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Irrigation during ripening may reduce sunburn damages on berries of *Vitis vinifera* L. 'Sangiovese'

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Abstract

In the Mediterranean wine-growing areas, high temperatures often hasten sugar accumulation causing, in black berry varieties, the decoupling between technological and phenolic maturity. Moreover, heat waves, occurring more frequently in the last decades, may cause severe sunburn damages on clusters with serious consequences on yield. Considering these issues, the approach to vineyard management has recently been reconsidered and also irrigation may be applied in an innovative way. The present study aimed to investigate the effects of irrigation during ripening on sunburn berry incidence and yield, and grape composition at harvest. The trial was conducted in 2021 on adult vines of *Vitis vinifera* L. 'Sangiovese', trained to vertical shoot positioned (VSP) spur-pruned cordon. Treatments were laid out in a strip-plot design and the main factors were irrigation and cluster exposure. Irrigation treatments were: a) irrigation from the beginning of veraison to harvest to maintain vines well-watered; b) no irrigation. Cluster exposure treatments were: c) removal of main and lateral leaves from the eight basal nodes of each shoot at the beginning of veraison; d) no leaf removal. From veraison to harvest, berry temperature was continuously measured with thermocouples inserted under berry skin, while the incidence and severity of sunburn damages were recorded weekly on all the cluster of the tagged plant. Midday stem water potential was also measured from the end of July to late August. At harvest, yield parameters were measured and grape composition analyzed, while frozen berries were used for anthocyanin analysis with HPLC. As expected, leaf removal caused berry necrosis and berry shrivel due to the increase of berry temperature, but irrigation halved the severity of those sunburn damages. Sugar and anthocyanin concentrations were slightly affected by leaf removal but decreased significantly with irrigation. This study documented an interesting approach to tackle sunburn damages and to slow down sugar accumulation, which still needs to be modulated to avoid detrimental effects on anthocyanin accumulation.

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

INTRODUCTION

Climate change has been causing the increase of heatwave frequency and the anomalous distribution of the precipitations, leading to prolonged periods of drought (Masson-Delmotte et al., 2018). These climatic conditions severely affect the cultivation of grapevine for wine production (Schultz, 2000) and in the last decades, many researchers described the increase of sunburn damages and their negative consequences on berry ripening.

As reported by Tarara and Spayd (2005) and Bonada et al. (2013), high temperatures and prolonged water stress promotes the occurrence of berry necrosis and berry shrivel, leading to yield loss and the deterioration of berry biochemical composition.

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Regarding berry ripening, high temperatures contribute to the acceleration of sugar accumulation, the intensification of malic acid degradation and the reduction of the synthesis of anthocyanin, often causing the decoupling between technological ripening and phenolic maturity in black berry varieties (Jones and Davis, 2000; Sadras and Moran, 2012). In the vintages in which these conditions occur, harvest at proper technological ripening may lead to the production of wines poorly colored and characterized by unpleasant astringency, while delaying the harvest to reach the desired phenolic maturity may lead to excessive alcohol concentration and very low acidity (Allegro et al., 2020).

In this challenging scenario, many adaptation strategies based on canopy management were evaluated (Palliotti et al., 2014) but still little was done on irrigation. It is well known that vineyard irrigation strategies during ripening in semi-arid areas are aimed to maintain the leaf photosynthetic activity and to increase the concentrations of sugars and anthocyanins (Santesteban et al., 2011; Casassa et al., 2015). Despite these results, nowadays this approach may result anachronistic due to global warming, because more and more frequently, even in temperate areas, it is needed to slow down sugar accumulation to avoid the decoupling between technological ripening and phenolic maturity. Therefore, irrigation during ripening was proposed as an adaptation strategy to climate change and in this view, the study conducted by Fernandez et al. (2013) showed that this approach was successful in reducing the concentration of soluble solids without causing negative effects on the phenolic compounds.

Based on these findings, the present study was aimed to evaluate the effects of irrigation during ripening not only on the berry composition but even on the occurrence of berry sunburn symptoms on *Vitis vinifera* L. 'Sangiovese'.

MATERIALS AND METHODS

Plant material and experimental design

The trial was conducted in 2021 in a 9-year-old irrigated experimental vineyard of the University of Bologna (Bologna, 44°32'N, 11°22'E) laid on the flat Po Valley. 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 VSP spur pruned cordon. Winter pruning left 6 two-buds spurs and during spring 12 shoots per vine were left.

The experiment was conducted on 60 vines, and treatments were laid out in a strip-plot design with 3 blocks and 5 replicates for each block. The two main factors were irrigation and cluster exposure. Irrigation treatments were: a) irrigation from the beginning of berry softening (22 July) to harvest, supplying 10 mm of water per week to maintain vines well-watered (I); b) no irrigation (NI). Cluster exposure treatments were: c) removal of main and lateral leaves from the eight basal nodes of each shoot at the beginning of veraison (29 July) to favor the appearance of the sunburn symptoms (LR); d) no leaf removal (C).

Climate data acquisition, sunburn damage and stem water potential assessment

The temperature of 12 berries per treatment was recorded from veraison to harvest with thermocouples (Winet Srl, Cesena, Italy) and the meteorological parameters were monitored by a weather station (Davis Instruments, Hayward, CA, USA) closed to the vineyard. The incidence and severity of sunburn necrosis and berry shrivel were assessed by visual inspections: the proportion of damaged clusters (incidence) and the percentages of berries showing the symptoms (severity) were recorded each week in August and at harvest (20 September). Midday stem water potential (Ψ_{stem}) was measured in three days during ripening with a Pump-Up pressure chamber (PMS Instruments, Albany, OR, USA) on mature leaves that had been wrapped in plastic film and aluminum foil 2 h before the measurements. These measurements were conducted on nine vines per treatment, taking one leaf per vine.

Berry sampling, yield components and composition parameters at harvest

Two batches of samples were collected at harvest from each tagged vine, one of 30 berries to assess total soluble solid concentration, pH and titratable acidity and the other (20 berries) to assess 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 measured with a Crison Titrator (Crison Instruments, Barcelona, Spain). Anthocyanin analysis was performed via HPLC, following the method described in 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

Data were analyzed using the mixed procedure available in SAS v9.0 (SAS Institute, Cary, NC, USA). Treatment comparisons were analyzed using Tukey's honestly significant difference with mean separation at $P \leq 0.05$.

RESULTS AND DISCUSSION

Sunburn damages

The summer of 2021 was characterized by intense heat waves associated with a prolonged drought. During the 7-week period between the day of leaf removal and harvest, the air temperature rose over 35 °C for 35 hours and only 21 mm of precipitations were recorded. These climatic conditions lead to the progressive decrease of stem water potential of the NI vines, while no effect of leaf removal was found as regard to vines water status (Table 1). Conversely, as expected, leaf removal drastically increased berry temperature, but interestingly also irrigation affected this parameter, in fact I+LR vines showed a significant reduction of maximum berry temperature and of the number of hours in which berry temperature exceeded both 35 °C and 40 °C compared to NI+LR vines (Table 2; Figure 1), probably due to the potential higher transpiration of the well-hydrated berries (Gambetta et al., 2021).

The very high berry temperatures recorded after leaf removal (29 July) suddenly caused severe symptoms of sunburn necrosis in both LR treatments, while in C vines no damage was found. Also berry shrivel was found only on LR vines but appeared later during ripening along with the decrease of the midday stem water potential. At harvest, the severity of sunburn necrosis was halved by irrigation, which also decreased the incidence and severity of berry shrivel (Table 3). As reported by Hulands et al. (2014) the appearance of sunburn damages is due to the combination of intense light incidence and high berry temperature, a condition that in our 'Sangiovese' berries was determined by the intense leaf removal. On the other hand, the clusters protected from the direct sunlight by a dense canopy in the C treatments, were not damaged as also found by Rustioni et al. (2014). Furthermore, the appearance of sunburn symptoms is also favored by drought (Carvalho et al., 2016) and that explains the increase of sunburn necrosis and berry shrivel in the NI vines compared to the I vines.

Table 1. Midday stem water potential (Ψ_{stem}) measured on adult 'Sangiovese' leaves (N=9). Year 2021.

Treatment	Ψ_{stem} 30 July (bar)	Ψ_{stem} 11 August (bar)	Ψ_{stem} 24 August (bar)
NI + C	-4.55	-5.93	-7.95
NI + LR	-4.85	-5.63	-7.53
I + C	-3.45	-2.73	-3.85
I + LR	-3.58	-2.93	-3.55
<i>Significance</i>			
Irrigation	*	*	*
Leaf removal	ns	ns	ns
Interaction I x LR	ns	ns	ns

* = $P < 0.05$; ns = not significant. Treatment comparisons were analyzed using Tukey's honestly significant difference.

Table 2. 'Sangiovese' berry temperatures of recorded between 29 July 2020 and 20 September 2020 (N=12). Year 2021.

Treatment	Maximum berry temperature (°C)	Berry temperature > 35 °C (hr)	Berry temperature > 40 °C (hr)
NI + C	37.5	18	0
NI + LR	44.2	239	18
I + C	37.4	16	0
I + LR	41.3	163	3
<i>Significance</i>			
Irrigation	*	*	*
Leaf removal	*	*	*
Interaction I x LR	ns	ns	ns

* = $P < 0.05$; ns = not significant. Treatment comparisons were analyzed using Tukey's honestly significant difference.

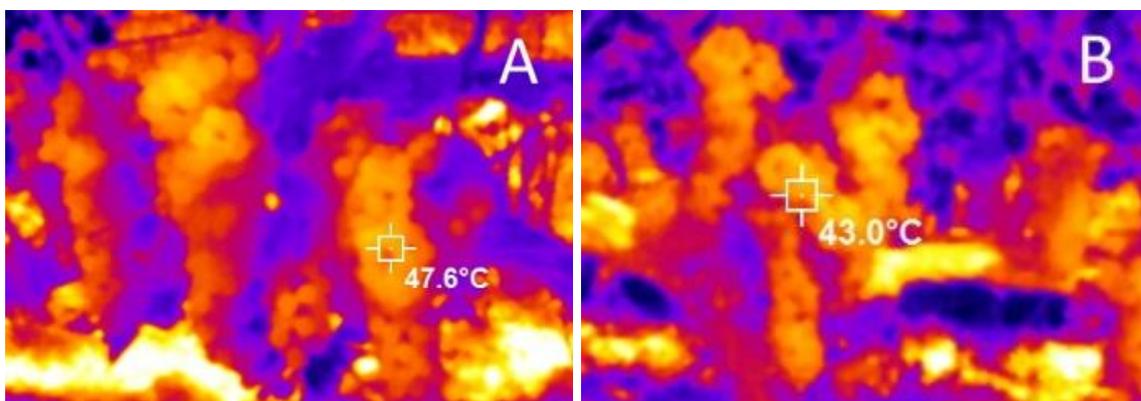


Figure 1. Thermocamera images of a NI+LR cluster (A) and a I+LR cluster (B), taken on 30 July 2021 at 10:30 am.

Table 3. Incidence and severity of different sunburn berry symptoms visually assessed on 'Sangiovese' vines at harvest (N=15). Year 2021.

Treatment	Incidence of sunburn necrosis (%)	Severity of sunburn necrosis (%)	Incidence of berry shrivel (%)	Severity of berry shrivel (%)
NI + LR	53.3	21.5	38.9	4.5
I + LR	50.0	10.3	28.5	3.1
<i>Significance</i>	ns	*	*	*

* = $P < 0.05$; ns = not significant. Treatment comparisons were analyzed using Tukey's honestly significant difference.

Yield and berry composition

Both the absence of irrigation and leaf removal reduced cluster weight and therefore the yield (Table 4). It is worthy of notice that this effect was caused by the lower weight of LR berries and the sunburn necrosis that led to the complete desiccation of the berries, in particular in the NI+LR clusters.

With regard to compositional parameters, irrigation lowered sugar and anthocyanin concentrations, while leaf removal reduced titratable acidity (Table 5). The lower concentrations of sugars and anthocyanins were associated to the higher yield that apparently reduced the source to sink ratio (although the leaf area was not measured, no regrowth of lateral shoots was noticed after irrigation) as explained by Pastore et al. (2011) in a study conducted on 'Sangiovese' grapevines. The reduction of titratable acidity due to leaf removal was instead probably linked to the higher berry temperature that stimulated the degradation of malic acid (Lakso and Kliewer, 1975).

In conclusion, irrigation was effective in reducing sunburn damages, while, concerning berry composition, this technique induced the slowing down of sugar accumulation, but caused detrimental effects on anthocyanins. These negative effects were not found in a study conducted on 'Merlot' vineyard, where ramping up the irrigation in the last phases of ripening did not influence anthocyanin concentration (Mendez et al., 2011).

Table 4. Yield parameters at harvest of 'Sangiovese' vines (N=15). Year 2021.

Treatment	Cluster (n°/vine)	Yield (kg/vine)	Average cluster weight (g)	Average berry weight (g)	Average skin weight (g)
NI + C	15.6	5.88	377	2.66	0.34
NI + LR	15.4	3.91	251	2.21	0.29
I + C	16.9	6.72	400	2.65	0.29
I + LR	16.5	5.66	344	2.41	0.28
<i>Significance</i>					
Irrigation	ns	*	*	ns	ns
Leaf removal	ns	*	*	*	ns
Interaction I x LR	ns	ns	ns	ns	ns

* = $P < 0.05$; ns = not significant. Treatment comparisons were analyzed using Tukey's honestly significant difference.

Table 5. Berry composition parameters at harvest of 'Sangiovese' vines (N=15). Year 2021.

Treatment	Total soluble solids (°Brix)	pH	Titrateable acidity (g/L)	Anthocyanins (mg/g of skin)	Anthocyanins (mg/kg of berry)
NI + C	22.7	3.38	7.98	4.89	622
NI + LR	22.1	3.32	7.44	5.53	719
I + C	21.7	3.39	8.56	4.23	460
I + LR	20.8	3.35	7.21	4.27	505
<i>Significance</i>					
Irrigation	*	ns	ns	*	*
Leaf removal	ns	ns	*	ns	ns
Interaction I x LR	ns	ns	ns	ns	ns

* = P < 0.05; ns = not significant. Different letters within a column indicate a significant difference after Tukey's honestly significant difference test.

CONCLUSION

In our trial, which was conducted on the fertile Po Valley, vines were vigorous and the abundant foliage around the cluster avoided sunburn damages. Leaf removal at the beginning of veraison was performed to reproduce the conditions of low vigorous vineyards subjected to water stress that, in particular in 'Sangiovese' grapevines, leads to the abscission of the basal leaves. Under the microclimatic conditions induced by defoliation, which are often found in the hillside vineyards, associated to heat waves events, irrigation applied during ripening to maintain the vines well-watered, reduced sunburn damages and saved about one-third of the yield. Moreover, the concentration of sugar was reduced showing that irrigation may be a powerful tool to control both the hastening of soluble solids accumulation and the berry damages frequently occurring as a consequence of heat waves. Considering the anthocyanins, the irrigation from the beginning of veraison led to unsuccessful results, but it should be taken into consideration that in our condition, the high productivity of the vines limited ripening parameters to sub-optimal levels and the concentration of anthocyanins was in all the cases relatively low. Therefore, it should be very interesting to verify the effects of late irrigation in vineyards with more ripen berries, because in these conditions, the expected sugar reduction might not cause detrimental effects on anthocyanins.

As a final remark, the irrigation during ripening showed promising results in counteracting some negative effects of climate change but it needs to be improved with a careful evaluation of the timing and the amount of water supplied, to avoid negative consequences on anthocyanin accumulation.

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