MANAGEMENT OF POSTHARVEST GRAPE WITHERING TO OPTIMISE THE AROMA OF THE FINAL WINE: A CASE STUDY ON AMARONE

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Abstract

Amarone wine is different from regular dry wine due to the postharvest withering of Corvina, Corvinone and Rondinella grapes. Grapes were withered in a commercial facility with variability in terms of temperature and relative humidity (R.H.). Sugar content reached 230-240 g L^{-1} and 280 g L^{-1} at 20% and 30% mass loss, respectively. Most of VOCs (volatile organic compounds) decreased during withering but few VOCs increased during withering and we considered as markers; in Corvinone they were methylhexanoate, dimethylsuccinate, nerol, nonanoate and benzyl alcohol; in Corvina, benzyl alcohol, isoamyl alcohol, 1-hexanol, p-cymen-8-ol, 2,3 pinanediol, 3-oxo-ionol and 3-methyl-1-pentanol, coumaran and damascenone; in Rondinella, hexanol, nonanoate, methyl vanillate, damascenone, 3-oxo-ionol, eugenol, p-cymen-8-ol, 2,3

pinanediol, coumaran and raspberry keton. Olfactive descriptors of the wines and the potential aroma of the combination of Corvina wine with the wines of the other two varieties at different percentages of mass loss are reported.

Keywords: grape withering, VOCs markers, wine, aroma

1. Introduction

Passito wines are produced after berry dehydration is applied as a postharvest treatment before vinification. Special technologies are used to induce postharvest water loss from the berries as described by Accordini (2013). Mencarelli & Tonutti (2013) identified three different processes of water loss in wine grape berries: 1) dehydration, which is well controlled in terms of temperature, relative humidity (RH) and ventilation; 2) drying, involving uncontrolled conditions such as sun-drying; and 3) withering, when the process occurs in a naturally ventilated room with or without a partial control of temperature and RH.

The amount of water loss, due to the thermohygrometric and ventilation conditions, influences the concentration of the phenolic metabolites produced (Rolle, Giacosa, Río Segade, Ferrarini, Torchio & Gerbi, 2013; Panceri, Gomes, De Gois, Borge & Bordignon-Luiz, 2013). It has been shown that the rate and the amount of mass loss (m.l.) significantly influence the changes in the polyphenol gene expression (Bonghi, Rizzini, Gambuti, Moio, Chkaiban, & Tonutti, 2012) and that the dehydration temperature affects the gene expression and polyphenolic metabolites (Zamboni et al., 2008; Mencarelli, Bellincontro, Nicoletti, Cirilli, Muleo & Corradini, 2010; Marquez, Serratosa, Lopez-Toledano & Merida, 2012). Volatile organic compounds (VOCs) are also greatly influenced by postharvest water stress of wine grapes (Franco, Peinado, Medina & Moreno, 2004; Costantini, Bellincontro, De Santis, Botondi & Mencarelli, 2006; Santonico, Bellincontro, De Santis, Di Natale & Mencarelli 2011; Noguerol-Pato, González-Álvarez, González-Barreiro, Cancho-Grande & Simal-Gándara, 2013). During postharvest dehydration, berry VOCs increase due to water loss (concentration effect), however some classes of volatiles increase more than expected, as shown by Nogerol-Pato et al. (2013) and Centioni, Tiberi, Pietromarchi, Bellincontro & Mencarelli (2014). If the dehydration process technically controls water loss, the metabolic change can be managed to obtain a final product with the desired characteristics.

Amarone wine is the most well-known dry wine produced from dehydrated grape and economically speaking represents one of the most important Italian wines (6500 ha produce 13 million 750 mL bottles with an average commercial price of 62 USD/bottle). It is produced from three main red grape varieties: Corvina, Corvinone, and Rondinella. Corvina is the main variety for the production of Amarone. It has been studied, in relationship to postharvest withering, in terms of molecular analysis (Zamboni et al, 2008), skin wall modification (Zoccatelli et al, 2013), mechanical properties and polyphenol composition (Rolle et al, 2013).

Ferrarini (2014) carried out an extensive comparison of the withering kinetics of the three main varieties of Amarone in different thermohygrometric conditions and the effects on acidity, sugars, and colour. Ferrarini coined the term "Amarone sweet spot" to indicate the point where the composition and metabolic evolution of dehydrated grapes reach an equilibrium to optimize the quality of Amarone wine. This spot is not easy to define because it requires a continuous analytical process which can only be done commercially using non-destructive sensors because the metabolic process is very dynamic and changes year by year.

Knowledge of VOC changes in wines, from different percentages of m.l. of grape and different varieties, during withering in commercial facilities, is very important in planning the quality of the final wine. How great should the m.l. be for specific varieties be? How many grapes of one variety with a percentage of m.l. are necessary for a particular aroma? To answer these questions, we carried out a study on the grape withering of the three main varieties, Corvina, Corvinone, and Rondinella, by sampling berries at harvest and at 20%, 30% of m.l. and analysing both the VOCs of grapes and of the wines obtained. In this paper, we report data on the wine VOCs focusing on the pattern of specific compounds which decreased or increased in the wines from grapes withered at 20% and 30%, choosing Amarone as wine but the findings can be worthwhile also for other similar wines. Samplings was performed at 10, 20, 30%, and 50% m.l. but here m.l. of 20 and 30% are presented as these are typical percentages used with grapes to produce Amarone

2. Materials and Methods

2.1. Grapes and withering process

The red wine grape varieties Corvina, Corvinone and Rondinella (*Vitis vinifera* L.) were harvested in the second half of September (2013) with a sugar content of 170-180 g L^{-1} and titratable acidity of 6.3-6.9 g L^{-1}, from the vineyards of Cantina Valpolicella di Negrar in the Valpolicella area, close to Verona (Italy). Bunches without any visible sign of fungi and wounds were carefully harvested, and placed in perforated plastic boxes (40cm x 60cm x 12cm) in two layers for a total of about 8 kg. For each variety, 100 plastic boxes were collected and placed inside a large withering commercial facility, located in Cantina Valpolicella di Negrar (Verona), as described by Accordini (2013). The system consisted essentially of dehumidifiers running at ambient temperature with 10–15 air changes per hour. The dehumidifiers have a humid air inlet turned towards the dehydration loft and an opening at the top which directs the air above the trays where the grapes are laid out to dehydrate. There are two other openings on the sides, the air at ambient temperature goes through one opening, while the other releases hot air resulting from the cooling of the hot plate inside the dehumidifier. This hot air is released outside so that the temperature of the loft does not increase. Inside the dehydration loft there are large fans (120 cm diameter) which move to distribute the dry air over all the grapes. When this system is properly managed, on cool and sunny days, the external air is only circulated in the dehydration loft. On wet and rainy days on the other hand, when humidity is close to saturation, the humidity levels are kept between 60% and 70% within the dehydration loft.

The plastic boxes were placed on a scale to continuously monitor the mass loss. The tests were run until the grapes reached 50% of mass loss, however sampling for chemical analyses and vinification were carried out only at 20% and 30% m.l. About 200 kg of grapes for each variety were removed after the withering process, at 20% and 30% m.l. and immediately processed for wine production. In total there were 3 samples for each variety, including the wine made from fresh harvested grapes.

2.2. Vinification

Grapes were manually emptied from the plastic boxes on the grape-sorting tables in order to eliminate rotten berries. Grapes were then crushed and destemmed. 5 g hL^{-1} of SO_2 was added.

Fermentation started with the addition of commercial yeast (Premium Zinfandel, Enologica Vason, VR, Italy) after rehydration, in three stainless steel containers for each variety and each weight loss. These yeasts resist high sugar content and produce a high content of glycerol, low acetic acid, and high alcohol content (18% v/v) with a low degradation of malic acid. The temperature was controlled between 25 and 30°C. After 24 h from the beginning of fermentation, malolactic bacteria (ELIOS 1- Lallemand-Italia, VR, Italy) were inoculated. During fermentation and simultaneous maceration, cap management consisted of two daily punch downs (morning and afternoon, 1 min each). Fermentation ended when sugars were below 2 g L^{-1} for the wine at harvest, and between 3.5 and 7.0 for the wine from withered grapes.

After racking, the pomace was pressed and resulted in wine added to the main wine. Rackings were done after 24/48 h after pressing and until complete wine clarity; 2-4 g hL^{-1} of SO_2 were added after the 1st racking. The wine was placed in glass containers in a cold temperature for tartaric stabilization.

In mid-January, after analytical controls, SO_2 adjustment was performed, and after filtering through 1 μ filter cartridge, the wines were bottled in 750 mL bottles, and capped with a plastic air-tight stopper.

2.3. Chemical analyses

Analyses of wines made from grapes at harvest and after 20 and 30% m.l. were performed by a calibrated Winescan FT 120 (Foss, Hillerod, DK) to measure sugars, acidity, pH, glycerol, volatile acidity, total polyphenols and total anthocyanins.

For each variety, ten bottles (the number of bottles was high to be sure to have enough sample for analyses) of wine at each sampling were collected from the stainless steel tank. For VOC analysis, three bottles of wine were used and the rest was used for sensorial analysis.

Aroma compounds were extracted from wines by solid phase extraction (SPE) according to the protocol described by Di Stefano (1991). Gas chromatographic analysis was carried out using an Agilent 7890A gas-chromatograph (Agilent Technology, Santa Clara, Ca, USA) and an Agilent 5975C quadrupole Mass Spectrometer (MS). The carrier gas was helium at a constant flow rate of 1 mL min^{-1}. The capillary column was an HP-Innowax (30 m length, 0.25 mm i.d., 0.25 mm film thickness) from Agilent. The temperature program of the column oven started at 30 °C, then increased from 30 °C min^{-1} to 60 °C, 2 °C min-1 to 190 °C, and 5 °C min^{-1} to 230 °C. The MS detector scanned within a mass range of m z^{-1} 30-450. Volatile compounds were tentatively identified by comparing the mass spectra with those available in the data system library (NIST 08, National Institute of Standards and Technology, Gaithersburg, MD, 2008) and using published retention indices. A positive characterisation was achieved when a volatile compound was identified with a probability of >70% in at least three independent samples. When possible, the identity of the compounds was further confirmed by comparison of the retention times with authentic standards here reported: isoamyl alcohol, (E)-furan linalool ox., (Z)-furan linalool ox., 1-hexanol, 1-pentanol, t-2-hexen-1-ol, 2-hexenal, (E)-, 2-phenylethanol, acetophenone, α-citral, β-citral, trans 3-Hexen-1-ol, cis 3-Hexen-1-o α-terpineol, β-citronellol, benzaldehyde, benzyl alcohol, α-ionol, 1-octanol, guaiacol, vanillin, eugenol, geranic acid, geraniol, acetovanillone, homovanillyl alcohol, linalool, methyl salicylate, myrtenol, nerol, farnesol, t-cinnamate.

All reagents and standards were purchased from Sigma-Aldrich (St Louis, MO). The quantification was carried out by comparing the peak area of each compound to that of the internal standard (1-heptanol).

2.4. Sensorial analysis

The objective of this sensorial analysis was to compare the olfactive perception of the wines made from the grapes of the three varieties, dehydrated at different percentage of mass loss, to validate the findings of VOCs analysis. We did not use an official panel of few persons but we use an unofficial tasting with 24 persons (5 researchers, 5 winery directors, 3 wine chemical industry agents, 7 winemakers, 4 wine marketing agents) represented by producers and winemakers who were not professional panelists but who knew very well the characteristics of Amarone wine. The reason of this decision has been conditioned by the final objective of this research work which is winery-addressed. We have followed the basic lines of the Quantitative Descriptive Analysis (QDA®**)** where products require similar characteristics and the panelists are able to discriminate. The unofficial panelists were asked, after smelling, to evaluate the main known aromatic descriptors based on own experience on Amarone tasting, and writing down the olfactive perceptions. There was no score of olfactive perception. Tasting was performed in the Cantina Valpolicella di Negrar; when more than 50% (12) tasters recorded the same aromatic nuance, the descriptor was reported.

2.6 OAV

To evaluate the contribution of a specific volatile compound to the wine aroma the odour threshold (OT) and the odour activity value (OAV) was determined. The OAV was calculated as the ratio between the concentration of an individual compound and

the perception threshold described in the literature. Compounds with OAV > 1 should be considered to contribute individually to the wine aroma, although it was suggested that it is also necessary to consider the contribution of those substances with OAV > 0.2, because of the synergic effect of similar compounds with similar structure or odour ((Gómez-Míguez, Gómez-Míguez, Vicario, &
Heredia, 2007)

2.5. Statistical analysis

Statistical analysis was performed using SPSS version 17.0 for Windows (SPSS Inc., Chicago, IL, USA). The Tukey B test for *p< 0.01 or 0.05* was used in order to establish statistical differences by one-way analysis of variance (ANOVA).

3. Results and Discussion

Figure 1 reports the temperature pattern and relative humidity during grape withering. In the first 40 days, the temperature inside the withering room followed the outside temperature exactly, reaching about 12°C, which means that the system worked with open windows and fans sucking air from the outside to inside. From day 40 to day 65, the outside temperature was higher than inside which means that the cooling system was working inside to cool the grapes. Up to the end of the withering period, the temperature inside was maintained constantly higher than outside. All three grape varieties reached 10% and 20% m.l. at the same time, while 30% m.l. was achieved on day 50, 64 and 72, in Rondinella, Corvinone and Corvina, respectively, with rates of mass loss of 0.60, 0.47, and 0.42 %/day. At 50% m.l., the variability was: 120, 132 and 140 days in Rondinella, Corvinone and Corvina, respectively. As explained above, only samples from 20% and 30% m.l. were analysed and used for vinification because these are the m.l. used for Amarone wine.

Sugar content in grapes reached 230-240 g L^{-1} at 20% m.l. in the three grape varieties and 280 g L^{-1} at 30% m.l. (data not shown). Titratable acidity was 6.3, 6.5, 6.9 g L^{-1}, in Corvina, Corvinone and Rondinella wines at harvest, respectively, and rose to 6.70, 7.45, and 6.89 g/L at 30% m.l. (**Table 1**).. Rondinella showed the highest acidity in the wine produced at harvest; the acidity decreased, in all the varieties, at 20% m.l. and then increased again in the last sampling (30% m.l.); Corvinone wine had the highest acidity. This acidity pattern is well known during grape dehydration. The decrease in acidity during slow dehydration is an event that was also observed in long term dehydration under uncontrolled environmental conditions in Malvasia and Trebbiano (Bellincontro et al. 2002) as well as in other varieties (Zoccatelli et al., 2013; Noguerol-Pato et al. 2013), and it has been attributed to malic acid depletion because this acid is strongly dependent on water stress and temperature (Lopez et al. 1988, Salon et al. 2005, Koundouras et al. 2006; Ferrarini, 2014). This event occurs even in on-vine dehydration (Figuereido-Gonzales et al., 2013). pH value of wines increased in all three varieties during withering without the changes showed by the acidity at 20% m.l. (**Table 1**). This pH behaviour is not anomalous in grape dehydration and is due to the great release of cations such as K^+ which, above all at low temperatures as was our case, chemical reacts with weak acids (tartaric and malic acids) producing the typical buffer effect of weak acids and their salts as with grape must (Zoccatelli et al., 2013). A significant progressive increase was observed in glycerol, achieving similar values in the three varieties, in the wine from 30% m.l. grapes (**Table 1**). As expected in these types of wine, volatile acidity enhanced from around 0.44, 0.48, and 0.52 mg L^{-1} in Rondinella, Corvinone, and Corvina, respectively, up to about 0.62-0.68 mg L^{-1} in all the samples, without significant differences. A large increase in the content of total polyphenols and total anthocyanins was noted in wines from 20% and 30% m.l. grapes (**Table 1**). Corvina and Rondinella wines showed the initial highest and lowest contents of polyphenols, with 1326 mg L^{-1} and 930 mg L^{-1}, respectively. At 20% m.l., the increase was null in Corvina wine, while in Corvinone and Rondinella, increases of 30% and 70% of total polyphenols were detected. In wines from 30% m.l. grapes, the total polyphenols increased to 25%, 80%, and 91% in Corvina, Corvinone, and Rondinella, respectively. Also the total anthocyanins rose significantly: from 47% (20% m.l.) and 62% (30% m.l.) in Corvina, from 55% to 63% in Corvinone, and from 39% to 54% in Rondinella. Water loss during drying, dehydration or withering generally leads to a solute concentration. In addition, depending on the rate and amount of water loss, metabolites can be oxidised in combination with water loss (Serratosa, Lopez-Toledano, Merida & Medina, 2008) or a new synthesis of phenolic compounds can occur (Cirilli et al, 2012). In our case, the long process of water loss due to the low temperature and high relative humidity, affected the metabolism of the berry not only in term of water stress (in our case the high RH mitigates the effect of water stress) but also in term of senescense. In this regard, Zoccatelli et al. (2013) reported: "Grapes that dehydrate slowly rather than quickly need more time to lose weight and may thus be more subject to a senescence syndrome that may account for different metabolic and transcriptional responses". Polyphenols are metabolites very reactive to biotic and abiotic stress. Also in berry dehydration there was a significant increase in some phenolics but not in all of them

(Mencarelli et al, 2010; Bonghi et al, 2012; De Sanctis, Silvestrini, Luneia, Botondi, Bellincontro & Mencarelli, 2012; Rolle et al, 2013) depending on the amount of water loss and dehydration temperature in well-controlled conditions of water loss. Figueiredo-González, Cancho-Grande & Simal-Gándara (2013) did not find a similar increase but they worked in a non-specified environmental condition with a very high percentage of water loss (62%) over a very long period (82 days). This involved a sugar increase of 0.3°Brix day^{-1} and weight loss rate of 0.8% day^{-1}. Thus, a great water loss and long time of withering could be the cause of a significant polyphenol loss due to oxidation and to the senescence metabolism. As suggested by Ferrarini (2014), the "time" factor more than the amount of water loss plays an important role for the quality of withering.

Our data showed a higher increase in polyphenols than expected, thus it is conceivable that the low withering temperature delayed water loss stress without provoking immediate cell death but triggering a grape tissue response in term of higher extractability but also in higher synthesis in polyphenols. Ferrarini (2014) reported a similar increase in polyphenols during the withering of Corvina, Corvinone and Rondinella, which also had a higher extractability due to cell wall degradation (Zoccatelli et al, 2013). In Corvina grapes dehydrated in controlled conditions, Rolle et al. (2013) found an increase in total flavonoids of skin and seeds, proanthocyanidins, and low-weight flavan-3-ols of seeds. Panceri et al. (2013) also found a great increase in polyphenols and anthocyanins in Carbernet Sauvignon and Merlot during dehydration under well-controlled conditions. As regards polyphenols biosynthesis, Bonghi, Rizzini, Gambuti, Moio, Chkaiban, & Tonutti (2012) reported, in Raboso grapes subjected to slow and fast dehydration, an upregulation of genes of stilbenes and flavonols while there was downregulation of the one of flavon-3-ols.

In the aroma formation of Amarone wine, in addition to the VOCs from genetic characteristics and fermentation, a significant contribution to the wine aroma comes from the withering/dehydration process. As reported by Tonutti and Bonghi (2013) and D'Onofrio (2013), the physiology of the berry cell is greatly affected by the water loss occurring during withering/dehydration and by the technology process. In our case, the pool of VOC changes during withering: most decrease, a few compounds do not change, and a few increase. Not all of them play a significant role in the final aroma of the wine, since some have low concentrations or a very low perception threshold, however they all contribute to what is referred to as the wine's "bouquet".

Table 2 reports the concentrations of the main classes of compounds. 188 VOCs were detected (supplement), and we have decided not to report all of them in text but they have been grouped into aliphatic alcohols, benzenoids, monoterpenes, nor-isoprenoids, acids, and esters. Further on, specific VOCs changes which decreased or increased during withering were reported. Aliphatic alcohols were higher in Corvinone and Rondinella wines at harvest. During withering, they did not change in Corvina wine, while in Corvinone and Rondinella they decreased significantly, and, in the end, the concentration was higher in Corvina than in the other two wines. Benzenoid concentration was the highest in Rondinella and Corvinone at harvest and decreased progressively during withering, reaching 13721, 14990, and 17937 µg L^{-1} in Corvinone, Corvina and Rondinella, respectively. The monoterpene content was low compared to the other class of compounds (**Table 2**) and decreased significantly during withering especially at 30% m.l. Nor-isoprenoids had similar concentrations: there was a significant increase (2-3 folds) at 20% m.l. then a great decline in all the varieties at 30% m.l.. Acids increased significantly during withering in the three varieties and, especially, in Rondinella. As expected, the ester concentration also declined significantly in the wines from withered grapes, from 10000-12000 µg L^{-1} to 4000-5500 µg L^{-1} in wines from 30% m.l. grapes. Most of these esters come from fermentation process and give fruity notes to wines. In our tests, 65% of total acids consisted of 2,6 dimetyl 6-hydroxy-2,7-octadienoate followed by hexadecanoate and nonanoate in the three varieties but the highest concentration was in Rondinella. If the decrease in most classes of compounds (benzenoids, monoterpenes, nor-isoprenoids) is due to the oxidative process which occurs during the postharvest withering, the increase in acids in the wines from dehydrated grapes, above all at 30% m.l., is probably due to the higher extractability as a consequence of the degradation of the cell membrane and cell wall with intense water loss. Most of these acids are fatty acids and their contribution to the aroma is very low. When they are in high concentrations, they generally give negative aroma descriptors in wines (Bakker & Clarke, 2012).

By analysing the concentration of single compounds for each wine variety, Rondinella wine, at 30% m.l., showed the highest number of compounds with the highest concentration (25) among the three varieties, while Corvina and Corvinone, had only 13 and 5 compounds, respectively. Thus, Rondinella wine, at 30% m.l., had the highest concentration of VOCs. This result does not mean, however, that Rondinella has the strongest aroma, because there is no strict correlation between concentration and perception. Indeed, the sensory perception depends on the partition coefficient which is related to hydrophobicity of the volatile compound. In addition, the use of threshold levels and partition coefficients for assessing volatile odour in a beverage depends on the temperature of acqueous solution containing the volatile compound, the presence of any other constituents in substantive amount (e.g. sugars, acids, ethanol), the concentration of volatile compound, and the presence of other volatile compounds (Bakker and Clarke, 2012).

Table 3 lists selected (according to their concentration) compounds of each variety whose concentration decreased during withering. The discussion about the VOC concentrations, their odour threshold (OT), when available, and about the odour activity value (OAV) is henceforth reported. In Corvinone, the loss of compounds had already taken place in wines from 20% m.l. grapes. Regarding esters, the concentrations of ethyl(S)-(-)-lactate (ethereal, buttery, fruity nuances), which was in the highest concentration among esters, and diethyl malate (apple) were below the threshold values. More important for olfactive perception, isopenthyl acetate (fruity) and ethyl 2-methylbutanoate (fruity, herbaceous), were signifcantly above the threshold and with OAVs very high and, even though they decreased during dehydration by about 80%, their concentration remained with high OAV. As regard 4-ethoxy ethylbenzoate (fruity, guava, fejoa, raspberry nuances) we did not find the threshold value. In terms of alcohols, the greatest loss was 2-phenylethanol (rose-honey like), the most concentrated alcohol which was significantly higher than the threshold. This compound was considered by Versini et al. (1999) to be one of the aroma markers for Amarone. Isoamyl alcohol, the second concentrated alcohol after 2-phenylethanol, was below the perception threshold, while guaiacol was much higher than the OT (1764 vs 10). As the aromatic nuance of guaiacol (smoky, medicine) is one of the most common aromatic marker in passito red wine, its high concentration was expected. Regarding nor-isoprenoids, β-damascenone (fruity, honey) had the highest concentration which was reduced by almost 50% already in 20% m.l. wines, remaining much higher than the OT. As regards this compound it is needed to specify that the OT changes greatly between the aboratory matrix and wine and so its contrivution to aroma can be more indirect than direct (Pineau, Barbe, Van Leeuwen, Dubourdieu, 2007). Few compounds rose during dehydration and we have considered them as markers for Corvinone withering, because their concentration increased with the withering process. Among esters, methylhexanoate, dimethylsuccinate, and ethylvanillate, all characterized by fruity and sweet aroma nuances, increased in 20% m.l. grapes and then slightly decreased or remained constant, but the last one was below the OT (**Table 4**). In the class of acids, hexanoic acid and nonanoic acid increased and the former, during withering, overpassed the OT while for the latter we did not find any reference. These acids are fatty acids coming from cell membrane degradation mainly of yeasts during the wine process but in Amarone, because of the withering process, their concentration can increase due to greater cell degradation due to water loss. The odour notes are not always pleasant. Specific aromatic compounds such as nerol, and benzyl alcohol greatly increased (4-6 fold), but only nerol was significantly higher than OT while benzyl alcol concentration was much lower (**Table 4**). The other important compound in term of aroma contribution was the cinnamate which slightly rose with withering but the concentration was significantly higher than the OT (**Table 4**).

In Corvina wines, compounds such as isopenthyl acetate, ethyl 2-methylbutanoate, 2-phenylethanol, and 4-ethoxy ethylbenzoate decreased during withering but the concentration was significantly higher than threshold and with high values of OAV (**Table 3**). This is similar to our findings in Corvinone wines. There was also a significant loss of 1-hexadecanol, trans-8-OH-linalool, triacetin, and N-(3-methylbutyl) acetamide which is considered a *Botrytis cinerea* marker (Tosi et al., 2012). In contrast, as markers, benzyl alcohol increased greatly and, at higher concentration, than in Corvinone wines (**Table 4)** already at 20% m.l., and was the only volatile compound found in common between Corvina and Corvinone wines. Anyway the concentration was much lower than the OT. Isoamyl alcohol had the highest concentration but, the opposite to what observed in Corvinone wine, increased from 9659 $\mu g\ L^{-1}$ up to 10317, at 30% of m.l. (**Table 4**); its concentration was significantly lower than the OT but if we consider the OAV in Table 4, the values are higher than 0.2 which, for some authors (Gómez-Míguez, Gómez-Míguez, Vicario, & Heredia, 2007), the lowest limit. At the same time, the pattern could be of interest from a metabolic viewpoint because it derives from aminoacid catabolism, thus its increase would indicate that cell metabolism is compromised. The other identified markers were 1-hexanol (below the OT), p-cymen-8-ol and 2,3 pinanediol, with very low concentrations, although a reference OT value could not be found in the literature. These compounds are in the terpenol class and are characterized by balsamic nuances which are typical of the Amarone aroma. Versini et al. (1999) reported these compounds in monoterpene form together with α and β-terpinene and terpinolene and with 4-terpineol, which was considered an important contributor to Amarone aroma. We found this last compound at very low concentration in Corvinone and at higher concentration at 30% m.l. in Corvina (15.8 μL/L) but overall in Rondinella (21.3 μL/L) (data not shown). Moreover, β-damascenone was significantly higher than OT and increased greatly with withering and its contribution to Corvina wine is important. 3-oxo-ionol, coumaran and 3-methyl-1-pentanol were other compounds whose concentration rose during withering and we have not found any OT reference (**Table 4**).

In Rondinella wine, a significant decrease was found for ethyl(S)-(-)-lactate but, as told before, the concentration was much lower than the OT, while the decrease of 2-phenylethanol, the compound with the highest concentration (at the same level as the Corvinone wine), was great at 30% m.l. (**Table 3**); as for Corvina, triacetin and 4-ethoxy ethylbenzoate diminished significantly already at 20% m.l. (**Table 3**). In the class of alcohols, as markers, we measured an increasing trend of 1-hexanol and benzyl alcohol but the values were below the OT (**Table 4**) while above the OT, eugenol, a typical aroma of Amarone wine, as well as p-cymen-8-ol, 2,3 pinanediol, and methyl p-hydroxycinnamate were found, contributing to the typical balsamic aroma. As in Corvina wines, β-damascenone and 3-oxo-ionol increased significantly in Rondinella wines as well as coumaran and raspberry keton, another typical aroma nuance of Amarone wine (**Table 4**).

In conclusion, 8, 9 and 12 VOCs markers were identified for Corvinone, Corvina, and Rondinella, respectively. There are 6 compounds in common between Rondinella and Corvina; only one, benzyl alcohol, is common between Corvina and Corvinone, while there are no compounds in common between Corvinone and Rondinella. Thus, the VOCs markers, regardless the OT, characterizing Corvinone wine are mainly esters such as methylhexanoate (fruity), ethylvanillate (smoky), dimethylsuccinate (fruity) and acids such as cinnamate (cinnamon), hexanoate (sweat), and nonanoate (waxy, fatty). As reported above, esters are mainly produced during the fermentation process and are lost during aging. The esters produced during grape withering are also easily lost depending on the dehydration temperature (Santonico et al, 2010). As regards the monoterpene alcohol, nerol (rose), monoterpene biosynthesis occurs during grape ripening, starting from berry set. These compounds are mainly found in the berry skin. Thus, concentrations of geraniol and nerol, which characterize the aroma of young wines, can rapidly decrease after 2/3 years of bottle ageing and no longer contribute in the same way to the wine aroma (Darriet, Thibon & Dubourdieu, 2012). In our case, the significant increase in nerol in Corvinone wine is to attribute to the stress effect as a consequence of water loss, since terpenes act as plant volatile messengers (Loreto & Schnitzler, 2010). The increase in fatty acids and their esters such as nonanoate and methylhexanoate in wines from the greater mass loss of berries (20 and 30% m.l.), might be the result of berry cell wall degradation during withering (Zoccatelli et al, 2013) but also due to the yeast degradation during fermentation. Finally, dimethyl succinate is an ester which has been found in high concentration in Madeira wines during ageing (Câmara, Alves & Marques, 2006). In Corvina there was an increase in the compounds known for the balsamic olfactive nuances, such as p-cymen-8-ol (balsamic), 2,3 pinanediol (resin), as well as in the compounds derived from water stress and carotenoid degradation during withering, such as β-damascenone (apple compote) and 3-oxo-ionol (tobacco), and coumaran (green tea nuance). In Rondinella, the marker compounds were similar to the ones of Corvina with the highest increase in hexanol (as in Corvina) and nonanoate (as in Corvinone).

The olfactive descriptors of wines, separated by variety, perceived by the expert panelists is shown in Figure 2. Corvinone wine from 20% m.l. grapes had more complex aroma than the one from 30% m.l.; fruity, floral, fruit compote, and balsamic nuances were the descriptors of 20% m.l. wine while 30% m.l. wine was characterized by ginger and tobacco nuances; notes such as smoky, withered rose, honey and medicinal were perceived as in wine at 20% m.l. as in the one at 30% m.l. In Corvina, we assisted to greater complexity of aroma in 30% m.l. wine which was characterized by fruity, floral and fruit compote (which were expressed also in 20% ml. wine such as in Corvinone only 20% m.l. wine) but also balsamic, resin, spicy, vanillic olfactive notes were detected which were no perceived in 20% m.l. wine. In Rondinella wines, 20% m.l. wine was perceived as more complex than 30% m.l. wine as for Corvinone: fruit, tropical fruit, fruit compote, honey and malt nuances were present in 20% m.l. wine while in 30% m.l. wine only apple compote, overripe fruit, and green tea descriptors were identified. It appears that Corvina takes advantage from greater mass loss while Corvinone and Rondinella reach the typical aromatic features at 20% mass loss, obviously with the same time of withering in this case. This beahviour has been observed also in the analysis of VOCs of the berries during the withering (Mencarelli, Bellincontro, Accordini, Cuzzola & D'Onofrio, 2014). In order to give some useful indications to wineries and winemakers, in **Table 5**, the combinations of the olfactive descriptors of the Corvina wines from 30 % m.l. grapes (the main variety and the regular percentage of mass loss used) with those of Rondinella and Corvinone wines from 20 and 30% m.l., is reported. Thus each box reports the addition of the aroma descriptors of the three wines, in this case combined 1:1 or 1:1:1, coming from the three main Amarone varieties. This is just a sum of the olfactive descriptors of wine without any ageing and it does not want to represent the real situation of the particular combination, but it is evident that combination of three varieties or the increase of percentage of mass loss increase the aroma complexity. This does not mean that the aroma is better because i.e. the combination of 30% Corvina with Rondinella 30% gives medicinal nuance which is unpleasant. Anyway, to confirm that the *modus operandi* is not wrong, the aroma descriptors are not distant from known olfactory perception of Amarone. Indeed, it has been reported that olfactive perceptions are traditionally reminiscent of jam, cherries in alcohol and fresh fruit (marasca cherry, cherry and wild berries), with notes of herbs and tobacco and more spicy and vanilla notes (Ugolini, 2003). Accordini (2013) also cited: "The sweet, balsamic and dried fruit olfactory notes harmonize well with an alcohol content that frequently exceeds 16%". Varietal wine of Corvina is reported to provide spicy nuances (cinnamon, clove) and red fruit (cherry) while varietal wine of Corvinone provides mild spicy nuance, often of black pepper (Ferrarini, 2014). This nuance seems due to rotundone, a sesquiterpene compound concentrated on the berry skin wax. We did not find this compound in our wines in wines but as reported by Zhang, Howell, Krstic, Herderich, Barlow, & Fuentes (2015) this compound is very sensitive to different agronomic factors which reduce the concentration such as an early ripening (Amarone grapes are harvested early), sun exposure, vigour, clone, climactic variation and also is greatly lost during vinification (Caputi, L., Carlin, S., Ghiglieno, I., Stefanini, M., Valenti, L., Vrhovsek, U., et al, 2011).

4. CONCLUSIONS

Significant changes in VOCs take place during dehydration. Wines produced from dehydrated grapes have a completely different aroma compared to wines from non-dehydrated grapes. In the case of Amarone, the wines from the three varieties behaved similarly in terms of the losses of the main classes of compounds during withering, but behaved differently in terms of the increase in some compounds which were considered as markers. Corvina and Rondinella have markers with the aromatic nuances of balsamic, tobacco, apple compote and green tea, while Corvinone has markers with fruity, cinnamon, smoky nuances.

In an attempt to give an useful indication to winemakers and producers to blend the wine produced from the single variety, we have created a small matrix of odourant descriptors where Corvina wine from 30% m.l. grapes is combined with Corvinone and Rondinella wines from 20 and 30% m.l. grapes. In addition different amounts of Corvina, Corvinone, and Rondinella grapes can be used, that have been withered with different percentages of mass loss, to obtain different Amarone wines. The concentration of some of these VOCs is likely the effect of the asymptomatic presence of *Botrytis cinerea* in the berry (Fedrizzi et al., 2011), as well as specific compounds such as N-(3-methylbutyl)-acetamide. This is because it is very difficult to control the fungus in the huge commercial facilities used for grape withering in the Valpolicella area where our tests were performed.

Conflict of interest

The authors declare no conflicts of interest

ACKNOWLEDGMENTS

We would like to thank Cantina Valpolicella di Negrar for the use of their facilities and for the financial support.

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FIGURE AND TABLE CAPTION

Figure 1. Temperature (T°C) and relative humidity (RH%) patterns outside and inside the commercial facility during grape withering. Vertical dotted lines indicate the days when the indicated mass loss (m.l.) was reached. The rectangle and the oval in the days of dehydration axis (top), indicate the variability needed to reach 30% and 50% of grape mass loss (m.l.), respectively, among the three varieties.

Figure 2. Olfactive descriptors of Corvinone, Corvina and Rondinella (from top to the bottom) of wines from 20 and 30% mass loss grapes. The reported descriptors are the ones perceived by the panelists (only descriptors perceived by more than 50% of the tasters are reported).

Table 1. Main enological parameters measured in Corvina, Corvinone, and Rondinella wines produced at harvest (0), 20%, and 30% of grape mass loss (m.l.), respectively. Data are the average (±sd) of three analyses carried out on three separate bottles. Different letters within the column represent significant statistical differences per $p < 0.05$.

Table 2. Main categories of VOCs (Aliphatic alcohols, Benzenoids, Monoterpenes, Nor-isoprenoids, Acids, and Esters) measured in Corvina, Corvinone, and Rondinella wines produced at harvest, 20%, and 30% of grape m.l., respectively. Data are the average (±sd) of three analyses carried out on three separate bottles. Different letters in the same class of compounds represent significant statistical differences per $p < 0.01$ *or* 0.05.

Table 3. Decreasing VOCs in Corvina, Corvinone, and Rondinella wines produced at harvest, 20%, and 30% of grape m.l., respectively. Principal descriptors of aromatic impact are also reported for each volatile. VOC = volatile organic compound; OT = odour threshold; OAV = odour active values. Data are expressed in $\mu g\ L^{-1}$ and are the average of three analyses (±sd) carried out on three separate bottles. Different letters within each row represent significant statistical differences per $p<0.01$ *or* 0.05

Table 4. VOC markers of Corvinone, Corvina and Rondinella wines**.** Principal descriptors of aromatic impact are reported for each volatile. OT = odour threshold; OAV = odour active values. Data are expressed in $\mu g\ L^{-1}$ and are the average of three analyses (±sd) carried out on three separate bottles. Different letters within each row represent significant statistical differences per $p<0.01$ *or* 0.05.

Table 5. Combination of olfactive descriptors of Corvina wine from 30% mass loss (m.l.) grape with Corvinone and Rondinella wines produced from 20% and 30% of grape mass loss. The boxes with the descriptors as perceived by the panelists (only descriptors perceived by more than 50% of the tasters are reported) refer to the sum of the descriptors of the wines at the indicated percentage of mmass loss (m.l.) for each variety. When the same aroma descriptor was detected in both wines, it was reported as single descriptor.

Table 1

	Titratable acidity (g L^{-1})	**pH**	**Glycerol** (mg L^{-1})	**Volatile acidity** (g L^{-1})	**Total polyphenols** (mg L^{-1})	**Total anthocyanins** (mg L^{-1})
Corvina 0	6.30 (±0.04)e	3.13 (±0.02)ef	6.60 (±0.18)d	0.52 (±0.03)bc	1326 (±24)c	125 (±11)f
Corvina 20%	5.46 (±0.09)h	3.31 (±0.04)b	8.10 (±0.32)c	0.48 (±0.03)cd	1376 (±43)c	184 (±10)de
Corvina 30%	6.70 (±0.10)cd	3.42 (±0.05)a	9.40 (±0.40)a	0.62 (±0.08)ab	1652 (±28)b	203 (±21)cd
Corvinone 0	6.50 (±0.06)de	3.20 (±0.03)d	6.00 (±0.21)de	0.48 (±0.09)cd	1024 (±37)d	161 (±12)e
Corvinone 20%	5.72 (±0.11)g	3.34 (±0.06)ab	8.70 (±0.23)b	0.47 (±0.03)cd	1338 (±37)c	249 (±18)b
Corvinone 30%	7.45 (±0.09)a	3.38 (±0.06)a	9.54 (±0.65)a	0.68 (±0.06)a	1840 (±41)a	263 (±18)ab
Rondinella 0	6.90 (±0.07)bc	3.07 (±0.04)f	5.65 (±0.25)e	0.44 (±0.04)d	930 (±22)d	181 (±20)de
Rondinella 20%	5.90 (±0.10)fg	3.23 (±0.07)cd	9.00 (±0.23)ab	0.51 (±0.06)cd	1595 (±27)b	251 (±19)b
Rondinella 30%	6.89 (±0.06)bc	3.30 (±0.05)bc	9.48 (±0.18)a	0.65 (±0.08)a	1779 (±30)a	278 (±27)a

Table 1

Table 2

	At harvest	20%	30%
Aliphatic alcohols (µg L^{-1})			
Corvina	12941 (±282)def	11971(±253)fg	12162 (±102)efg
Corvinone	15727 (±131)a	11907 (±153)fg	10299 (±156)h
Rondinella	14003 (±276)bc	13461 (±151)cd	11520 (±202)g
Benzenoids (µg L^{-1})			
Corvina	18178 (±202)cd	19937 (±387)b	14990 (±290)ef
Corvinone	24930 (±287)a	20048 (±190)b	13721 (±285)f
Rondinella	25290 (±300)a	25359 (±253)a	17937 (±184)d
Monoterpenes (µg L^{-1})			
Corvina	336 (±32)bc	311 (±21)c	76 (±8)e
Corvinone	373 (±43)ab	313 (±17)c	74 (±8)e
Rondinella	367 (±28)ab	336 (±32)bc	186 (±10)d
Nor-isoprenoids (µg L^{-1})			
Corvina	326 (±21)c	555 (±31)b	26 (±3)f
Corvinone	560 (±23)b	991 (±42)a	84 (±6)e
Rondinella	294 (±35)c	1019 (±42)a	109 (±6)d
Acids (µg L^{-1})			
Corvina	499 (±25)f	429 (±23)f	1336 (±76)b
Corvinone	650 (±25)e	708 (±19)cd	1367 (±78)b
Rondinella	682 (±34)de	769 (±27)c	1874 (±93)a
Esters (µg L^{-1})			
Corvina	11064 (±166)bc	7575 (±108)e	4055 (±120)i
Corvinone	12001 (±176)a	8067 (±120)de	4980 (±91)h
Rondinella	10682 (±239)c	6551 (±108)f	5523 (±90)gh

Table 2

Table 3 & 4

Table 3

			harvest			20% of m.l.			30% of m.l.		
CORVINONE	descriptor	OT§	VOC	sd	OAV	VOC	sd	OAV	VOC	sd	OAV
Isopenthyl acetate	Fruity	30	480.0	±30a	16.00	410.0	±26b	13.67	319.0	±18c	10.63
Isoamyl alcohol	Fruity-winery whisky, malt	30000	12462.0	±110a	0.42	10165.0	±70b	0.34	10036.0	±85b	0.33
Ethyl lactate	Ethereal, buttery, fruity	250000	3999.0	±31a	0.02	674.0	±25b	0.00	659.0	±17b	0.00
Ethyl 2-methylbutanoate	Fruity (pineapple, banana), apple, herbaceous	1	324.0	±18a	324	167.0	±17b	167	138.0	±9c	138
β-Damascenone	Fruity, honey	0.05	185.0	±11a	3700	102.0	±9b	2040	72.0	±9c	1440
Guaiacol	Smoke, sweet , medicine	10	1764.0	±110a	176	1058.00	±91b	105	1068.0	±40b	106
2-phenylethyl alcohol	Floral, woody (rose-honey like)	10000	24150.0	±120a	2.42	13062.0	±65b	1.31	13062.0	±50b	1.31
Diethyl malate	Apple	760000	1704.0	±32a	0.00	577.0	±21b	0.00	560.0	±11b	0.00
4-ethoxy-ethylbenzoate	Fruity (raspberry, guava, fejoa)	*	1237.0	±31a		176.0	±11b		159.0	±10c	
CORVINA											
Isopenthyl acetate	Fruity	30	442.0	±31a	14.73	351.0	±37b	11.70	326.0	±17b	10.87
Ethyl lactate	Ethereal, buttery, fruity	250000	3446.0	±62a	0.01	2134.0	±41b	0.01	1786.0	±31c	0.01
Ethyl 2-methylbutanoate	Fruity (pineapple, banana), apple, herbaceous	1	260.0	±16a	260	182.0	±8b	182	141.0	±11c	141
1-hexadecanol	Waxy, floral	**	2499.0	±111a		1221.0	±31b		792.0	±67c	
2-phenylethyl alcohol	Floral, woody (rose-honey like)	10000	17679.0	±125a	1.77	18370.0	±97a	1.84	13988.0	±104b	1.40
***trans*-8-OH-linalool**	Floral	**	228.0	±11a		169.0	±9b		130.0	±12c	
Diethyl succinate	Fruity	100000	3247.0	±37a	0.03	2024.0	±51b	0.02	1018.0	±21c	0.01
Triacetin	Mild tropical fruit	*	1486.0	±12a		1195.0	±27b		648.0	±44c	
4-ethoxy-ethylbenzoate	Fruity (raspberry, guava, fejoa)	*	1127.0	±72a		533.0	±33b		208.0	±22c	
N-(3-methylbutyl) acetamide	Mild vinegar	*	1727.0	±82a		1646.0	±62a		611.0	±35b	
RONDINELLA											
Isopenthyl acetate	Fruity	30	270.0	±27a	9.00	178.0	±31b	5.93	100.0	±14c	3.33
Isoamyl alcohol	Fruity-winery, whisky, malt	30000	10870.0	±112a	0.36	10433.0	±69b	0.35	10377.0	±92b	0.35
Ethyl lactate	Ethereal, buttery, fruity	250000	2953.0	±61a	0.01	1273.0	±35b	0.01	233.0	±27c	0.00
Ethyl 2-methylbutanoate	Fruity (pineapple, banana), apple, herbaceous	1	300.0	±12a	300	246.0	±7b	246	170.0	±16c	170
1-hexadecanol	Waxy, floral	**	2261.0	±42a		2080.0	±12b		1800.0	±12c	
2-phenylethyl alcohol	Floral, woody (rose-honey like)	10000	24738.0	±133a	2.47	24235.0	±92b	2.42	13988.0	±66c	1.40

***trans*-8-OH-linalool**	Floral	**	280.00	±22a		131.0	±13b		134.0	±10b	
Diethyl succinate	Fruity	100000	2744.00	±74a	0.03	2250.0	±107b	0.02	1526.0	±67c	0.02
Triacetin	Mild tropical fruit	*	1740.00	±77a		693.0	±22b		726.0	±17b	
4-ethoxy-ethylbenzoate	Fruity (raspberry, guava, fejoa)	*	1312.00	±21a		576.0	±19b		564.0	±14c	

OT = odour threshold (μg L^{-1}); §references of odour perception threshold reported in literature (Guth, 1997; López De Lerma et al., 2012)
VOC = volatile organic compound (μg L^{-1}); sd = standard deviation; OAV = odour activity value
*not found in literature
**not significant

TABLE 4

CORVINONE	descriptor	OT§	harvest VOC	harvest sd	harvest OAV	20% of m.l. VOC	20% of m.l. sd	20% of m.l. OAV	30% of m.l. VOC	30% of m.l. sd	30% of m.l. OAV
Methyl hexanoate	Fruity (apricot, pineapple)	84	114.0	±8b	1.36	146.0	±10a	1.74	146.0	±10a	1.74
Dimethyl succinate	Faint, pleasant odour	*	14.0	±2b		31.0	±4a		25.0	±4a	
Nerol	Floral, rose	400	170.0	±16c	0.43	578.0	±22a	1.45	440.0	±22b	1.10
Hexanoic acid	Sweat	140	122.0	±10b	0.87	310.0	±9a	2.21	310.0	±9a	2.21
Nonanoic acid	Nutty odour	*	43.0	±12b		165.0	±11a		178.0	±11a	
Ethyl vanillate	Sweet	990	244.0	±21b	0.25	377.0	±10a	0.38	228.0	±10b	0.23
Cinnamic acid	Cinnamon	5.1	74.0	±8b	14.51	94.0	±11a	18.43	94.0	±11a	18.43
Benzyl alcohol	Nutty	200000	15.0	±16b	0.00	195.0	±8a	0.00	185.0	±8a	0.00
CORVINA											
Isoamyl alcohol	Burnt, whisky, malt	30000	9659.0	±110b	0.32197	9499.0	±130b	0.31663	10317.0	77±a	0.34
1-Hexanol	Herbaceous, resin, flower	8000	579.0	±30c	0.07238	1078.0	±65b	0.13475	1786.0	39±a	0.22
Benzyl alcohol	Floral, phenolic, balsamic	200000	50.0	±3c	0.00025	1107.0	±30b	0.00554	1230.0	31±a	0.01
p-Cymen-8-ol	Camphor, balsamic	*	1.0	±0b		34.0	±6a		35.0	3±a	
2,3-Pinanediol	Resin, balsamic	*	4.0	±0c		6.0	±0b		10.0	±0a	
β-Damascenone	Apple, rose, honey	0.05[1]	150.0	±11c	3000	364.0	±22b	7280	500.0	18±a	10000
3-*Oxo*-ionol	tobacco	**	121.0	±9c		147.0	±10b		180.0	17±a	
Coumaran	Green tea	*	20.0	±3c		30.0	±6b		79.0	3±a	
3-Methyl-1-pentanol	Fusel	500	31.0	±2b	0.062	58.0	±3a	0.116	59.0	1±a	0.12
RONDINELLA											
1-Hexanol	Herbaceous, resin, flower	8000	705.0	±18c	0.09	809	±19b	0.10	1786	±19a	0.22
Benzyl alcohol	Nutty	200000	32.0	0c	0.00	371	±16a	0.00	320	±11b	0.00
Methyl *p*-hydroxy cinnamate	Balsamic	*	31.0	0b		67	±9a		81	±7a	
Eugenol	Clove	6	30.0	±4b	5.00	60	±7a	10.00	60	±1a	10.00
Methyl vanillate	Spicy, vanille	3000	190.0	±12c	0.06	326	±19a	0.11	263	±11b	0.09
***p*-Cymen-8-ol**	Camphor, balsamic	*	6.0	0b		41	±7a		40	±4a	
2,3-Pinanediol	Resin, balsamic	*	2.0	0b		78	±7a		80	±9a	
β-Damascenone	Apple, rose, honey	0.05	139.0	±7c	2780	613	±14a	12260	563	±11b	11260
3-*Oxo*-ionol	Tobacco	**	181.0	±8c		339	±11a		219	±7b	
Nonanoic acid	Nutty odour	*	24.0	±4c		84	±6b		200	±14a	
Coumaran	Green tea	*	10.0	0c		20	±2b		42	±8a	
Raspberry keton	Fruity, red fruit	*	12.0	0b		32	±6a		40	±7a	

OT = odour threshold (μg L^{-1}); [§]references of odour perception threshold reported in literature (Takeoka et al., 1991; Ferreira et al., 2000; Ferreira et al., 2002; Lopez et al., 2002; Culleré et al., 2004; Guth, 1997; Zhang et al., 2012)

VOC = volatile compound (μg L^{-1}); sd = standard deviation

OAV = odour activity value; [1] β-Damascenone is characterized by a very low perception threshold in hydroalcoholic solution as compared to red wine, where it is over 1000-fold higher (Pineau et al., 2007)

*not found in literature

**not significant

Table 5

	Corvina 30% m.l.
Corvinone 20% m.l. + Rondinella 20% m.l.	*balsamic, resin, spicy, floral, fruit compote, vanillic, fruity, tropical fruit, apple compote, tobacco, ginger*
Corvinone 30% m.l. + Rondinella 30% m.l.	*balsamic, resin, spicy, floral, fruit compote, vanillic, tobacco, ginger, apple compote, green tea, overripe fruit, medicinal*
Corvinone 30% m.l.	*balsamic, resin, spicy, floral, fruit compote, vanillic, intense tobacco, ginger*
Rondinella 30% m.l.	*apple compote, balsamic, green tea, spicy, overripe fruit, medicinal, intense tobacco, ginger*

Figure(s)
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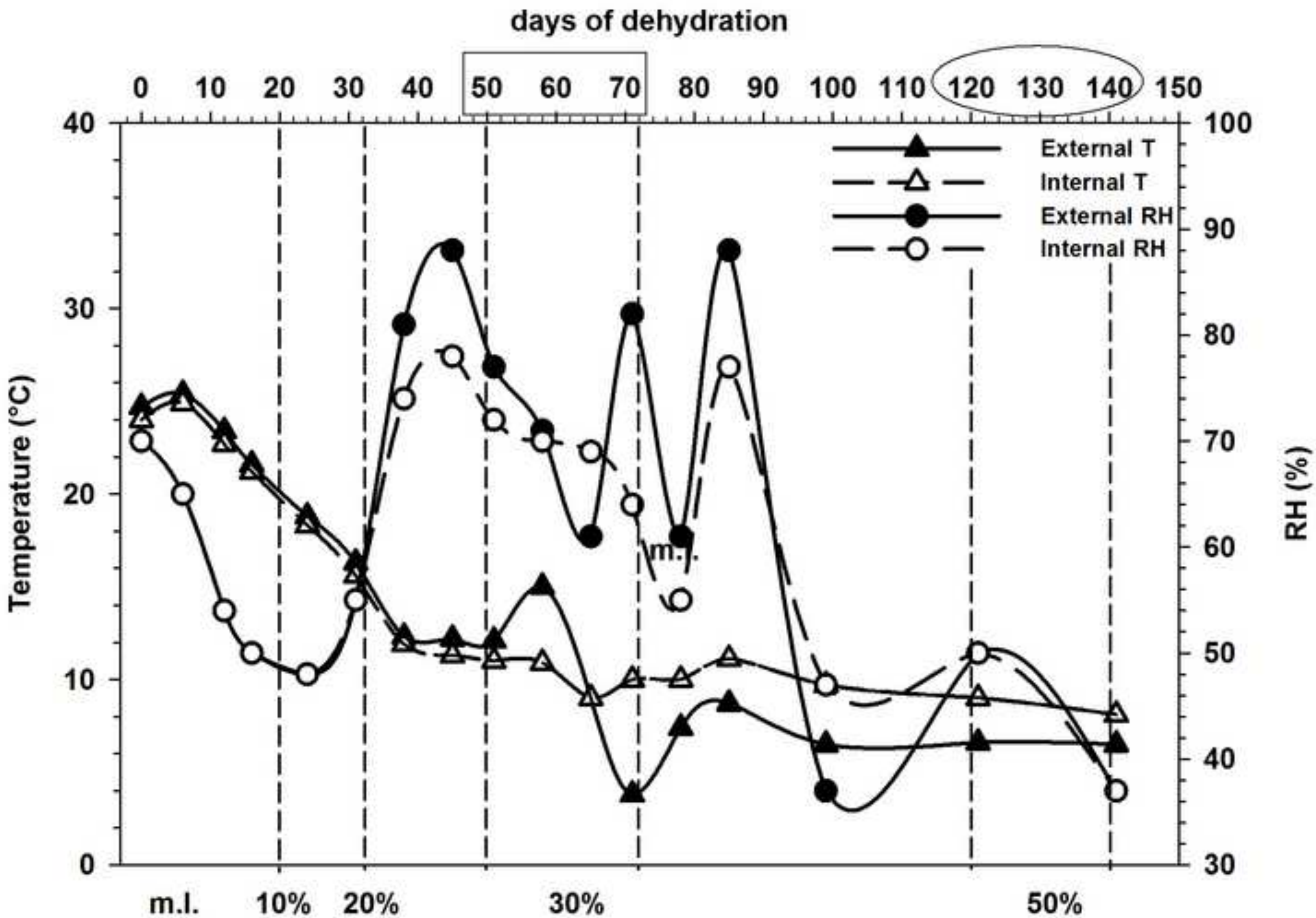

Figure 2

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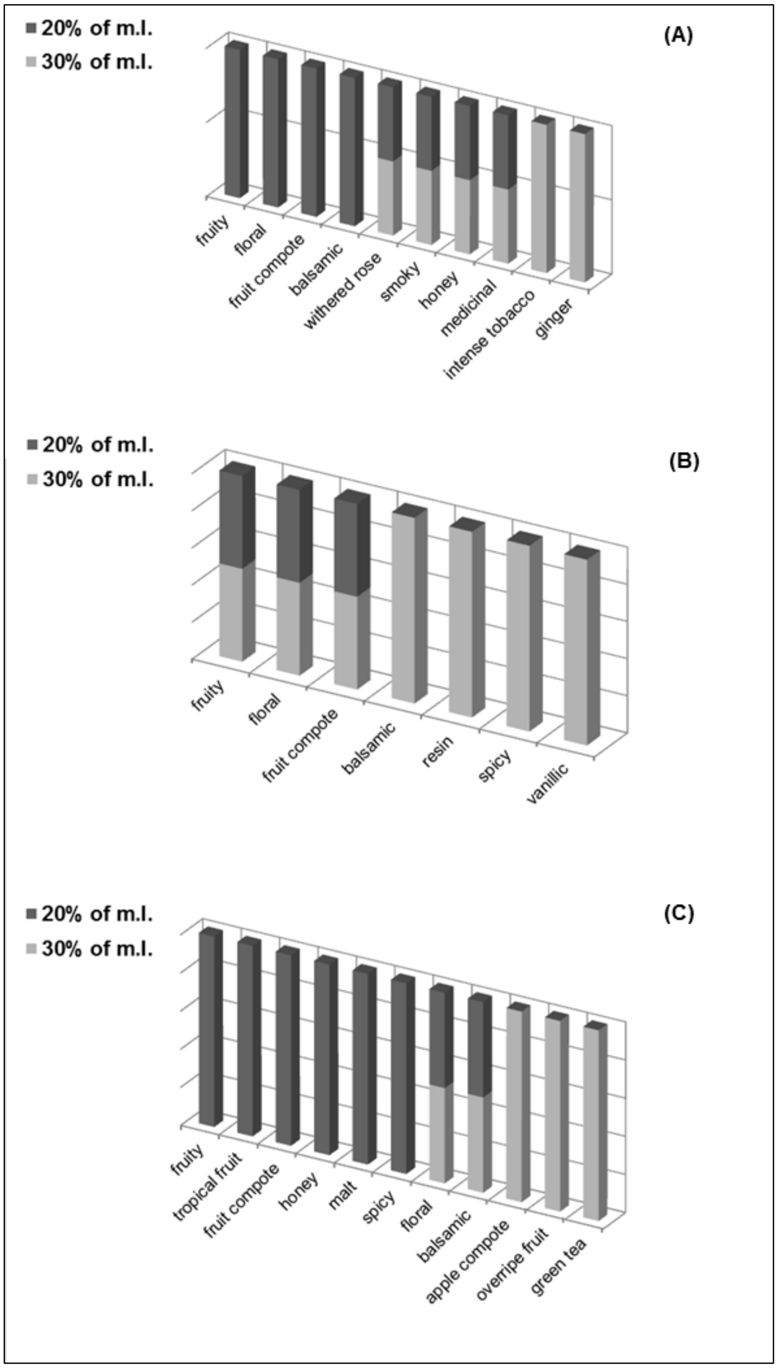

(A) Corvinone
(B) Corvina
(C) Rondinella