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Effects of Fruit Bagging on Microclimate and Grape Quality

Jili He 

Zhuji Puxi Crops Professional Cooperative, Zhuji, 311800, Zhejiang, China

 Corresponding author: 1198115935@qq.comBioscience Methods, 2026, Vol.17, No.5 doi: [10.5376/bm.2026.17.0022](https://doi.org/10.5376/bm.2026.17.0022)

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Abstract Fruit bagging is an important horticultural practice widely applied in grape production to improve fruit appearance, reduce environmental stress, and enhance market value. The microenvironment created by fruit bags plays a crucial role in regulating temperature, humidity, light conditions, and gas exchange around grape clusters, thereby influencing fruit development and quality formation. This review summarizes recent advances in the effects of fruit bagging on grape microclimate, physiological responses, and quality characteristics. Different bag materials, colors, and covering periods modify light distribution, thermal conditions, and moisture dynamics, which subsequently affect fruit growth, sugar accumulation, organic acid metabolism, anthocyanin biosynthesis, and flavor compound formation. At the physiological and molecular levels, bagging regulates source-sink carbon allocation, hormone signaling pathways, and secondary metabolic processes involved in fruit maturation and coloration. In addition, optimized bagging strategies combined with canopy management, precise timing, and environmental monitoring can improve disease resistance and promote high-quality grape production. Case studies demonstrate that appropriate selection of bag types and management practices effectively enhances grape quality under diverse climatic conditions. Future research should focus on developing intelligent and sustainable bagging technologies, integrating microclimate monitoring systems, and establishing precision management strategies for efficient and environmentally friendly viticulture.

Keywords Fruit bagging; Grape quality; Microclimate regulation; Sugar accumulation; Anthocyanin biosynthesis

1 Introduction

Table grapes are a globally important fruit crop, valued both economically and nutritionally, and improving grape quality has become a central goal of modern viticulture as consumer demand increasingly emphasizes appearance, sweetness, acidity, flavor, and other market-defining traits. At the same time, conventional efforts to raise yield and quality have often increased reliance on agrochemicals, creating pressure to develop production systems that better balance fruit quality, food safety, and environmental sustainability (Luca et al., 2023). This challenge is especially important because grape quality is shaped not only by genotype, but also by environmental and agronomic factors that regulate berry color, sugar accumulation, acidity, flavor, and secondary metabolites during development. In grapes, light and other abiotic conditions strongly influence these traits, making canopy- and fruit-zone microclimate management a key pathway for quality improvement in both fresh-market and specialty production systems (Wang et al., 2022).

Within this context, fruit bagging has emerged as an increasingly important physical protection technology in viticulture. Pre-harvest bagging is widely recognized as a good agricultural practice that can create a modified microenvironment around the fruit, reduce damage from pests, pathogens, birds, sunburn, and mechanical injury, and lower agrochemical residues while also influencing visual and internal quality attributes. Its adoption across fruit industries in Asia, Australia, Europe, and the Americas reflects growing demand for safer and more environmentally friendly cultivation methods, although the benefits of bagging remain dependent on bag material, timing, cultivar, and local climatic conditions. In grapes specifically, bagging has been studied and developed as a low-environmental-impact technique in Mediterranean production areas and elsewhere, with the aim of integrating it into existing vineyard management systems to improve commercial quality while reducing the need for chemical treatments. Even so, reported outcomes remain variable, which has sustained interest in optimizing bagging protocols for specific cultivars and production environments (Pisciotta et al., 2020).

Research on grape bagging has progressively moved from simple protection trials to more detailed analyses of berry microclimate, ripening physiology, and metabolite regulation. Earlier work showed that bagging can alter the temperature and humidity conditions surrounding grape clusters, increase day-night thermal differences, reduce fruit shrinkage, and in some systems improve carbohydrate assimilation, yield, and economic return, indicating that the bag acts not merely as a barrier but as a microenvironmental regulator. More recent studies have shown that the effects of bagging on grape quality are highly dependent on the light environment created inside the bag. Because different bag materials and colors transmit light differently, they can alter berry ripening, sugar accumulation, anthocyanin synthesis, phenolics, and aroma compounds in distinct ways, with some treatments improving sensory or compositional quality and others delaying maturation or suppressing coloration (Wang et al., 2022).

Current evidence therefore supports a nuanced view of fruit bagging in grapes: it can improve fruit protection, reduce pesticide residues, and in some cases enhance bunch weight, berry appearance, flavor-related compounds, or marketability, but it can also delay ripening or inhibit color development under low-light conditions. For example, bagging has been shown to reduce pesticide residues while improving some quality traits in white table grapes, yet other studies report lower soluble sugars and delayed anthocyanin accumulation in shaded berries unless bags are removed before harvest to restore light exposure (Luca et al., 2023). Against this background, the objective of the present paper is to examine how fruit bagging modifies the grape cluster microclimate and how those microclimatic changes translate into effects on berry development and final fruit quality. Particular attention is given to the interactions among bag type, light transmission, temperature and humidity conditions, and cultivar-specific berry responses, with the broader aim of clarifying how bagging can be optimized as a sustainable viticultural practice.

2 Characteristics of Fruit Bagging Microenvironment in Grape Production

2.1 Effects of bagging on temperature regulation around fruit clusters

Fruit bagging modifies the thermal environment around grape clusters, but the magnitude and direction of change depend strongly on bag material and local radiation load. In Mediterranean table grapes, air temperatures around unbagged clusters were slightly higher than those inside paper bags, while a broader review of grape bagging reported that temperatures inside paper bags were modestly lower during July to September, with only a slight reversal in October (Pisciotta et al., 2020; Ali et al., 2021). These results indicate that paper-based bagging does not necessarily create overheating; under field conditions, it can instead buffer fruit clusters from direct solar heating and smooth short-term thermal extremes.

Temperature effects are nonetheless not uniform across bag types, because plastic and highly enclosed systems can trap more heat than ventilated or paper-based coverings. In organic grape production, clear plastic bags advanced ripening relative to brown paper bags and also caused abnormal overgrowths and sunburn, whereas in colored polypropylene bagging systems, lower temperature inside the bag was proposed as one factor contributing to larger berry size under white bags (Kiran et al., 2020). Taken together, these findings suggest that temperature regulation by bagging is best understood as a balance between radiation interception and heat retention, with breathable paper or light-colored bags generally providing a milder thermal microclimate than transparent plastic enclosures.

2.2 Influence of bagging on humidity and gas exchange conditions

Bagging also changes the moisture environment around grape bunches, although humidity responses vary with bag permeability and ventilation design. In Cabernet Sauvignon, temperature inside bags was only slightly elevated while relative humidity was slightly decreased compared with the canopy environment, likely because the two-layer Kraft bags were fitted with ventilation support; by contrast, postharvest plastic-film bag studies in table grapes showed that non-perforated bags maintained the highest relative humidity and reduced weight loss most effectively (Amorim et al., 2020). This contrast shows that bag structure, especially whether it is ventilated or tightly sealed, determines whether the cluster microenvironment shifts toward moisture retention or toward a more balanced exchange with outside air.

The gas environment created by bagging is equally important because restricted permeability can alter respiration and transpiration around the fruit. Plastic-film bags for table grapes were explicitly described as atmosphere-modifying packages that hinder CO₂ escape and O₂ entry, while perforation-controlled packaging work in other fruits showed that adjusting the number of perforations can stabilize favorable O₂, CO₂, and humidity levels by regulating fruit respiration and transpiration (Amorim et al., 2020; Herrera et al., 2024). Although most direct grape evidence here comes from postharvest systems, the same principle applies to preharvest bagging: gas exchange is not simply blocked, but engineered by material permeability and venting, which in turn influences water loss, condensation risk, and fruit metabolic activity.

2.3 Regulation of light environment by different bagging materials

The most consistent microenvironmental effect of fruit bagging in grapes is the modification of the light regime reaching the berry surface. Cluster bagging in Cabernet Sauvignon markedly reduced both photosynthetically active radiation and solar radiation throughout berry development, and work in Muscat-flavored table grapes likewise showed that bags of different materials and colors have different light transmittances that alter the fruit microenvironment and ultimately fruit quality (Wang et al., 2022). Light regulation is therefore the main mechanism by which bagging materials differ biologically, because variation in transmittance changes not only exposure intensity but also the spectral composition of light perceived by berry tissues.

Differences among bag colors and materials produce distinct quality outcomes because high- and low-transmittance bags do not regulate berry development in the same way. In 'Kyoho' grapes, light transmittance ranked white > yellow > blue, and higher transmittance increased soluble solids and anthocyanin content, whereas lower transmittance reduced berry cracking and increased sub-epidermal thickness; similarly, in multi-bag trials on Muscat-flavored grapes, transparent and white bags promoted phenolics and monoterpenes, while pink and blue bags showed inhibitory effects (Wang et al., 2022). These findings show that bagging materials should not be treated as interchangeable coverings, since their optical properties directly shape the balance between visual protection, ripening progress, skin integrity, and the accumulation of flavor- and color-related metabolites.

3 Effects of Fruit Bagging on Grape Growth and Development

3.1 Effects on fruit expansion and morphological development

Fruit bagging can promote berry expansion and improve commercial morphology, but the effect depends strongly on bag material, timing, and cultivar. In Mediterranean table grapes, bagged bunches were heavier than unbagged controls across cultivars, mainly because of higher berry number and berry weight in some seedless varieties, while parchment bags in another study increased berry length, width, and weight more clearly than paper or non-woven materials (Pisciotta et al., 2020; Luca et al., 2023). These results indicate that bagging can support fruit enlargement, but the benefit is not universal across all bag types.

Color-specific and stage-specific bagging studies reach a similar conclusion. In 'Muscat Hamburg', white non-woven polypropylene bags produced the highest bunch weight, berry diameter, berry weight, and yield per vine in both evaluated seasons, whereas in 'Kyoho' grape the highest berry weight was obtained when bagging was applied late, at 7 to 9 weeks after full bloom, rather than throughout the whole development period (Kiran et al., 2020). Together, these findings suggest that moderate microclimate modification during key expansion phases is more favorable for berry growth than prolonged or poorly timed enclosure.

Bagging also affects berry texture and skin-related morphology, which are important components of market quality. In Sicily-grown table grapes, bagging altered mechanical traits, increasing berry hardness in seedless cultivars while lowering skin break force in all varieties, which indicates a softer and easier-to-chew skin; broader reviews similarly note that bagging often improves size uniformity and reduces deformities caused by environmental stress (Pisciotta et al., 2020; K et al., 2025). This combination of improved external uniformity and modified skin mechanics helps explain why bagged grapes often meet fresh-market standards even when compositional effects are mixed.

Not all morphological responses are positive, however. In Cabernet Sauvignon, solar interception by bags had limited effects on berry weight at harvest, suggesting that shading does not necessarily translate into larger berries, while clear plastic bags in organic production caused abnormal overgrowths and sunburn despite advancing ripening. The overall evidence therefore supports a material-sensitive view in which breathable or light-modifying bags can improve fruit expansion, whereas excessive enclosure or inappropriate plastic coverings can impair normal morphological development.

3.2 Influence on fruit ripening process and phenological development

Bagging frequently delays grape ripening because it reduces light exposure during critical phases of sugar accumulation and skin coloration. In two Chinese cultivars, bagging lowered soluble sugar content, delayed pigment development, and therefore delayed maturation, while a recent metabolomic and transcriptomic study in 'Ruidu Kemei' also concluded that bagging inhibited fruit growth and delayed ripening even though some quality indices were higher at the over-mature stage (Yuying et al., 2023). These studies support the view that bagging often shifts berry development toward a later ripening trajectory rather than simply reducing final quality.

The effect on ripening is especially clear for anthocyanin accumulation. In Cabernet Sauvignon, bagging after véraison significantly inhibited skin anthocyanin accumulation, whereas early bagging followed by re-exposure to sunlight increased flavan-3-ol and flavonol concentrations, showing that timing relative to véraison determines whether light exclusion suppresses or redirects phenolic development. This means bagging is not only a protective practice but also a developmental regulator whose phenological effects depend on when berries are re-exposed to light.

Bag removal can partially reverse delayed ripening responses. In 'Shenhua' and 'Shenfeng', fruit color and soluble solids rapidly returned toward normal after bags were removed, and in a teinturier grape, anthocyanin derivatives accumulated rapidly after re-exposure to light, accompanied by increased expression of light-responsive regulators and anthocyanin biosynthetic genes (Li et al., 2023). These results indicate that at least part of the bagging effect is reversible and mediated through light-sensitive metabolic pathways rather than irreversible developmental damage.

At the mechanistic level, the ripening response to bagging interacts with core sugar and hormone pathways that normally regulate grape maturation. Independent ripening studies show that sucrose and abscisic acid promote sugar accumulation, anthocyanin biosynthesis, and ripening-related gene expression, while sucrose concentrations above 2% can induce anthocyanin synthesis even without added ABA, helping explain why light restriction that disrupts sugar signaling can slow normal ripening progression. Bagging effects on phenology therefore appear to arise from altered light conditions that secondarily reshape the metabolic signals driving maturation.

3.3 Effects on fruit surface protection and disease reduction

Fruit bagging provides direct surface protection by forming a physical barrier between the cluster and external hazards. In grapes, this barrier reduces mechanical injury, bird damage, and exposure to whole-canopy agrochemical sprays, while broader reviews of preharvest bagging identify protection against pathogens, insect pests, abrasions, sunburn, and residues as one of its most consistent advantages (Luca et al., 2023; Buthelezi et al., 2021). This protective function is central to the value of bagging in high-quality table grape production because berry surface defects strongly reduce marketability.

Direct field evidence shows that bagging can sharply reduce disease and pest incidence. Under organic conditions, brown paper bags reduced grape berry moth infestation to 1.8-2.3%, black mold to 0.6-2%, gray mold to 1.1-2.2%, and powdery mildew to 0-5.4%, compared with very high damage levels in non-bagged controls; the same study found that pesticide application did not improve protection beyond bagging alone. These results suggest that, when properly applied, bagging can function as an effective non-chemical protective strategy rather than merely a supplement to spraying.

Bagging also reduces surface contamination by pesticide residues, which is an important part of fruit protection in a food-safety sense. In two white table grape cultivars, all bagging treatments greatly reduced agrochemical residues at harvest, and review evidence likewise emphasizes that bags physically block agrochemical deposition onto the fruit surface during preharvest spraying (Luca et al., 2023; Kiran et al., 2020). This residue-reduction effect strengthens the role of bagging as a surface-management tool for residue-sensitive fresh-market grapes.

Protection effects may also extend into postharvest behavior by altering the microbial ecology of the fruit surface. Although demonstrated in pear rather than grape, bagging maintained higher fungal diversity on the fruit surface, increased non-pathogenic or antagonistic fungi, and reduced postharvest decay, suggesting a plausible biological route by which preharvest surface shielding can lower later spoilage risk; in stored grapes, protective packaging systems that better control fungal decay likewise improve fruit preservation during storage (Figure 1) (Gao et al., 2022). Overall, the evidence indicates that fruit bagging protects grape surfaces through combined physical exclusion, residue prevention, and disease-suppression mechanisms.

Fruit bagging protects table grapes from preharvest environmental and biological stresses

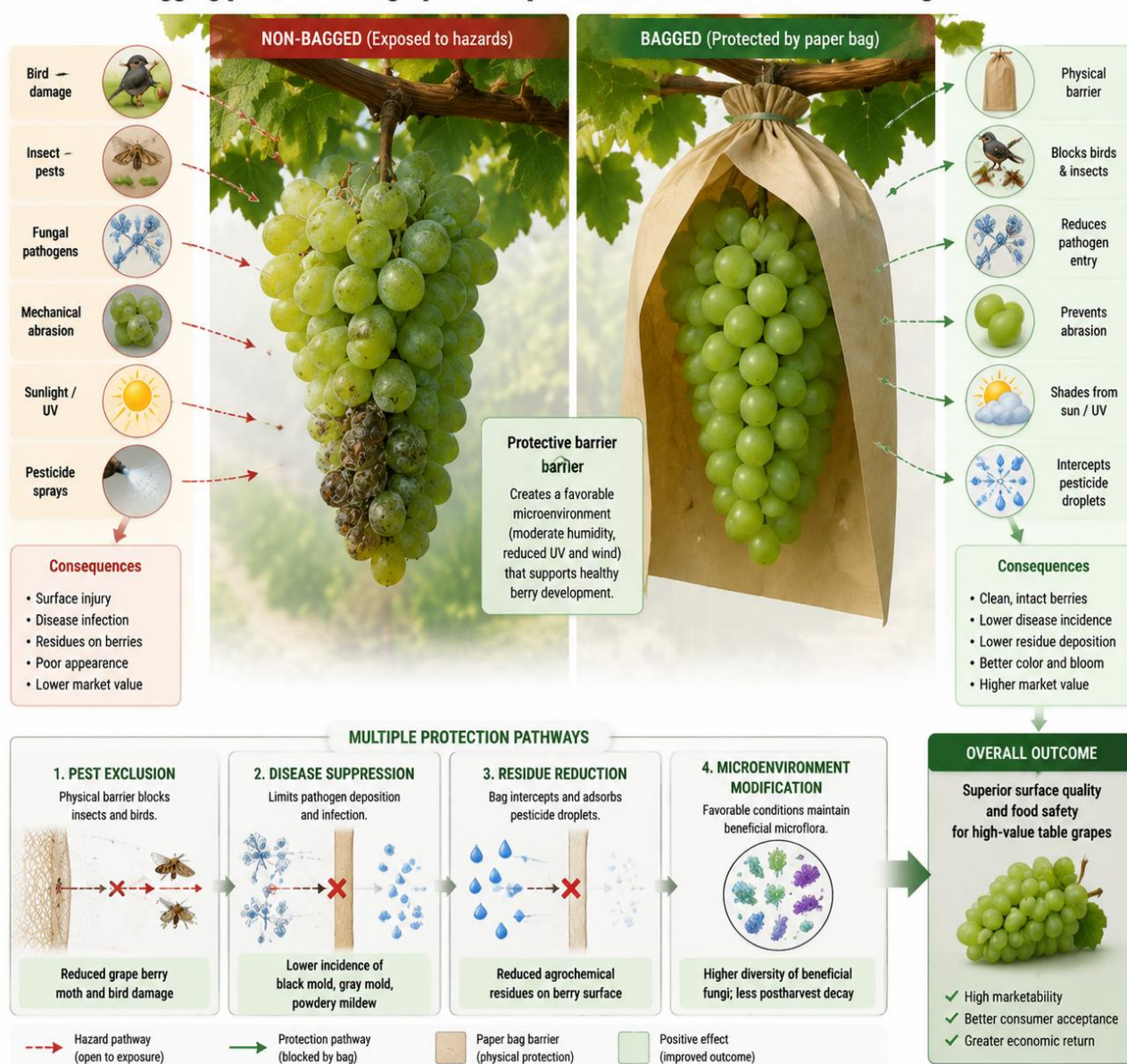


Figure 1 Multifunctional protective mechanisms of fruit bagging in table grapes: physical exclusion, contamination reduction, and surface quality preservation

4 Effects of Fruit Bagging on Grape Quality Attributes

4.1 Regulation of soluble sugar accumulation and carbohydrate metabolism

Fruit bagging alters soluble sugar accumulation in grapes, but the direction of effect depends on cultivar, developmental stage, and light regime. In Muscat-flavored table grapes, several bag types, including transparent, mesh, yellow, white, and blue bags, significantly increased total soluble solids in two cultivars, while in 'Red Globe' bagging raised total sugar content at the late stage of development and increased relative sucrose content and acid invertase activity (Wang et al., 2022). These results suggest that some bagging systems promote carbohydrate accumulation by modifying the berry microenvironment rather than uniformly suppressing ripening.

Other studies show the opposite pattern under stronger shading or prolonged light exclusion. In 'Shenhua' and 'Shenfeng', bagged berries had lower soluble sugar contents than unbagged berries, although sugar levels recovered rapidly after bag removal, while controlled shading in 'Marselan' reduced fructose, glucose, and total sugar accumulation and delayed ripening as light transmission declined (Nan et al., 2024). This indicates that the carbohydrate response to bagging is largely driven by the optical properties of the bag and the duration of reduced light exposure.

At the metabolic level, bagging appears to reshape sugar metabolism through changes in enzyme activity and carbon-partitioning pathways. In 'Red Globe', early changes in invertase activity under bagging were proposed to contribute to later sugar accumulation, and transcriptomic analysis of 'Ruidu Kemei' identified differentially expressed genes linked to starch and sucrose metabolism, glycolysis, and the tricarboxylic acid cycle under bagged conditions (Yuying et al., 2023). These findings support a mechanistic interpretation in which bagging affects not only final sugar concentration but also the regulatory network controlling carbon use during berry development.

This interpretation is consistent with broader evidence on grape carbon economy. Sugar accumulation in grape berries depends on imported carbon and is a core process in ripening, while more general fruit studies show that soluble sugar metabolism is governed by coordinated action of enzymes, transporters, and their spatiotemporal gene expression (Lu et al., 2024; Wu et al., 2025). Bagging therefore influences sweetness and maturity partly by altering the environmental signals that regulate these carbohydrate metabolism systems.

4.2 Effects on organic acids and flavor formation

The effects of fruit bagging on organic acids in grapes are generally weaker and less consistent than its effects on sugars. In 'Ruidu Kemei', bagging increased the sugar-acid ratio but had no significant effect on titratable acidity at the over-mature stage, while in Cabernet Sauvignon, bagging had limited effects on total soluble solids and titratable acidity at harvest despite clear shifts in berry light exposure (Yuying et al., 2023). This suggests that bagging often changes perceived taste balance more through sugar responses than through large changes in acid concentration.

A similar conclusion emerges from broader bagging literature. Reviews note that bagging can increase or decrease sugars and organic acids depending on species and treatment, but grape berries often show relatively small changes in these core compositional traits, and citrus work likewise found that bagging exerted little effect on sugars and organic acids when applied late in fruit development (Ali et al., 2021; Jiang et al., 2022). The available evidence therefore supports a moderate view in which acid metabolism is affected by bagging less consistently than berry color or aroma.

By contrast, flavor-related volatile formation appears highly responsive to bagging, especially to bag color and material. In Muscat-flavored grapes, the dominant volatiles included linalool, geraniol, β -myrcene, and ocimenes, and transparent and white bags promoted phenolics and monoterpenes, whereas pink and blue bags inhibited them (Wang et al., 2022). Because monoterpenes are key contributors to floral and fruity notes in table grapes, these findings indicate that bagging can materially reshape sensory quality even when sugar and acid responses are modest.

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

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

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).

6.3 Integration of bagging with other vineyard management practices

Bagging is most effective when integrated with other vineyard practices that improve cluster-zone microclimate and reduce disease pressure. Reviews of grapevine pest management argue that cultural and physical methods should complement other control tools rather than be treated in isolation, especially as reliance on synthetic pesticides becomes less sustainable (Pavan et al., 2026). This logic fits grape bagging well, because bagging provides direct fruit protection while pruning, irrigation, and canopy management regulate the surrounding environment that still shapes temperature, humidity, and pathogen risk.

Field evidence supports combining bagging with practices such as defoliation, bunch-density reduction, and irrigation control to strengthen disease suppression and quality preservation. In vineyards, defoliation, reduced bunch density, and irrigation cut-off significantly reduced *Aspergillus* occurrence on berries and altered the carposphere microbiome in ways associated with lower disease pressure (Testempasis et al., 2023). At a broader systems level, extensive vineyard management with vegetation cover and low pesticide use increased biodiversity and ecosystem services, including pest control, suggesting that bagging should be positioned within low-input, ecology-based production systems rather than as a stand-alone intervention (Winter et al., 2025).

7 Case Studies: Application of Fruit Bagging in Commercial Grape Production

7.1 Effects of different bag colors on red grape anthocyanin accumulation

Commercial experience with red grapes shows that bag color strongly regulates anthocyanin accumulation by modifying cluster light environment rather than by providing a uniform bagging effect. In three red table grape cultivars, anthocyanin responses differed among seven bag types: mesh bags produced the highest anthocyanin content in RDZH, yellow bags were best in RDHY, and transparent or mesh bags outperformed paper bags in RDHM, showing that the optimal color or material is cultivar-dependent (Wang et al., 2022). A separate production-oriented study in 'Kyoho' likewise found that bagging effects on skin anthocyanins were inconsistent and depended on bag color, bag material, and whether an umbrella was added, confirming that commercial color management must be tailored rather than generalized (Zhou et al., 2020).

The practical lesson from red-grape systems is that some bag colors suppress total anthocyanin accumulation even when they improve uniformity or alter anthocyanin composition. In 'Kyoho', white, green, and yellow bags significantly reduced soluble solids and both total and individual anthocyanin concentrations, with green and yellow bags causing the strongest inhibition (Figure 2) (Zhou et al., 2020). By contrast, in teinturier grape 'Yan 73', red and blue photosensitive bags increased redness and brightness and raised anthocyanin, total phenol, and antioxidant activity, indicating that spectral selectivity rather than simple shading is the key design principle for premium color enhancement (Zhang et al., 2025).

A second case-study pattern is that bagging timing determines whether color suppression is temporary or persistent. In 'Shenhua' and 'Shenfeng', bagging imposed low-light stress, lowered soluble sugars, and delayed pigment development, but fruit color and soluble solids recovered rapidly after bag removal near maturity. Cabernet Sauvignon showed the same stage dependence at higher physiological resolution: bagging during véraison or late ripening inhibited anthocyanin accumulation, whereas early shading followed by sunlight re-exposure could preserve or even enhance final phenolic outcomes.

From a commercial perspective, the best red-grape strategy is therefore not simply “bag or do not bag,” but to choose spectrally appropriate materials and define a removal window that restores light before final coloration. Transparent and white polypropylene micro-perforation bags promoted phenolics and monoterpenes more consistently than pink or blue bags in Muscat-flavored table grapes, while yellow bags specifically increased anthocyanins in RDHY but inhibited certain traits in other cultivars (Wang et al., 2022). More generally, Mediterranean field data indicate that bagging can either promote or inhibit fruit color depending on bag type, bagging date, bag removal date, and climate, which is why color-targeted protocols must be cultivar- and region-specific (Pisciotta et al., 2020).



Figure 2 Mechanistic model illustrating how fruit bag color and material regulate anthocyanin accumulation in red table grapes through modification of cluster light environments

7.2 Bagging management for improving table grape quality under rainy conditions

Under rainy conditions, bagging works best as part of a moisture-exclusion strategy aimed at reducing fruit wetness, surface contamination, and disease pressure. In open-field rain-shelter systems, fruit bagging was reported to prevent fruit surface contamination, reduce pesticide residues, and protect clusters from bird damage, while broader grape studies identify fruit bagging as a physical barrier against microbial pathogens, insects, and mechanical injury (Wang et al., 2022; Luca et al., 2023). This makes bagging especially relevant where frequent rain increases disease incidence and repeated spraying raises residue concerns. Direct disease-control evidence in grapes is strong for paper-bag systems. Brown paper bagging reduced grape berry moth infestation to 1.8%–2.3%, black mold to 0.6%–2.0%, gray mold to 1.1%–2.2%, and powdery mildew to 0.0–5.4%, compared with severe damage in non-bagged controls, and these benefits were achieved even without additional pesticide benefit from spraying. In rainy regions, whole-vine rain shelters further reduced canopy leaf wetness and relative humidity and lowered the severity of ripe rot, white rot, downy mildew, gray mold, and brown spot, showing that cluster bagging and rainfall exclusion address complementary parts of the same moisture-driven disease problem.

Quality improvement under wet conditions also depends on avoiding bag materials that create heat injury or excessive enclosure. Clear plastic bags advanced ripening but caused abnormal overgrowths and sunburn, whereas brown paper bags improved fruit quality and yield while still providing strong physical protection, making breathable paper materials more suitable for humid production environments. This material effect is consistent with Mediterranean table-grape results showing that parchment bags produced larger and better-colored berries and that all tested bags substantially reduced agrochemical residues at harvest (Luca et al., 2023). Commercial rainy-region management also benefits from combining bunch protection with broader protected cultivation. In 'Niagara Rosada', both plastic cover and bunch bagging improved physical and chemical traits across two seasons and delayed maturation, indicating that dual protection can stabilize quality when climate is limiting (Guerios et al., 2021). At larger scale, rain shelter increased grape yield by 110%-176% and farmer income by 80-193% compared with fungicide-based management, suggesting that bagging under rainy conditions is most valuable when integrated with canopy-scale rainfall protection rather than used as an isolated intervention.

7.3 Integrated bagging strategies for premium grape production

Premium grape production uses bagging not only for protection but to coordinate appearance, compositional quality, and food safety. In Sicily, paper, parchment, and non-woven bags applied from BBCH 75 to harvest all reduced agrochemical residues, while parchment bags also produced bigger and better-colored berries, demonstrating how bag choice can align residue reduction with premium visual standards (Luca et al., 2023). The same study showed that bagging can be developed as a protocol added to existing table-grape management in Mediterranean climates rather than as a stand-alone replacement for vineyard practices (Pisciotta et al., 2020). Integrated premium systems also rely on matching bag design to target quality traits such as sweetness, phenolics, and aroma. In Muscat-flavored grapes, transparent polypropylene micro-perforation bags, followed by white polypropylene bags, were the most effective for sweet-sour balance, phenolics, and monoterpene accumulation, whereas pink and blue bags had the strongest negative effects (Wang et al., 2022). In 'Ruidu Kemei', bagging increased total soluble solids and sugar-acid ratio at the over-mature stage but also delayed ripening and altered hundreds of metabolites and thousands of genes, showing that premium-quality gains can come with a developmental trade-off that must be managed operationally (Yuying et al., 2023).

A further premium-production lesson is that bagging should be integrated with timing control rather than maintained continuously until harvest in every market class. In Cabernet Sauvignon, early bagging followed by sunlight re-exposure increased flavan-3-ols and flavonols, whereas bagging after véraison inhibited skin anthocyanins, showing that staged removal can improve secondary-metabolite profiles without sacrificing final color. Similarly, in 'Niagara Rosada', protected plants or bagged bunches outperformed the untreated control for all evaluated traits, but both plastic cover and bagging delayed maturation, which means harvest scheduling is part of quality optimization in commercial premium programs (Guerios et al., 2021).

8 Perspectives and Conclusions

Future grape bagging technologies will likely move beyond passive protection toward smart, sustainable, and crop-specific systems. Recent reviews identify biodegradable and sensor-enabled bags as the main innovation directions, arguing that conventional materials create environmental concerns while next-generation designs can combine fruit protection with lower ecological impact. This transition is also supported by broader packaging research, which highlights growing use of biodegradable, edible, and smart packaging platforms that can preserve fruit quality while reducing waste and environmental burden. Material innovation is especially important because future grape bagging must achieve both field durability and end-of-life sustainability. Reviews of fruit packaging emphasize bio-based films derived from cellulose and starch as practical alternatives to petroleum plastics, while recent film-engineering work shows that recyclable cellulose-containing systems can improve moisture resistance, structural integrity, and fruit freshness retention under humid conditions. For viticulture, this means that future bags should be designed not only for spectral selectivity and ventilation, but also for recyclability or biodegradability after field use.

Smart bagging will also depend on embedding microclimate-responsive sensing into the bag itself. Sensor-oriented reviews propose bags capable of real-time tracking of temperature, relative humidity, ethylene, and light flux, allowing growers to adjust irrigation, canopy operations, or bag removal timing according to the fruit's actual microenvironment. More general fruit-monitoring literature reaches the same conclusion, noting that smart packaging can continuously monitor temperature, humidity, and gas composition and use wireless communication to improve freshness control and traceability. A second innovation frontier is the automation and customization of bagging operations. Recent reviews point to robotic applicators, autonomous platforms, and machine-vision-guided deployment as ways to reduce the labor bottleneck that currently limits commercial adoption, while customizable bag dimensions and materials are expected to better match cultivar-specific and market-specific requirements. This is particularly relevant because current grape studies already show that bag performance differs by material, shape, color, and closing system, so technical standardization will require adaptable rather than uniform designs.

The next step for grape bagging is to integrate it with precision viticulture, where bagging decisions are guided by sensor data rather than fixed calendars. Precision viticulture relies on reliable climatic and soil information to support site-specific actions, and grape quality is especially sensitive to local variation in temperature, humidity, and radiation at both microclimate and mesoclimate scales. Because bagging directly modifies the cluster microenvironment, its optimization should be linked to these same variables instead of being treated as an isolated practice. Sensor networks also make it possible to connect bagging with water, disease, and harvest management. IoT-focused viticulture surveys show that even relatively simple sensor sets can support disease monitoring, phenological tracking, and vineyard water-regime assessment, while more integrated systems combining humidity, radiation, soil water, and imaging data can assist irrigation management, canopy decisions, stress monitoring, and harvest timing. In practice, this creates a framework in which growers could decide when to bag, ventilate, or remove bags based on dynamic risk and ripening signals.

Non-destructive sensing is especially promising for evaluating whether bagging is improving or impairing quality development. Portable fluorescence sensing has already shown strong utility for tracking grape flavonols, estimating sugar content, and predicting optimal harvest time under different vineyard microclimates and canopy treatments. Smartphone-based thermal imaging and canopy apps also offer low-cost routes for assessing vine water status, canopy architecture, and spatial variability, which could make bagging adjustments more feasible in commercial vineyards without requiring highly specialized equipment. Bagging should therefore be viewed as one component of a broader digital decision-support system. Reviews of smart viticulture emphasize that sensing technologies, AI, and user-friendly software are valuable only when they improve decisions on canopy architecture, pests, water status, yield, and fruit composition, while climate-adaptation work similarly argues for integrated technological systems that help growers respond rapidly to variable weather and quality risks. The most useful future bagging systems will likely combine in-bag sensing, vineyard-scale monitoring, and predictive analytics to manage fruit microclimate from bagging through harvest and storage.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

- Amorim M.N., Miranda I.B., Santos Í.E.A., Turco S., Caçula B.T.S., Lourençoni D., and Guimarães M., 2020, Plastic film bags on the refrigeration of table grapes, *Revista Brasileira de Ciências Agrárias-Brazilian Journal of Agricultural Sciences*, 15(4): 1-8.
<https://doi.org/10.5039/agraria.v15i4a8415>
- Andreu-Coll L., Noguera-Artiaga L., Sendra E., and Hernández F., 2025, Impact of preharvest bagging on the volatile profile of Vinalopó table grapes, *Agronomy*, 15(5): 1066.
<https://doi.org/10.3390/agronomy15051066>

- Buthelezi N., Mafeo T.P., and Mathaba N., 2021, Preharvest bagging as an alternative technique for enhancing fruit quality: A review, *HortTechnology*, 31(1): 4-13.
<https://doi.org/10.21273/horttech04658-20>
- Gao C., Zhang Y., Li H., Gao Q., Cheng Y., Ogunyemi S.O., and Guan J., 2022, Fruit bagging reduces the postharvest decay and alters the diversity of fruit surface fungal community in 'Yali' pear, *BMC Microbiology*, 22(1): 239.
<https://doi.org/10.1186/s12866-022-02653-4>
- Guerios I.T., Cuquel F.L., and Biasi L.A., 2021, Bagging of bunches and protected production in 'Niagara Rosada' vineyard, *Pesquisa Agropecuária Gaúcha*, 27(1): 90-98.
<https://doi.org/10.36812/pag.202127190-98>
- He L., Ren Z., Wang Y., Fu Y., Li Y.-G., Meng N., and Pan Q., 2020, Variation of growth-to-ripening time interval induced by abscisic acid and synthetic auxin affecting transcriptome and flavor compounds in Cabernet Sauvignon grape berry, *Plants*, 9(5): 630.
<https://doi.org/10.3390/plants9050630>
- Herrera K.Y., Jaramillo J., Riaño C., Suárez C., Sierra C.A., Zuluaga C., and Castellanos D.A., 2024, Evaluation of perforation-mediated modified atmosphere packaging for the commercialization of bulk purple passion fruit under refrigeration, *Journal of Food Science*, 89(12): 8673-8688.
<https://doi.org/10.1111/1750-3841.17547>
- Jiang A.-M., Zheng L., Wang D., Kang C., Wu J., Fang P., Cao J., and Sun C., 2022, Effects of fruit bagging on the physiochemical changes of grapefruit (*Citrus paradisi*), *Food Quality and Safety*, 6: fyac049.
<https://doi.org/10.1093/fqsafe/fyac049>
- Kiran A., Kavitha C., Soorianathasundaram K., and Sritharan N., 2020, Impact of fruit bagging with different coloured non-woven polypropylene bags on yield attributes in grapes, *Asian Journal of Dairy and Food Research*, 39: 359-362.
<https://doi.org/10.18805/ajdfr.dr-1547>
- Kumar A., Maiti C., Sarkar A., Alila P., and Patil P., 2023, Effect of bagging materials and time on fruit quality of litchi (*Litchi chinensis*) cv. Shahi in Nagaland, *The Indian Journal of Agricultural Sciences*, 93(11): 1262-1265.
<https://doi.org/10.56093/ijas.v93i11.140978>
- Li H., Bai Y., Yang Y., Zheng H., Xu X., Li H., Wang W., and Tao J.-J., 2023, Transcriptomic analyses reveal light-regulated anthocyanin accumulation in 'ZhongShan-HongYu' grape berries, *Scientia Horticulturae*, 309: 111669.
<https://doi.org/10.1016/j.scienta.2022.111669>
- Liang X.G., Chen H.M., Pan Y.Q., Wang Z.W., Huang C., Chen Z.Y., Tang W., Chen X.M., Shen S., and Zhou S.L., 2025, Yield more in the shadow: Mitigating shading-induced yield penalty of maize via optimizing source-sink carbon partitioning, *European Journal of Agronomy*, 162: 127421.
<https://doi.org/10.1016/j.eja.2024.127421>
- Lu L., Delrot S., and Liang Z., 2024, From acidity to sweetness: A comprehensive review of carbon accumulation in grape berries, *Molecular Horticulture*, 4(1): 22.
<https://doi.org/10.1186/s43897-024-00100-8>
- Luca L., Scollo F., Distefano G., Ferlito F., Bennici S., Inzirillo I., Gentile A., La Malfa S.L., and Nicolosi E., 2023, Pre-harvest bagging of table grapes reduces accumulations of agrochemical residues and increases fruit quality, *Agriculture*, 13(10): 1933.
<https://doi.org/10.3390/agriculture13101933>
- Martínez-Lüscher J., and Kurtural S., 2021, Same season and carry-over effects of source-sink adjustments on grapevine yields and non-structural carbohydrates, *Frontiers in Plant Science*, 12: 695319.
<https://doi.org/10.3389/fpls.2021.695319>
- Nan X., Li W., Shao M., Cui Z., Wang H., Huo J., Chen L., and Chen B., 2024, Shading treatment reduces grape sugar content by suppressing photosynthesis-antenna protein pathway gene expression in grape berries, *International Journal of Molecular Sciences*, 25(9): 5029.
<https://doi.org/10.3390/ijms25095029>
- Pavan F., Cargnus E., and Zandigiacomo P., 2026, Vineyard design, cultural practices and physical methods for controlling grapevine pests and disease vectors in Europe: A review, *Insects*, 17(1): 113.
<https://doi.org/10.3390/insects17010113>
- Pisciotta A., Planeta D., Giacosa S., Pissoni M.A., Di Lorenzo R., and Rolle L., 2020, Quality of grapes grown inside paper bags in Mediterranean area, *Agronomy*, 10(6): 792.
<https://doi.org/10.3390/agronomy10060792>
- Poupard M., Gallo A., Boulord R., Guillem P., Rolland G., Simonneau T., Christophe A., and Pallas B., 2024, Source-sink manipulations through shading, crop load and water deficit affect plant morphogenesis and carbon sink priorities leading to contrasted plant carbon status in grapevine, *Annals of Botany*, 136(1): 49-66.
<https://doi.org/10.1093/aob/mcae203>
- Srivastava K., Soni S., Kumar D., and Dwivedi S., 2023, Effect of different bagging materials on guava fruit physiology and its quality attributes, *Plant Physiology Reports*, 28(2): 238-246.
<https://doi.org/10.1007/s40502-023-00733-9>
- Sun Y., Yang X., Wu R., Lv S., Li Y., Jia H., Yang Y., Li B., Chen W., Allan A., Jiang G., Shi Y., and Chen K., 2024, DNA methylation controlling abscisic acid catabolism responds to light to mediate strawberry fruit ripening, *Journal of Integrative Plant Biology*, 66(8): 1718-1734.
<https://doi.org/10.1111/jipb.13681>

- Testempasis S., Papazlatani C., Theocharis S., Karas P., Koundouras S., Karpouzas D., Karaoglanidis G., Hossain M.M., and Cordero-Bueso G., 2023, Vineyard practices reduce the incidence of *Aspergillus* spp. and alter the composition of carposphere microbiome in grapes (*Vitis vinifera* L.), *Frontiers in Microbiology*, 14: 1257644.
<https://doi.org/10.3389/fmicb.2023.1257644>
- Wang C., Wang L., Ye J., and Xu F., 2022, Fruit quality of *Vitis vinifera*: How plant metabolites are affected by genetic, environmental, and agronomic factors, *Scientia Horticulturae*, 305: 111404.
<https://doi.org/10.1016/j.scienta.2022.111404>
- Winter S., Paredes D., Beaumelle L., Alcalá Herrera R., Chen Y., Hoffmann C., Sander M., Dumitrața D., Batáry P., and Rusch A., 2025, Extensive vineyard management and semi-natural habitats increase biodiversity and ecosystem services: Insights from a global meta-analysis, *Journal of Environmental Management*, 395: 128029.
<https://doi.org/10.1016/j.jenvman.2025.128029>
- Wu J., Lu L., Meng Z., Qin Y., Guo L., Ran M., Peng P., Tang Y., Huang G., Li W., and Li L., 2025, Advancements on the mechanism of soluble sugar metabolism in fruits, *Horticulturae*, 11(9): 1001.
<https://doi.org/10.3390/horticulturae11091001>
- Yan H., Pei X., Zhang H., Li X., Zhang X., Zhao M., Chiang V., Sederoff R., and Zhao X., 2021, MYB-mediated regulation of anthocyanin biosynthesis, *International Journal of Molecular Sciences*, 22(6): 3103.
<https://doi.org/10.3390/ijms22063103>
- Zhang K., Wang W., Xie Y., Cao J., Cao H., Wang X., and Xi Z., 2025, Effects of photoselective cluster bags on 'Yan 73' Teinturier grape skin, flesh and wine: From color, phenolics, antioxidation, aromas and sensory perspective, *Food Chemistry*, 2025: 147326.
<https://doi.org/10.1016/j.foodchem.2025.147326>
- Zhen Z., Cui C., Hong L., Jiang C., Yuhui Z., and Guo Y., 2024, The VvHY5-VvMYB24-VvMYBA1 transcription factor cascade regulates the biosynthesis of anthocyanin in grape, *Horticultural Plant Journal*, 11(3): 1066-1077.
<https://doi.org/10.1016/j.hpj.2024.02.005>
- Zhou S.H., Guo R., Wei R., Liu J., Yu H., Shi X., Zhang Y., Xie T., and Cheng G., 2020, Effects of bagging or the combination of umbrella and bag treatments on anthocyanin accumulation in the berry skin of 'Kyoho' (*Vitis labruscana*) grape, *Food Science and Technology*, 40(2): 394-400.
<https://doi.org/10.1590/fst.41218>

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