

in CRY2, HY5/HYHs, MYBA1, UFGT, FLS4, LAR, and ANR that tracked changes in flavonoid accumulation under light exclusion and re-exposure. This shows that bagging modifies secondary metabolism mainly through transcriptional light signaling rather than through temperature effects alone.

At the regulatory level, MYB transcription factors occupy the core of the anthocyanin network, but their activity is tightly linked to upstream light-responsive regulators. MYB proteins are dominant regulators of anthocyanin biosynthesis across plants, and recent grape work identified a VvHY5-VvMYB24-VvMYBA1 cascade in which the light-responsive factor VvHY5 activates VvMYB24, which then cooperates with VvMYBA1 to increase VvDFR and VvUFGT expression (Yan et al., 2021; Zhen et al., 2024). Under bagging, reduced light would be expected to weaken this cascade, thereby lowering anthocyanin accumulation and suppressing red coloration.

Bagging also affects the composition of secondary metabolites beyond anthocyanins by changing the timing and extent of re-exposure to light. In Cabernet Sauvignon, re-exposure after early bagging significantly elevated flavan-3-ol and flavonol concentrations, whereas shading studies showed that flavonols were the most drastically reduced flavonoids and that MYB12 and FLS4 responded rapidly to changing light levels. These findings indicate that different branches of phenylpropanoid metabolism have different light sensitivities, with flavonols appearing especially responsive to bagging-induced light restriction.

6 Optimization Strategies for Fruit Bagging Technology in Viticulture

6.1 Selection of bag materials and structural characteristics

The first priority in optimizing grape bagging is to match bag material and structure to the intended balance among protection, microclimate regulation, and fruit quality. Evidence from table grapes shows that bag performance depends on material type, since paper, parchment, and non-woven polypropylene do not produce equivalent quality outcomes, and parchment bags in particular improved berry size and color while all bag types reduced residue accumulation (Luca et al., 2023). More broadly, bagging reviews emphasize that standardization of bag materials remains a major need because material permeability, color, and construction determine whether bagging preserves or improves fruit quality under field conditions (Ali et al., 2021).

Structural traits should be selected to regulate light transmission and ventilation rather than simply maximize enclosure. In grapes, white non-woven UV-stabilized polypropylene bags produced the best berry size and yield attributes, likely because they allowed more favorable light penetration and a suitable internal microclimate (Kiran et al., 2020). Evidence across fruit systems likewise shows that high-transmittance bags are generally preferable to highly opaque ones, because bags with very low light transmission tend to depress sugar accumulation, phenolic content, and antioxidant capacity, whereas moderate light transmission better preserves internal quality.

6.2 Optimization of bagging time and duration

Bagging time and duration should be optimized according to cultivar phenology, because prolonged light exclusion during ripening can delay maturation and suppress desirable skin coloration. In two grape cultivars bagged at 45 days after anthesis, low-light treatments reduced soluble solids and delayed pigment development, but fruit color and sugar levels recovered rapidly after bag removal near maturity, indicating that duration of enclosure is a key controllable variable. This stage dependence is reinforced in Cabernet Sauvignon, where early bagging followed by re-exposure after véraison increased some flavonoids, whereas bagging after véraison markedly inhibited anthocyanin accumulation.

The practical implication is that bagging should usually begin after the fruit becomes sufficiently developed to benefit from protection, but bags should not remain on clusters so long that they impose unnecessary low-light stress during the final ripening phase. In grapes, the effects of bagging on color depend on the stage of development, bagging date, bag type, bag removal date, and climatic conditions, underscoring the need for cultivar-specific scheduling (Pisciotta et al., 2020). Evidence from other fruit crops points in the same direction: early bagging around 15 days after fruit set often outperformed later timing for quality protection, while 30 days after fruit set could favor some compositional traits depending on material, showing that timing must be tuned to crop development rather than fixed as a universal rule (Kumar et al., 2023; Srivastava et al., 2023).