BIO Web of Conferences **13**, 04004 (2019) https://doi.org/10.1051/bioconf/20191304004
CO.NA.VI. 2018

Kaolin treatments on Pinot noir grapevines for the control of heat stress damages

Tommaso Frioni[1], *Sergio* Tombesi[1], *Elisa* Luciani[2], *Paolo* Sabbatini[3], *Julian* G. Berrios[4] and *Alberto* Palliotti[2,*]

[1] Dipartimento di Produzioni Vegetali Sostenibili, Università Cattolica del Sacro Cuore, Via E. Parmense 84, 29121 Piacenza, Italy.
[2]Dipartimento di Scienze Agrarie, Alimentari e Ambientali, Università di Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy.
[3] Department of Horticulture, 1066 Bogue Street, East Lansing, Michigan State University, USA
[4] Departamento de Produccion Vexetal, Universidad de Santiago de Compostela, Escola Politecnica Superior, Campus Universitario - E-27002 Lugo, Spain

Abstract. The aim of the study was to verify if vineyard kaolin application during the 2017 hot summer could reduce the negative effects of high temperatures and heat stress on canopy physiological processes, yield and fruit quality. The kaolin was applied once at the beginning of August, at 3% concentration, in a Pinot Noir vineyard. The application was performed only to the west side of the rows, where the vines were more subjected to heat stress. The 2017 summer was very hot, with maximum air temperature higher than 35 °C for several consecutive days in June, July and August and with heat waves that reached 42.3 °C in August. The kaolin coating works by significantly reducing leaf temperatures in comparison to untreated vines, with an average of about -4 °C and up to -6 °C. Moreover, it maintains high the photosynthetic activity preventing irreversible photoinhibition phenomena, whereas untreated vines exhibit a marked physiological damage with chlorotic and necrotic leaves, dehydrated berries and sunburn damages. At harvest, 30-35% of the untreated vines were affected by severe water stress symptoms and produced unmarketable fruits. In comparison to the untreated vines, those sprayed with kaolin showed a higher yield (+27%), higher anthocyanins (+35%) and higher concentration of organic acids (+11%).

1. Introduction

In many wine growing regions, strategies for adapting viticultural practices to the challenges of the climate change are based on innovative management techniques and they have become crucial in order to mitigate the negative effects of high temperatures and water stress. In these situations, it is easy to have photo-inhibition phenomena in the leaves, resulting in chlorosis and necrosis, reduction of berry growth and significant reduction of fruit quality at harvest due to a rapid increase in sugar and pH, alteration of the phenols metabolism and drop of organic acids and aroma compounds [1, 2, 3]. Because of this, resulting wines are less able to be aged, have poor color and aromatic profiles, and have excessive alcohol content, all of which is poorly appreciated by today's consumers. In addition, the phenomena of excessive dehydration of the berries and damage from sunburn is quite challenging from a viticultural perspective. Recently, new viticultural techniques can modulate technological ripening, in particular reducing the accumulation of sugars and sometimes reducing the degradation of organic acids. Those techniques are: a) defoliation in post-veraison in the upper-middle portion of the canopy; b) use of natural anti-transpirants; c) overhead irrigation of the canopy; and d) late winter pruning [1, 4, 5]. Therefore, during the summers where the air temperature (T) reaches values above 40-42 °C, it is becoming pivotal to apply viticultural practices that can reduce or minimize the effects of extreme temperatures on vine growth and development and on fruit quality. One solution could be the use of white clays, sprayed on the canopy, able to produce a sunscreen effect and to reduce the temperature of the tissues because of the high reflection of the solar radiation. This effect could reduce photoinhibitions and maintain vine yield and grape chemical composition at harvest. The use of kaolin in agriculture is not new. It has, in fact, been used since the 1930s to protect crops from high T. Its main effect is represented by an increase in the reflection of solar radiation, especially the infrared fraction, that, in turn, reduces the leaf T. In this paper, we report the results obtained in 2017 in a commercial vineyard of Pinot Noir that showed clear symptoms of heat stress in leaves and grapes. The basal portion of the canopy was staring to yellow and the grapes were beginning to dehydrate. The aim was to verify if, in these

* Corresponding author: alberto.palliotti@unipg.it

critical conditions, the use of kaolin could contain heat stress damages and maintain vine basic physiological processes.

2. Heat stresses in 2017 and the working hypothesis

The summer of 2017 was characterized by heat stress events, dangerous for the survival of the vines. According to the Australian Grape and Wine Authority, [6] a heat event occurs when T higher than 35 °C are recorded for 2-3 consecutive days or when T higher than 40 °C are recorded for one day. In the area of study, on consecutive days in June (12-16 and 20-27), the maximum air T exceeded 35 °C, in July, the same situation was presented (4 -14, 19-23 and 29-31), while in August, except for the interval 11-14, all other days the T max was higher than the threshold of 35 °C. In relation to the critical T of 40 °C, from 1 to 6 August the T was above the threshold, with peaks of 42.3 °C on 3 and 4 August. At the beginning of August, many vineyards in central Italy, especially those not irrigated, reported—independently of the cultivar— clear heat stress damages, with yellow and necrotic leaves. The grapes, especially those external to the canopy and directly exposed to solar radiation in the afternoon, showed dehydration damages and sunburn.

3. Materials and methods

The trial was carried out in 2017 in a non-irrigated commercial vineyard (Castello di Magione Winery) located in Central Italy (Umbria region), near the natural basin of Trasimeno Lake, province of Perugia. The vineyard is a 10-year-old planting of *Vitis vinifera* L. cv. Pinot noir planted at 2.5 × 0.8 m inter-row and intra-row, trained to a vertically shoot-positioned and pruned to a Guyot trellis with North-South oriented rows. On 3 August, after multiple days with air temperature above 40 °C, a kaolin (trade names Surround, Serbios) treatment was applied at a dose of 3 kg/100 liters of water on five adjacent rows, whereas another 5 rows were treated only with water and used as control. The kaolin was distributed in the morning by a mechanical sprayer only on the canopy side exposed to the West, sunny in the afternoon and therefore more sensitive to heat stress. The experimental layout consisted of 40 vines organized in a Complete Randomized Block Design (RCBD). Net photosynthesis, transpiration rate, chlorophyll fluorescence analysis and leaf temperature (T) were collected and at harvest yield components and basic fruit chemistry measured. Photosynthesis was measured at saturating light conditions during the hottest hours of the day (between 1300 and 1400 hours) on two leaves per vine at 0 (immediately after treatment), 7 and 18 days after kaolin spraying (3 August, 10 August and 21 August. Because of their spatial distribution and configuration, most of leaves of pertaining to treated vines resulted to be partially covered by the product. Therefore, the same measurements were also carried out 2 and 4 weeks after the treatment (17 August and 31 August), but discriminating portions of leaves sprinkled with kaolin and without kaolin present in the same treated vines. Gas-exchange measurements were made using a portable open system, LCA-3 infrared gas-analyzer (ADC Bio Scientific Ltd, Herts, UK), leaf temperature was measured using an infrared thermometer (Type K, ASSIcontrol, Varese. Italy). Leaf chlorophyll fluorescence was measured with a portable continuous excitation fluorimeter (Handy-PEA, Hansatech Institute Ltd, Norfolk, UK). Dark adaptation was achieved by covering the sample area to be analyzed with a small, lightweight leaf clip for at least 20 min. The small shutter plate of the clip was then opened and the dark-adapted leaf tissue was exposed to an actinic light flash (wavelength of 650 nm, intensity>3000 µmol m^{-2} s^{-1}). The instrument measured the Fv/Fm ratio, which is the maximum efficiency of PSII, where Fm is the fluorescence maximum over the induction curve. Fv (variable fluorescence) was calculated as the difference between Fm and Fo, where Fo is the ground fluorescence [7]. The area above the fluorescence curve between Fo and Fm (Area), which indicates the pool size of plastoquinone on the reducing size of PSII, was also automatically calculated.

4. Statistical analysis

Data were subjected to analysis of variance (ANOVA); data were compared using a Student's *t* test (P < 0.05 level).

3. Results

The measurements carried out immediately after the treatment and during the hottest hours of the day on leaves exposed to the full sun, confirmed a noteworthy effect of the kaolin in reducing the leaf T, with an average difference of about 4-6 °C from the untreated control (Table 1).

Table 1. Effect of kaolin on temperature in Pinot noir leaves exposed in conditions of full insulation treated on 3 August 2017. Measurements were taken between 13.00-14.00 immediately after the treatment and after several days.

Data	T air	Untreated	Kaolin	ΔT	t^1
3 August	39.4	48.7	42.7	-6.0	*
4 August	40.1	49.1	44.6	-4.5	*
5 August	40.6	49.4	45.2	-4.2	*
8 August	39.5	47.0	43.0	-4.0	*

[1]* means significant difference per *P*<0.05 (*t*-test di Student)

One week after the treatment, (August 10th), contrary to the vines sprayed with kaolin, the leaves of untreated vines showed a compromised physiological activity, with very low values of photosynthesis and transpiration rates and a clear chronic photoinhibitions phenomenon, as evidenced by values of Fv/Fm below 0.5 (Table 2). Eighteen days after the treatment (21 August), on a notably cooler day with a maximum air temperature of 28.1 °C, the leaves of vines treated with kaolin showed values of photosynthesis and transpiration comparable with those of non-stressed vines (P_n= 12.6 µmol m^2 s^{-1} and

E= 2.7 mmol m^2 s^{-1}) and optimal efficiency of photosystems (Fv/Fm> 0.78) (Table 2). At the same time, untreated vines continued to exhibit a marked physiological suffering, as evidenced by the low values found in all the parameters analyzed. Moreover, control vines had several leaves affected by chlorosis and necrosis and external bunches with dehydrated berries.

Table 2. Effect of kaolin on leaf temperature (T), net photosynthesis (P_n), transpiration rate (E), Fv/Fm (efficiency of PSII) and Area parameter (size of plastoquinone pool) in well exposed external leaves of Pinot noir vines. Kaolin treatment was executed on 3 August. Data were taken 7 and 18 days after treatment (10 August and 21 August) in the interval 13.00-14.00.

	T air (°C)	T leaf (°C)	P_n (µmol CO_2 m^{-2} s^{-1})	E (mmol H_2O m^{-2} s^{-1})	F_v/F_m	Area*
10 August						
Untreated	36.4	47.4 b	0.9 b	0.8 b	0.486 b	18900 b
Kaolin		42.2 a	5.1 a	2.2 a	0.704 a	32900 a
21 August						
Untreated	28.1	31.3 b	3.4 b	1.3 b	0.520 b	21500 b
Kaolin		29.6 a	12.6 a	2.7 a	0.782 a	35000 a

Means followed by different letters are significantly different at the 0.05 probability level.
* Arbitrary units

Table 3. Air and leaf temperature (T), net photosynthesis (P_n), Fv/Fm (PSII efficiency) and (Area) (plastoquinone pool size) in portions of whitish leaves, sprinkled with kaolin, and portions without kaolin present in the same leaves from treated vines. Data were taken 2 and 4 weeks after treatment (17 August and 31 August) in the interval 13.00-14.00.

	T air (°C)	T leaf (°C)	P_n (µmol CO_2 m^{-2} s^{-1})	F_v/F_m	Area*
17 August	38.5				
Portion of leaf with kaolin		42.8 b	2.6 a	0.607 a	21000 b
Portion of leaf without kaolin		47.6 a	-0.3 b	0.283 b	10000 a
31 August	31.6				
Portion of leaf with kaolin		33.3 b	11.5 a	0.780 a	38600 b
Portion of leaf without kaolin		36.2 a	0.4 b	0.224 b	13500 a

Means followed by different letters are significantly different at the 0.05 probability level.
*Arbitrary units

Usually, the application of kaolin on the leaves is not uniform, and random areas not sprayed are often present, even just a few cm². Those areas 2 weeks after the treatment were chlorotic and characterized by a reduced physiological activity (Table 3). Targeted measurements, carried out 2 and 4 weeks after the treatment, showed that, unlike leaf portions covered by kaolin, the areas not covered in the same leaf, showed photosynthetic rates of about -0.3 µmol CO_2 $m^{-2}s^{-1}$. The same areas were irreversibly photo-inhibited, as demonstrated by Fv/Fm values, reduced by about 3-4 times compared to the optimal ones. The Area parameter also decreased by over 2-3 time the optimal value (Table 3). These results show a high capacity of kaolin to preserve the integrity of the plant tissues, protecting them from critical T, as well as the basic physiological functions, and to allow full recovery of the latter at the end of the heat stress.

At harvest, 30-35% of the untreated vines had grapes not suitable for winemaking due to excessive dehydration, while the other 65-70% of untreated vines showed, compared to the vines treated with kaolin, a yield reduction of about 21% (-0.3 kg/vine), a severe reduction of the organic acids and a loss of anthocyanins of about 35% (Table 4). Soluble solids and polyphenols did not show significant changes.

Table 4. Yield and grape composition at harvest in Pinot noir vines treated with Kaolin and untreated.

Parameters	Untreated	Kaolin
Yield (kg/vine)	1.1 b	1.4 a
Average cluster weight (g)	110 b	148 a
Soluble solids (°Brix)	23.2	23.0
Titrable acidity (g/l)	5.4 b	6.0 a
Total anthocyanins (g/l)	240 b	325 a
Total polyphenols (g/l)	916	910

Means followed by different letters are significantly different at the 0.05 probability level.

4. Discussion

In summers like the one that occurred in 2017 at the site of the experiment, high T strongly and negatively affected leaf physiology and berry quality. The consequences of high temperatures are drastic reductions of physiological mechanisms and the lack of dissipation of energy by transpiration. This leads to the rise of leaf temperature to approximately 49-50 °C (8-10 °C more than the air T), and the subsequent appearance of chronic photoinhibitions phenomena, with extended chlorosis and necrosis of leaf tissues. Grapes positioned externally in the canopy undergo excessive dehydration and sunburn damages and therefore become unsuitable for wine production. As a result, yield can be drastically reduced, fruit composition can be compromised, and there exists serious risk of vines dying. In these conditions, the use of kaolin with sunscreen function allows growers to limit the damages from heat stress and preserve the integrity of the leaf and grape tissues, the basic physiology and some key elements of grape composition. Technically, the application of kaolin can be performed by monitoring the air T and using, for example, the formula of the Australian Grape and Wine Authority [6], which suggests treating when the maximum air T exceeds 40 °C for at least one day or when the maximum air T exceeds 35 °C for 2-3 consecutive days. Obviously, after every rain, the effectiveness of the product decreases due to washout and a new treatment is required. In order to minimize the cost and dose per hectare, it can be profitable to use kaolin not on the entire vineyard, but only on the faces of the sun-drenched rows in the afternoon, since they are more sensitive to heat stress.

5. Conclusions

The application of kaolin in the vineyards during critical summers can be a useful technique to limit damages to photosynthetic apparatus and to preserve yield, grape composition as well as leaf and grape tissue integrity. Moreover, it is quick to apply, flexible and requires no special equipment. Finally, the costs are limited; spraying only one side of each row (50% of the vineyard) costs about 18-20 Euros/ha per treatment.

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