uniform. In 'Kyoho', red, green, blue, and white paper bags promoted ester accumulation but inhibited aldehydes, alcohols, terpenes, ketones, and acids, with green bags showing the strongest effect, while recent Vinalopó data showed that bagged grapes had relatively more aldehydes associated with green and fresh notes, whereas non-bagged grapes contained more alcohols and esters linked to fruity and overripe aromas (Andreu-Coll et al., 2025). Fruit bagging therefore modifies flavor formation mainly by redirecting volatile biosynthesis and volatile-family balance rather than by causing a simple increase or decrease in total aroma.

4.3 Influence on anthocyanins, phenolics and antioxidant compounds

The most consistent quality effect of fruit bagging in colored grapes is the suppression of anthocyanin accumulation under low-light conditions. In 'Shenhua' and 'Shenfeng', bagged berries developed poorer skin color and lower anthocyanin content than unbagged fruit, and in 'ZhongShan-HongYu' bagging without light caused obvious inhibition of anthocyanin accumulation (Li et al., 2023). This agrees with the broader view that berry coloration remains highly dependent on light exposure during ripening.

The inhibitory effect, however, is often reversible after re-exposure to light. In Cabernet Sauvignon, early bagging followed by sunlight re-exposure significantly elevated flavan-3-ol and flavonol concentrations, while in 'ZhongShan-HongYu' malvidin, cyanidin, and delphinidin derivatives accumulated rapidly after bag removal (Li et al., 2023). These findings indicate that bagging does not simply block phenolic metabolism permanently, but instead shifts the timing and composition of phenolic accumulation according to light recovery.

Responses of total phenolics and antioxidant-related compounds vary with bag design. In Muscat-flavored grapes, mesh, transparent, and white bags improved phenolic content to some extent, while a recent study using photoselective bags in teinturier grape showed that red and blue bags enhanced total phenols, anthocyanins, and antioxidant activity by increasing phenylpropanoid-pathway enzyme activities (Wang et al., 2022; Zhang et al., 2025). This suggests that not all bagging-induced shading is equivalent: spectral selectivity can either suppress or enhance phenolic quality depending on the wavelengths transmitted.

At the molecular level, light-responsive regulation explains much of this variability. In Cabernet Sauvignon, light-responsive transcriptional changes in CRY2, HY5/HYHs, MYBA1, and flavonoid-pathway genes coincided with altered phenolic accumulation under bagging, while in 'Shenhua' and 'Shenfeng' anthocyanin biosynthesis was linked to the expression of VvMYB genes together with the light-response factors VvHY5 and VvCOP1. Overall, fruit bagging influences grape quality most strongly through its control of the berry light environment, which in turn regulates sugar accumulation, aroma metabolism, and especially anthocyanin and phenolic biosynthesis.

5 Physiological and Molecular Mechanisms of Bagging-Induced Quality Regulation

5.1 Regulation of photosynthetic carbon allocation and source-sink balance

Fruit bagging regulates grape quality first by altering the local light environment around the cluster, which changes carbon supply to the berry and shifts source-sink relations during ripening. In grapevine, shading decreases carbon assimilation and can maintain vegetative growth at the expense of berries, while cluster bagging in Cabernet Sauvignon intercepted solar radiation but had limited effects on final berry weight and soluble solids at harvest, indicating that bagging modifies carbon economy more through developmental timing than through severe carbon starvation (Poupard et al., 2024). This helps explain why bagged fruit often shows delayed sugar accumulation during véraison but only modest differences at maturity when sink activity and post-bag light recovery compensate part of the early reduction in carbon import.

Whole-vine evidence further shows that grape ripening speed depends on balancing leaf source strength with fruit sink demand. Defoliation experiments delayed véraison and harvest by up to nine weeks and reduced root starch reserves, while bagged Jingyou grape berries showed lower soluble solids and reducing sugars during maturation, with quality improving after bag removal before harvest (Martínez-Lüscher and Kurtural, 2021). Together, these