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Coping with heatwaves: key points to implement mitigation strategies for berry survival

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Extreme heat events have become more frequent and can have a significant impact on agricultural crops, including in viticulture. Since the 1970s, both the duration and frequency of these events have increased, resulting in yield losses as well as deleterious changes to grape composition due to modifications to technical, flavour and phenolic maturity, in addition to other problematic issues such as sunburn[1]. Understanding why, when and how is crucial to help mitigate the effects of extreme heat, on grape, vine and wine and ensure vineyard sustainability, yield and wine quality[2].

Plant Response to Heat

Extreme heat and heatwaves cause varying degrees of damage, based on how long they last, how intense they are, when they occur and whether other environmental stressors are present[1]. In general, rising temperatures tend to reduce photosynthesis and increase transpiration. While vines can tolerate heat and drought individually, they struggle to cope with heatwaves under water deficit conditions. Hydric stress is exacerbated by plants delaying stomatal closure to regulate temperature increases, especially in anisohydric varieties, and in high drainage (e.g., sandy) soils. Under simultaneous extreme heat and water stress, hydraulic failure and cell death occur, resulting in wilting canopies that increase fruit exposure and bunch temperature. Heat stress significantly affects grape composition and wine quality, altering the content of sugars, acids, amino acids, and secondary metabolites[2], and leading to decreased quality and unbalanced wines with higher ethanol content.

Sub- and lethal berry damage

Heat events can be catalogued as sub-lethal or lethal depending on temperature and degree of damage. While sub-lethal events (>35 °C) change berry composition and decrease overall quality, lethal events (>40 °C) usually lead to significant losses of yield.

Sunburn browning (SB), a sub-lethal form of damage, is caused by a combination of high radiation and high temperature. It is observed mainly after véraison and manifests as yellow, brown, or bronze spots on the sun-exposed side of the fruit; the colour of these lesions will depend on berry colour and are more evident in white than black grapes[1]. The main symptoms of SB are observed on the skin which loses its green colour due to the degradation of chlorophyll, turns brown due to polyphenol oxidation[3], and thickens. Affected white grapes develop brown lesions, while black grapes lose their colour due to anthocyanin degradation. Although changes to sugar and acid contents have been reported, SB mainly affects the skin and does not affect the pulp, with other effects appearing to be mainly related to high temperature rather than SB itself. Low levels of SB induce an accumulation of important aroma compounds like linalool and α-terpinene, but higher damage levels result in their degradation and loss of positive floral and fruity aromas and wine typicity. In general, SB leads to downgrading of the fruit and economical losses for grape growers of up to 50 % of the crop's value. Information on the consequences of SB on wine quality is difficult to find, but a few reports have indicated increased bitterness and browning (oxidation) of white wines. Water-stressed vines are less susceptible to SB due to better light adaptation and photoprotective compounds[1].

Severe (lethal) damage and sunburn necrosis (SN) can be generally observed at air temperatures above 40 °C, although fruit surface temperature (FST) is a better indicator than ambient temperature, as FST can be 12 – 15 °C higher. SN leads to cell death, shrivelling of entire berries and significant losses of yield. An increased proportion of shrivelled berries harvested can also impact wine colour and aroma (Figure 1A, B). Lethal temperature thresholds for berries vary with phenology due to changes in composition: pre-véraison Shiraz berries suffer necrosis from FST 43 °C and from 55 °C post-véraison[4,5,6]. Other studies have also investigated the lethal temperature threshold for Riesling, Bacchus, and Calardis blanc[7]. Altogether, results suggest lethal temperature for *Vitis vinifera* berries vary from 37 °C (flowering) to 50 °C (during ripening) (Figure 1C).

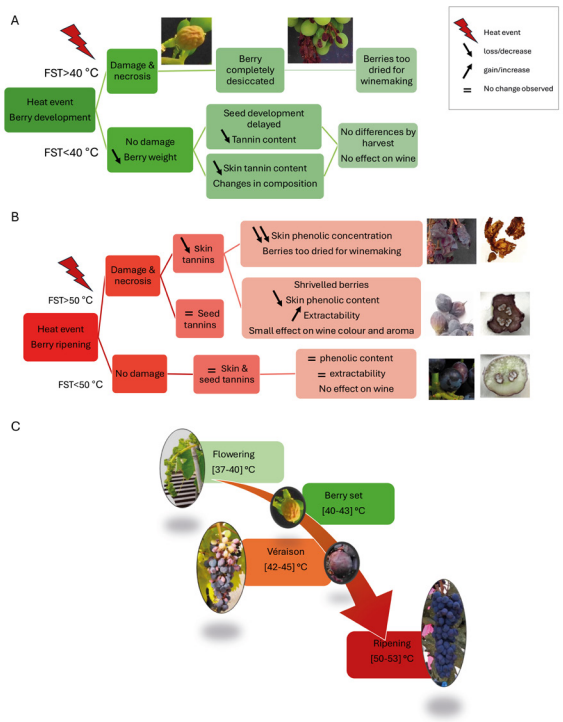


FIGURE 1. Effect of pre- (A) and post-véraison (B) heat events on berry development and grape and wine composition depending on fruit surface temperature (FST) and (C) Surface temperature ranges from which lethal damage may occur for *Vitis vinifera* flowers and berries.

The sources used for this Figure are available upon request from the authors.

Grape susceptibility to SB and SN varies by variety, developmental stage, skin colour, bunch location, and wind velocity. Recent research showed that at higher wind velocities, SN incidence and severity decrease due to lower berry FST[7], contradicting the air-drying effects

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sometimes reported by growers. Regardless of skin colour, both black and white varieties can suffer severe SB and SN damage. Amongst white varieties, Muscat of Alexandria and Riesling are highly susceptible to SB, while Sauvignon Blanc and Chardonnay are more tolerant. Grapes face distinct vulnerability windows regarding heat damage: SB risk is highest post-véraison, while SN primarily threatens berries during the earlier developmental stages. Understanding these critical periods is essential for producers to time protective interventions effectively.

Heatwave mitigation strategies

The success of any mitigation strategy hinges on understanding when berries are at risk of lethal damage (Figure 1C), that FST differs from forecasted air temperature, and the efficiency of the chosen strategies. Most strategies include maximising transpirational cooling and minimising radiation interception to maintain canopies and grapes as cool as possible. To do this, methods include increased irrigation, canopy management (pruning, trellis type/height, leaf removal), shading, mid-row management, reflective sprays, in-canopy misters, vineyard design (row orientation, cover crops), and grape variety choice[8] (Figure 2). These strategies vary in effectiveness and can be ranked by their ability to reduce air/canopy and FST (Figure 3). They also vary in relation to cost, sustainability, and the scale at

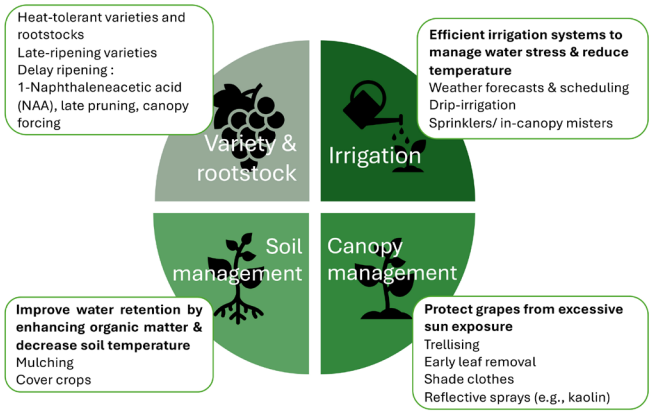


FIGURE 2. Heatwave mitigation strategies.

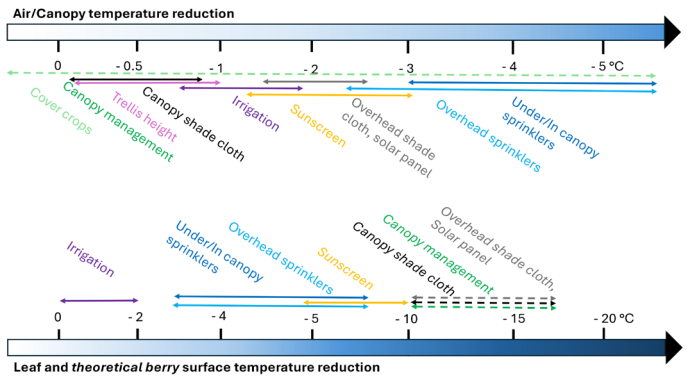


FIGURE 3. Canopy, leaf, and berry temperature reduction by different vineyard mitigation strategies (solid lines: measured values in referenced articles; dashed lines: theoretical values).

The sources used for this Figure are available upon request from the authors.

which they can be implemented. Their efficacy will depend on the maximum temperatures attained, how quickly they are deployed, and phenological stage.

The most common advice includes irrigating before and during a heatwave to wet as much of the rootzone as possible, reduce soil temperature, and maximise transpiration cooling. Time of irrigation depends on the type of soil: clay soils can be irrigated days in advance of a heatwave, while sandier soils should be irrigated the day or night before. While this only achieves a modest reduction in air and fruit temperature, this practice aims to decrease vine stress and ensure canopy viability. Night irrigation is more efficient than irrigating during the day. A more efficient use of water includes the use of overhead or in-canopy sprinklers, which significantly reduces air vapour pressure deficits and achieves the greatest reduction in canopy temperature. However, any strategy that uses water is contingent on having enough water to deploy irrigation, having the infrastructure in place to deliver water on time, and having the right to irrigate. While common in Australia and other irrigated regions, most European vineyards rely solely on rain for irrigation and can only obtain the right to irrigate under exceptional circumstances. Mulching presents an adequate alternative to decreasing soil temperature and reflective heating of the bunch zone and canopy, and water evaporation. Managing the canopy or using shade cloths to provide shade and avoid excessive sunlight, are excellent ways to achieve up to approximately 15 °C in temperature reduction. However, these interventions are most feasible when integrated into initial vineyard design rather than retrofitted to existing plantings. Sunscreens like clay (e.g., kaolin) can sometimes decrease SB incidence, particularly close to harvest. These particle-film technology products can be applied in the advent of a heatwave to protect canopies by reflecting sunlight and reducing radiative heating. Other products such as lime, talc, and antitranspirants are being tested, with various results also depending on leaf and grape coverage, product formulation, adhesion properties, and the timing and frequency of application relative to heat events.

It is advisable to combine two or more strategies, and to consider complementary actions during harvest (partially harvesting green berries, harvesting at night, berry sorting to eliminate damaged berries) and in the winery (e.g., water addition where permitted, choice of yeast and winemaking techniques, dealcoholisation, etc.). Unfortunately, there are few viable and effective short-term mitigation strategies. If a vineyard is located in an area prone to heatwaves, it is recommended to consider more permanent solutions that range from implementing shading structures to reimagining row orientation and reconsidering planted varieties. Understanding these parameters better will help growers choose the right mitigation method. ■

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