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Blends of wood chips from oak and cherry: impact on the general phenolic parameters and sensory profile of a white wine during the aging process

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Summary

Today, there is a restricted knowledge about the potential impact of the use of different wood chip species on the white wine aging process. This lack of knowledge is even greater when wood species are used in blends of different species. Thus, the aim was to carry out a comparative analysis of the impact of different blends of wood chip species, involving oak and cherry wood, on different phenolic and color parameters, browning potential index and sensory profile of a white wine during the aging process. During the aging time studied, the use of wood chips induced an increase of wine phenolic content and color intensity, particularly in wines aged in contact with cherry wood chips alone or in blends with oak wood chips. A similar tendency was also detected for browning potential index. Regarding the sensorial results, the use of different wood chip species has an impact on the increase of "woody aroma" for the wines aged with oak wood chip species and also an increase of "body" and "astringency" descriptors for the wines aged with oak chips alone or blended with cherry chips. This work advances our understanding of the impact of different wood chip species separately or by the use of blends on white wine quality.

K e y w o r d s : aging time; phenolic content; white wine; wood chips blends; sensory profile.

Introduction

Wine aging with alternative systems consists of adding wood to wine so that it acquires certain properties recalling wine that is aged in barrels. Thus, pieces of wood from different types, such as, wood origin, size and toasting level, are usually used to simulating the aging process in barrels (Gallego *et al.* 2012, Navojska *et al.* 2012, Oberholster *et al.* 2015). It is also important to note that the increased used of these alternatives are mainly related to low investments, similar sensorial results obtained in shorter time and simplicity of use (Fernández de Simón *et al.* 2009). In Europe, alternative products could not be used until 2006, and only some experimental practices were allowed (EEC 822/87). The EEC regulation No. 606/2009 of 10 July 2009 modified previous rules by regulating the use of pieces of oak for winemaking and the description and presentation of wine undergoing this treatment. It states that the pieces of oak wood used for winemaking and aging must be exclusively come from the *Quercus* genus and with different toasting levels or also without toasting.

The oak wood chips may be added in different moments of winemaking process, namely, during alcoholic fermentation (Rodriguez-Bencomo *et al.* 2010, Gomez Garcia-Carpintero *et al.* 2011, Kyraleou *et al.* 2016a) or, alternatively, they can be placed into the tanks of finished wine, much of the time, the most used option (Del Álamo Sanza and Nevares 2006, Koussissi *et al.* 2009, Kyraleou *et al.* 2016b).

In general, the use of oak wood chips is described essentially in red wine technology and aging. Thus, several works were published about the impact of different oak wood chips on red wine composition and sensory properties (De Coninck *et al.* 2006, Gonçalves and Jordão 2009, Pérez-Magariño *et al.* 2009, Gortzi *et al.* 2013, Oberholster *et al.* 2015). However, for white wines only a few works described the potential impact of the use of oak wood chips on white wine characteristics (Gutiérrez Afonso 2002, Pérez-Coello *et al.* 2000, Sánchez-Palomo *et al.* 2017). In addition, most of these works use oak wood, and the possibility of using other woods, although not authorized by the OIV and European Union, as in the case of acacia and cherry wood, has also been the object of comparative studies, especially in red wines (Sanz *et al.* 2010, Chinnici *et al.* 2015, Tavares *et al.* 2017), and more recently in white wines (Délia *et al.* 2017, Alañón *et al.* 2018) and rosé wines (Santos *et al.* 2019). In fact, currently the use of other non oak wood species is an important question, because the increasing demand of oak wood caused a remarkable potential increase in costs due to the limited availability of material. Furthermore, the high demand of oak wood products has also an ecologically negative impact of harvesting oak trees in forests, where the replacement of trees is not guaranteed.

Nevertheless, the studies that have been carried out reported the use each of the different wood chips species separately and not through the use of mixtures of these

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different wood species. Thus, it will be interesting to take potential advantage of the specific characteristics of each wood species (such as oak and cherry) and analyze the potential impact on the quality of the wines when mixed, making possible to analyze their possible complementarity when blended. However, in the case of oak wood chips, the producer companies already use lots containing blends of different species of oak wood and also with different toasting level (Jordão *et al*. 2012, Gómez-Gallego *et al*. 2015).

Thus, in this context, the main goal of this study was to carry out a comparative analysis of the impact of different blends of wood chip species involving *Q. alba*, *Q. petraea* and *P. avium* on different global phenolic composition, color properties and sensory parameters of a "Encruzado" white wine during the aging process.

Material and Methods

White wine: The wine used in this experiment was a white wine made entirely from a Portuguese *Vitis vinifera* white grape variety "Encruzado", harvested during the vintage 2017 and vinified by the experimental winery at the "Instituto Superior de Agronomia" in Lisbon, following the classical procedure for white wines.

The sulphitation of the grapes (50 mg·L^{-1} of SO_2) was followed by a natural clarification process for 24 h at 11 °C. The must was fermented in a stainless steel tank using a standard *Saccharomyces cerevisiae* yeast strain (Fermol Arome Plus; AEB Group, Brescia, Italy) and inoculated at 20 g·hL^{-1}. The alcoholic fermentation process was completed in 13 d keeping the temperature around 18 °C. After the alcoholic fermentation the wine was racked and removed from contact with the lees.

Experimental conditions: A total of three different wood chip species was used: cherry (*Prunus avium*), American (*Quercus alba*) and French (*Quercus petraea*) oak wood chips purchased from AEB Bioquímica Portuguesa S.A. company (Viseu, Portugal). According to the company producer, all the wood chips presented a medium toasting level and an average particle size of 8 mm.

At a laboratory scale different wood chip blends were produced, containing wood chip mixtures properly homogenized from the different wood species studied in the proportion of 50 %. Thus, the following mixtures of wood chips were made: cherry wood with American oak; cherry wood with French oak and American oak with French oak. In addition, single lots containing only wood chips from one specie were also used as a control.

The white wine samples (10 liters each) were aged in contact with the different wood chip blends and single wood chip lots (0.5 g·L^{-1}) in glass bottles for 60 aging days at cellar temperature (between 14-15 °C) and stirred manually twice a week for 1 min. A standard white wine (without wood chip addition) was also considered. The wine samples were filtered (pore diameters 13 µm) before laboratory analysis. The concentration of wood chips used in this experimental work took into account previous works carried out on white and rosé wines (Délia *et al.* 2017, Santos *et al*. 2019), as well as taking into account the low phenolic content quantified in the white wine used in this experiment (Tab. 1).

General physico-chemical characterization: The general white wine physico-chemical characterization (pH, total and volatile acidity, alcohol content, total and free sulfur dioxide) was made following the analytical methods recommended by OIV (2012). All analyses were done in duplicate.

Phenolic and color parameters analysis: Total polyphenolic content from white wines was determined according to Ribéreau-Gayon *et al*. (2006), while non-flavonoid and flavonoid phenols were determined by use of the Kramling and Singleton (1969) methodology. All of these parameters were expressed as gallic acid equivalents by means of calibration curves with standard gallic acid from Extra-Synthese (Genay, France).

Color intensity at 420 nm was evaluated following the methodology described by OIV (2012). Browning potential index was determined following the methodology proposed by Singleton and Kramling (1976). Thus briefly: Test tubes were filled with 20 mL of the wine to be tested. Control and test samples were sparged thoroughly with nitrogen and oxygen, respectively. All tubes were sealed hermetically and kept at 55 °C for 5 d. The test was conducted with treated and untreated wine, and the browning value difference was calculated by measuring the increase in absorbance at 420 nm. Tannicity was quantified following the procedure developed by De Freitas and Mateus (2001). This method includes a dilution 1:50 with a hydroalcoholic solution (12 % vol., pH = 3.2 and T = 20 °C), followed by analysis in the turbidimeter (d0). Then, 8 mL of the previous dilution and 300 µL of BSA (Bovine Serum Albumin) are put into a tube and after agitation and 45 minutes in darkness, a second reading is carried out (d1). The final value (NTU·mL^{-1}) was calculated from: Tannicity = (d1 - d0)/0.08.

Sensory evaluation: Each white wine sample was stored for 24 hours at room temperature before sensorial analysis, which was performed at 20-22 °C in a sensorial analysis room with individual booths for each expert and according to standardized procedures (ISO 3591, 1977). All evaluations were conducted in the morning from 10:00 to 12:00 h. Twelve expert judges with wine tasting experience, most of them winemakers, evaluated the white wine samples during a single sensory evaluation session, after 15, 30 and 60 aging days in contact with the different wood chips.

All expert judges were previously selected and trained during 6 months considered the sensorial attributes of white wines, in particular for white wines from "Encruzado" grape variety, one of the most common Portuguese white grape variety used to produce wines with potential wood contact. During this training period several sessions were carried out in order to get a judges training about the meaning of each attribute and achieving intensity rating in a reliable way. The procedures are described in ISO 11132 (2012a) and the practices explained in general guidelines for the selection, training and monitoring of selected assessors and expert sensory assessor in ISO 8586 (2012b).

It is important to note that all wine sensorial attributes used were selected by consensus in order to adequately describe the white wine appearance, aroma and taste sensory similarities and differences under supervision of the panel leader. Thus, the sensorial attributes used were the following: appearance ("color intensity" and "limpidity"), aroma ("intensity" and "quality", "woody", "oxidation", "almond", "spicy", "vegetal", "floral" and "fruity"), taste sensations ("acidity", "body", "astringency", "balance", "flavor quality" and "persistency"), and "global appreciation". Persistency attribute was considerate as the ability of wine tastes and aromas to remain present in the mouth after wine has been swallowed, while flavor quality attribute was considerate as the balance between wine aromas, tasted, and tactile sensations.

The experts scored each sensory attribute (appearance, aroma and taste sensations), on a 1 to 5 point scale (1 = absence; 2 = little intensity; 3 = moderate intensity; 4 = intense; 5 = high intensity), while global appreciation was scored on a 0 to 20 point scale (0 to 4 = bad; 5 to 9 = mediocre; 10 to 13 = pleasant; 14 to 17 = good; 18 to 20 = very good). Finally, wine samples were presented to the panel in tasting glasses marked with three digit numbers and in a randomized order.

Statistical analysis: The data are presented as mean ± standard deviation. Results obtained were statistically tested by analysis of variance (ANOVA, one-way). Tukey test ($p < 0.05$) was applied to the data to determine significant differences between white wines. In addition, a principal component analysis (PCA) was also used to analyze the data and to study the relations between the white wines aged in contact with the different wood chip blends during 60 aging days and their chemical and sensory characteristics. All analyses were performed using SPSS Software program version 25.0 (SPSS Inc. Headquarters, Chicago, Illinois, U.S.A.).

Results and Discussion

At the beginning of the white wine aging process with different wood chip blends, the general wine physico-chemical characteristics, phenolic composition and browning potential index are shown in Tab. 1. It is evident that the white wine used in this study showed acceptable physico-chemical standards, showing a low volatile acidity (0.28 g L^{-1} acetic acid) and an adequate SO_2 free values (24 mg L^{-1}). In addition, for phenolic composition, the white wine used exhibited the typical phenolic content quantified for white wines made from "Encruzado" grape variety already show in a previous study (Délia *et al*. 2017).

Table 1

General physico-chemical, phenolic composition and browning potential index of the "Encruzado" white wine used in the study

Parameters	Values
General physico-chemical composition[a)]	
Volatile acidity ($g \cdot L^{-1}$ acetic acid)	0.28 ± 0.02
Total SO2 ($mg \cdot L^{-1}$)	88 ± 2.0
Free SO2 ($mg \cdot L^{-1}$)	24 ± 1.3
pH	3.42 ± 0.01
Total acidity ($g \cdot L^{-1}$ tartaric acid)	5.25 ± 0.03
Alcohol degree (%, v/v 20 °C)	14.6 ± 0.1
Phenolic composition and browning potential index[b)]	
Total phenols ($mg \cdot L^{-1}$ gallic acid eq.)	268.26 ± 3.23
Non-flavonoid phenols ($mg \cdot L^{-1}$ gallic acid eq.)	93.00 ± 0.92
Flavonoid phenols ($mg \cdot L^{-1}$ gallic acid eq.)	175.26 ± 2.65
Color intensity (abs. units at 420 nm)	0.085 ± 0.002
Tanning power ($NTU \cdot mL^{-1}$)	10.26 ± 2.24
Browning potential index[c)]	0.036 ± 0.005

a) Average values of two replicates ± standard deviation;
b) Average values of three replicates ± standard deviation;
c) Absorbance difference values obtained in the wine samples with and without nitrogen.

General phenolic parameters evolution: The results obtained for general phenolic parameters of the white wines aged in contact with the different blends of wood chip species during 60 aging days are shown in Tab. 2. For total phenolic contents, taking into account the initial value of the white wine before being placed in contact with the different wood chip species (Tab. 1), an increase of the values in all wines after 15 aging days was observed. Thus after this aging period, control wine (without wood chips contact) showed the significantly lowest value (264.5 $mg \cdot L^{-1}$ of gallic acid equivalents), while white wines aged in contact with wood chips showed in general a tendency for higher total phenolic content (ranged from 266.6 to 286.6 $mg \cdot L^{-1}$ of gallic acid equivalents). In fact, the majority of the published works reported a higher phenolic composition of red and white wines aged in contact with oak wood as well as with other wood species (De Coninck *et al*. 2006, Kozlovic *et al*. 2010, Nunes *et al*. 2017, Tavares *et al*. 2017). These increase in total phenol content is an evident consequence of a phenolic molecules transfer from wood to wine. In addition, according to several authors (Délia *et al*. 2017, Santos *et al*. 2019), even a short wine maturation in contact with wood is sufficient for a significant increase of wood phenols in wines, particularly when wood chips are used. The significantly highest total phenolic content was found in the white wine aged in contact with a blend containing wood chips from cherry and American oak woods (286.6 $mg \cdot L^{-1}$ of gallic acid equivalents). On the other hand, among the other white wines aged in contact with the different wood chips, the values for total phenols were not significantly different between them, except for the white wine aged in contact with single French oak wood chips, which showed a significantly lower value (266.6 $mg \cdot L^{-1}$ of gallic acid equivalents), having this value was even very similar to the value obtained for the control wine after 15 aging days (264.5 $mg \cdot L^{-1}$ of gallic acid equivalents).

Between 15 and 60 aging d, there was a general tendency for a slight decrease or stabilization of total phenolic content in most of white wines. The slight decrease was more evident for the white wines aged in contact with American oak wood chips alone and the blend containing cherry and American oak wood chips, where there was a decrease between 2.5 and 4.6 % of total phenolic content, respectively. This decrease in total phenols since 15 aging days could be due to the precipitation of phenolic compounds and above all due to

Table 2

Evolution of global phenolic parameters, color intensity, tannicity and browning potential index during 60 aging days of a white wine from "Encruzado" grape variety in contact with different wood chip blends

Parameters	Aging time / white wines						
	15 days						
	C	CAm	CFr	CCh	Fr + Ch	Ch +Am	Fr + Am
Total phenols (mg·L^{-1} gallic acid eq.)	264.5 ± 0.26^{a}	272.4 ± 2.0^{c}	266.6 ± 0.1^{a,b}	271.1 ± 1.2^{c}	270.7 ± 0.4^{c}	286.6 ± 1.8^{d}	269.6 ± 1.0^{b,c}
Non-flavonoid phenols (mg·L^{-1} gallic acid eq.)	92.1 ± 0.2^{a}	103.0 ± 4.0^{b}	96.2 ± 1.3^{a}	92.0 ± 0.1^{a}	93.9 ± 0.1^{a}	107.6 ± 5.1^{b,c}	109.9 ± 6.2^{c}
Flavonoid phenols (mg·L^{-1} gallic acid eq.)	172.3 ± 0.3^{b,c,d}	169.3 ± 5.2^{b,c,d}	170.3 ± 1.4^{b,c}	179.7 ± 1.1^{e}	176.7 ± 0.3^{c,d,e}	178.9 ± 6.8^{d,e}	159.7 ± 5.3^{a}
Color intensity (Abs. units at 420 nm)	0.090 ± 0.004^{a}	0.122 ± 0.000^{e}	0.109 ± 0.001^{c,d}	0.099 ± 0.001^{b}	0.114 ± 0.002^{d}	0.106 ± 0.000^{c,d}	0.104 ± 0.001^{a,b}
Tannicity (NTU·mL^{-1})	2.48 ± 0.57^{a}	4.65 ± 0.61^{a}	3.21 ± 1.74^{a}	3.19 ± 0.80^{a}	2.88 ± 0.18^{a}	3.50 ± 0.18^{a}	3.31 ± 1.15^{a}
Browning potential index$^{a)}$	0.034 ± 0.002^{c}	0.028 ± 0.002^{c}	0.016 ± 0.007^{b}	0.039 ± 0.004^{c}	0.017 ± 0.004^{b}	0.004 ± 0.002^{a}	0.030 ± 0.001^{c}
Parameters	Aging time / white wines						
	30 days						
	C	CAm	CFr	CCh	Fr + Ch	Ch + Am	Fr + Am
Total phenols (mg·L^{-1} gallic acid eq.)	263.2 ± 0.2^{a}	263.0 ± 1.8^{a}	266.7 ± 0.7^{b}	274.6 ± 1.0^{d}	272.2 ± 0.7^{c,d}	271.1 ± 0.1^{c}	268.4 ± 0.8^{b}
Non-flavonoid phenols (mg·L^{-1} gallic acid eq.)	94.7 ± 0.1^{a}	96.4 ± 1.8^{a,b}	104.4 ± 0.9^{e}	97.7 ± 1.3^{b,c}	100.1 ± 1.8^{c,d}	96.2 ± 0.6^{a,b}	102.0 ± 2.1^{d,e}
Flavonoid phenols (mg·L^{-1} gallic acid eq.)	168.5 ± 0.1^{b}	166.6 ± 2.1^{b}	162.3 ± 1.6^{a}	176.9 ± 1.3^{d}	172.1 ± 2.5^{c}	174.9 ± 0.6^{c,d}	166.4 ± 1.6^{b}
Color intensity (Abs. units at 420 nm)	0.092 ± 0.001^{b}	0.092 ± 0.004^{b}	0.090 ± 0.004^{a,b}	0.092 ± 0.004^{b}	0.086 ± 0.001^{a}	0.093 ± 0.002^{b}	0.094 ± 0.002^{b}
Tannicity (NTU·mL^{-1})	4.86 ± 0.55^{a}	8.19 ± 0.62^{c,d}	10.71 ± 0.90^{e}	5.63 ± 0.63^{a,b}	8.85 ± 0.76^{c}	7.71 ± 1.34 ^{c,d}	6.81 ± 0.60^{b,c}
Browning potential index$^{a)}$	0.031 ± 0.002^{b}	0.015 ± 0.002^{a}	0.032 ± 0.006^{b}	0.033 ± 0.002^{b}	0.032 ± 0.005^{b}	0.029 ± 0.000^{b}	0.017 ± 0.002^{a}
Parameters	Aging time / white wines						
	60 days						
	C	CAm	CFr	CCh	Fr + Ch	Ch + Am	Fr + Am
Total phenols (mg·L^{-1} gallic acid eq.)	260.8 ± 1.15^{a}	265.4 ± 1.5^{b}	266.5 ± 3.2^{b,c}	275.0 ± 0.9^{d}	272.9 ± 1.0^{d}	273.2 ± 2.5^{d}	269.0 ± 1.6^{c}
Non-flavonoid phenols (mg·L^{-1} gallic acid eq.)	95.9 ± 1.3^{b,c}	97.4 ± 1.4^{c,d}	98.6 ± 0.5^{d}	94.5 ± 0.7^{a,b}	98.3 ± 1.0^{d}	93.0 ± 1.1^{a}	101.0 ± 1.4^{e}
Flavonoid phenols (mg·L^{-1} gallic acid eq.)	164.9 ± 2.1^{a}	167.9 ± 1.1^{a}	167.8 ± 3.4^{a}	180.4 ± 1.4^{c}	174.5 ± 1.9^{b}	180.1 ± 3.5^{c}	167.9 ± 0.7^{a}
Color intensity (Abs. units at 420 nm)	0.080 ± 0.005^{a}	0.087 ± 0.000^{a}	0.085 ± 0.003^{a}	0.088 ± 0.004^{c}	0.084 ± 0.000^{b}	0.109 ± 0.007^{c}	0.093 ± 0.000^{a}
Tannicity (NTU·mL^{-1})	13.79 ± 1.71^{a}	16.13 ± 2.70^{a,b}	15.50 ± 2.14^{a,b}	15.29 ± 3.77^{a,b}	22.08 ± 4.23^{b,c}	24.75 ± 5.48^{c}	18.88 ± 3.70^{a,b,c}
Browning potential index$^{a)}$	0.021 ± 0.001^{a}	0.025 ± 0.000^{a}	0.035 ± 0.001^{b}	0.045 ± 0.004^{c}	0.035 ± 0.004^{b}	0.022 ± 0.002^{a}	0.027 ± 0.003 ^{a,b}

C - control wine; CAm - wine with American oak chips; CFr - wine with French oak chips; CCh - wine with cherry chips; Fr+Ch - wine with a blend of French oak and cherry chips; Ch+Am - wine with a blend of American oak and cherry chips; Fr+Am - wine with a blend of French and American oak chips; [(a)] Absorbance difference values obtained in the wine samples with and without nitrogen. All data express the average of three replicates ± standard deviation; data points for same aging time and analytical parameter (in line) showing the same letter are not significantly different ($p < 0.05$).

oxidation and polymerization phenomena, where phenolic linkage from wood plays an important role. The low ellagitannins content that characterized American oak and cherry woods (Jordão *et al*. 2007, 2016) could also help to explain the potential slight oxidation of phenolic content detected in wines aged in contact with American oak wood and for the blend containing this oak wood species and cherry wood chips. However, for the wines aged in contact with single cherry wood chips and also aged with the blend containing French oak and cherry wood chips, a slight increase of the values over the 60 aging days was detected.

After 60 aging days, white wine samples aged in contact with cherry wood chips, alone or in blends containing this wood specie with the two oak wood species used showed significantly highest values of total phenols. Nevertheless, its important to take into account that, all of these trends were not entirely clear in terms of wood species. In this context, it is important to note that the wood chips concentration used in our study (0.5 g·L^{-1}) was very low, and therefore this could help to explain the low differentiation among the wines aged with different wood chip species, including when is used wood chips blends.

For the non-flavonoid phenols (Tab. 2), wines aged in contact with single American oak wood chips, with a blend containing cherry and American oak wood chips and also with a blend containing French and American oak wood chips showed the significantly highest values (103.0, 107.6 and 109.9 mg·L^{-1} of gallic acid equivalents, respectively) after 15 aging d. It was also clear that 15 aging d were sufficient for the extraction of non flavonoid phenols from American oak wood chips to the white wines, because a decrease of the values after this storage time was detected (particularly for wines aged with single American oak chips and also for wines aged with the blend containing this oak wood specie and cherry wood chips). Thus, this result predicts the possibility of shorter contact times between wines and this wood chip specie being sufficient for the potential extraction of extractable non flavonoid phenolic compounds, which includes ellagitannins and several phenolic acids. Moreover, the physical properties and the structure of different wood species, such as the proportion of latewood to early wood and the abundance of fibers, may influence the extraction of individual compounds into the wine, without going deeper into the natural variability composition of wood. Thus, wines aged with French oak and cherry wood chips alone and also with a blend containing French oak and cherry wood chips showed the significantly highest values (104.4, 97.7 and 100.1 mg·L^{-1} of gallic acid equivalents, respectively) only after 30 aging days, followed by a decrease of the values.

After 60 storage days, in general, the wines aged in contact with French oak wood chips alone or blended with other wood chip species, showed the significantly highest values for non flavonoid phenols (values ranged between 98.3 and 101.0 mg L^{-1} of gallic acid equivalents) while the wines aged in contact with cherry wood chips alone or blended with American oak wood chips showed the significantly lowest values (values ranged between 93.0 and 98.3 mg·L^{-1} of gallic acid equivalents). Previous works described higher non flavonoid compounds in European oak wood species, namely French oak (Jordão *et al*. 2007, 2016), corresponding to higher potential extraction of several individual compounds, such as, gallic, protocatechuic, vanillic, caffeic, syringic and *p*-coumaric acids, ellagitannins and ellagic acid from this oak wood species to the wine. In addition, for American oak and cherry heartwood very low values and in some case even an absence of hydrolysable tannins was already described by other authors in woods and in wines aged in contact with these woods species (Sanz *et al*. 2010).

Concerning the evolution of flavonoid phenols (Tab. 2), it was possible to detect that the white wines aged in contact with the blends containing oak and cherry wood chips and also cherry chips alone showed the significantly highest values during all the storage period in study. The favorable porosity of cherry woods could be considered a potential reason for an easier extraction of flavonoid phenolic compounds from these wood chips associated with the quantitative potential flavonoid phenols from oak wood species. Previously, several authors (Sanz *et al*. 2010, Zhang *et al*. 2015, Jordão *et al*. 2016) detected (+)-catechin and condensed tannins only in cherry wood and not in oak wood species, which may help to explain the results obtained in our study. In addition, other works (Délia *et al*. 2017, Tavares *et al*. 2017) reported higher values of flavonoid phenols in red and white wines aged in contact with cherry wood chips compared with wines aged in contact with oak wood species.

In general, flavonoid phenols content oscillated over the aging time studied. However, an exception occurred for the wine aged in contact with the blend containing French and American oak wood chips, where there was a tendency for an increase of flavonoid phenol values. With an opposite evolution, control wine aged without any contact with wood chips showed a continuous decrease of flavonoid phenol values. After 60 aging days, the significantly highest flavonoid phenols were quantified from the wines, in descending order, aged with cherry chips alone (180.4 mg·L^{-1} of gallic acid equivalents), with a blend containing cherry and American oak chips (180.1 mg·L^{-1} of gallic acid equivalents), and with a blend containing cherry and French oak chips (174.5 mg·L^{-1} of gallic acid equivalents).

Regarding tannicity (Tab. 2), all wines showed an evident increase throughout the aging time considered. In addition, as expected, the control white wine was the one that showed the lowest values over aging time. This parameter stands for the expression of the adstringency perception of a wine, namely, the capacity that some phenolic compounds as tannins have to interact with proteins, stimulating the astringent character of the wine in taste. In addition, generally white wines show intermediate values but much lower compared to rosé and red wines. Thus, according to the results obtained, after 60 aging days, the highest tannicity values were quantified for the white wines aged in contact with the blends containing cherry wood chips with American and with oak French wood chips and also for the blend containing the two oak wood chip species, respectively, 24.75, 22.08 and 18.88 NTU·mL^{-1}. Thus, it was clear that the wood chip blends containing cherry wood chips and also the blends with French and American oak wood species induced an increase of the white wine astringent character. In fact, high phenolic composition, that characterize particularly French oak heartwood (Jordão *et al*. 2012, Chira and Teissedre 2015) and also the presence of (+)-catechin and procyanidins quantified in cherry wood chips (Sanz *et al*. 2010, Zhang *et al*. 2015, Jordão *et al*. 2016) could explain the high tannicity quantified in white wine aged in contact these blends, especially after 60 aging days.

For color intensity (Tab. 2), all white wines aged in contact with wood chips showed changes throughout the aging time, particularly an increase after 15 aging d, followed by a decrease of the values. In addition, for the same aging time, control wine showed in general the lowest values for color intensity. The interaction between several wood compounds and wine phenolic composition induces a formation of a diversity of new compounds which affect the initial white wine color changes by an increase of yellow color (Vivas *et al*. 2008). In addition, the yellow color increase could also correspond to a higher potential extraction of phenolic compounds such as, gallic acid, ellagic acid and hydrolysable tannins from wood to the wines during the first aging weeks. This impact its particularly high for the wines aged in contact with oak wood, because, these wood species has in general more levels of phenolic compounds, such as hydrolysable tannins, than cherry heartwood (Jordão *et al*. 2007, Sanz *et al*. 2010, Jordão *et al*. 2016). In fact, it was clear that color intensity increase was higher in all wines aged in contact with oak wood chips (alone or in blends) than that observed for wine aged only with cherry wood chips. In addition, the wood composition itself, namely by the presence of wood extractable phenols, may after some time, have a protective effect of the white wine color, allowing over time the color to stabilize or at least not increase by the protective effect of these wood extractable phenols.

White wines aged in contact with American oak wood chips alone or aged with the blend containing French oak with cherry wood chips showed the significantly highest values (0.122 and 0.114 abs. units, respectively) after 15 aging d. However, the results did not show a clear trend among the different wines after the storage time studied (60 aging d), depending on the wood chip species or the type of blends used.

Browning potential index evolution: The results for the evolution of the browning potential index of white wines aged in contact with different wood chip blends over 60 aging d are shown in Tab. 2. In fact, in white wines, one of the main problems is the unstable color during aging time. In this sense, browning results from the oxidation of phenols to quinones, which in turn polymerize to form high molecular weight phenolic compounds with a typical yellow-brown hue.

During all aging time considered, wines aged in contact with French oak wood chips alone or blended with cherry wood chips showed a clear tendency for an increment of the browning potential index. For the remaining wines there was a strong oscillation of the values. However, for the control wine a decrease of browning potential index occurred during all aging time studied. Thus, after 60 aging d, the browning potential showed in descending order the following sequence: CCh>Fr+Ch>CFr>Fr+Am>CAm>Ch+Am>C. In addition, the results also showed that in general, white wines with the highest flavonoid content after 60 aging d (particularly for wines aged with cherry wood chips or with a blend containing cherry and French oak chips) showed the highest browning potential index. Several authors (Singleton 1987, Cheynier *et al.* 1989) have demonstrated that oxidative browning of white wines is related to polyphenol chemical oxidation, particularly with flavanol phenol oxidation. On the other hand, Es-Safi *et al.* (2000) also demonstrated an oxidant process, where flavanols are converted into yellow xanthylium pigments, contributing also to white wine browning.

The results here obtained also make clear that for the same aging time, in general white wines aged in contact with cherry wood chips alone showed the highest values of browning potential index. Similar tendency was also detected for the wines aged with cherry wood chips alone or blended with American oak wood chips. However, when cherry wood was blended with oak wood chips, for the same aging time, a decrease of browning potential index was detected. In fact, it is well known that the contact of wood by means of chips with white wines implied a decrease on the browning potential index, due to the release of phenolic compounds from wood to wines (Kammerer and Carle 2009, Nunes *et al*. 2017, Délia *et al*. 2017). In addition, in the course of storage time, the formation of phenolic polymers and the antioxidant properties of some phenolic compounds, such as wood ellagitannins, quickly absorbing the dissolved oxygen and facilitating the hydroperoxidation of wine constituents (Vivas and Glories 1996). In this way, there will be an increase in stability of white wines to oxidation. This tendency confirms the results reported by Délia *et al*. (2017), where white wines aged with cherry chips exhibited the highest browning potential values which pointed it out as the most sensitive to oxidation. This fact was in consonance to low content of oxidizable polyphenols that characterized cherry heartwood (Alañón *et al*. 2011).

Evolution of sensory characteristics: Sensorial profile evolution for aroma and taste descriptors of the white wines aged in contact with different wood chips (alone or blended) is shown by means of spider web diagrams in Figs 1 and 2. The most marked differences during all aging times were related to several wine aroma descriptors (Fig. 1), namely, for "quality", "woody" and "oxidation", while for taste descriptors (Fig. 2), "body", "astringency" and "flavor quality" were the parameters where were detected more pronounced changes. In addition, it was also clear that during the aging time, in general, the panel test has reduced the scores given for most of the aroma descriptors from white wines aged in contact with the different wood chips, except for the "oxidation" descriptor. This aroma descriptor was scored over time with higher values, probably as a consequence of some qualitative degradation of the wine aroma.

At the beginning of the aging time (15 aging d), white wine aged with American oak chips showed significantly higher scores for two aroma descriptors, "aroma quality" and "fruity", while wine aged in contact with a blend of chips containing French and American oak showed significantly higher scores for "woody" aroma (Fig. 1). Control wine obtained lower scores by the panel test for the majority of aroma descriptors ("aroma quality", "aroma intensity", "woody", "fruity" and "floral"). In addition as expected, this wine showed the lowest scores during all aging times for "woody" aroma descriptor. Nevertheless, over the aging time, the scores given by the panel test to control wine have improved significantly, particularly for the "aroma quality", "fruity" and "floral" descriptors.

Among wine samples aged in contact with the different wood chip species and blends, while initially (after 15 d) clear differences were evident between most wines for the majority of aroma descriptors (for example "woody" aroma for wine aged with the blend containing French and American oaks chips), with the course of time these differences reduced. After 60 aging d, all white wines aged with wood chips showed higher scores for "oxidation" aroma descriptor (Fig. 1). This may indicate that wine contact time with the

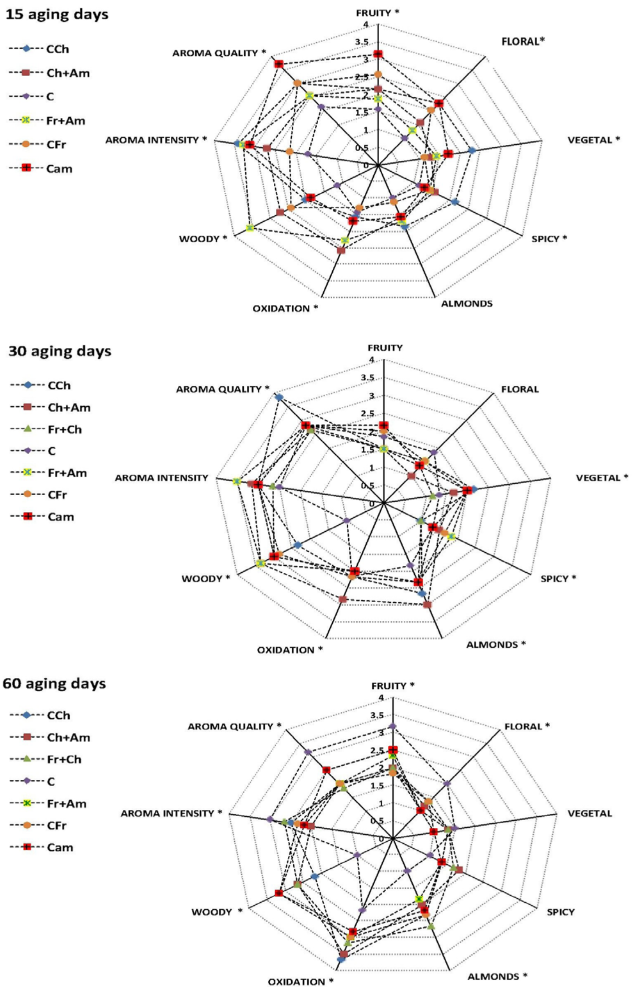

Fig. 1: Evolution of sensory profile for aroma parameters during 60 aging d of a white wine from "Encruzado" grape variety in contact with different wood chips blends. * sensory parameters where there are significant differences between the white wines (Tukey test, $p < 0.05$). C - control wine; Cam - wine with American oak chips; CFr - wine with French oak chips; CCh - wine with cherry chips; Fr+Ch - wine with a blend of French oak and cherry chips; Ch+Am - wine with a blend of American oak and cherry chips; Fr+Am - wine with a blend of French and American oak chips.

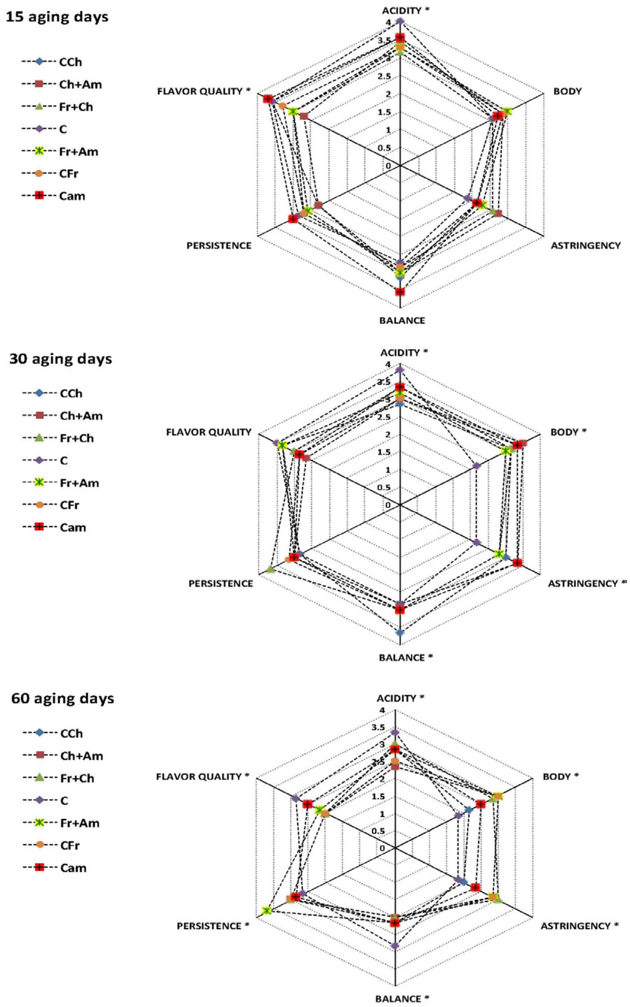

Fig. 2: Evolution of sensory profile for taste parameters during 60 aging d of a white wine from "Encruzado" grape variety in contact with different wood chip blends. *sensory parameters where there are significant differences between the white wines (Tukey test, $p < 0.05$). C - control wine; Cam - wine with American oak chips; CFr - wine with French oak chips; CCh - wine with cherry chips; Fr+Ch - wine with a blend of French oak and cherry chips; Ch+Am - wine with a blend of American oak and cherry chips; Fr+Am - wine with a blend of French and American oak chips.

chips was excessive, since during these contact times the oxygen contained in the chip pores and released into the wine may have contributed to an increase of the scores of this descriptor with respect to the control wine. In addition, the highest "oxidation" aroma scores were quantified for the wines that were in contact with cherry wood chips (alone or blended with American oak wood). It should be noted that this result follows the same trend as previously observed for browning potential index (Tab. 2). This fact confirmed previous works that have reported much more sensibility to oxidation reactions in wine aged in contact with cherry as a result of low contents of polyphenols, such as procyanidins, that characterizes cherry heartwood, leading to a higher oxidative environment than the other wood species (Chinnici *et al*. 2015). In addition according to Karbowiak *et al*. (2009), for white wines, oxidation causes a decrease in pleasant sensory levels along with the appearance of off-flavors as "honey-like" or "cooked vegetables", and the brown coloration of wine. Among wine samples aged in contact with the different wood chips species and blends, the wine contact with oak wood chips alone (French and American species) induced the significantly highest values for "woody" aroma descriptor (Fig. 1). The use of blends containing cherry wood chips induced a decrease of scores for this aroma descriptor. According to several authors (Pérez-Prieto *et al*. 2002, De Coninck *et al*. 2006), these differences could be probably explained as a result of more *trans* and especially *cis*-β- methyl-γ -octalactone content in wines aged in contact with oak woods, which had an important role in the "woody" character. For 'Chardonnay' wines aged with American and Hungarian oak wood chips, Guchu *et al*. (2006) reported a positive impact of some volatile compounds, namely *cis*-oak lactone on wood aroma giving coconut sensory character.

Concerning to taste descriptors (Fig. 2) also several changes occurred during the aging period considered. Thus, it was clear that for "acidity" descriptor during all aging times, the control wine showed the significantly highest scores, but at same time the lowest scores for "body" and "astringency". In fact, throughout the storage time, an increase of the differentiation between the wines in relation to the "body", "persistence" and "astringency" descriptors were perceived by the panel, where the wines aged in contact with wood chips evidenced higher scores in comparison with the control wine. These results showed in general, the same tendency obtained for wines tannicity results (Tab. 2), where for the same aging time, in general, white wines aged in contact with wood chips showed the highest tannicity values, particularly for the wines aged in contact whit the wood chips blends. According to Chira and Teissedre (2015) wood ellagitannin concentration and other extractable phenolic wood components are closely correlated with several wine sensory descriptors, namely "persistency", "astringency" and "round tannins".

After 60 aging days, white wines aged with oak chips alone or blended with cherry chips showed the highest scores for "body" and "astringency" (Fig. 2). Among the wines aged in contact with wood chips, the wine aged with cherry chips was the one that obtained the lowest scores for these two sensory descriptors. In addition, white wine aged in contact with a blend containing American and French oak wood chips showed the highest scores for "persistence". In addition, the scores for "flavor quality" descriptor decreased in all wines aged in contact with the wood chips, showing lower scores after 60 aging days than the control wine. Thus, it seems that even for a low wood chips concentration, as used (0.5 $g \cdot L^{-1}$), 60 aging days in contact with wood chips could be excessive in terms of the sensory balance of these white wines, independently of wood chip species used. This fact was also clear in the lowest scores attributed for the "balance" descriptor by the panel test for wines aged in contact with wood chips in relation to the control wine.

Finally, the results for overall appreciation scores obtained from sensory analysis (Tab. 3) pointed out in evidence significant decrease of scores attributed by the panel during the aging time considered, although the wine aged in contact with cherry wood chips alone and control wine showed a less pronounced decrease. After 60 aging days, these two white wines showed the significantly best overall appreciation scores from the panel test. However, at the beginning of the aging time considered (15 aging d)ays, wines aged in contact with American or French oak wood chips alone and wine aged in contact with cherry wood chips also alone showed the significantly highest scores attributed by the panel test. The remaining wines had similar and lowest scores for overall appreciation. Thus, these results lead once again to the conclusion that, 60 aging days in contact with the different wood chips studied will eventually to be excessive for the overall appreciation of the white wines. In addition, it was also clear that the use of blends containing cherry and oak wood chips did not lead to better results, concerning the wine global appreciation.

Table 3

Evolution of sensory overall appreciation scores during 60 aging days of a white wine from "Encruzado" grape variety in contact with different wood chips blends

White wines	Aging time		
	15 days	30 days	60 days
	Global appreciation scores		
C	13.71 ± 0.95 ^{a}	14.83 ± 1.16 ^{b}	13.00 ± 0.89 ^{d}
CAm	15.85 ± 0.69 ^{c}	14.16 ± 0.40 ^{a,b}	11.16 ± 0.75 ^{a,b,c}
CFr	14.57 ± 0.78 ^{b}	14.16 ± 0.41 ^{a,b}	10.00 ± 0.20 ^{a}
CCh	15.14 ± 0.69 ^{b,c}	14.66 ± 1.03 ^{b}	12.50 ± 1.04 ^{c,d}
Fr+Ch	13.42 ± 0.53 ^{a}	13.83 ± 0.75 ^{a,b}	10.16 ± 0.40 ^{a}
Ch+Am	13.28 ± 0.48 ^{a}	13.16 ± 0.76 ^{a}	10.50 ± 0.83 ^{a,b}
Fr+Am	13.57 ± 0.78 ^{a}	13.50 ± 0.83 ^{a}	11.66 ± 1.03 ^{b,c,d}

C - control wine; CAm - wine with American oak chips; CFr - wine with French oak chips; CCh - wine with cherry chips; Fr+Ch - wine with a blend of French oak and cherry chips; Ch+Am - wine with a blend of American oak and cherry chips; Fr+Am - wine with a blend of French and American oak chips; global appreciation was scored on a 0 to 20 point scale; data points for same aging time (in column) showing the same letter are not significantly different (Tukey's test $p < 0.05$).

Principal components analysis applied to wine composition and sensory characterization: To better understand the relationship between white wines aged in contact with different wood chip species (alone or in blends) concerning the general phenolic parameters and sensorial profile, a principal component analysis (PCA) was performed. The corresponding loading plots that established the relative importance of each variable are shown in Fig. 3. Therefore, this figure shows the relationship between the white wines and the several independent phenolic and sensorial parameters evaluated. The PCA showed that the first two PCs explained 60.6 % of the total variance (Fig. 3-I). The first PC (PC1, 43.2 % of the variance), was positively correlated with several sensorial descriptors, such as, "balance", "color intensity", "aroma quality", "flavor quality", "floral aroma", "acidity" and "overall appreciation", and negatively correlated with "oxidation aroma" sensorial descriptor and tannicity (phenolic parameter). The second PC (PC2, 17.4 % of the variance) was positively correlated with several sensorial descriptors, such as, "body", "astringency", "woody aroma" and "almond aroma", and negatively related with the sensorial descriptor "fruity aroma".

In Fig. 3-II, it is possible to visualize the spatial distribution of the white wines aged in contact with different wood chips species evaluated (alone and blended) concerning to the different parameters considered. Thus, after a cluster analysis, one group is formed by all white wines aged in contact with the different wood chips species during 60 aging d (Fr + Ch60, CFr60, Ch + Am60, Fr + Am60, CCh60 and CAm60 wine samples); these white wines were positively related with "oxidation aroma" sensorial descriptor and the phenolic parameter, tannicity. Another group is formed by two white wines aged in contact during 15 aging d with cherry chips (CCh15) and American oak chips (CAm15). These two white wines were positively related with the following sensorial descriptors: "balance", "color intensity", "aroma quality", "flavor quality", "floral aroma", "acidity" and "overall appreciation". The third group is formed by 4 white wines, control wines without wood chips contact during all aging times considered (C15, C30 and C60) and also the wine aged in contact with French oak wood chips during 15 aging d (CFr15). These wines were positively related with the sensorial descriptor "fruity aroma". Finally, a last group is formed by the majority of white wines aged in contact with wood chip blends during 15 and 30 aging d (Fr+Am15, Ch+Am15, Fr+Ch15, Ch+Am30 and Fr+Am30) and also 3 wines aged in contact with a single wood chip species during 30 aging d (CFr30, CAm30 and CCh30).

These white wines were positively related with several sensorial descriptors, such as, "almond", "body", and "spicy" aromas, "astringency" and "body" tastes, and also with the majority of the global phenolic parameters analyzed (total phenols, flavonoid phenols and non flavonoid phenols).

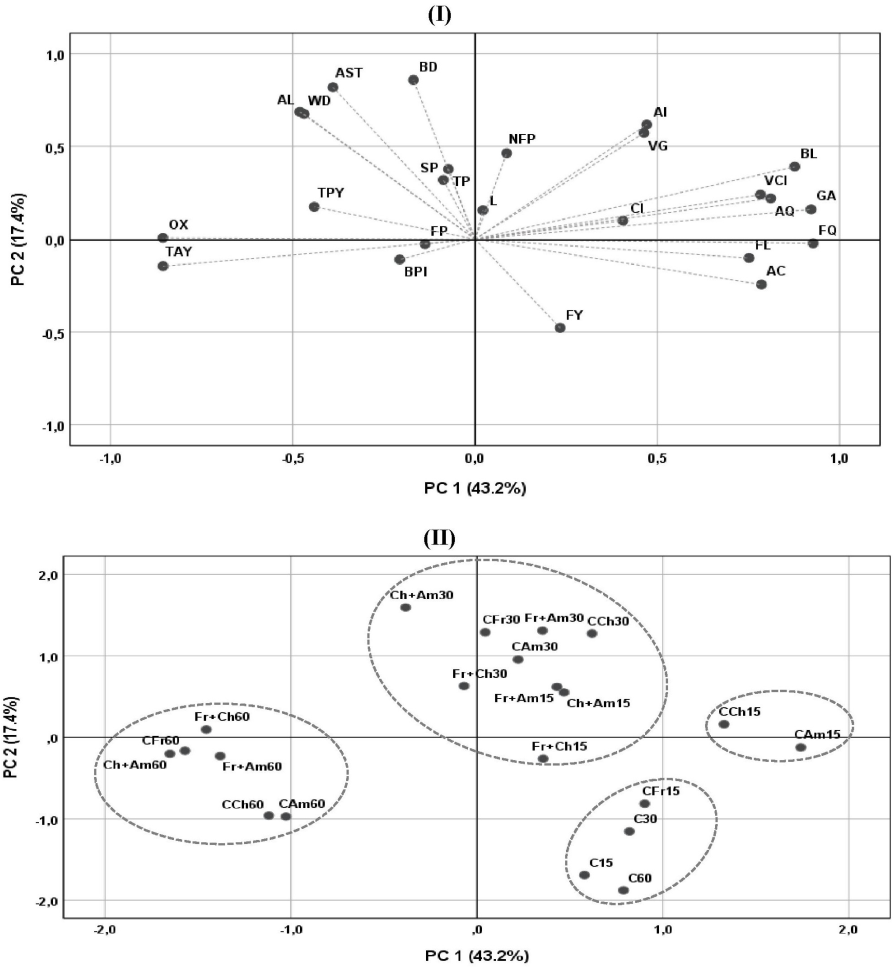

Fig. 3: Principal component analysis (PC1 and PC2) for different sensorial attributes and global phenolic parameters from a white wine from "Encruzado" grape variety during 60 aging d in contact with different wood chips blends (I - projection of sensorial attributes and global phenolic parameters; II - projection of white wines samples). Phenolic parameters: TP - total phenols; FP - flavonoid phenols; NFP - non flavonoid phenols; TAY - tannicity; CI - color intensity; BPI - browning potential index. Sensorial attributes: VCI - color intensity; L - limpidity; AI - aroma intensity; AQ - aroma quality; WD - woody aroma; OX - oxidation aroma; AL - almond aroma; SP - spicy aroma; VG - vegetal aroma; FL - floral aroma; FY - fruity aroma; AC - acidity; BD - body; AST - astringency; BL - balance; TPY - taste persistency; FQ - flavor quality; GA - overall appreciation. C - control wine; CAm - wine with American oak chips; CFr - wine with French oak chips; CCh - wine with cherry chips; Fr+Ch - wine with a blend of French oak and cherry chips; Ch+Am - wine with a blend of American oak and cherry chips; Fr+Am - wine with a blend of French and American oak chips. Aging d: After 15; 30 and 60 aging d.

Conclusions

This study provides information on the impact of the use of wood chips from different species, especially oak and cherry woods, when used alone or in blends, on the quality of "Encruzado" white wines during aging time. The results obtained demonstrate that the use of cherry wood chips alone or blended with oak wood chips from *Quercus petraea* or Q. *alba* species, compared with the use of oak wood chips species alone, had a slight impact on the increase of phenolic content of white wines. This impact was mainly detected in the first weeks of the aging process. In addition, the use of blends of chips containing cherry and oak wood could induce an increase more evident of white wine tannicity during the aging time and also an increase of the potential sensibility to oxidation reactions of white wines during the aging process. Concerning the sensorial results, the use of different wood chip species has a significant impact on some sensorial attributes of white wines during the aging process, particularly by the increase of "woody aroma" for the wines aged with oak wood chip species. In addition, wines aged with oak chips alone or blended with cherry chips showed an increase of the scores for "body" and "astringency" descriptors. It is also important to note that 60 aging days in contact with the different wood chip species could be eventually excessive for the overall appreciation of the white wines, because concerning the wine global appreciation, a decrease of sensorial scores was detected. The evidences obtained in our work are interesting from a practical point of view, especially when the option for aging white wines by the use of wood chips from different botanical species may be an option for winemakers to produce wines with potential new profiles. Nevertheless, further research will be necessary to improve the knowledge about the potential impact of the use of oak and non-oak wood chip species on white wine quality, such as, the use of different wood chip concentrations and blends for example at different steps of white wines winemaking.

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