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Assessment of the temperature threshold for the occurrence of sunburn damage in *Vitis vinifera* L. 'Sangiovese'

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Abstract

In the last decades the occurrence of sunburn damage in vineyards has intensified due to climate change, resulting in serious consequences for yield and berry composition. Recognizing the significance of this emerging issue, the present study aimed to assess the temperature threshold causing sunburn damage under different levels of cluster exposure and vine water status. The experiment was conducted in 2021 and 2022 on 'Sangiovese' vines, cultivated near Bologna and trained to VSP spur-pruned cordon. Treatments were arranged in a strip-plot design and the main factors were: cluster exposure (leaf removal of the basal leaves at veraison *vs* no leaf removal) and irrigation (irrigation from berry softening to the end of August *vs* no irrigation). Berry temperature was continuously recorded by thermocouples connected to a WSN, and the evolution of sunburn damage (i.e., necrosis and berry shrivel) was visually estimated every week. Yield parameters and berry composition were assessed at harvest and anthocyanin analysis was conducted by HPLC on frozen berries. In both years, the temperature of the most exposed berries raised over 40°C for more than 40 hours, and the combined effect of light incidence and high temperatures caused the appearance of intense sunburn damage. On the other hand, no symptoms were found on the berries shaded by the foliage. Moreover, irrigation mitigated berry temperature, reducing the severity of sunburn damage. The sunburn damage caused by leaf removal lowered cluster weight and, consequently, yield, but irrigation limited both the incidence of symptoms and yield loss. Finally, the concentrations of soluble solids and anthocyanins were lowered by irrigation. The results of this study will be used to develop a warning tech solution that will alert growers to the risk of sunburn damage and suggest management techniques to reduce the impact on the berries.

Keywords: berry shrivel, climate change, cluster exposure, necrosis, water management

INTRODUCTION

Climate change has been causing a significant intensification of extreme weather events, such as heatwaves, droughts, and anomalies in both the frequency and intensity of rainfall (Droulia and Charalampopoulos, 2022). In this context, viticulture may face challenges from extremely high temperatures during summer, leading to an increased risk of berry sunburn. Berry sunburn is a complex disorder in grapevines, particularly during the ripening phase, which can diminish berry quality and result in severe yield loss (Bondada and Keller, 2012). Sunburn presents as necrosis and/or shriveling of berries, where necrosis is a lethal damage primarily influenced by the combined effects of direct solar incidence and high temperatures (Hulands et al., 2014; Gambetta et al., 2019). Meanwhile, berry shriveling resembles a partial dehydration of the berry (Bahr et al., 2021; Bondada and Keller, 2012). Defoliation around clusters is a common practice aimed at improving aeration, spray

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penetration, berry coloration and reducing disease pressure. However, we hypothesized that defoliation, even when performed at veraison when the photoprotectants accumulation is at its maximum (Pastore et al., 2013), could impact the occurrence of sunburn. The fall of basal leaves can also occur in vineyard in warm areas due to extreme high temperatures and water stress, leading to sudden exposure of clusters to direct light. Therefore, predicting sunburn becomes crucial to applying successful strategies for mitigating its impacts. Although key drivers of sunburn, such as local light conditions and heat impact on the berry surface, and cultivar-specific susceptibility have been identified (Gambetta et al., 2021), clear models for sunburn prediction are still lacking. Similar to most artificial intelligence applications in agriculture, technology-driven vineyard management begins with data acquisition, followed by data processing, model construction, and in-field predictions (Ammoniaci et al., 2021; Tardaguila et al., 2021). The use of proximal Wireless Sensor Network (WSN) for temperature monitoring (i.e., thermocouples inserted on berry skins continuously detecting their temperature) along with the examination of sunburn damages throughout ripening, allowed us to achieve the aim of this study: to assess the temperature threshold causing sunburn damage in *Vitis vinifera* 'Sangiovese'. This will lay the groundwork for developing Decision Support Systems (DSS) for viticulturist. Additionally, we investigated the role of irrigation applied during ripening as a strategy to reduce the sunburn appearance on the berries.

MATERIALS AND METHODS

Plant material and experimental design

The trial was conducted in 2021 and 2022 in an irrigated experimental vineyard at the University of Bologna (Bologna, 44°32'N, 11°22'E) located in the flat Po Valley and established in 2012. The vines were *Vitis vinifera* L. 'Sangiovese', clone 12T grafted onto SO4 rootstock, spaced at 1 m within the row (oriented North-East to South-West) and 3 m between rows, and trained to a Vertical Shoot Position (VSP) spur pruned cordon. Winter pruning left 6 two-buds spurs, and during spring, 12 shoots per vine were retained. At the phenological phase “berries beginning to touch”, the number of clusters was uniformed, leaving 16 clusters per vine.

The experiment was conducted on 60 vines, and treatments were arranged in a strip-plot design with 3 blocks and 5 replicates for each block. The two main factors considered were cluster exposure and irrigation. Cluster exposure treatments included: a) removal of main and lateral leaves from the eight basal nodes of each shoot at the beginning of veraison to encourage the appearance of sunburn symptoms (LR); b) no leaf removal (C). Irrigation treatments comprised: c) irrigation from berry softening (which is considered the beginning of veraison) to harvest, supplying 10 mm of water per week to keep the vines well-watered (WW); d) no irrigation (NI). The water was applied with a drip irrigation system and the amount was determined to over irrigate vines showing no symptom of water stress.

Climate data acquisition, sunburn damage, and stem water potential assessment

The temperature of 12 berries per treatment was recorded from veraison to harvest using thermocouples (Winet Srl, Cesena, Italy) that were inserted in one berry of the exposed part of different bunches located on both sides of each row. Meteorological parameters were monitored by a weather station (Davis Instruments, Hayward, CA, USA) located near the vineyard. The incidence and severity of sunburn necrosis and berry shrivel were assessed trough visual inspections: the proportion of damaged clusters (incidence) and the percentages of berries exhibiting the symptoms (severity) were recorded each week in August and at harvest.

Midday stem water potential (Ψstem) was measured on three days during ripening, using a Pump-Up pressure chamber (PMS Instruments, Albany, OR, USA). The measurements were taken on 9 main leaves per treatment (node number 12–15), that had been wrapped in plastic film and aluminum foil two hours before the assessments.

Berry sampling, yield components, and composition parameters at harvest

Two sets of samples were collected at harvest from each tagged vine: one comprising 30 berries to assess total soluble solid concentration, pH, and titratable acidity and another consisting of 20 berries to evaluate the concentration of anthocyanins. The yield of each vine was then weighed, and the number of clusters was counted.

Total soluble solids concentration was measured with a temperature-compensating Maselli R50 refractometer (Maselli Misure, Parma, Italy), while pH and titratable acidity were determined with a Crison Titrator (Crison Instruments, Barcelona, Spain). Anthocyanin analysis was conducted via HPLC, following the method described by Mattivi et al., (2006), using a Waters 1525 HPLC (Waters, Milford, MA) equipped with a diode array detector and a Phenomenex reversed-phase column with pre-column (Phenomenex, Castel Maggiore, Italy). Anthocyanins were quantified at 520 nm using an external calibration curve with malvidin-3-glucoside chloride as the standard (Sigma-Aldric, St. Louis, MO, USA), as described by Mattivi et al., (2006).

Statistical analysis

Treatment effect was tested using both one-way analysis of variance (ANOVA) and two-way ANOVA, employing the basic R studio (Core Team, 2020) function *aov*. One-way ANOVA was followed by a Tukey's test for pairwise comparison with mean separation at $P < 0.05$. Heatmaps and graphs were generated using basic Excel tools.

RESULTS AND DISCUSSION

Evolution and occurrence of sunburn damages in relation to cluster temperatures

The summer of both 2021 and 2022 was characterized by frequent and prolonged heatwaves. The weather station installed in the experimental vineyard recorded air temperatures exceeding 35 °C on 8 and 5 days in 2021 and 2022, respectively. In these climatic conditions, the temperature of LR (leaf removal) berries, exposed to the South-East side of the canopy, exceeded 35 °C for over one hundred hours in both years. On the North-West side, the hours with temperatures above 35 °C ranged between 45 and 63 °C (Table 1 and 2). As expected, in the C (control) vines, where clusters were shaded by the foliage, berry temperature exceeded 35 °C for less than 20 hours per year. A similar trend was observed in 2022, even if in the C berries exposed to the South-East, a higher number of hours with temperature above 35 °C were recorded compared to the previous year. Berry temperature higher than 40 °C were recorded only on LR vines (Tables 3 and 4), with the highest number of hours above this threshold found on the South-East side of the non-irrigated vines (more than 40 hours in both years). Regarding the role of irrigation, there is a tendency for well-watered berries to exhibit lower temperatures compared to non-irrigated (NI) ones, except for the data recorded on the North-West side in 2022. Even though the non-irrigated vines did not experience water stress (midday stem water potential never dropped below -8 bar, data not shown), the higher potential transpiration of well-hydrated berries may have contributed to reducing berry temperature (Gambetta et al., 2021). Sunburn damage occurred on LR berries in both years, but no symptoms were found on the control ones, thanks to the foliage around the clusters that prevented direct light incidence and kept berry temperatures below 40 °C.

Table 1. ∑ hours of berry temperature > 35°C from 29th of July to 20th of September 2021 for defoliated (LR) and control (C) vines of differently watered and exposed clusters (n = 6).

Treatment	Orientation – water management	29 – 30 July	31 Jul – 04 Aug	05 – 11 Aug	12 – 18 Aug	19 – 24 Aug	25 Aug – 20 Sep
LR	SE – NI	4	6	35 a	42 a	21 a	47 a
	SE – WW	3	2	22 b	31 ab	12 b	43 a
	NW – NI	2	2	14 bc	30 ab	7 bc	8 b
	NW - WW	2	2	11 bcd	29 bc	4 c	1 b
C	SE – NI	0	0	4 cd	12 cd	2 c	1 b
	SE – WW	0	0	1 d	5 d	0 c	1 b
	NW – NI	0	0	1 d	5 d	0 c	0 b
	NW - WW	1	0	4 cd	1 d	0 c	0 b

Different letters within a column indicate significant differences according to ANOVA and post-hoc Tukey test ($p < 0.05$). WW = well watered; NI = no irrigation; SE = south-east direction; NW = north-west direction.

Table 2. ∑ hours of berry temperature > 35°C from 29th of July to 20th of September 2022 for defoliated (LR) and control (C) vines of differently watered and exposed clusters (n = 6).

Treatment	Orientation – water management	29 Jul – 02 Aug	02 Jul – 05 Aug	06 Jul – 08 Aug	09 Aug – 11 Aug	12 Aug – 16 Aug	17 Aug – 23 Aug	24 Aug – 30 Aug	31 Aug - 06 Sep	07 Sep – 20 Sep
LR	SE – NI	14 ab	22 a	10 a	13 a	18 a	23 a	21 a	11 a	18 a
	SE – WW	16 a	19 a	9 ab	9 ab	12 ab	15 ab	17 ab	6 ab	10 ab
	NW – NI	9 ab	17 ab	9 ab	5 bc	8 bc	10 bcd	5 bc	4 ab	2 b
	NW - WW	13 ab	15 abc	9 ab	7 bc	11 ab	14 abc	8 abc	5 ab	2 b
C	SE – NI	4 ab	9 bcd	5 bc	3 bc	1 bc	6 bcd	7 abc	4 ab	9 ab
	SE – WW	8 ab	11 bcd	6 abc	3 bc	5 bc	5 cd	5 bc	2 b	3 b
	NW – NI	0 b	5 d	4 c	1 c	0 c	1 d	0 c	0 b	0 b
	NW - WW	5 ab	7 cd	5 bc	1 c	0 c	1 d	1 c	0 b	0 b

Different letters within a column indicate significant differences according to ANOVA and post-hoc Tukey test ($p < 0.05$). WW = well watered; NI = no irrigation; SE = south-east direction; NW = north-west direction.

The evolution of sunburn necrosis was quite similar in 2021 and 2022 (Figure 1). In both years, as soon as leaf removal was applied (29th July), this damage appeared on the South-East side of the canopy. On the North-West side, berry necrosis occurred in mid-August in 2021, while in 2022, the damage appeared earlier when the berry temperatures exceeded 40°C (Table 3 and 4). Additionally, irrigation lowered the incidence of necrosis, possibly due to the lower berry temperatures recorded in well-watered berries. Considering the evolution of sunburn necrosis and berry temperatures exceeding 40°C in different timeframes from leaf removal to harvest, it might be hypothesized that, under direct solar incidence, this temperature could be considered the threshold level for the occurrence of sunburn necrosis on 'Sangiovese' berries.

Berry shrivel appeared later than necrosis, and the non-irrigated berries on the South-East side showed the highest incidence. Moreover, in both years, the incidence of this symptom reached a peak a few days after it occurred and then decreased until harvest. This suggests that part of the shriveled berries becomes completely desiccated as harvest approaches (Bondada and Keller, 2012), thereby increasing the incidence of necrosis.

Table 3. ∑ hours of berry temperature > 40°C from 29th of July to 20th of September 2021 for defoliated (LR) vines of differently watered and exposed clusters (n = 6).

Orientation – water management	29 – 30 Jul	31 Jul – 04 Aug	05 – 11 Aug	12 – 18 Aug	19 – 24 Aug	25 Aug – 20 Sep
SE – NI	2	2	12 a	17 a	7 a	4
SE – WW	1	1	2 b	7 b	1 b	3
NW – NI	0	0	1 b	4 b	1 b	0
NW - WW	0	0	1 b	1 b	0 b	0

Different letters within a column indicate significant differences according to ANOVA and post-hoc Tukey test ($p<0.05$). WW = well watered; NI = no irrigation; SE = south-east direction; NW = north-west direction.

Table 4. ∑ hours of berry temperature > 40°C from 29th of July to 20th of September 2022 for defoliated (LR) vines of differently watered and exposed clusters (N=6).

Orientation – water management	29 Jul – 02 Aug	02 Jul – 05 Aug	06 Aug – 08 Aug	09 Aug – 11 Aug	12 Aug – 16 Aug	17 Aug – 23 Aug	24 Aug – 30 Aug	31 Aug – 06 Sep	07 Sept – 20 Sep
SE – NI	6	12 a	4	3	7 a	5	3	2	1
SE – WW	6	8 ab	2	2	3 b	4	5	2	1
NW – NI	1	4 b	2	1	1 ab	2	1	0	0
NW - WW	5	7 ab	3	2	3 b	5	2	1	0

Different letters within a column indicate significant differences according to ANOVA and post-hoc Tukey test ($p < 0.05$). WW = well watered; NI = no irrigation; SE = south-east direction; NW = north-west direction.

Effect of cluster exposure and water management on yield and berry composition

Averaged data from 2021 and 2022 indicate that exposed clusters showed a lower incidence of *Botrytis cinerea* (Table 3) due to the modification of microclimatic conditions (Intrieri et al., 2008; Pastore et al., 2017) aligning with findings from previous studies on Sauvignon blanc (Würz et al., 2020).

The number of clusters was uniformed before veraison, so changes of yield were attributed to differences in cluster weight. The intense sunburn damages previously described led to a reduction in the weight of exposed berries and so clusters, resulting in a significant yield loss in LR vines. Conversely, irrigation mitigated the negative effects of high levels of radiation and temperatures exceeding 40 °C observed in LR berries. This positive role of irrigation was also observed in Riesling grapevines (Müller et al., 2023). Furthermore, the weight of LR berry (those unaffected by any sunburn damage) was lower than the C berries, indicating that the sun exposure and the consequent higher temperatures limited the increase in berry size, likely, due to a higher transpiration rate.

The composition of grapes at harvest was differentially affected by sun exposure and water management. Total soluble solids and anthocyanin concentration were lower in irrigated vines, probably because the higher yield reduced the source/sink ratio, negatively impacting the accumulation of these compounds (Pastore et al., 2013). On the other hand, leaf removal reduced titratable acidity, as previously observed in other grapevine varieties (Pastore et al., 2017), due to the increase in berry temperatures accelerating malic acid breakdown (Lakso and Kliewer, 1975).

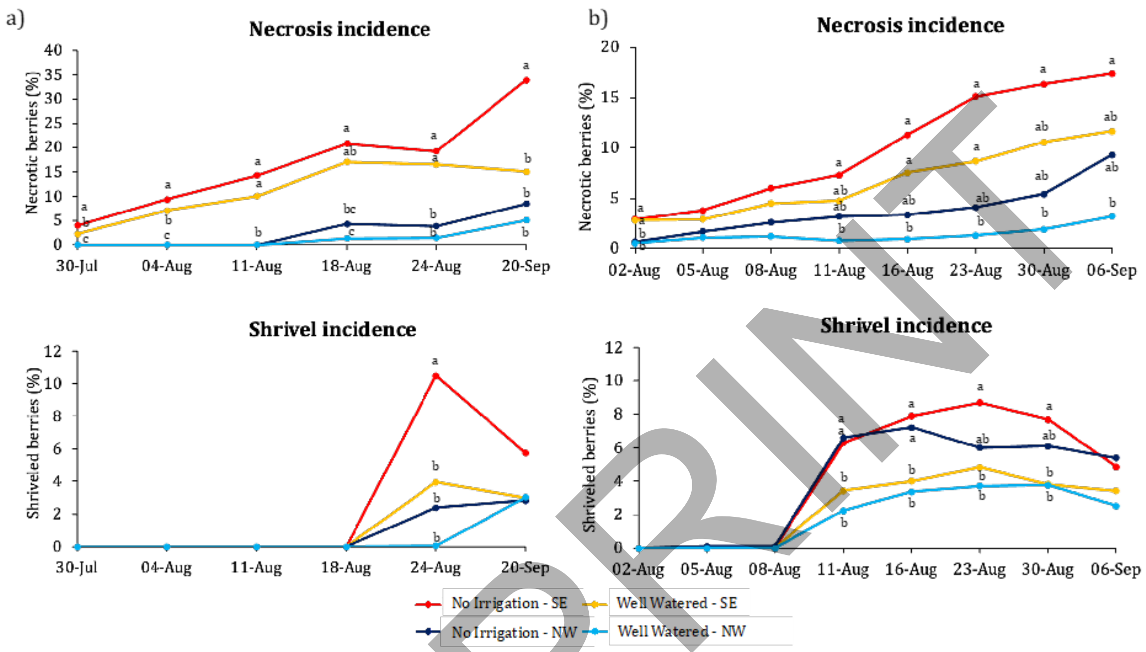

Figure 1. Sunburn damages evolution in defoliated (LR) clusters differently watered and exposed, for a) 2021 and b) 2022, expressed as necrosis and shrivel incidence (n = 15). Letters indicate significant differences according to ANOVA and post-hoc Tukey test ($p < 0.05$). SE = south-east direction; NW = north-west direction.

Table 5. Yield parameters and berry composition data at harvest for the different treatments averaged for year 2021 and 2022 (n=15).

Treatment	Cluster rot (%)	Yield (kg/vine)	Cluster weight (g)	Berry weight (g)	Total soluble solids (°Brix)	pH	Titratable acidity (mg/L)	Anthocyanins (mg/kg)
C + NI	4,0	6.27	378	2.58	23.3	3.47	6.99	631
C + WW	4,7	6.86	405	2.55	22.0	3.49	7.49	492
LR + NI	1,7	3.96	252	2.24	22.3	3.43	6.82	713
LR + WW	0,7	5.37	330	2.48	22.1	3.53	6.29	522
Significance								
Irrigation	n.s.	*	*	n.s.	*	n.s.	n.s.	*
Exposure	*	*	*	*	n.s.	n.s.	*	n.s.
Irrigation × exposure	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.

Two-way ANOVA was performed and treatment comparisons were analyzed using Tukey's honestly significant difference. * = $p < 0.05$; n.s. = not significant.

The application of irrigation from berry softening may be considered a mitigating strategy for sunburn damages and could also be employed to limit total soluble solids accumulation preventing excessive sugar concentration at harvest (Fernández et al., 2013). However, while irrigation during ripening has become a common practice in some wine-producing areas to address the decoupling between phenolic and technological maturity caused by climate change (Mendez et al., 2011), the reduction in anthocyanins observed in our 'Sangiovese' vineyard emphasized the need for a more precise calibration of water supply scheduling.

CONCLUSIONS

The results of this experiment highlight the impact of varying sun exposure on the development of sunburn damage on 'Sangiovese' berries. The data collected by the thermocouples and the weather station connected with the WSN revealed a direct correlation between berry temperatures exceeding 40°C, direct light exposure, and the onset of sunburn symptoms. Collectively, these data lay the foundation for developing a DSS model, valuable for alerting growers to the threat of sunburn and providing guidance on the best management practices to minimize the risk of occurrence. One such effective strategy is irrigation during ripening, which proved effective in reducing sunburn damages in 'Sangiovese'.

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