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Overview of Kaolin Outcomes from Vine to Wine: Cerceal white variety case study

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Abstract: Kaolin protective effect was assessed in a white grapevine cultivar 'Cerceal' in 'Alentejo' Region (southeast Portugal) where plants face extreme conditions during summer season. We addressed the hypothesis that kaolin effects lead to several changes in leaves, fruits and wine characteristics on the primary and secondary metabolism. Results showed that kaolin reduces leaf temperature which provoke an improvement in physiological parameters such as net photosynthesis and water use efficiency. This protection interferes with berries colour, leaving them more yellowish, and an increase in phenolic compounds were observed in all fruit tissues (skin, seed and pulp). Also, both berry and wine characteristics were strongly affected, with an increase of tartaric and malic acid and consequently high total acidity, while the sugar concentration decreased 8.9% in berries provoking a low wine alcohol level. Results also showed that kaolin induces high potassium, magnesium and iron, and low copper and aluminum concentrations. Moreover, the control wine showed higher content of esters related with hostile notes whereas wine from kaolin treated vines presented higher content of esters associated with fruity notes. Overall, the results strengthen the promising nature of kaolin application as summer stress mitigation strategy protecting grapevine plants and improving fruits quality and more balanced wines.

Keywords: Acidity attributes, fruit minerals, grapevine physiology, phenolic compounds, volatile compounds

1. Introduction

Viticulture and winemaking promote economic, social and environmental benefits, through trademark, rural income, employment, and tourism [1]. Nonetheless, currently the most challenge for the wine industry is the climate change, essentially under Mediterranean conditions, [2], due to projected shifts in precipitation and temperature. Among the Portugal's wineregions, the Alentejo Demarcated Region (southeast) stands out due to the more pronounced harsh climate conditions and where water scarcity is a major problem. The reoccurrence of combined environmental stresses poses a risk to the crop yield and quality. Extreme temperature ($>35^{\circ}\text{C}$) through the growing season, as occurs in grape Portuguese areas, can harshly damage leaf photosynthetic efficiency and berry metabolism [3]. Water deficit affects berry quality in a developmental manner [4]. Grape leaf and berry metabolite composition are affected by this climatic extreme and consequently affects the wine quality increasing sugar levels and thus the wine alcohol percentage. Changes also occurs at cellular level, where plants react to stress related stimuli by mediating the biosynthesis of an extensive range of chemical species with different properties, from compatible solutes [5] to complex phytochemicals. In spite of the confirmed primary metabolite contribution to an elevated plant resistance to stress [6-8], their secondary metabolites are mostly involved in defense and other facultative processes, such as biotic and abiotic stress responses [9, 10]. Among the metabolic pathways involved in stress responses in grapevine berries, polyphenol metabolism is extremely important to fruit quality, due its composition of flavonoid classes, such as anthocyanins, flavonols, flavanones and flavanols, which act as potent antioxidants, helping plants cope with abiotic stress. Polyphenols are defined as natural products [11] with different functions, such as defense against herbivores and pathogens, mechanical support (lignin), pollinator attractants, UV-B damage amelioration and allelopathic effects [12].

2. Materials and Methods

2.1. Weather conditions and kaolin application

Meteorological conditions prevailing during the experimental periods are presented in Fig. 1. The period of the study was very dry in both 2016 and 2017 years, except for some significant rainfall events at spring and in early autumn in 2016 (always below 35 mm d⁻¹), and light rain in the same period in 2017. Daily maximum air temperature (Tmax) was usually over 30 $^{\circ}\text{C}$ from May onwards, and over 40 $^{\circ}\text{C}$ in some days from July to September. The 5% (w/v) kaolin (KL, Surround WP®; Engelhard Corp., Iselin, NJ) application was done in June 6 (DOY 129; Tmax = 30.0 $^{\circ}\text{C}$) in 2016 and July 3 (DOY 155; Tmax, = 38.5 $^{\circ}\text{C}$) in 2017. No significant precipitation was registered till the end of the experiments. The field measurements and material collection prior to analysis were done in DOY 181 and DOY 222 in 2016 and in DOY 180 and DOY 209 in 2017, respectively.

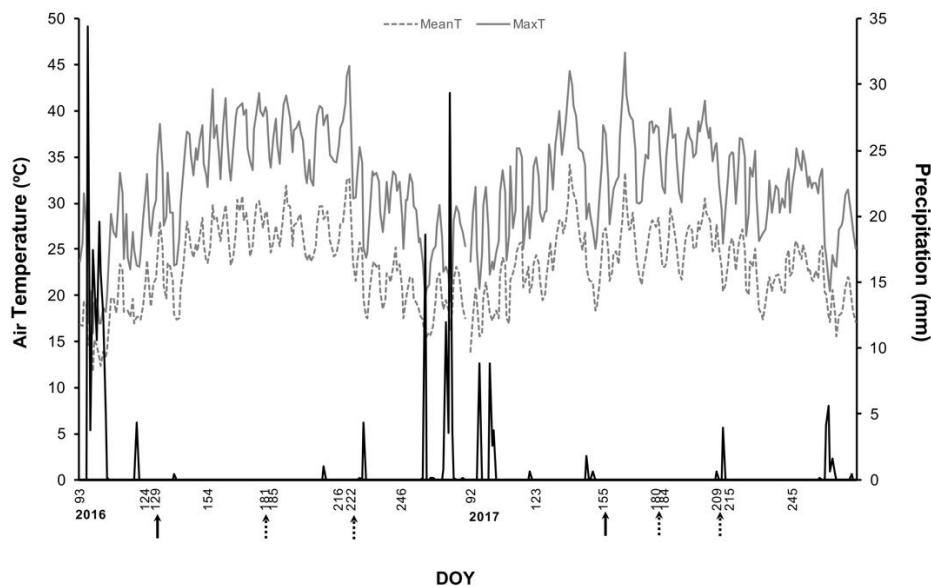


Figure 1 – Daily mean temperature (Tmean), maximum temperature (Tmax), and precipitation (black line) in 2016 and 2017. The filled arrows show the days of the kaolin application in 2016 (DOY 129) and 2017 (DOY155), and dashed arrows indicate the days of experimental measurements and material collection for prior analysis. DOY: day of the year.

2.2. Plant material and Experimental Design

Samples were obtained from Cerceal, a white *Vitis vinifera* L., variety grafted on 1103P rootstock, located in a commercial vineyard “Herdade do Esporão” (38°22'48.1"N, 07°33'38.4"W), in southeast Portugal. The climate is of the Mediterranean-like type with dry and hot summers, moderate precipitation during the winter months and dryness during the summer [25]. Records from a meteorological station, some 10 km away from the experimental vineyard, were collected. Vines were managed using the organic production mode. The white Cerceal cv. has a row with 200 m long (200 plants) in which two different conditions were set up: an experimental control (C; 100 plants) and another pulverised with kaolin (100 plants). The vines had 7-year old and were unilaterally cordon trained and pruned.

2.3. Foliar leaf temperature

Leaf temperature was measured with an infrared thermometer (Infratrace KM800S, England) with a 15° field view, at veraison and maturation in the midday period. Measurements were performed under clear sunny days and on sun-exposed and fully expanded leaves at the middle of the shoots (usually between 8th and 11th nodes on the shoot axes). The average temperature of three randomly selected leaves (in eight plants) per treatment ($3 \times 8 = 24$) was obtained by holding the thermometer at about 1 m above the foliar surface.

2.4. Physiological parameters

Leaf gas exchange, chlorophyll a fluorescence and OJIP test were obtained in both 2016 and 2017 years during the summer season (at veraison and maturation). In these times several field measurements were done.

2.4.1. Leaf gas exchange

Leaf gas exchange was measured with an infrared gas analyzer (LC Pro+, ADC Bioscientific Ltd., UK), operating in the open mode. Measurements were carried out DOY 181 (veraison) and DOY 222 (maturation) in 2016 and DOY 180 (veraison) and 209 DOY (maturation) in 2017, in two time periods: morning (09:00–10:30) and midday (14:00–15:30). Net

Photosynthesis (PN), stomatal conductance (gs), transpiration rate (E), and intercellular CO₂ concentration/ambient CO₂ ratio (Ci/Ca) were estimated according to von Caemmerer and Farquhar (1981). To eliminate the possible effects of air humidity and temperature on transpiration, the PN/gs ratio, rather than the PN/E ratio, was calculated to evaluate the intrinsic water-use efficiency (iWUE) [26].

2.4.2. Chlorophyll a fluorescence analysis and OJIP test

Chlorophyll a fluorescence emission was measured at morning (09:00–10:30) and midday (14:00 – 15:30) on fully expanded leaves in both developmental stages with a Pulse Amplitude Modulation Fluorometer (mini-PAM, Photosynthesis Yield Analyzer; Walz, Effeltrich, Germany), using two scripts: i) in the first script, the measurements were done on well sun exposed leaves. In this procedure, after a 35 s exposure to actinic light (1,450 $\mu\text{mol m}^{-2} \text{s}^{-1}$), light-adapted steady-state fluorescence yield (Fs) was averaged, followed by exposure to saturating pulse light (6,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$) for 0.6 s to establish Fm'. The sample was then shaded for 5 s with a far-red light source to determine F0'. ii) In a second script, using the dark leaf clip (DLC-8), the same leaf portion used in first script was immediately dark acclimated for 30–45 min. After this, the maximum photochemical efficiency of PSII was given by Fv/Fm = (Fm – F0)/Fm, where F0 corresponds to the minimum fluorescence level excited by very low intensity of measuring light to keep PSII reaction centers open, and Fm corresponds to the maximum fluorescence level elicited by a pulse of saturating light (6,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$) which closes all PSII reaction centers. From these measurements, several fluorescence attributes were calculated [27, 28]: photochemical quenching ($qP = (Fm' - Fs)/(Fm' - F0')$), non-photochemical quenching ($NPQ = (Fm - Fm')/Fm'$), and efficiency of electron transport as a measure of the quantum effective efficiency of PSII ($\Phi_{PSII} = \Delta F/Fm' = (Fm' - Fs)/Fm'$). The photosynthetic electron transport rate was estimated as ETR ($\mu\text{mol m}^{-2} \text{s}^{-1}$) = ($\Delta F/Fm'$) \times PPF_D \times 0.5 \times 0.84, where PPF_D is the photosynthetic photon flux density incident on the leaf, 0.5 is the factor that assumes equal distribution of energy between the two photosystems, and the leaf absorbance used was 0.84 because is the most common value for C₃ plants [27]. The analysis of the fluorescence transients using the JIP test were performed according to our previous study [20].

2.5. Pests control

To study the kaolin pesticide effect against *Panonychus ulmi* (Koch, 1836) and *Scaphoideus titanus* (Ball, 1932), 10 leaves of the upper third of canopy in 10 contiguous plants were observed and the percentage of leaves with symptoms were registered at veraison stage in 2017. The incidence was expressed as the percentage (%) of affected leaves.

2.6. Fruit surface colour index and biometric parameters

Berry colour was determined by a spectrophotometer Konica Minolta Sensing's CM-2500c portable (Minolta Corp., Osaka, Japan) in thirty berries per treatment (three measurements were made around the equatorial belt of each berry) in the maturation stage, in 2017. This colour system, evaluated lightness, L* (0, black – 100, white), chroma, C*ab (0, achromatic), and hue angle, hab (0, red – 90, yellow – 180, green – 270, blue) as previously described [29]. Fruit biometric parameters were measured (mm) and weighed (mg) individually in situ in triplicate (n = 30 per treatment and in each stage). The width and height were measured to calculate the average of grape berry radius in order to estimate the absolute volume (mm³) of each one. Both colour and fruit biometric parameters were obtained in the maturation stage in 2017.

2.7. Phenolic compounds and antioxidant activity

The total phenolic contents from whole fruit in both veraison and maturation stages and from skin, pulp and seed of the fruit in maturation stage were determined by the Folin–Ciocalteu method [30] during 2017. Briefly, the extract is added, 20 μL sample (4 mg/ml) or gallic acid

standards in MeOH, 90 μ L distilled H₂O and 10 μ L of Folin–Ciocalteau reagent solution. After 6 min, 80 μ L of 7% Na₂CO₃ is added and mix gently. The reaction mixture was kept in dark for 2 hours and its absorbance was measured at 750 nm in microplate. Total phenolics was expressed as mg gallic acid equivalents per gram of extract (mg g⁻¹ DW).

The aluminum chloride (AlCl₃) complex method at 510 nm was used for the quantification of the total flavonoids content of extracts [31] and was expressed as mg of catechin equivalents per gram of extract (mg CAE/g DW). The ortho-diphenols content was estimated according to the colorimetric method based on a complex reaction with sodium molybdate dehydrate at 370 nm [32]. The results were expressed as mg of gallic acid equivalents per gram of extract (mg GAE/g DW). The condensed tannins contents were determined according to the vanillin-HCl assay [33] at 500 nm. The results were expressed as mg of catechin equivalents per gram of extract (mg CAE/g DW).

The radical scavenging activity on ABTS radical was evaluated by the method of Trolox equivalent antioxidant capacity assay at 734 nm was applied [31] and were obtained in the same samples used for total phenols. ABTS were expressed as mg of trolox equivalents per gram of extract (mg TE g⁻¹ DW). The radical scavenging activity on the DPPH radical was evaluated [31] being previously adapted to microplates [34]. DPPH were expressed as mg of trolox equivalents per gram of extract (mg TE g⁻¹ DW).

2.8. Total soluble proteins

The total soluble proteins were obtained from whole fruit in both veraison and maturation stages during 2017 and were extracted using an extraction buffer containing phosphate (Fisher Scientific, U.K.) of pH 7.5 mixed with EDTA-ethylenediaminetetraacetic acid (Panreac, Barcelona, Spain). The work solution include the extraction buffer described above, PMSF-Phenylmethanesulfonyl fluoride (Panreac, Barcelona, Spain), PVP-Polyvinylpyrrolidone (Sigma, St. Louis, MO, USA) according to the method of Bradford (1976) [35] at 595 nm. All the absorbance of this work were determined using PowerWave XS2 microplate scanning spectrophotometer (Bio-TekInstruments, USA). Total soluble proteins were expressed as mg bovine serum albumin equivalents per gram of extract (mg BSAE g⁻¹ DW) ($y=14.029x + 0.6234$, R²=0.981).

2.9. Brix^o and acidity parameters

Brix^o were measured (n = 30 per treatment), at maturation in 2017, using an ATAGO digital refractometer (CO., LTD. Tokyo, Japan). The Brix scale or degrees Brix^o is numerically equal to the percent of sugar and other dissolved solids in the solution [36].

The physico-chemical parameters of grapes, such as pH and total acidity, and wine, such as alcohol degree and total acidity, were analyzed according to the OIV [37] methodologies. The tartaric and malic acid were measured enzymatically (Miura One, TDI S.A.).

2.10. Trace elements quantification

Some elements quantification was obtained in 2017 in the grape berries at maturation and in the wine must, during fermentation process according [38]. In the wine samples obtained from vines under different treatments (C and KI) only the Al (aluminum) were quantified. Prior to the analyses each sample was vigorously shaken. An aliquot (0.5 g) of sample was weighed directly into the digestion vessels. The digestion was performed by adding HNO₃ (1.0mL) and H₂O₂ (5.0mL) to each sample. The mixture was left at room temperature with a marble (preventing evaporation) for 24 hours, and afterwards the marbles were removed, and the samples left overnight at room temperature. After this period, the sample was heated using a block heater at 50°C during 1 h followed by 100°C during 1 h (temperature at which the release of Nitric Oxide brown fumes starts), 120°C during 1 h and finally left overnight at 155°C (usual time needed to obtain a clear digestion mixture), or until the solution was clear, with a glass marble on the top of the culture tube (to avoid drying before digestion and sample charring). After this period the

glass marbles were removed, and the contents were dried at 155°C. After cooling to room temperature, 10.0 mL of HNO₃ matrix solution (1.5 mL of acid to 1000 mL of water) was added to the digested samples and stirred. Some of the solutions were diluted in order to allow the determination of the respective metals. All samples were analyzed in triplicate. The copper (Cu) and potassium (K) were determined by flame atomic emission spectrometry and calcium (Ca), magnesium (Mg), iron (Fe) and zinc (Zn) metals were analyzed by flame atomic absorption spectrometry (Thermo Scientific ICE 3000). The Al were analyzed by atomic absorption spectrometry in graphite furnace (Unicam 939 AA spectrometer, GF90 furnace). Each run of samples was preceded by calibration using aqueous mixed standards prepared in HNO₃ (1.0M). For this purpose, five different dilutions of standards were used, besides the blank, with the range of concentrations being selected according to the expected concentrations of the elements of interest.

2.11. Analysis of wine volatile compounds by HS-SPME-GC-MS

Solid phase microextraction (SPME) was used for the extraction of volatile compounds from grapevine berries at maturation and wine from 2017 samples. One milliliter of sample was measured to a 20 mL headspace vial (La-Pha-Pack®) and was capped with a white PTFE silicone septum (Specanalitica). The SPME operating conditions were: extraction temperature 40 °C for 40 min, rotating speed 100 rpm and desorption time 10 min at 250 °C. Analysis were carried out in a GCMS-QP2010 Plus (Shimadzu®) equipped with an AOC-5000 autosampler (Shimadzu®). A divinylbenzene/carboxen/polydimethylsiloxane (DVB/Car/PDMS) fiber (SUPELCO Analytical, Bellefonte, PA, USA) was used for headspace SPME sampling. For the analysis a capillary column Sapiens – 5- MS (Teknokroma), 30 m, 0.25 mm (IS), 0.25 µm (film thickness) was used. The working conditions were: injector temperature: 250 °C, injection mode: splitless during 1.5 min, detector temperature: 250 °C. High-purity helium (\geq 99.999 %) was used as the carrier gas, column oven temperature was kept at 40°C for 5 min, increased to 170°C at a rate of 5°C min-1, 230°C at 30°C min-1 and maintained for 4 min, then was raised to 300°C at 30°C min-1 and maintained for 2 min; carrier gas (He) with a flow of 2.00 mL min-1. In MS interface temperature was 250°C and ion source temperature was 250°C. Mass spectra were acquired in electron ionization (EI) mode at 70 eV. in a m/z range between 29 – 300 with a scan speed of 555 scans s-1. The compounds were identified using the mass spectra libraries, NIST 21, 27, 107, 147 and Wiley 229.

Firstly, the peak areas data of all compounds were extracted from the chromatograms and used to build the full data matrix from 'Cerceal' wines consisting of 6 observations (2 treatments of wine samples, each one by 3 replicates) and 51 variables (volatile components).

2.12. Statistical Analysis

Statistical analyses were performed with SPSS 20.0 software. After testing for ANOVA assumptions (homogeneity of variances with the Levene's mean test, and normality with the Kolmogorov-Smirnov test), statistical differences among stages and treatments were evaluated by two-way factorial ANOVA, followed by the post hoc Tukey's test and in some cases only within the stage one-way ANOVA was done. Significant differences were considered for $p < 0.05$ and *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ represent significant differences. Absence of superscript indicates no significant difference between treatments. Values are presented as mean \pm standard deviation (SD). Regarding volatile compounds a hierarchical cluster analysis (HCA) combined with the heatmap visualization was applied for the dataset using the MetaboAnalyst 3.0 (web software, The Metabolomics Innovation Centre (TMIC), Canada). The area of each variable was auto scaled. The significance of the compounds detected in samples were compared between control and kaolin treated samples, through a two-sided Mann-Whitney test (using the SPSS software 20.0 (IBM, New York, USA). Differences corresponding to $p < 0.05$ were considered significant ($p < 0.05$, analyses were marked with ** in Figure 4).

3. Results

3.1. Physiological and pests control changes under kaolin application

Kaolin particle film showed several physiological effects. Regarding to the Fig. 2, leaf temperature, which can be considered the first bound between weather conditions and plant health, was positively affected by KI application in *veraison* and maturation in both years.

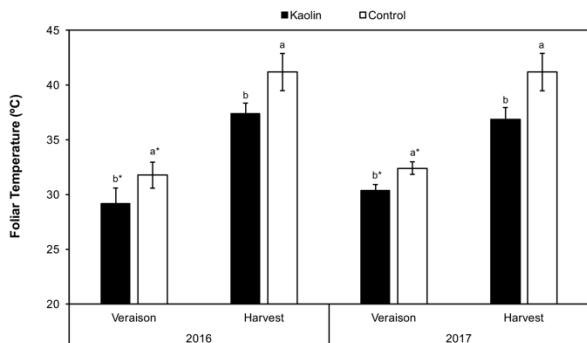


Figure 2 – Leaf temperature of control and kaolin treated leaves in *veraison* and maturation in the midday period in 2016 and 2017. Values are presented as mean \pm SD (n=24 per treatment). Different lower case letters represent significant differences between treatments (control vs kaolin), in the same stage of the season, and * represent significant differences between stages within the same treatment ($p < 0.05$). Absence of superscript indicates no significant differences.

The kaolin treated leaves showed decreases of 8.2% and 9.3% and 6.4% and 10.4% in leaf temperature in *veraison* and maturation stages of 2016 and 2017, respectively. Regarding to leaf gas exchange parameters (Table 1) the results showed low values of stomatal conductance (g_s), net photosynthesis (P_N) and intrinsic water use efficiency (iWUE) in the maturation stage in both years and periods of the day (morning and midday), comparing with the *veraison* stage. The KI treatment leads to a significantly high P_N and iWUE and low C_i/C_a ratio in both stages and periods in 2016 and 2017.

Table 1 – Gas exchange parameters, namely transpiration rate (E , $\text{mmol m}^{-2}\text{s}^{-1}$), stomatal conductance (g_s , $\text{mmol m}^{-2}\text{s}^{-1}$), photosynthesis net (P_N , $\text{mmol m}^{-2}\text{s}^{-1}$), intrinsic water use efficiency (iWUE, $\mu\text{mol mol}^{-1}$) and ratio of intercellular to atmospheric CO_2 concentration (C_i/C_a), at morning and midday periods in *veraison* and maturation stages in kaolin and control leaves (n = 10). Different lower case letters represent significant differences between treatments (control vs kaolin), in the same period of the day (morning/midday) and stage of the season (*veraison*/maturation). * represent significant differences between stages of the season within the same period of the day ($p < 0.05$). Absence of superscript indicates no significant differences.

Stage	Treatment	Morning				
2016						
Veraison	Kaolin	4.07 ± 0.632*	251.9 ± 59.6*	13.0 ± 3.04*	50.3 ± 4.19 a*	0.706 ± 0.028 b*
	Control	4.10 ± 0.627*	245.7 ± 47.9*	10.3 ± 2.13*	40.8 ± 6.29 b*	0.745 ± 0.037 a*
Harvest	Kaolin	2.27 ± 0.014 a	57.3 ± 11.3	2.23 ± 0.348 a	38.9 ± 5.32 a	0.772 ± 0.043 b
	Control	2.07 ± 0.109 b	51.7 ± 15.2	0.953 ± 0.144 b	18.4 ± 8.52 b	0.894 ± 0.025 a
2017						
Veraison	Kaolin	3.65 ± 0.958	266.6 ± 93.5 a*	10.7 ± 1.64 a*	48.2 ± 7.82 a*	0.755 ± 0.116
	Control	3.00 ± 0.641	149.1 ± 51.8 b*	7.2 ± 1.48 b*	40.4 ± 8.71 b*	0.767 ± 0.095
Harvest	Kaolin	3.10 ± 0.897	154.3 ± 66.9 a	8.66 ± 2.16 a	56.1 ± 2.34 a	0.744 ± 0.015
	Control	3.00 ± 0.634	138.0 ± 55.7 b	3.95 ± 1.28 b	28.6 ± 5.05 b	0.840 ± 0.023
Midday						
2016						
Veraison	Kaolin	3.74 ± 0.742*	173.5 ± 57.3*	10.4 ± 2.57*	59.9 ± 6.57*	0.661 ± 0.025 b*
	Control	3.81 ± 0.663*	171.5 ± 48.0*	9.75 ± 3.03*	56.8 ± 5.48*	0.684 ± 0.034 a*
Harvest	Kaolin	2.15 ± 0.465	101.8 ± 21.1	4.07 ± 1.07 a	40.0 ± 5.39 a	0.766 ± 0.046 b
	Control	2.16 ± 0.428	92.3 ± 36.3	1.89 ± 0.382 b	20.4 ± 11.7 b	0.859 ± 0.059 a
2017						
Veraison	Kaolin	2.52 ± 0.218	105.0 ± 10.6	7.36 ± 1.50 a*	70.1 ± 13.1 a*	0.644 ± 0.081 b*
	Control	2.79 ± 0.317	102.8 ± 15.0	5.48 ± 0.702 b*	53.3 ± 8.75 b*	0.720 ± 0.045 a*
Harvest	Kaolin	2.67 ± 0.604	111.1 ± 37.4	6.93 ± 1.60 a	62.3 ± 7.8 a	0.675 ± 0.049 b
	Control	2.45 ± 0.661	91.0 ± 27.6	3.21 ± 0.879 b	35.3 ± 5.75 b	0.797 ± 0.035 a

Relating to g_s , the results only showed differences in the morning period in 2017 with high values in the KI-treated plants. The transpiration rate (E) only present significant high value in the KI-treated plants in the maturation stage in the morning period in 2016.

The Table 2 presents parameters related to chlorophyll a fluorescence data. Regarding to 2016, only differences were observed in the midday period, except for the ETR which values were higher in the kaolin treated plants. Overall, kaolin application boosts F_v/F_m , Φ_{PSII} , qP and ETR values, while leads to a decrease in the F_0 and NPQ values.

The Figure 3 shows the higher values of KI treated plants in parameters related to the OJIP test, specifically the efficiency of energy conservation in the electron transport (Ψ_0) and performance index (PI_{ABS}) in both years and stages in morning and midday periods.

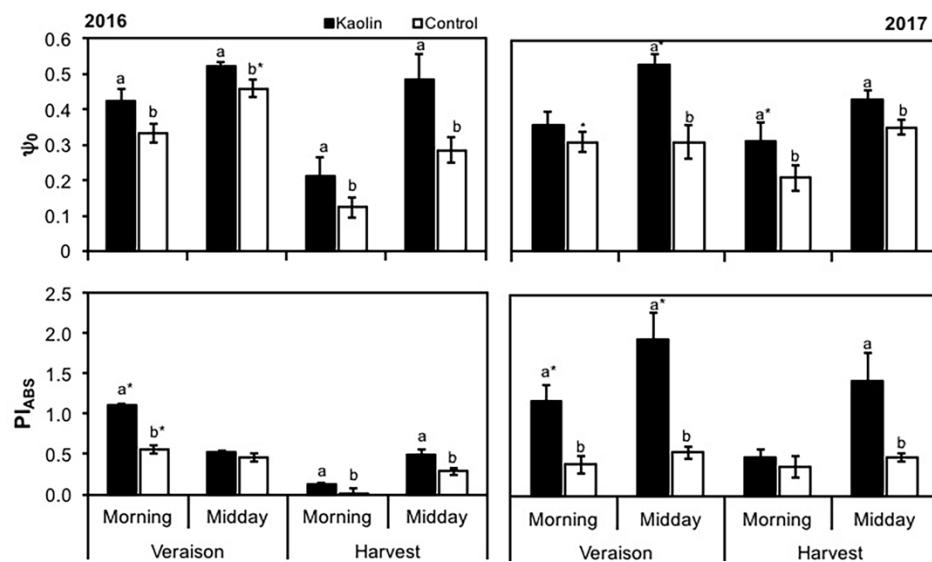


Figure 3 – JIP parameters in control and kaolin treated grapevines from veraison and maturation stages in the midday period in 2016 and 2017. Values are presented as mean ± SD (n=10). Different lower case letters represent significant differences between treatments (control vs kaolin), in the same period of the day (morning/midday) within the stage of the season (veraison/maturation), and * represent significant differences between stages of the season within the same period of the day (p < 0.05). Absence of superscript indicates no significant differences.

The results revealed that the incidence of *Panonychus ulmi* was reduced by 10% in leaves sprayed

with Surround WP® (Kl) compared to control fruit (C – 20%; Kl – 10%) (Fig S1). Furthermore, *Scaphoideus titanus* incidence was also significantly reduced by 30%, after Kl sprays (C – 30%; Kl – 0%).

Table 2 – Chlorophyll a fluorescence parameters, namely basal fluorescence (F_0), maximum quantum efficiency of photosystem II (F_v/F_m), effective PSII efficiency (Φ_{PSII}), photochemical quenching (qP), electron transport rate (ETR, $\mu\text{mol e}^- \text{ m}^{-2} \text{ s}^{-1}$) and non-photochemical quenching (NPQ) at morning and midday periods in *veraison* and maturation stages in kaolin and control leaves ($n = 10$). Different lower case letters represent significant differences between treatments (control vs kaolin), in the same period of the day (morning/midday) within the stage of the season (*veraison*/maturation), and * represent significant differences between stages of the season within the same period of the day ($p < 0.05$). Absence of superscript indicates no significant differences.

Treatment	Stage	Morning						Midday					
		F_0	F_v/F_m	Φ_{PSII}	qP	ETR	NPQ	F_0	F_v/F_m	Φ_{PSII}	qP	ETR	NPQ
2016													
Kaolin	<i>Veraison</i>	514.5 ^a 9.9	0.740 ^a 0.51	0.220 ^a 0.44*	0.800 ^a 0.52	141.4 ^a 7.4 a*	0.820 ^a 0.36	372.0 ^a 8.2 b*	0.750 ^a 0.13 a*	0.207 ^a 0.40	0.410 ^a 0.12*	130.2 ^a 8.3*	0.710 ^a 0.54 b
Control		536.5 ^a 0.9	0.700 ^a 0.33	0.190 ^a 0.41*	0.890 ^a 0.97	121.3 ^a 5.6 b*	1.260 ^a 0.49	473.8 ^a 2.0 a*	0.730 ^a 0.03 b*	0.220 ^a 0.22	0.380 ^a 0.12	143.4 ^a 3.8	1.790 ^a 0.79 a
Harvest													
Kaolin		405.0 ^a 7.9	0.790 ^a 0.57	0.310 ^a 0.59	0.610 ^a 0.31	252.0 ^a 8.0 a	0.870 ^a 0.200	521.0 ^a 4.0 b	0.630 ^a 0.18 a	0.230 ^a 0.032 a	0.560 ^a 0.061 a	180.1 ^a 3.9 a	1.140 ^a 0.31
Control		448.3 ^a 21.4	0.680 ^a 0.85	0.330 ^a 0.64	0.630 ^a 0.75	237.9 ^a 4.3 b	0.707 ^a 0.16	597.3 ^a 3.3 a	0.530 ^a 0.046 b	0.200 ^a 0.045 b	0.610 ^a 0.032 b	154.4 ^a 3.8 b	1.390 ^a 0.195
2017													
Veraison													
Kaolin		485.0 ^a 6.9 b*	0.750 ^a 0.25 a	0.110 ^a 0.27 a*	0.360 ^a 0.79 a*	88.5 ^a 1.1 a*	3.520 ^a 0.281*	510.0 ^a 8.9 b*	0.730 ^a 0.17*	0.050 ^a 0.02*	0.190 ^a 0.61*	45.1 ^a 4.6*	2.750 ^a 0.63 b*
Control		603.2 ^a 8.7 a*	0.670 ^a 0.26 b	0.080 ^a 0.41 a*	0.280 ^a 0.61 b*	63.8 ^a 2.6 b*	3.940 ^a 0.97*	599.0 ^a 1.8 a*	0.702 ^a 0.29	0.050 ^a 0.01*	0.190 ^a 0.24*	40.8 ^a 2.6*	4.090 ^a 0.85 a*
Harvest													
Kaolin		1684.0 ^a 6.7 b	0.770 ^a 0.39 a	0.450 ^a 0.09 a	1.000 ^a 0.14 a	345.2 ^a 7.3 a	2.430 ^a 0.74 b	359.8 ^a 4.4 b	0.780 ^a 0.14 a	0.180 ^a 0.015 a	0.400 ^a 0.019 a	138.3 ^a 4.7 a	2.080 ^a 0.132 b
Control		1816.6 ^a 0.9 a	0.620 ^a 0.70 b	0.420 ^a 0.18 b	0.970 ^a 0.04 b	324.2 ^a 8.5 b	4.220 ^a 0.04 a	427.8 ^a 7.7 a	0.710 ^a 0.15 b	0.1760 ^a 0.12 b	0.390 ^a 0.088 b	103.6 ^a 8.9 b	3.150 ^a 0.24 a

3.2. Kaolin effects on fruit quality

In white grapes varieties is predictable that skin berry colour changes during grape maturation, from an initial green to a yellow/brownish at maturation. The Kl effects on the colour skin parameters in the maturation stage was evaluated and results are shown in Table 3. Accordingly, Kl leads to a decrease in a^* and b^* parameters, *i.e.* a rise of green and a little decline of yellow color, giving thus more yellowish colouring to the skin compared to the brownish colouring to the skin in control fruits. Also, a decrease was observed in the chroma values (C^*ab) and no differences were obtained on the lightness (L^*). Relevant differences existed in hue (h_{ab}), being higher in fruits from Kl treated plants. Furthermore, C^*ab is positively correlated with b^* , independently from treatment, showing correlation coefficients (r) of 1.00 and 0.988, for Kl and control treatments respectively (all Pearson's correlations were significant at $P < 0.05$, data not shown). Usually, hue (h_{ab}) showed an inverse correlation with a^* . Our results are in agreement with this tendency with $r = -0.992$ for Kl and -0.991 for control treatments (all correlations were significant at $P < 0.05$).

Table 3 – Kaolin effect on colorimetric parameters analyzed for all grape skin color variants and Brix° of fruits picked in the maturation period, and total acidity (g L⁻¹ of tartaric acid), pH, tartaric and malic acid concentration (g L⁻¹) of fruits picked in the *veraison* and maturation stages, in 2017. Values are presented as mean \pm SD. Significant differences were presented between treatments and considered for $p < 0.05$ and *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ represent significant differences; ns indicates no significant differences.

Kaolin	Control	Significance	
Véraison			
Total acidity	10.5 \pm 0.767	8.76 \pm 0.386	
pH	2.92 \pm 0.049	3.05 \pm 0.009	***
Tartaric acid	7.04 \pm 0.516	5.59 \pm 0.308	***
Malic acid	1.82 \pm 0.360	2.35 \pm 0.417	*
Harvest			
Colour parameters			
b^*	13.9 \pm 1.63	15.1 \pm 1.87	*
C^*ab	14.0 \pm 1.62	15.4 \pm 1.99	***
h_{ab}	91.3 \pm 3.92	81.9 \pm 6.11	***
Brix°	17.5 \pm 1.03	19.2 \pm 2.16	*
Total acidity	4.88 \pm 0.176	4.48 \pm 0.036	***
pH	3.44 \pm 0.090	3.61 \pm 0.070	**
Tartaric acid	3.88 \pm 0.161	3.25 \pm 0.251	***
Malic acid	0.910 \pm 0.105	0.683 \pm 0.049	***

Kaolin application shows influence in the Brix° and acidity parameters (Table 3). A decrease of 8.9% were observed in the Brix° of fruits from KI treated plants. As expectable, a decrease in the total acidity as well as in the tartaric and malic acids concentration from *veraison* to maturation stage were observed. However, KI berries presented 16.6% and 8.2% higher total acidity in *veraison* and maturation stage, respectively. Regarding pH in KI fruits, the results showed an increase between *veraison* and maturation stage being the treated fruits more 4.3% and 4.7% acids than control ones, respectively. Both tartaric and malic acids decreased from *veraison* to maturation stage. In the *veraison* stage KI fruits presented more 20.6% of tartaric acid and less 22.3% of malic acid concentration. However, in the maturation stage the tartaric acid concentrations remains 16.2% higher in KI fruits. The malic acid concentration decrease 24.9% in KI berries comparing to the fruits from the control plants.

Results showed that although fruit height was not affected by foliar KI application, neither differences were observed between stages, the diameter was modified, also leading a different fruit volume (Table 4) in the *veraison* stage. So, the fruit diameter and volume in this stage were significantly higher in kaolin-treated plants being these fruits approximately 8.6% wider and with 14.3% more volume. In the maturation stage no differences were observed.

Table 4 – Kaolin application effect on height (mm), diameter (mm) and volume (mm³) of berries, and phenols (mg g⁻¹ DW), flavonoids (mg g⁻¹ DW), *ortho*-diphenols (mg g⁻¹ DW), tannins (mg g⁻¹ DW), protein (mg g⁻¹ DW) and antioxidant activity (mg g⁻¹ DW; obtained by ABTS and DPPH methods) of whole fruits at the *veraison* and at maturation stages in 2017. Values are presented as mean \pm SD. Different lower case letters represent significant differences between treatments (control vs kaolin), in the same stage of the season (*veraison*/maturation) and * represent significant differences between stages of the season within the same treatment ($p < 0.05$). Absence of superscript indicates no significant differences.

Parameters	Kaolin	Control	Kaolin	Control	
	<i>Veraison</i>		<i>Harvest</i>		
Biometry	Height	12.1 \pm 0.616	11.5 \pm 0.814	13.2 \pm 0.429	12.9 \pm 0.705
	Diameter	11.3 \pm 0.434a*	10.4 \pm 0.783b*	12.1 \pm 0.449	12.3 \pm 0.515
	Volume	136.7 \pm 11.4a*	119.6 \pm 17.1b*	159.6 \pm 10.6	59.4 \pm 14.1
Biochemistry	Phenols	76.2 \pm 3.09*	76.5 \pm 3.04*	56.0 \pm 1.32a	50.2 \pm 1.52b
	Flavonoids	27.5 \pm 1.54b*	33.0 \pm 1.02a*	15.2 \pm 0.776	15.0 \pm 0.699
	Ortho diphenols	196.1 \pm 8.00b*	216.4 \pm 8.96a*	150.1 \pm 1.47a	47.4 \pm 1.22b
	Tannins	42.8 \pm 1.26*	45.4 \pm 1.73*	19.8 \pm 0.289a	18.6 \pm 0.289b
	ABTS	208.5 \pm 7.10a*	124.3 \pm 15.1b*	176.9 \pm 2.80a	67.9 \pm 3.78b
	DPPH	207.3 \pm 5.44b	220.8 \pm 0.832a*	212.8 \pm 7.94a	88.8 \pm 11.9b
	Protein	9.18 \pm 0.140b*	9.75 \pm 0.140a*	15.1 \pm 0.071a	13.8 \pm 0.405b

In the Table 4 are presented some fruit quality parameters related with secondary metabolism and primary metabolism (protein content). Generally, the secondary metabolism decreased from *veraison* to maturation stage and the protein content increased. The KI application do not have effect in the total phenols and tannins concentration in the *veraison* stage (Table 4). However, the flavonoids, *ortho*-diphenols, and protein content as well as DPPH presented lower values than control fruits and, ABTS showed higher value in the same stage. From *veraison* to maturation the KI effect change the tendency. At maturation stage the fruits from KI treated plants showed higher total phenols (+ 11.6%), *ortho*-diphenols (+ 1.83%), tannins (+ 6.45%) and protein content (+ 9.42%). Regarding to antioxidant activity obtained by ABTS and DPPH methods the KI fruits also presented higher values (+ 5.36% and 12.7%, respectively) in this stage (Table 4). Deepening the study, the Table 5 showed the same secondary metabolism parameters and the antioxidant activity in different berry tissues, namely seed, skin and pulp. Independent of the treatment, our results showed, as expected, higher content of phenols, flavonoids and tannins and, also higher ABTS values in the seeds. However, the skin presented the higher content of *ortho*-diphenols as well as higher DPPH value (antioxidant activity). KI treated plants presented berries with higher content of flavonoids (+ 10.3%), *ortho*-diphenols (+ 32.5%), tannins (+ 27.3%), and DPPH value (+

25.8%) in the seeds; higher content of total phenols (+ 13.1%), flavonoids (+ 25.5%), *ortho*-diphenols (+ 29.4%), tannins (+ 7.46%), and ABTS value (+ 11.0%) in the skin; and higher content of total phenols (+ 39.7%), flavonoids (+ 41.1%), *ortho*-diphenols (+ 13.8%) and tannins (+ 14.4%) in the pulp.

Table 5 – Phenols, flavonoids, *ortho*-diphenols and tannins, and antioxidant activity (ABTS and DPPH) (mg g⁻¹ DW) in the seeds, skins, and pulps of fruits from KI treated and untreated (control) plants. Values are presented as mean ± SD. Significant differences were presented between treatments and considered for p < 0.05 and *** p < 0.001, ** p < 0.01, * p < 0.05 represent significant differences; ns indicates no significant differences.

	Tissues	Kaolin	Control	Significance
Phenols	Seed	99.4 ± 4.40	95.7 ± 4.42	ns
	Skin	49.5 ± 1.28	43.0 ± 0.853	**
	Pulp	22.4 ± 0.942	13.5 ± 0.554	***
Flavonoids	Seed	46.7 ± 1.00	41.9 ± 1.90	*
	Skin	13.7 ± 0.476	10.2 ± 0.289	***
	Pulp	2.58 ± 0.127	1.52 ± 0.046	***
Ortho diphenols	Seed	198.3 ± 16.9	133.9 ± 2.00	**
	Skin	19.0 ± 7.38	154.6 ± 1.27	***
	Pulp	164.1 ± 1.97	141.5 ± 11.2	*
Tannins	Seed	57.5 ± 1.42	41.8 ± 0.946	***
	Skin	20.1 ± 0.144	18.6 ± 0.144	***
	Pulp	9.26 ± 0.382	7.93 ± 0.250	***
ABTS	Seed	97.1 ± 7.56	96.6 ± 2.30	ns
	Skin	185.9 ± 7.56	165.4 ± 3.97	*
	Pulp	109.6 ± 29.6	88.9 ± 15.2	ns
DPPH	Seed	145.3 ± 6.25	182.1 ± 5.21	***
	Skin	91.0 ± 5.51	77.2 ± 11.9	ns
	Pulp	128.5 ± 0.425	129.8 ± 1.13	ns

Noticeably, the mineral analysis also showed that mature berries and must from vines treated with kaolin had a significantly lower quantity of aluminum (Al) and copper (Cu) and high quantity of potassium (K), iron (Fe), magnesium (Mg) and zinc (Zn) than berries from the control vines (Table 6).

Table 6 – Mineral composition of white grape berries and must in different stages of 'Cerceal' cv. from kaolin treated and untreated (control) plants. Values are presented as mean ± SD. Different lower case letters represent significant differences between treatments (control vs kaolin), in the same stage of the season (*veraison*/maturation) and * represent significant differences between stages of the season within the same treatment (p < 0.05). Absence of superscript indicates no significant differences. N.D. means that concentration was so lower that was Not Detected.

	Treatment	Stage	Al(µg g ⁻¹)	K(mg g ⁻¹)	Ca(mg g ⁻¹)	Fe(µg g ⁻¹)	Mg(mg g ⁻¹)	Cu(µg g ⁻¹)	Zn(µg g ⁻¹)
Fruit	kaolin	Harvest	35.7 ± 2.62 b	15.7 ± 0.651 a	4.01 ± 0.240	20.5 ± 0.800 a	0.612 ± 0.049 a	1.46 ± 0.050 b	14.8 ± 0.500 a
	Control		38.9 ± 0.351 a	13.2 ± 1.40 b	4.02 ± 0.255	18.6 ± 2.410 b	0.452 ± 0.002 b	1.48 ± 0.015 a	6.99 ± 1.33 b
	kaolin	September 1 ^b	821.0 ± 1.21 a*	548.3 ± 2.52 c	27.2 ± 1.40 a*	0.994 ± 0.004 a*	65.2 ± 0.751 a	9.10 ± 0.001 a*	N.D.
Must	kaolin	September 2 ^b	561.4 ± 0.586 b	910.3 ± 1.53 a*	23.4 ± 0.889 b*	0.997 ± 0.002 a*	53.7 ± 0.300 b	8.00 ± 0.001 b*	N.D.
	kaolin	October 4 ^b	185.5 ± 0.854 c*	844.7 ± 1.15 b*	29.2 ± 0.709 a*	0.889 ± 0.009 b*	65.0 ± 0.153 a*	1.80 ± 0.001 c*	N.D.
	Control	September 1 ^b	960.9 ± 0.001 a	511.7 ± 2.52 c	34.7 ± 0.577 a	0.858 ± 0.008 a	66.2 ± 0.361 b	20.6 ± 0.003 c	N.D.
	Control	September 2 ^b	564.0 ± 0.002 b	772.7 ± 3.06 a	29.6 ± 0.611 b	0.819 ± 0.019 b	55.2 ± 0.265 c	14.0 ± 0.001 a	N.D.
	Control	October 4 ^b	326.4 ± 1.22 c	706.3 ± 2.51 b	24.7 ± 1.25 c	0.767 ± 0.009 c	73.3 ± 0.379 a	14.1 ± 0.002 b	N.D.

3.3. Kaolin application consequences in white 'Cerceal' wine

As KI is an aluminum silicate, we quantified the aluminum concentration in the wine (Table 7). Accordingly, the Al content is significant lower (- 12.9%) in wine of KI treated plants than in control one. The alcohol degree was also lower in KI wine (3.57%) and an increase in total acidity, malic and tartaric acid were obtained (+ 16.3%, 11.1% and 7.08% in KI samples, respectively).

Table 7 – Aluminium concentration (µg g⁻¹), total acidity (g L⁻¹ of tartaric acid), pH, alcohol degree (% v/v) and tartaric and malic acid concentration (g L⁻¹) of wine of white 'Cerceal' cv. from KI treated and untreated

(control) grapevines. Values are presented as mean \pm SD. Significant differences were presented between treatments and considered for $p < 0.05$ and *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ represent significant differences.

	Kaolin	Control	Significance
AI	96.3 ± 2.82	110.6 ± 0.151	**
Alcohol degree	13.5 ± 0.191	14.0 ± 0.123	*
Total Acidity	6.34 ± 0.168	5.45 ± 0.081	***
Malic acid	1.30 ± 0.006	1.17 ± 0.026	***
Tartaric acid	2.57 ± 0.058	2.40 ± 0.001	***

We also evaluated the wine volatile compounds (Table 8). The heatmap (Figure 4) shows a graphical representation of the chromatographic data (presented in Table 8) achieved for the 51 volatile components, allowing a rapid visual evaluation of the wine's volatile profiles. The chromatic scale of the heatmap allows access the relative amount of each volatile component (from dark blue, minimum, to dark red, maximum). Whereas the dendrogram (Figure 4) built from the HCA is an exploratory tool that reveals two clusters corresponding to the two types of wines, i.e. control and kaolin. From the 51 volatile components detected, 53% (corresponding to 27 components) exhibited differences statistically significant between both types of wines (differences corresponding to $p < 0.05$).

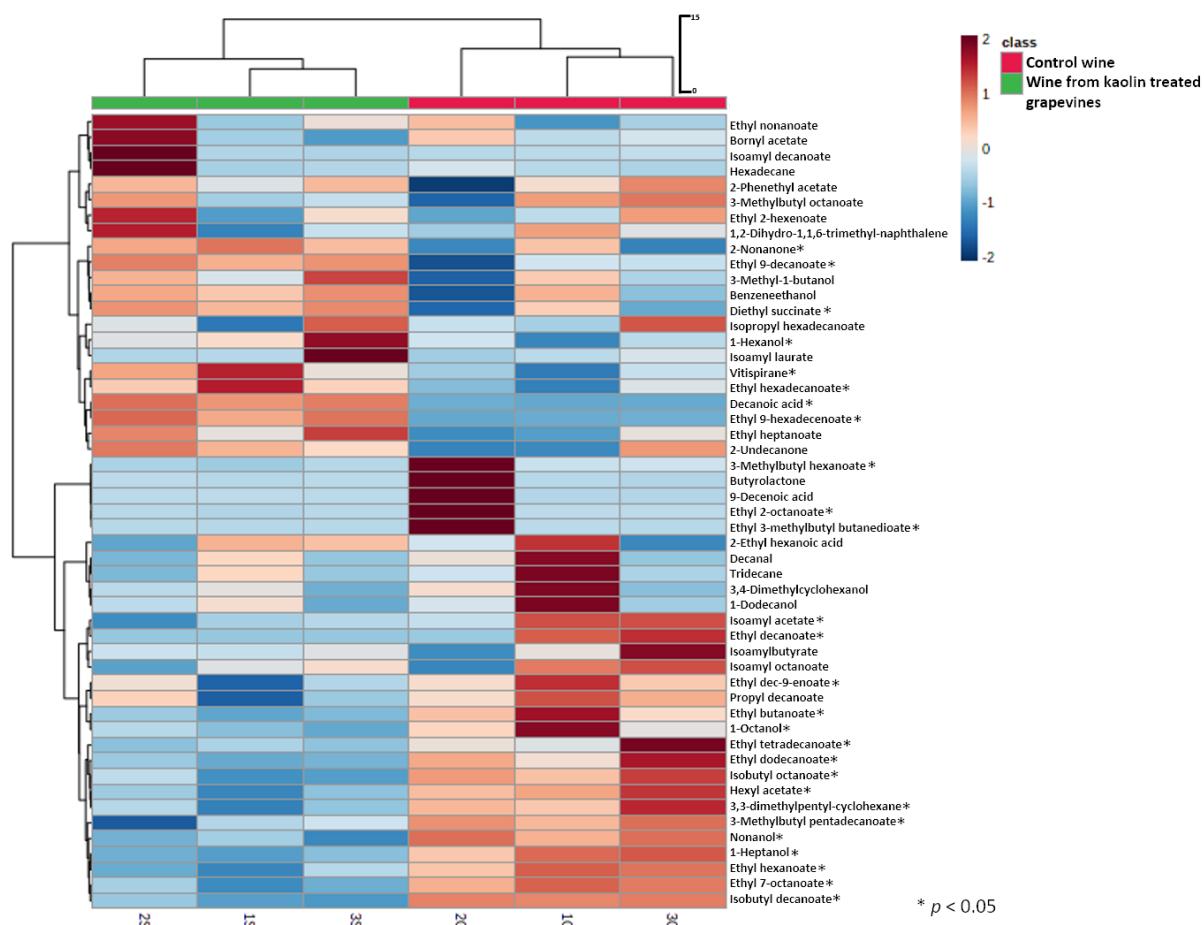


Figure 4 – Heatmap and dendrogram representation of the 51 volatile components from 'Cerceal' cv. wines under study: control and kaolin treated grapevines, which reveals the distinction among wines. The content of each compound was illustrated through different colors (from dark blue, minimum, to dark red, maximum). Dendrogram for the HCA results using Ward's cluster algorithm to the data set was also included. Differences corresponding to $p < 0.05$ were considered significant and were marked with **.

4. Discussion

4.1. Kaolin modulates grapevine plant physiology and pests control

The kaolin particle film was initially developed for suppression of arthropod pests and diseases by its repellent effect [39, 40]. Our results confirm that KI spraying reduce the incidence of pests in grapevines (Supplementary data), reinforcing their repellent benefit as reported in other crops *e.g.* apple, pear and olive trees [40-42]. Increased plant productivity results from insect control with KI has also been documented [42, 43]. This work, as well as a previous one done by our group in red grape cultivars in the Douro valley (NE Portugal) [44] reinforce that the treatment of grapevine leaves with the inert clay mineral kaolin increases also physiological capacity of plants [44]. The clay particles protect leaves from excessive radiation leading to a lower leaf temperature (Fig. 2) and thus better iWUE, extremely linked to the lower ABA accumulation [14], reducing potentially damage triggered by visible and ultraviolet radiations and therefore decreases heat stress and sunburn injury [45]. Grapevine KI plants under better temperature and irradiation conditions showed higher P_N values (Table 1). In control leaves were evident nonstomatal limitations to photosynthesis, as revealed by the decrease of P_N and iWUE and the increase of C_i/C_a ratio (Table 1), either through CO_2 diffusion and carboxylation efficiency [46], and/or photochemical perturbations. At this level, the decrease in P_N under saturating light conditions was associated with a reduction of Φ_{PSII} , F_v/F_m and ETR (Table 2). Also, linking the decrease of F_v/F_m with the increase of F_0 , these results suggest that the photoprotective capacity of these leaves was surpassed and photoinhibitory damage in the PSII occurred [47], as seen previously in plant reaction to high temperature and water stress [48]. The KI photoprotection induction is also supported by the higher qP and lower NPQ values, which suggest an effective radiative and nonradiative dissipation of the excess energy, avoiding the photosystem damages by oxidation [49].

4.2. Kaolin boost grapevine fruit quality

It is known that during grape berry development a complex series of physicochemical modifications, such as changes in size, colour, chemical composition and flavour occurs [50]. Temperature influences both cell division and enlargement and in excess, such as in our study ($> 35^{\circ}C$), reduce growth rate and size. However, solar radiation is also crucial for berry growth [51], which could explain that KI treatment induces 11.2% lower increase in berry diameter than control ones, from *veraison* to maturation stages, supposedly due to more shaded fruits provoked by high number of healthy leaves that exist because of the leaf KI protection from sunburn. White berries from *V. vinifera* varieties are the consequence of the inactivation of anthocyanin biosynthesis, thus that grape green-yellowish colour is mainly linked to catabolic pathways instead of specific pigment accumulation [52]. During the maturation process a degradation of carotenoids and chlorophylls pigments occurs [53] being, according C^*ab coordinates, the yellowish color of the fruits related with the b^* value. In spite of the high b^* value of control fruits, both KI and control berries have a positive b^* (Table 3) and, consequently yellowish colour. However, the negative a^* value of the KI fruits (greener) compared with the positive one (more reddish) obtained for control berries, reveals that KI fruits are more yellowish compared with the brownish-yellow of control ones. This difference could be related with the low chlorophylls/carotenoids ratio, and the ripening characteristic oxidative burst, promoting the appearance of the yellowish colour of the fruits [53]. During the berry ripening stage, pH should increase, mainly related with the decline of tartaric and malic acid [54]. These acids decrease and were observed in berries of both treatments, resulting in a decrease of overall total acidity (Table 3). Tartaric acid concentration decreases from *veraison* to maturation stage, contrary to other studies reporting that their content remain relatively constant in the grape berry and are not related to climatic conditions [55]. Inversely, malic acid concentration in grapes depending on several factors, such as climate conditions, especially irradiance [55] and temperature [56], as the most important ones. The positive protection of KI treatment leads to a berries with higher tartaric

and malic acid concentration (Table 3). Probably, this is due to the sun protection of fruits by the healthy leaves and their shade effects on lower acid degradation. It is known that higher level of organic acids (particularly tartaric acid) is a positive characteristic of grapevine varieties in warm climates, such in this studied region and others most threatened by climate change [57]. For this reason, KI treatment showed potential to produce well balanced wines avoiding the intensive needed of acidification of must/wine. As referred before, organic acids (malic and tartaric acids) and sugars concentration showed opposite behaviour [54] as we observed in our study. In fact, KI fruits have more tartaric and malic and low sugar concentration than control berries (Table 3). These results in white grapevine fruits, as previous ones in red berries [10, 17, 21], reinforce that KI treatment boosts, mainly in the mature grape berry (maturation period), the quantities of phenolic compounds, including total phenolics and tannins, leading also to an augment of antioxidant activity (Table 4). This happened because in response to kaolin there are a global stimulation of phenylpropanoid and flavonoid-flavonol pathways at the gene expression and/or protein activity levels [21]. This fact should have major implications in fruit and wine quality, while protecting plant against abiotic stress. An analysis focused on secondary metabolism in the different fruit tissues showed as predictable that the major quantity of phenolics are found in the seed, after in the skin, and only a little percentage in the pulp [58]. However, we observe that KI provokes an increase of total phenols, flavonoids, tannins and *ortho*-diphenols compared with the control (Table 5). Amongst polyphenols, *ortho*-diphenols are known as the most significant in relation to their antioxidant activity which are related to hydrogen donation, i.e., their capacity to improve radical stability by forming an intra-molecular hydrogen bond between the hydrogen of their hydroxyl group and their phenoxy radicals [59]. Grape berry mineral content is also important and involved in wine chemical composition. Among the several minerals present in grape berries, potassium (K^+) usually represents the most abundant cation because is accumulated during the entire period (pre- and post-*veraison*) with a huge rise at the beginning of ripening [60]. The KI use leads to an enhance of K^+ . Looking in a technological point of view, this effect is beneficial because K^+ influences the pH of musts and wines and thereby their chemical and microbiological stability, in addition to the perception of wine flavour [61]. Taking into account that the factors that affect K^+ accumulation include their soil availability and weather conditions effects, this study reinforces the KI protective capacity against summer stress, since the pedoclimatic conditions were similar for all plants under study. This high accumulation is reflected in the must when the KI application also boost their content (Table 6). Magnesium is considered to be a phloem-mobile element and, their amount increased during ripening but at different rates depending on the response of berry to vine water relations [62]. This finding allows us to highlight the KI capacity on the WUE avoiding water stress, which were enable the increase the quantity of Mg^{++} in KI fruits and must. With magnesium, other mineral elements such as calcium and copper also play a role in osmotic balance. In spite of copper being an essential micronutrient for all living organisms, including humans [63], elevated copper concentrations in grapevine can cause oxidative spoilage leading to browning of white wine as well as haze formation [64], which it will hardly happen in the KI must when the copper quantity is much lower than control one. Of the several questions that winemakers have about KI application, the most frequent one refers to aluminum. As KI is an aluminum silicate ($Al_2Si_2O_5(OH)_4$) there was a fear that high quantities of this metal would be found in grapes and wines whose plants were sprayed with it. However, these results confirm that the powdered aluminum was not absorbed into the fruits, nor to the musts (Table 6), which is reflected in the wine (Table 7 and Table 8), and even its concentrations are even lower than those of the

4.3. Positive effect of kaolin application in white wine balance

One of the main challenges for the wine industry is climate change, because has enormous effect on vine phenology and physiology and consequently in yield and grape composition. Among climate change-related consequences, the advanced maturation times and temperatures are the most significant because these leads to an increase in grape sugar concentrations, which provokes high wine alcohol and lower acidities, especially in warm regions [65]. White varieties with highest level of tartaric and malic acid are suggested to be of great interest for breeding new cultivars. These are the principal organic acids in wine representing 70–90% of total grape acidity [66]. Their concentration is one of the most key quality characteristics of grapes for wine production, and has an essential impact on the colour, flavour and stability of wine [67]. Relating to white wines from warm regions, malic acid can even have positive effect on wine balance. In such cases malolactic fermentation may result in significant changes of the wine aromatic profile and in increase of lactic and buttery characteristics and a decrease in fruity characteristics [68]. Looking to our results, KI pulverization should be also used in white cultivars in locals with severe summer conditions due their capacity to trigger high total acidity (higher malic and tartaric acid) and lower alcohol degree (Table 7) which are characteristics well appreciated by the new wine consumers. After analysis of volatile compounds it is possible to see that, in general, the control wine exhibited higher content of esters with C_{11} to C_{18} and decanoic acid, which if present in amount higher than their aroma threshold, may contribute with unpleasant notes, such as wax, soap or fatty [69, 70]. On the other hand, in general, wine from kaolin treated grapevines presented higher content of esters with $<C_{12}$, which are associated with fruity notes [69]. Also, control wine present higher content of vitispirane, a C_{13} -norisoprenoid. As observed for several fruits, including grape berries, during ripening may occurs diverse reactions modulated by enzymes, namely degradation processes, such as carotenoids cleavage resulting in formation of norisoprenoids [71-73]. Hydroxylated C_{13} -norisoprenoids often occur in plants as glycosides and can be liberated from these by enzymatic or acid hydrolysis and then transformed into aroma compounds, such as vitispirane. The statistically differences observed between both types of wines in the content of vitispirane may infer the impact of kaolin treatment of grapevines on the carotenoids cleavage. Vitispirane is associated with camphour and eucalyptus notes [74], but as its odor threshold is relatively high (800 μ g/kg, wine) [69]. **Further research is needed, namely sensorial analysis assays, to properly evaluate the impact of the observed statistically differences related with wines volatile profiles on the aroma characteristics of control wine and wine from kaolin treated grapevines.**

Table 8 – Kaolin effect on volatile composition (VOCs) of ‘Cerceal’ cv. wines determined by HS-SPME/GC-MS. Values are presented as mean area \pm SD.

‘Cerceal’ wines VOCs composition				
Retention time (min)	Compound	Formula	Control	Kaolin
3.423	3-Methyl-1-butanol	C5H12O	1.18E+09 \pm 9.68E+07	1.29E+09 \pm 7.14E+07
5.133	Ethyl butanoate	C6H12O2	6.90E+06 \pm 7.44E+05	5.47E+06 \pm 1.63E+05
7.740	1-Hexanol	C6H14O	1.61E+06 \pm 1.96E+05	2.06E+06 \pm 3.69E+05

7.911	Isoamyl acetate	C7H14O2	1.35E+08 ± 8.29E+06	1.22E+08 ± 3.82E+06
9.300	Butyrolactone	C4H6O2	1.56E+06 ± 2.42E+06	2.31E+05 ± 3.48E+04
11.448	1-Heptanol	C7H16O	4.35E+06 ± 6.98E+05	1.45E+06 ± 2.43E+05
12.399	Ethyl hexanoate	C8H16O2	3.47E+08 ± 1.66E+07	2.75E+08 ± 1.83E+07
12.877	Hexyl acetate	C8H16O2	1.18E+07 ± 9.53E+05	8.57E+06 ± 6.96E+05
13.921	Ethyl 2-hexenoate	C8H14O2	4.06E+05 ± 1.07E+05	4.56E+05 ± 1.60E+05
14.309	Isoamylbutyrate	C9H18O2	1.99E+05 ± 3.32E+04	1.90E+05 ± 2.83E+03
14.916	1-Octanol	C8H18O	1.34E+06 ± 4.59E+05	7.15E+05 ± 1.19E+05
15.488	2-Nonanone	C9H18O	1.54E+06 ± 4.72E+05	2.22E+06 ± 1.29E+05
15.694	Ethyl heptanoate	C9H18O2	5.62E+06 ± 9.98E+05	7.87E+06 ± 1.04E+06
16.149	Benzeneethanol	C8H10O	1.77E+08 ± 1.38E+07	1.92E+08 ± 2.43E+06
16.857	2-Ethyl hexanoic acid	C8H16O2	2.00E+05 ± 1.54E+05	2.03E+05 ± 9.78E+04
18.083	Nonanol	C9H20O	1.27E+06 ± 7.12E+04	8.15E+05 ± 8.99E+04
18.285	Diethyl succinate	C8H14O4	1.40E+07 ± 1.50E+06	1.62E+07 ± 2.74E+05
18.477	Ethyl 7-octenoate	C10H18O2	1.98E+09 ± 6.41E+07	1.54E+09 ± 8.84E+07
19.043	Decanal	C10H20O	9.95E+05 ± 5.35E+05	6.58E+05 ± 2.39E+05
19.666	3,4-Dimethylcyclohexanol	C8H16O	4.97E+05 ± 2.80E+05	3.17E+05 ± 8.95E+04
20.151	Ethyl 2-octenoate	C10H18O2	2.53E+06 ± 3.69E+06	2.64E+05 ± 7.79E+04
20.319	3-Methylbutyl hexanoate	C11H22O2	2.36E+06 ± 2.06E+06	8.03E+05 ± 1.27E+05
20.430	2-Phenethyl acetate	C10H12O2	3.67E+06 ± 3.04E+06	4.96E+06 ± 7.77E+05

20.937	Vitispirane	C13H20O	6.80E+05 ± 2.78E+05	1.42E+06 ± 3.72E+05
21.266	Bornyl acetate	C12H20O2	2.71E+05 ± 4.59E+04	2.87E+05 ± 1.79E+05
21.474	2-Undecanone	C11H22O	2.45E+05 ± 1.18E+05	3.64E+05 ± 3.76E+04
21.553	Ethyl nonanoate	C11H22O2	7.32E+06 ± 2.36E+06	9.56E+06 ± 3.52E+06
21.633	Tridecane	C13H28	1.00E+06 ± 1.01E+06	4.06E+05 ± 4.22E+05
22.939	Isobutyl octanoate (Caprylic acid isobutyl ester)	C12H24O2	2.07E+06 ± 2.49E+05	1.15E+06 ± 2.27E+05
23.067	1,2-Dihydro-1,1,6-trimethyl-naphthalene	C13H16	1.33E+06 ± 1.23E+05	1.32E+06 ± 2.75E+05
23.609	9-Decenoic acid	C10H18O2	5.56E+08 ± 7.86E+08	2.19E+07 ± 4.16E+06
23.814	Decanoic acid	C10H20O2	7.19E+06 ± 3.32E+06	3.73E+08 ± 2.62E+07
24.050	Ethyl 9-decanoate	C12H22O2	3.43E+08 ± 2.87E+08	8.49E+08 ± 5.84E+07
24.361	Ethyl decanoate (Capric acid ethyl ester)	C12H24O2	8.17E+08 ± 6.91E+08	9.13E+06 ± 2.12E+05
24.600	Ethyl dec-9-enoate	C12H22O2	1.22E+07 ± 3.60E+06	5.36E+06 ± 4.53E+06
25.073	Ethyl 3-methylbutyl butanedioate	C11H20O4	5.60E+06 ± 9.22E+06	1.80E+05 ± 4.80E+04
25.484	3-Methylbutyl octanoate	C13H26O2	1.25E+07 ± 9.03E+06	1.21E+07 ± 4.42E+06
25.562	Isoamyl octanoate (Isoamyl caprylate)	C13H26O2	1.77E+06 ± 1.47E+06	1.10E+06 ± 6.58E+05
26.247	1-Dodecanol	C12H26O	1.12E+06 ± 6.61E+05	7.38E+05 ± 2.61E+05
26.615	Propyl decanoate	C13H26O2	2.47E+05 ± 4.43E+04	1.39E+05 ± 8.04E+04
27.925	Isobutyl decanoate (Isobutyl caprate)	C14H28O2	1.64E+06 ± 1.03E+04	1.06E+06 ± 7.47E+04
28.947	Ethyl 9-hexadecenoate (Ethyl oleate)	C18H34O2	4.29E+05 ± 8.58E+04	4.83E+06 ± 5.82E+05
29.091	Ethyl dodecanoate (Ethyl laurate)	C14H28O2	2.77E+08 ± 3.66E+07	2.02E+08 ± 7.67E+06

30.043	3,3-dimethylpentyl-cyclohexane	C13H26	1.39E+06 ± 1.94E+05	8.55E+05 ± 1.52E+05
30.205	3-Methylbutyl pentadecanoate	C20H40O2	9.99E+06 ± 1.05E+06	3.65E+06 ± 3.12E+06
30.279	Isoamyl decanoate	C15H30O2	8.45E+05 ± 1.87E+05	3.96E+06 ± 6.07E+06
32.478	Ethyl tetradecanoate (Ethyl myristate)	C16H32O2	3.53E+06 ± 2.97E+06	2.43E+05 ± 3.27E+05
32.514	Hexadecane	C16H34	6.16E+05 ± 4.46E+05	2.50E+06 ± 3.82E+06
32.893	Isoamyl laurate	C17H34O2	7.83E+05 ± 6.20E+05	3.10E+06 ± 4.36E+06
33.970	Ethyl hexadecanoate (Ethyl palmitate)	C18H36O2	4.52E+06 ± 4.05E+05	5.54E+06 ± 4.88E+05
34.216	Isopropyl hexadecanoate (Isopropyl Palmitate)	C19H38O2	3.03E+05 ± 1.02E+05	2.76E+05 ± 1.39E+05

5. Conclusions

We showed that kaolin application triggered an improvement in plant physiology, especially under conditions of abiotic stress, and can also be considered as an alternative to synthetic pest control. Moreover, kaolin application significantly influences the grape fruit metabolome in a way that provides berries with high phenolic compounds, tartaric and malic acids, total acidity and lower sugar content. Besides, it is essential to reinforce that a good influence was observed in wine having higher acidity and lower alcohol levels and seems to have improved the aroma. In sum, foliar kaolin application in grapevine leaves shows great potential as summer stress mitigation strategy because it clearly impacts on berry and wine quality as a result of many molecular and biochemical changes in key primary/secondary metabolic pathways.

Author Contributions:

Dinis, L.-T., Moutinho-Pereira, J., Correia, C., and Malheiro, A.C., conceived the idea and designed the experiments; Bernardo, S., Luzio, A., Dinis, L.-T., Flores, R., Alves, S., Correia, C. and Moutinho-Pereira, J., performed the experiments; Dinis, L.-T., JMP and SMR analysed the data; Matos, C., Costa, C.P., Rocha, S.M., Luzio, A., and Dinis, L.-T. provided materials, resources and scientific support; Dinis, L.-T. and Rocha, S.M. wrote the article with the contribution of all authors.

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Table 1 – Gas exchange parameters, namely transpiration rate (E, $\text{mmol m}^{-2}\text{s}^{-1}$), stomatal conductance (g_s , $\text{mmol m}^{-2} \text{s}^{-1}$), photosynthesis net (P_N , $\mu\text{mol m}^{-2} \text{s}^{-1}$), intrinsic water use efficiency (iWUE, $\mu\text{mol mol}^{-1}$) and ratio of intercellular to atmospheric CO₂ concentration (C_i/C_a), at morning and midday periods in *veraison* and maturation stages in kaolin and control leaves (n = 10). Different lower case letters represent significant differences between treatments (control vs kaolin), in the same period of the day (morning/midday) and stage of the season (*veraison*/maturation). * represent significant differences between stages of the season within the same period of the day (p < 0.05). Absence of superscript indicates no significant differences.

Stage	Treatment	Morning				
2016		E	g_s	P_N	iWUE	C_i/C_a
Veraison	Kaolin	4.07 ± 0.632*	251.9 ± 59.6*	13.0 ± 3.04*	50.3 ± 4.19a*	0.706 ± 0.028b*
	Control	4.10 ± 0.627*	245.7 ± 47.9*	10.3 ± 2.13*	40.8 ± 6.29b*	0.745 ± 0.037a*
Maturation	Kaolin	2.27 ± 0.014a	57.3 ± 11.3	2.23 ± 0.348a	38.9 ± 5.32a	0.772 ± 0.043b
	Control	2.07 ± 0.109b	51.7 ± 15.2	0.95 ± 0.144b	18.4 ± 8.52b	0.894 ± 0.025a
2017						
Veraison	Kaolin	3.65 ± 0.958	266.6 ± 93.5 a*	10.7 ± 1.64 a*	48.2 ± 7.82 a*	0.755 ± 0.116
	Control	3.00 ± 0.641	149.1 ± 51.8 b*	7.2 ± 1.48 b*	40.4 ± 8.71 b*	0.767 ± 0.095
Maturation	Kaolin	3.10 ± 0.897	154.3 ± 66.9 a	8.66 ± 2.16 a	56.1 ± 2.34 a	0.744 ± 0.015
	Control	3.00 ± 0.634	138.0 ± 55.7 b	3.95 ± 1.28 b	28.6 ± 5.05 b	0.840 ± 0.023
Midday						
2016						
Veraison	Kaolin	3.74 ± 0.742*	173.5 ± 57.3*	10.4 ± 2.57*	59.9 ± 6.57*	0.661 ± 0.025b*
	Control	3.81 ± 0.663*	171.5 ± 48.0*	9.75 ± 3.03*	56.8 ± 5.48*	0.684 ± 0.034a*

Maturation	Kaolin	2.15 ± 0.465	101.8 ± 21.1	4.07 ± 1.07a	40.0 ± 5.39a	0.766 ± 0.046b
	Control	2.16 ± 0.428	92.3 ± 36.3	1.89 ± 0.382b	20.4 ± 11.7b	0.859 ± 0.059a
2017						
Veraison	Kaolin	2.52 ± 0.218	105.0 ± 10.6	7.36 ± 1.50a*	70.1 ± 13.1a*	0.644 ± 0.081b*
	Control	2.79 ± 0.317	102.8 ± 15.0	5.48 ± 0.702b*	53.3 ± 8.75b*	0.720 ± 0.045a*
Maturation	Kaolin	2.67 ± 0.604	111.1 ± 37.4	6.93 ± 1.60a	62.3 ± 7.8a	0.675 ± 0.049b
	Control	2.45 ± 0.661	91.0 ± 27.6	3.21 ± 0.879b	35.3 ± 5.75b	0.797 ± 0.035a

Table 2 – Chlorophyll a fluorescence parameters, namely basal fluorescence (F_0), maximum quantum efficiency of photosystem II (F_v/F_m), effective PSII efficiency (Φ_{PSII}), photochemical quenching (qP), electron transport rate (ETR, $\mu\text{mol e}^- \text{ m}^{-2} \text{ s}^{-1}$) and non-photochemical quenching (NPQ) at morning and midday periods in *veraison* and maturation stages in kaolin and control leaves ($n = 10$). Different lower case letters represent significant differences between treatments (control vs kaolin), in the same period of the day (morning/midday) within the stage of the season (*veraison*/maturation), and * represent significant differences between stages of the season within the same period of the day ($p < 0.05$). Absence of superscript indicates no significant differences.

Stage Treatment		Morning					
2016		F_0	F_v/F_m	Φ_{PSII}	qP	ETR	NPQ
Veraison	Kaolin	514.5 \pm 99.9*	0.743 \pm 0.051	0.225 \pm 0.044*	0.803 \pm 0.052	141.4 \pm 17.4 a*	0.821 \pm 0.436
	Control	536.5 \pm 100.9*	0.700 \pm 0.033	0.193 \pm 0.041*	0.896 \pm 0.197	121.3 \pm 15.6 b*	1.26 \pm 0.349
Maturation	Kaolin	405.0 \pm 97.9	0.798 \pm 0.057	0.314 \pm 0.059	0.616 \pm 0.131	252.0 \pm 18.0 a	0.870 \pm 0.200
	Control	448.5 \pm 121.4	0.688 \pm 0.085	0.333 \pm 0.064	0.639 \pm 0.175	237.6 \pm 14.3 b	0.707 \pm 0.216
2017							
Veraison	Kaolin	485.0 \pm 36.9 b*	0.759 \pm 0.025 a	0.117 \pm 0.027 a*	0.365 \pm 0.079 a*	88.5 \pm 10.1 a*	3.52 \pm 0.281*
	Control	603.2 \pm 38.7 a*	0.675 \pm 0.026 b	0.084 \pm 0.041 b*	0.289 \pm 0.061 b*	63.8 \pm 13.2 b*	3.94 \pm 0.997*
Maturation	Kaolin	367.8 \pm 36.1 b	0.773 \pm 0.039 a	0.457 \pm 0.009 a	0.500 \pm 0.014 a	345.2 \pm 17.3 a	2.43 \pm 0.774 b
	Control	498.2 \pm 46.2 a	0.622 \pm 0.070 b	0.429 \pm 0.018 b	0.485 \pm 0.004 b	324.2 \pm 9.85 b	4.22 \pm 0.804 a
Midday							
2016							

Veraison	Kaolin	372.0 ± 40.2 b*	0.753 ± 0.013 a*	0.207 ± 0.040	0.414 ± 0.012*	130.1 ± 25.3*	0.71 ± 0.154 b
	Control	473.8 ± 52.0 a*	0.733 ± 0.003 b*	0.228 ± 0.022	0.388 ± 0.012	143.4 ± 13.8	1.79 ± 0.079 a
Maturation	Kaolin	521.0 ± 24.0 b	0.634 ± 0.018 a	0.238 ± 0.032 a	0.563 ± 0.061 a	180.1 ± 13.9 a	1.14 ± 0.031
	Control	597.3 ± 23.3 a	0.536 ± 0.046 b	0.204 ± 0.045 b	0.618 ± 0.032 b	154.4 ± 13.8 b	1.39 ± 0.195
2017							
Veraison	Kaolin	510.2 ± 58.9 b*	0.731 ± 0.017*	0.059 ± 0.002*	0.190 ± 0.061*	45.1 ± 11.6*	2.75 ± 0.263 b*
	Control	599.0 ± 13.8 a*	0.702 ± 0.029	0.054 ± 0.001*	0.198 ± 0.024*	40.8 ± 9.26*	4.09 ± 0.085 a*
Maturation	Kaolin	359.8 ± 59.4 b	0.789 ± 0.014 a	0.183 ± 0.015 a	0.404 ± 0.019 a	138.3 ± 14.7 a	2.08 ± 0.132 b
	Control	427.8 ± 68.7 a	0.718 ± 0.015 b	0.176 ± 0.012 b	0.391 ± 0.088 b	103.7 ± 6.89 b	3.15 ± 0.024 a

Table 3 – Kaolin effect on colorimetric parameters analyzed for all grape skin color variants and Brix° of fruits picked in the maturation period, and total acidity (g L⁻¹ of tartaric acid), pH, tartaric and malic acid concentration (g L⁻¹) of fruits picked in the *veraison* and maturation stages, in 2017. Values are presented as mean ± SD. Significant differences were presented between treatments and considered for p < 0.05 and *** p < 0.001, ** p < 0.01, * p < 0.05 represent significant differences; ns indicates no significant differences.

	Kaolin	Control	Significance
<i>Veraison</i>			
Total acidity	10.5 ± 0.767	8.76 ± 0.386	
pH	2.92 ± 0.049	3.05 ± 0.009	***
Tartaric acid	7.04 ± 0.516	5.59 ± 0.308	***
Malic acid	1.82 ± 0.360	2.35 ± 0.417	*
Maturation			
Colour parameters			
b*	13.9 ± 1.63	15.1 ± 1.87	*
C*ab	14.0 ± 1.62	15.4 ± 1.99	***
h_{ab}	91.3 ± 3.92	81.9 ± 6.11	***
Brix°	17.5 ± 1.03	19.2 ± 2.16	*
Total acidity	4.88 ± 0.176	4.48 ± 0.036	***
pH	3.44 ± 0.090	3.61 ± 0.070	**
Tartaric acid	3.88 ± 0.161	3.25 ± 0.251	***
Malic acid	0.910 ± 0.105	0.683 ± 0.049	***

Table 4 – Kaolin application effect on height (mm), diameter (mm) and volume (mm³) of berries, and phenols (mg g⁻¹ DW), flavonoids (mg g⁻¹ DW), *ortho*-diphenols (mg g⁻¹ DW), tannins (mg g⁻¹ DW), protein (mg g⁻¹ DW) and antioxidant activity (mg g⁻¹ DW; obtained by ABTS and DPPH methods) of whole fruits at the *veraison* and at maturation stages in 2017. Values are presented as mean \pm SD. Different lower case letters represent significant differences between treatments (control vs kaolin), in the same stage of the season (*veraison*/maturation) and * represent significant differences between stages of the season within the same treatment ($p < 0.05$). Absence of superscript indicates no significant differences.

	Parameters	Kaolin	Control	Kaolin	Control
		Veraison		Maturation	
Biometry	Height	12.1 \pm 0.616	11.5 \pm 0.814	13.2 \pm 0.429	12.9 \pm 0.705
	Diameter	11.3 \pm 0.434a*	10.4 \pm 0.783b*	12.1 \pm 0.449	12.3 \pm 0.515
	Volume	136.7 \pm 11.4a*	119.6 \pm 17.1b*	159.6 \pm 10.6	159.4 \pm 14.1
Biochemistry	Phenols	76.2 \pm 3.09*	76.5 \pm 3.04*	56.0 \pm 1.32a	50.2 \pm 1.52b
	Flavonoids	27.5 \pm 1.54b*	33.0 \pm 1.02a*	15.2 \pm 0.776	15.0 \pm 0.699
	Ortho-diphenols	196.1 \pm 8.00b*	216.4 \pm 8.96a*	150.1 \pm 1.47a	147.4 \pm 1.22b
	Tannins	42.8 \pm 1.26*	45.4 \pm 1.73*	19.8 \pm 0.289a	18.6 \pm 0.289b
	ABTS	208.5 \pm 7.10a*	124.3 \pm 15.1b*	176.9 \pm 2.80a	167.9 \pm 3.78b
	DPPH	207.3 \pm 5.44b	220.8 \pm 0.832a*	212.8 \pm 7.94a	188.8 \pm 11.9b
	Protein	9.18 \pm 0.140b*	9.75 \pm 0.140a*	15.1 \pm 0.071a	13.8 \pm 0.405b

Table 5 – Phenols, flavonoids, *ortho*-diphenols and tannins, and antioxidant activity (ABTS and DPPH) (mg g⁻¹ DW) in the seeds, skins, and pulps of fruits from KI treated and untreated (control) plants. Values are presented as mean ± SD. Significant differences were presented between treatments and considered for p < 0.05 and *** p < 0.001, ** p < 0.01, * p < 0.05 represent significant differences; ns indicates no significant differences.

	Tissues	Kaolin	Control	Significance
Phenols	Seed	99.4 ± 4.40	95.7 ± 4.42	ns
	Skin	49.5 ± 1.28	43.0 ± 0.853	**
	Pulp	22.4 ± 0.942	13.5 ± 0.554	***
Flavonoids	Seed	46.7 ± 1.00	41.9 ± 1.90	*
	Skin	13.7 ± 0.476	10.2 ± 0.289	***
	Pulp	2.58 ± 0.127	1.52 ± 0.046	***
Ortho-diphenols	Seed	198.3 ± 16.9	133.9 ± 2.00	**
	Skin	219.0 ± 7.38	154.6 ± 1.27	***
	Pulp	164.1 ± 1.97	141.5 ± 11.2	*
Tannins	Seed	57.5 ± 1.42	41.8 ± 0.946	***
	Skin	20.1 ± 0.144	18.6 ± 0.144	***
	Pulp	9.26 ± 0.382	7.93 ± 0.250	***
ABTS	Seed	297.1 ± 7.56	296.6 ± 2.30	ns
	Skin	185.9 ± 7.56	165.4 ± 3.97	*
	Pulp	109.6 ± 29.6	88.9 ± 15.2	ns
DPPH	Seed	245.3 ± 6.25	182.1 ± 5.21	***
	Skin	291.0 ± 5.51	277.2 ± 11.9	ns
	Pulp	228.5 ± 0.425	229.8 ± 1.13	ns

Table 6 – Mineral composition of white grape berries and must in different stages of ‘Cerceal’ cv. from kaolin treated and untreated (control) plants. Values are presented as mean \pm SD. Different lower case letters represent significant differences between treatments (control vs kaolin), in the same stage of the season (*veraison*/maturation) and * represent significant differences between stages of the season within the same treatment ($p < 0.05$). Absence of superscript indicates no significant differences. N.D. means that concentration was so lower that was Not Detected.

Treatment	Stage	Al ($\mu\text{g g}^{-1}$)	K (mg g^{-1})	Ca (mg g^{-1})	Fe ($\mu\text{g g}^{-1}$)	Mg (mg g^{-1})	Cu ($\mu\text{g g}^{-1}$)	Zn ($\mu\text{g g}^{-1}$)
Fruit								
kaolin	Maturation	35.7 \pm 2.62b	15.7 \pm 0.651a	4.01 \pm 0.240	20.5 \pm 0.800a	0.612 \pm 0.049a	1.46 \pm 0.050b	14.8 \pm 0.500a
Control		38.9 \pm 0.351a	13.2 \pm 1.40b	4.02 \pm 0.255	18.6 \pm 2.410b	0.452 \pm 0.002b	1.48 \pm 0.015a	6.99 \pm 1.33b
Must								
kaolin	September 15 th	821.0 \pm 1.21a*	548.3 \pm 2.52c	27.2 \pm 1.40a*	0.994 \pm 0.004a*	65.2 \pm 0.751a	9.10 \pm 0.001a*	N.D.
	September 23 th	561.4 \pm 0.586b	910.3 \pm 1.53a*	23.4 \pm 0.889b*	0.997 \pm 0.002a*	53.7 \pm 0.300b	8.00 \pm 0.001b*	N.D.
	October 4 th	185.5 \pm 0.854c*	844.7 \pm 1.15b*	29.2 \pm 0.709a*	0.889 \pm 0.009b*	65.0 \pm 0.153a*	1.80 \pm 0.001c*	N.D.
Control	September 15 th	960.9 \pm 0.001a	511.7 \pm 2.52c	34.7 \pm 0.577a	0.858 \pm 0.008a	66.2 \pm 0.361b	20.6 \pm 0.003c	N.D.
	September 23 th	564.0 \pm 0.002b	772.7 \pm 3.06a	29.6 \pm 0.611b	0.819 \pm 0.019b	55.2 \pm 0.265c	14.0 \pm 0.001a	N.D.
	October 4 th	326.4 \pm 1.22c	706.3 \pm 2.51b	24.7 \pm 1.25c	0.767 \pm 0.009c	73.3 \pm 0.379a	14.1 \pm 0.002b	N.D.

Table 7 – Aluminium concentration ($\mu\text{g g}^{-1}$), total acidity (g L^{-1} of tartaric acid), pH, alcohol degree (%, v/v) and tartaric and malic acid concentration (g L^{-1}) of wine of white ‘Cerceal’ cv. from KI treated and untreated (control) grapevines. Values are presented as mean \pm SD. Significant differences were presented between treatments and considered for $p < 0.05$ and *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ represent significant differences.

	Kaolin	Control	Significance
Al	96.3 \pm 2.82	110.6 \pm 0.151	**
Alcohol degree	13.5 \pm 0.191	14.0 \pm 0.123	*
Total Acidity	6.34 \pm 0.168	5.45 \pm 0.081	***
Malic acid	1.30 \pm 0.006	1.17 \pm 0.026	***
Tartaric acid	2.57 \pm 0.058	2.40 \pm 0.001	***