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Effects on Must Quality Produced from Sangiovese and Cabernet Grape Frozen/Withered Using a Forced Air Plant

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Worldwide the wine production is increasing in order to satisfy the expanding consumers demand. The improvement of post harvest and processing technologies for wine grape is considered essential to obtain high quality standards wines. In particular, the cooling soon after harvest represents one of the possible way to preserve the berries original quality especially for white wines rich of taste and flavour while withering is a natural process operation to increase the must soluble solid content for red wine if required. In this paper, the effect of different freezing/withering treatments on chemical-physical parameters of Sangiovese and Cabernet grapes must were investigated, in order to define the relation between the processing conditions of the freezing/withering plant and the final quality of must produced.
The freezing system reduced the average product temperature of about 35°C in 220 min, and the energy requirement of the system resulted strictly related to the grape variety and lower to -18°C due to the faster process. Overall, experimental data could be used to design the process protocol and the industrial scale plant for the post harvest wine grapes processing.
The withering process after 9 days produces an average grapes weight loss of 9.98% and 7.5% for the must of Sangiovese and Cabernet cv. respectively. No significant pH reduction has been detected, demonstrating the maintained quality of the original grape. Furthermore, the higher the fan power used, the higher soluble solid content, suggest that the implementation of a computerized controlled system could be useful to optimize the process parameters during the withering of grapes for producing must with higher sugar content i.e. wine with higher alcohol content.

1. Introduction

The effect of berries temperature control has been studied with greater emphasis for many table grape cv. and at the present is well known. But the proven effects of bunch cooling on the bioactive compounds, and on the preservation of microbiological attributes in relation with the positive change in aroma they require further investigation for wine cv. processed for winemaking end use. Fast cooling and following freezing reduces the berries decay due to enzymatic activities and microbial spoilage, like gray mold rot, blue rot, anthracnose and soft rot, *Botrytis* rot and *Fusarium* rot (Barkai-Golan, 2001), which dramatically affect nutritive values and organoleptic indexes of the produced wine. Moreover, rapid cooling to the optimal processing temperature is needed during ice-wines production, wherein grapes berries are mainly squashed at low temperature and most of the water is retained in the skins as ice and the juice with higher content of sugars, acids and aromatic compounds is extracted (Nurgel et al., 2004).
Withering is a forced, variable and progressive loss of water from parenchyma cells of the berry pulp, and is characterized by molecular event which occurred at metabolomic and transcriptomic level (Zenoni et al., 2016). During the withering process occurs a loss of water by evaporation through the skin and it is facilitated by air circulation around berry. Grapes withering is function not only of temperature, relative humidity and environmental pressure, but it depends on the characteristics of each cv. as the strength of the peel, the thickness of the cuticle, the protective layer of bloom and the berry size in terms of surface/volume ratio

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(Tonutti and Mencarelli., 2005; Esmaiili et al., 2007) and structure of the bunches. In general, withering allows to obtain a raw material with a higher concentration in sugars and a final product richer in extractive substances, flavours and glycerol. During the withering process takes place reactions and processes that affect the entire cell biochemistry, particularly the relations between the sugars, the content of organic acids, the transformation of the aromatics and of polyphenols, the changing of membrane permeability as well as the changing in the cellular constituents composition. (Bellincontro et al., 2004). The grape and the produced must final quality depend from the correct control of these changes. For this reason the withering in controlled chambers/plant offer higher guarantees of quality standards observance in the time than the withering on vine or in vineyard. Considering that the fast freezing soon after harvest and the environmental conditions of berries withering strongly influence the process and the final product in terms of time required and quality effects, it has been designed a laboratory plant for testing freezing and withering at the same time (i.e. the same lot of wine grape) at different air speed condition for freezing and withering Sangiovese and Cabernet grapes cv..

2. Materials and Methods

2.1 Pilot plant design

The two pilot plants (one for freezing and one for withering) have been designed and built up in the MAC Lab. They were made up of three separated galvanized steel tunnels, each one with the following dimensions: cross section 400 mm (perpendicular to airflow), height 1000 mm and length 630 mm. In order to manage the air flow rate through the grape bunches, each tunnel was equipped with an independent three-phase axial single fan, (EBM PAPST, A4D300 AA 02-02, Germany) activated using a 0.37 kW, 1.1 A, variable frequency drive (VFD) (EATON, M-Max Drive, USA). The values of air speed detected in the experimental plant were dependent on the fan electric supply frequency controlled by VFD. Considering that 20 Hz generate an air speed close to a normal cold storage room, the frequencies of 35 Hz and 50 Hz were considered suitable for the freezing and the withering tests.

During the withering and freezing trials, a thermocouples system (TC08, PCB Technologies, Italy), equipped with eight channels for the temperature control and connected to PICO^R software, was used to monitor in real time the temperature inside the product and at different positions and heights. Tunnel's fan oscillation frequencies have been set up at 20 up to 50 Hz and the corresponding air velocity (m s^{-1}) was assessed by means of Anemos model anemometer (La Filotecnica, Milan, Italy). A virtual instrument developed in LabVIEW^{TM} has been employed to detect the operative parameters and data recording (product and tunnels temperature, relative humidity, air flow, energy consumption). They have been installed inside a 12 m^3 cold room (one for freezing and one for withering).

2.2 Withering and freezing treatments

Experimental trials were performed on grape (*Vitis vinifera* L.) cv. Sangiovese and Cabernet grew in the south of Basilicata (Italy). For each tunnel the test were carried out using six trays (six repetitions) at the same time. In each tray approximately 1 kg of grape bunches were arranged in a single layer. For the freezing test the experimental plant (3 tunnels) was installed in a cold storage room where the temperature was set to -18°C and -13°C. During the berries cooling/freezing the temperature has been detected and the temperature decreasing kinetic has been calculated in order to measure the half cooling time for each treatment. Relative humidity inside the freezing room was monitored but not controlled. Withering treatment has been carried out inside a +8°C cooling room, wherein a Secco 14 model dehumidifier (Olimpia Splendid, Italy) was used to control and set up the relative humidity at 68%. The experiment lasted until the weight loss rate (% day^{-1}) reached the equilibrium and the weight loss percentage (WL%) was calculated by weight difference between fresh and withered sample as follow: 100 - [(weight of withered sample x 100)/weight of fresh sample].

2.3 Berries technological and physical-chemical parameters

At the beginning and at the end of each test, 3 bunches samples per plastic box were randomly selected for technological and physical-chemical analysis. Berries were manually crushed, the homogenate was filtered through a Whatman n°1 filter paper and used for determining pH, titratable acidity (TA), total soluble solids content (SS), and total phenolics compounds (TPC). Juice pH was measured with IP57 model pHmeter (XS instruments, Italy), TA was assessed by titration of 10 mL g of grape juice diluted with 150 mL of distilled water to pH 8.1 with 0.1 N NaOH, using three drops of phenolphthalein as colorimetric indicator and expressed as g L^{-1} of tartaric acid (OIV-MA-AS313-01, 2009). SS was determined by mean of a digital refractometer (Atago, model 2912-W04, Japan) and results were expressed as °Brix. The TPC was determined according to the Folin-Ciocalteu method (Slinkard et al., 1977), expressed as gallic acid equivalents (GAE). The Folin-Ciocalteau reagent was added to a suitable aliquot of the juice grape in the presence of the Na_2CO_3, and the absorption of the solution was measured at 750 nm.

Gallic acid standard solutions from 15 mg L^{-1} to 500 mg L^{-1} were used to calibrate the method. All analyses were performed in triplicate and the obtained result were statistically analyzed using MATLAB software involving a $p < 0.05$ level.

3. Results and discussion

3.1 Pilot plant parameters - characterization

In order to evaluate the effect of the product load in the experimental plant and its consequence on the air flow the air speed was measured at different frequencies supplied to the electric engine of the fan. The values of air velocities detected are obviously dependent on the fan supplied frequency and the results in Table 1 show that the load of product, despite the higher friction in the tunnel, increases the air flow rate of about 30% due to the reduction of the free section, that creates the condition to increase the air speed on the surface of the product, moreover, the higher density of air due to the low temperature affect the air flow i.e. the speed of the air. These results should be carefully considered in the design of an industrial plant working in these conditions. The half cooling time for freezing grape at different air temperature and speed is shown in Table 2. Reducing the air temperature used for freezing the cooling time decreases, the same result is reached increasing the air speed. Moreover these results should be evaluated in term of energy requirement for the process.

Table 1: Tunnel parameters: fan frequency (f) and corresponding air flow rate (Q) and speed (V) at different test conditions.

f (Hz)	Q (m^3 h^{-1})	v_{EMPTY} (m s^{-1})	T (°C)	v_{FULL} (m s^{-1})
35	987	1.36	- 18	1.81
			- 13	1.85
			+ 8	2.39
50	1400	1.83	- 18	2.08
			- 13	2.11
			+ 8	2.70

Table 2: Half cooling time (s) for freezing grape at different freezing air temperatures and speed

T (°C)	-13		-18	
f(Hz)	35	50	35	50
Sangiovese	3360	2460	2580	1920
Cabernet	3660	3000	3180	2820

The energy requirement in kWh/t at different freezing air temperature and speed is shown in Table 3. Considering that lower temperature causes lower energy consumption for refrigeration due to the reduction of the time required for the process, at the same speed of freezing air, because the cooling power requirement results non significantly different between -13°C and -18°C. Very important, in term of energy requirement result the cv., i.e. the structure of the bunches and the berries characteristics as result from the comparison of the data measured using different cv.

Normally, when the lower temperature is needed the higher is the energy requirement, but our study highlights as decreasing the freezing power and the fan oscillation's frequency it is not reached a benefit in terms of energy consumption. Indeed, data suggest as using lower temperature and higher fan oscillation frequency they lead to lower energy requirement, due to the lower half cooling time involved with these parameters. At -18°C and 50 Hz, the energy requirement compared with -18°C at 35 Hz reduces up to 24.88% and 10.45%, for Sangiovese and Cabernet cv. respectively. The higher values of energy consumption were obtained for Cabernet cv., wherein working at -13°C and 35 Hz we detected an increasing of 17.28% compared with the 50 Hz treatment at the same temperature. The withering process of grape involves the loss of water (WL) from the fruit, due to a reduction of fruit weight.

Table 3: Energy requirement kWh/t for freezing grape at different freezing air temperatures and speed

T (°C)	-13		-18	
f(Hz)	35	50	35	50
Sangiovese	382.9	283	294.1	220.9
Cabernet	417.2	345.1	362.4	324.5

As shown in Figure 1, each variety presents a specific attitude to WL. In Sangiovese cultivar, at the beginning of the test, the daily WL resulted 4.32%, but starting from the third treatment day the daily rate of weight loss decreased to about 1.26%. At the end of the treatment, after 9 days, the total WL resulted about 10%. The daily weight loss of Cabernet bunches presented a similar trend, but lower daily rate due to the different skin of the berries. In the first 2 days of test the daily WL result of 2.28% but starting from the third test day the daily WL resulted of 0.74%. Furthermore, up to ninth day lost 7.5% of initial weight. This result confirms the importance of the cultivar on the withering process. The data of Figure 1 shows that the speed of the air used during the withering process results much more important increasing the attitude of the grape variety to WL. Higher air speed produces higher daily WL but the difference between 35 Hz and 50 Hz result higher in Sangiovese cv. that presents an higher attitude to water loss with respect to Cabernet.

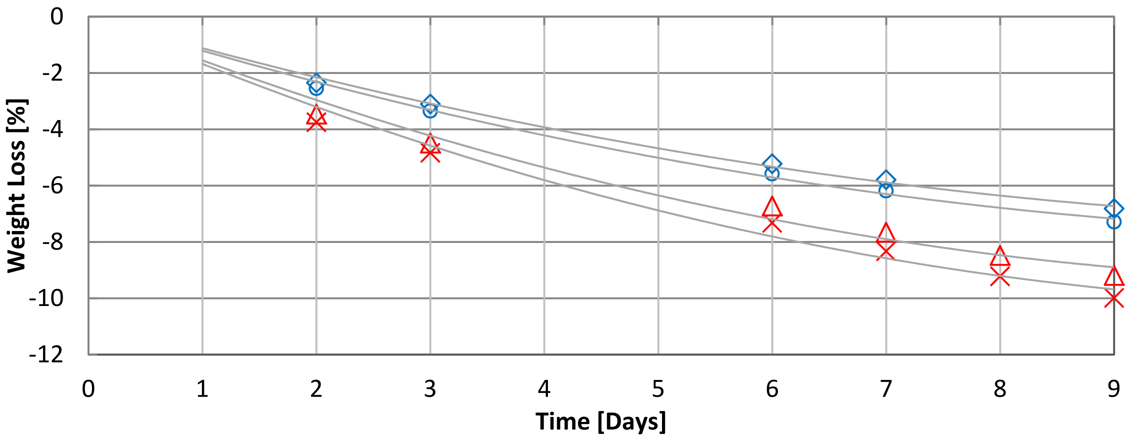

Figure 1: Measured average weight loss day^{-1} during the withering treatment at 8 °C for Sangiovese and Cabernet cultivar and at different setting of VFD (Δ Sangiovese, 35 Hz; X Sangiovese, 50 Hz; ◊ Cabenet, 35 Hz; ○ Cabernet, 50 Hz).

3.2 Analytical parameters

The results of the physical-chemical analysis of the characterization of the grapes before and after the cooling and withering treatments for the parameters of pH, TA, SS and TPC are presented in Figure 2.

3.2.1 Sangiovese

The effect of freezing treatment results significantly different for tartaric acid content (TA), total phenolics compounds (TPC) and soluble solid content (SS) from the control sample. Only for pH the samples resulted not different, despite the samples treated at -18°C resulted slightly different than the samples -13°C. The significant difference of polyphenols content represents an important result, because confirms the important role of the low temperature to preserve the most sensitive fraction to oxidation process that occurs when the grape remain exposed to the “field heat” before the processing operation. The concentration effect on the must due to the water loss in the withered samples resulted significantly different for TPC, SS and pH demonstrating the important effect, on must quality and composition, due to water loss.

3.2.2 Cabernet

The same trend of quality parameters obtained for Sangiovese resulted for Cabernet. In all the samples treated at low temperature TPC, TA and SS resulted significantly different respect the control, this result confirms the importance to cool the product as soon as possible and to maintain a low temperature till the beginning of the wine production, especially for TPC. Short term withering treatments produced, as expected, an increase in SS whether in Sangiovese or in Cabernet, this trend is statistically significant ($p < 0.05$) for both the cv. treated. In Sangiovese berries using the 35 Hz and 50 Hz treatments measured average SS increasing was of 14.08% and 17.02% respectively, while Cabernet grapes during the same treatments under controlled withering showed an increase of SS of 3.1% and 9.96%. This is mainly due to the water loss which leads to concentration of SS, rather than gluconeogenesis pathways. The values found for Sangiovese were similar to those observed in literature by Bellincontro et al. (2004), which carried out a berries withering inside a tunnel under controlled conditions and after 9 day they detected ~ 18% of SS increasing at the day 7. In most cases the analysis of data shows as cooling did not affect the SS amount. In Sangiovese the increase in acidity is strictly due to weight loss, while in Cabernet decrease is likely due to malic respiration (Amati et al., 1983).

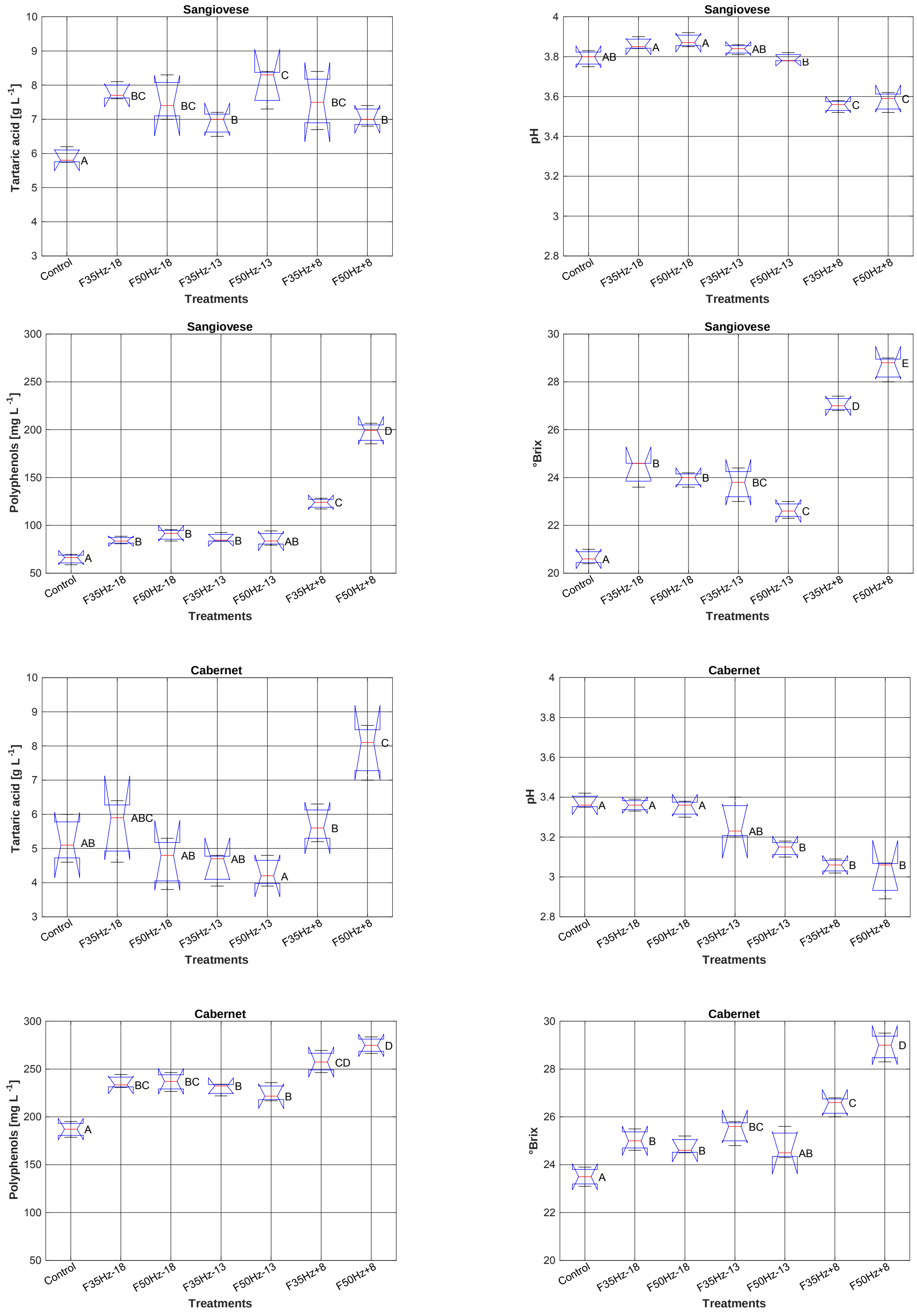

Figure 2: Notched boxplot values of chemical-physical results for Sangiovese (in the upper graphs) and Cabernet (in the lower graphs) cultivars. Notches with different letters are significantly different ($p < 0.05$). All data are expressed as average values ± standard deviation (n=3). Control: untreated sample; F35Hz-18: treatment at – 18 °C and VFD on 35 Hz;F50Hz-18: treatment at – 18 °C and VFD on 50 Hz; F35Hz-13: treatment at – 13 °C and VFD on 35 Hz; F50Hz-13: treatment at – 13°C and VFD on 50 Hz; F35Hz-18: treatment at – 18 °C and VFD on 35 Hz; F35Hz+8: treatment at +8 °C and VFD on 35 Hz; F50Hz+8: treatment at +8 °C and VFD on 50 Hz.

This pattern has been observed even in Malvasia and Trebbiano grapes dried naturally for 3 months, reaching the same values of weight loss (Bellincontro et al., 2002). In some cases the acidity is also affected by the effect of yeast fermentation that can produce organic acid, as well as the dissolution of minerals and acids released from the skin and pulp (Rizzon and Miele, 2002).

4. Conclusion

The wine industry is constantly looking for plant engineering and technological solutions aimed at the production of innovative high quality wines as the market requires, through the optimal management of the grapes after harvest to minimize mechanical damage, adopting processing operations that maximize the retention of aromatic compounds responsible for taste and flavour in wine. In the experimental trials the effects of freezing and withering of wine grapes they have been evaluated, performed in a laboratory prototype tunnels equipped with fans in suitably selected and strictly controlled operating conditions. In comparison between -13°C and -18°C the cooling time decreases at the lowest temperature, but these results should be evaluated in term of energy requirement for the process and further studies are needed in order evaluate the methodological compromise that best adapts to the process. The significant difference of polyphenol content, both for Sangiovese and Cabernet samples, represents an important result, because it confirms the important role of the low temperature to preserve the most sensitive fraction to oxidation process that occurs when the grape remains exposed to the “field heat” before the processing operation. Moreover, pilot plant in withering condition could be exploited for a rapid technological characterization of the cultivars on the basis of the skin break force, since water loss in the berries is strictly connected with it, and it would allow the oenological companies to choose which vineyards can be preferably intended to produce dried grapes. The results obtained could be usefully to design industrial plant for freezing and/or withering.

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