Research Article

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Acacia, cherry and oak wood chips used for a short aging period of rosé wines: effects on general phenolic parameters, volatile composition and sensory profile

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Abstract

BACKGROUND: There is a restricted knowledge about the potential impact of the use of different wood chip species on the rosé wine aging process. Thus, the aim of this work was to evaluate the general phenolic parameters, aroma composition and sensory profile of rosé wines during a short maturation (20 aging days) in contact with wood chips from oak, acacia and cherry. In addition, the different wood chips were added to a rosé wine without a previous clarification process (unfined wine) and to a rosé wine submitted to a clarification process (fined wine).

RESULTS: For the brief maturation time considered, the use of different wood chips induced a tendency for an increase of phenolic content, in particular for unfined rosé wine aged in contact with acacia chips. For volatile composition, the differentiation was clearer for aldehyde compounds group. Regarding sensorial overall appreciation the panel test preferred the unfined rosé wine aged in contact with acacia wood chips.

CONCLUSIONS: The results show that, in general, the use of different wood chip species (acacia, cherry and oak) for a brief maturation time of rosé wines could play an important role in rosé wine characteristics, in particular in their phenolic composition.

Keywords: phenolic content; rosé wines; sensory profile; volatile composition; wood chip species

INTRODUCTION

Since 2002, global rosé wine exports (9.8 million hectoliters in 2014) have seen sustained growth, stimulated by high demand from major consumer countries. According to OIV,[1] in 2014, global production of rosé wines (excluding sparkling wines) was estimated at 24.3 million hectoliters, which is 9.6% of world still wine production. Thus, the consumption of rosé wines represents a growing trend in the wine market, which is becoming an important part of the total wine market. Their consumption has increased especially in countries such as France and the USA.[2]

In general, for the production of rosé wines, red grape varieties are used that, once places in the tank, are subjected to a maceration during a very short time at low temperature. This short time is sufficiently long for the must to take on its pinkish color as a result of phenolic compound extraction from the grape skins. In addition, without any maceration process it is also possible to produced rosés with the characteristic pinkish color. Thereafter, and without starting the alcoholic fermentation, the free-run juice is bled in the same way as for white grape production. This free-run juice is taken for clarification by static clearing. Once clarified, this must is brought to fermentation at low temperatures. As a result of these specific winemaking processes used during rosé wine production, these wines have significantly lower phenolic levels than red wines. According to Salinas *et al.*,[3] the rosé wine color and aromas are fragile and frequently fleeting during the aging process.

Traditionally, there are three species of wood used in barrel making: *Quercus petraea* Liebl., *Quercus robur* L. and *Quercus alba* L.[4–7] In addition, there are a great number of research works

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related to the impact of these oak wood species on chemical and sensorial characteristics of red and white wines.[8–11] However, it is important to note that the increasing demand for oak wood has caused a remarkable increase in costs due to the limited availability of materials and an ecological impact on forests. Thus, the use of other wood species, such as acacia and cherry, may be an interesting option for the wine aging process. Several works regarding the use of acacia and cherry wood in the wine aging process have been published in the last couple of years. However, these works are focused on the impact of acacia and cherry on the quality of red and white wines.[12–16] Furthermore, in general, the studies using rosé wines focused on the winemaking, in particular on the maceration process,[3,17,18] aromatic composition and sensorial profile[19,20] but not on the aging process. Thus, in order to deepen the knowledge of the impact of the use of wood chips on chemical and sensorial characteristics of rosé wines, the work reported here evaluated the global phenolic parameters, aroma composition and sensory profile of these wines during a short aging period in contact with different wood chip species (oak, acacia and cherry). Also evaluated was the impact of the addition of wood chips on rosé wines with different initial phenolic content.

EXPERIMENTAL

Winemaking process

The wine used in this experiment was a rosé wine made entirely from a Portuguese *Vitis vinifera* red grape variety 'Touriga Nacional', harvested during the vintage 2015 and processed by the Casa da Passarella winery located in northwest Portugal (Lagarinhos, Dão region). The classical rosé winemaking process was followed, namely with a brief maceration process during 8 h and maintaining the temperature below 14 °C, before the pressing process. The must was fermented in a stainless steel tank without skin contact using a standard *Saccharomyces cerevisiae* yeast strain (Fermol Arôme Plus by AEB Group) and inoculated at 20 g h^{-1} L^{-1}. The alcoholic fermentation process was completed in two weeks keeping the temperature below 20 °C. After the alcoholic fermentation the wine was racked and removed from the lees. The rosé wine produced did not undergo malolactic fermentation.

Experimental conditions

A total of four different wood chip species were used: acacia (*Robinia pseudoacacia*) was supplied from SAI (Paredes, Portugal) and cherry (*Prunus avium*), American oak (*Quercus alba*) and French oak (*Quercus petraea*) wood chips were supplied from AEB Bioquímica (Viseu, Portugal). All the wood chips used presented a medium toasting level and a particle dimension of 8 mm (average size).

From the obtained rosé wine, two different rosé wine samples were used. These were a rosé wine without a previous clarification process (unfined wine) and a rosé wine submitted to a clarification process (fined wine) by the addition of different fining agents (50 g h^{-1} L^{-1} of PVPP, 1.5 g h^{-1} L^{-1} of isinglass and after 12 h adding 30 g h^{-1} L^{-1} of bentonite). All fining agents used were purchased from AEB Bioquímica (Viseu, Portugal). These two different rosé wine samples were aged in contact with different wood chip species (concentrations of 1.5 and 1.0 g L^{-1} for unfined and fined rosé wines, respectively) during 20 aging days at cellar temperature (between 15 and 18 °C) and stirred twice a week. Each assay was conducted at a laboratory scale (10 L for each rosé wine). For the two types of rosé wines, a control wine (without wood chip addition) was also considered in our study. The wine samples were filtered (pore diameters of 13 μm) before laboratory analysis.

General physicochemical characterization

General wine physicochemical characterization (pH, total and volatile acidity, alcohol level, total and free sulfur dioxide) was conducted following the analytical methods recommended by OIV.[21] All analyses were done in duplicate.

General phenolic composition and chromatic characteristics

Total polyphenolic content was determined according to the methodology of Ribéreau-Gayon *et al.*,[22] while non-flavonoid and flavonoid phenols were determined using the methodology described by Kramling and Singleton.[23] For these parameters the results were expressed as gallic acid equivalents by means of calibration curves that were obtained using a standard gallic acid purchased from Extra-Synthese (Genay, France).

Total pigments, total anthocyanins, degree of ionization of anthocyanins, colored anthocyanins, degree of polymerization of pigments and polymeric pigments were obtained as described by Somers and Evans.[24] Color intensity at 420, 520 and 620 nm and color hue were also evaluated following the methodology described by OIV.[21] In addition, tanning power was quantified following the methodology developed by De Freitas and Mateus.[25]

Finally, using the CIELab method, chromatic characteristics (scanned in the range 380–770 nm) were also determined by the calculation of several chromatic parameters: L^* (%; lightness), a^* (redness), b^* (yellowness) and chroma ($C^* = [(a^*)^2 + (b^*)^2]^{1/2}$) according to OIV[21] method. To distinguish the color more accurately, the color difference was also calculated using the following formula: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. All analyses were done in triplicate.

Volatile composition analysis using gas chromatography–mass spectrometry

Various volatile compounds were analyzed by the gas–liquid chromatography method described previously by Mihnea *et al.*[26] with the exception that compounds were also quantified using a mass spectrometry detector. Volatile compounds were isolated from rosé wines by liquid–liquid extraction. An amount of 250 mL of rosé wine sample, with 75 μL of 2-octanol (500 mg L^{-1} in absolute ethanol) added as internal standard, was extracted with 5 mL of dichloromethane. Extraction was carried out into an ice bath with continuous stirring for 3 h. The organic phase was separated by centrifugation (10 000×*g* for 10 min at a temperature <4 °C) and analyzed according to the following chromatographic conditions. A Carbowax 20M column (60 m × 0.32 mm, 0.25 μm film thickness) from Quadrex Corporation (Symta, Madrid, Spain) was used for separation. The carrier gas was helium and its flow rate was 0.8 mL min^{-1}. Oven temperature was initially 40 °C for 8 min, then increased to 85 °C at 10 °C min^{-1} and held for 1 min, then increased again to 230 °C at 2 °C min^{-1} and held final for 35 min. A Hewlett-Packard HP 5973 mass detector fitted with a Hewlett-Packard HP 6890 GC was used. Detection was in EI mode (70 eV) and identification was carried out using spectra obtained with commercial standard compounds and from NIST library. Quantification was carried out following the internal standard quantification method. Then, quantitative data of the relative areas (absolute areas/internal standard area) were interpolated in

the calibration graphs built from results obtained with pure reference compounds. All analyses were done in triplicate.

Sensory evaluation

Each rosé wine sample was stored for 24 h 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.[27] All evaluations were conducted in the morning from 10:00 to 12:00. Eight expert judges with wine tasting experience evaluated the rosé wine samples after 20 aging days in contact with wood chips, as well as the control wines.

All expert judges were previously selected and trained considering the sensorial attributes of rosé wines. During this training period several sessions were carried out in order to get judges trained about the meaning of each attribute and achieving intensity rating in a reliable way. Thus, the sensorial attributes used were the following: aspect (color intensity and limpidity), aroma (intensity and quality, red fruits, woody, floral and vegetal), taste sensations (acidity and bitterness), mouthfeel sensations (persistency, equilibrium and astringency) and global appreciation. Persistency attribute was considerate as the ability of wine tastes and aromas to remain present in the mouth after wine had been swallowed, while equilibrium attribute was considered as the balance between wine aromas, tastes and tactile sensation combination.

The experts scored each sensory attribute (aspect, aroma, taste and mouthfeel sensations) on a five-point scale (1 = absence; 2 = little intensity; 3 = moderate intensity; 4 = intense; 5 = high intensity), while global appreciation was scored also on a five-point scale (0–1 = bad; 2 = unpleasant; 3 = pleasant; 4 = good; 5 = very good). It is important to note that these wine sensorial attributes were selected by consensus in order to adequately describe the rosé wine aroma and taste sensory similarities and differences under supervision of the panel leader. 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). The Tukey test ($P < 0.05$) was applied to the data to determine significant differences between rosé wines. In addition, a principal component analysis (PCA) was also used to analyze the data and to study the relations among the rosé wines aged in contact with the different oak wood chips and their chemical and sensory characteristics. All analyses were performed using SPSS software version 23 (SPSS Inc., Chicago, IL, USA).

RESULTS

The general physicochemical and phenolic compositions of the two rosé wine samples (with and without any clarification process) used are presented in Table 1. It is evident that the rosé wine used in this study showed acceptable physicochemical standards, with low volatile acidity (0.26 g L^{-1} acetic acid) and adequate SO_2 free values (38 mg L^{-1}).

As expected, the unfined rosé wine sample showed higher phenolic content than fined rosé wine sample. This was particularly evident for the generality of the phenolic parameters evaluated, such as total phenols (284.41 and 203.71 mg L^{-1} gallic acid equivalents for unfined and fined rosé wines, respectively) and total anthocyanins (117.69 and 47.60 mg L^{-1} malvidin-3-monoglucoside equivalents for unfined and fined rosé wines, respectively). With these two different rosé wine phenolic contents the option was to add two different wood chip concentrations. Thus, for rosé wine with a lower phenolic content (fined rosé wine), the option was to use a concentration of 1.0 g L^{-1}, whereas for rosé wine with a higher phenolic content (unfined rosé wine), a slightly higher concentration was used, 1.5 g L^{-1}.

Table 1. General physicochemical and phenolic composition of the two rosé wines used in the study

Parameter	Unfined rosé wine	Fined rosé wine
General physicochemical composition[a]		
Volatile acidity (g L^{-1} acetic acid)	0.26 ± 0.02	
Total SO_2 (mg L^{-1})	146 ± 2.0	
Free SO_2 (mg L^{-1})	38 ± 1.3	
pH	3.23 ± 0.01	
Total acidity (g L^{-1} tartaric acid)	6.12 ± 0.06	
Alcohol degree (% v/v; 20 °C)	13.5 ± 0.1	
Phenolic composition[b]		
Total phenols (mg L^{-1} gallic acid eq.)	284.41 ± 5.63	203.71 ± 0.26
Non-flavonoid phenols (mg L^{-1} gallic acid eq.)	100.82 ± 2.24	82.75 ± 0.70
Flavonoid phenols (mg L^{-1} gallic acid eq.)	184.50 ± 5.41	121.87 ± 6.97
Total pigments (abs. units)	6.32 ± 0.30	2.49 ± 0.15
Polymeric pigments (abs. units)	0.26 ± 0.01	0.06 ± 0.01
Polymerization degree of pigments (abs. units)	4.21 ± 0.22	2.66 ± 0.34
Tanning power (NTU mL^{-1})	7.54 ± 1.23	2.87 ± 0.12
Total anthocyanin (mg L^{-1} malvidin-3-monoglucoside eq.)	117.69 ± 5.93	47.60 ± 2.80
Colored anthocyanins (mg L^{-1} malvidin-3-monoglucoside eq.)	2.26 ± 0.11	1.26 ± 0.230
Degree of ionization of anthocyanins (%)	1.92 ± 002	2.66 ± 0.34
Color intensity (abs. units × 10)	7.90 ± 0.04	2.71 ± 0.07
Color hue (abs. units)	0.922 ± 0.01	0.990 ± 0.07

[a] Average values of two replicates.
[b] Average values of three replicates.

General phenolic composition

The results obtained for general phenolic parameters of the two different rosé wines aged in contact with the different wood chip species after 20 aging days are shown in Fig. 1. For total phenolic contents, in general, an increase for all rosé wines aged in contact with wood chips was obtained. These differences were more evident for unfined rosé wines than for fined rosé wines (where the concentration of chips used was lower). Unfined rosé wines aged in contact with acacia wood chips showed significantly higher values for total phenols followed by the rosé wines aged with cherry and French oak wood chips. Control rosé wines showed the lowest total phenols content. All of these tendencies found for total phenolic compounds were also detected in general for flavonoid and non-flavonoid phenol compounds.

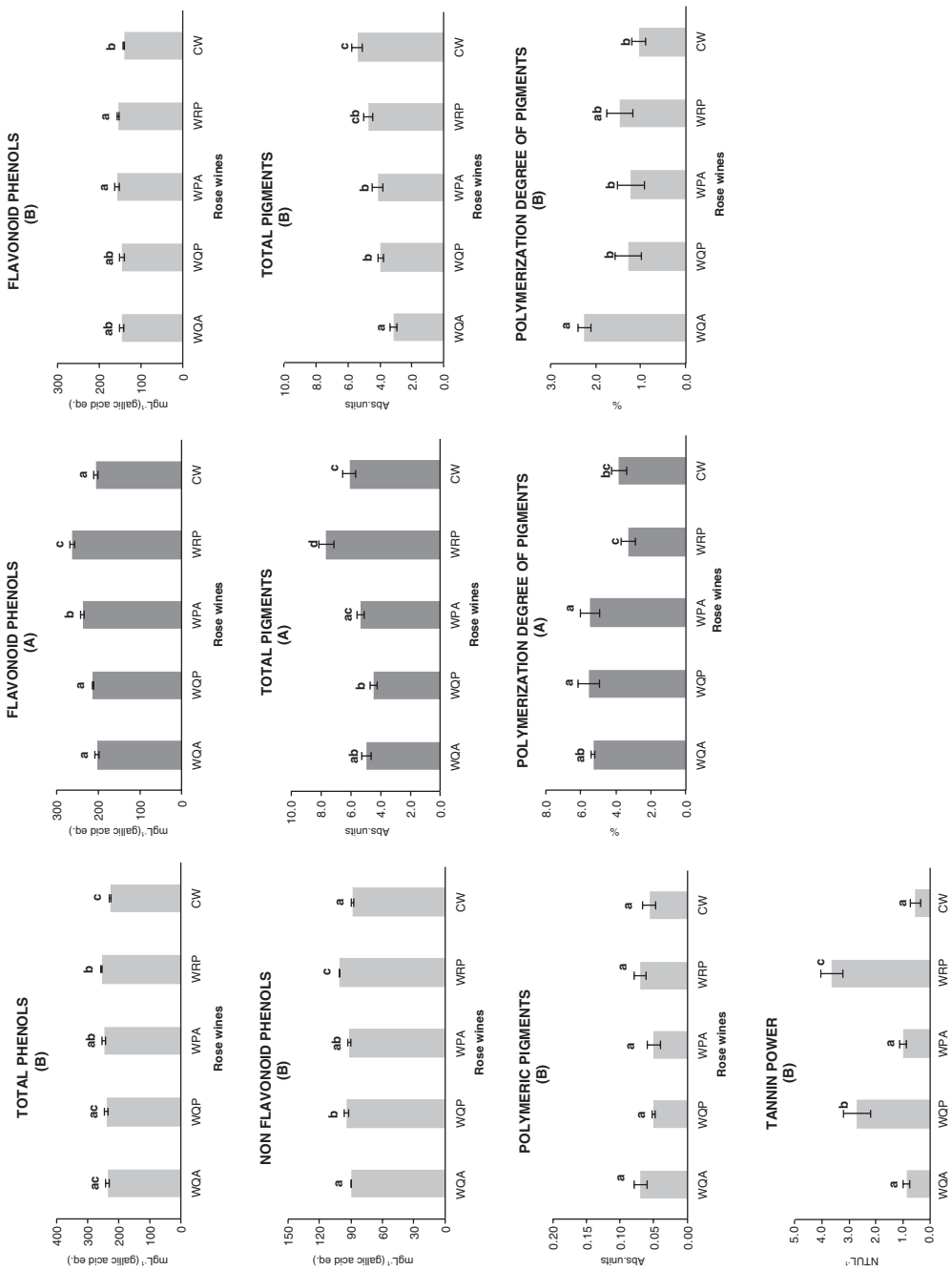

Figure 1. General phenolic composition from unfined (A) and fined (B) rosé wines aged in contact with different wood chip species with concentrations of 1.5 and 1.0 g L^{-1}, respectively, and obtained after 20 aging days. CW, control wine; WQA, wine aged with *Quercus alba* wood chips; WQP, wine aged with *Quercus petraea* wood chips; WRP, wine aged with *R. pseudoacacia* wood chips; WPA, wine aged with *Prunus avium* wood chips. †Values with same letters for each phenolic parameter and for the same rosé wine are not significantly different (Tukey test, $P < 0.05$); average values of three replicates.

With respect to total pigments, there was an evident significantly higher value for the unfined rosé wine also aged in contact with acacia wood chips followed by the unfined control wine. For the fined rosé wines, a similar tendency was observed.

The results obtained for polymeric pigments showed a tendency for higher values of this parameter for the unfined rosé aged in contact with cherry wood chips. However, no significant differences between all rosé wines were obtained. In addition, a similar tendency was also obtained for the fined rosé wines, but in that case also rosé wine aged in contact with American oak wood showed a tendency for higher polymeric pigment values.

Degree of polymerization of pigments of the unfined rosé wines showed a decreasing trend in the following sequence: wine aged in contact with French oak chips (5.53%), wine aged in contact with cherry chips (5.47%), wine aged in contact with American oak chips (5.29%), control wine (3.82%) and wine aged in contact with acacia chips (2.24%). For fined rosé wines, only the wine aged in contact with American oak wood chips showed significantly higher value with respect to the other rosé wines.

Finally, for tanning power results, unfined and fined rosé wines aged in contact with acacia wood chips showed in general significantly higher values, while for the remaining wines, there was no clear differentiation between them. However, fined rosé wine aged in contact with French oak wood chips also showed significantly higher value of tannin power.

Anthocyanins and color parameters

The results obtained for anthocyanin content and color parameters after 20 aging days are illustrated in Fig. 2. Unfined rosé wine aged in contact with acacia wood chips and also the control wine maintained significantly higher total anthocyanin content. The remaining rosé wines had lower and similar values between them. For the rosé wines where the wood chips were applied after the wine fining process (fined rosé wines), a similar tendency was observed; however, the differences were less substantial. In this case, control wine showed significantly higher total anthocyanin content. The remaining rosé wines showed intermediate values.

For colored anthocyanins, similar values were determined for all unfined rosé wines, except for the rosé wine aged in contact with cherry wood chips. This rosé wine showed significantly lower values. For fined rosé wines, although with some oscillations, the values were similar among all wines.

Regarding degree of ionization of anthocyanins, unfined rosé wines aged in contact with acacia and cherry wood chips showed significantly lower values. In particular, for the unfined rosé wine aged in contact with cherry wood chips, the results followed the same trend observed for colored anthocyanins. For the remaining unfined rosé wines no significant differences were found. In addition, for fined rosé wines, the values of degree of ionization of anthocyanins were similar among all wines.

Concerning color intensity and hue results, no significant differences were obtained for these parameters between all rosé wines, except for fined rosé wine aged in contact with cherry wood chips which showed significantly lower color hue values.

Table 2 presents the chromatic characteristics obtained using the CIELab method. For lightness values (L^*) of unfined rosé wines, significantly higher values were detected in rosé wines aged in contact with American oak and acacia wood chips, while for the remaining unfined rosé wines no significant differences were obtained. For lightness values o fined rosé wines, no significant differences were obtained, except for the rosé wine aged in contact with cherry wood chips that showed the significantly lowest L^* value. Concerning a^* values for all rosé wines (unfined and fined), no significant differences were obtained between wines. For b^* values, all unfined rosé wines showed similar values, except the rosé wine aged in contact with American oak wood chips, which showed the significantly lowest value. On the other hand, for fined rosé wines the addition of acacia wood chips induced significantly higher b^* values, while aging in contact with cherry wood chips induced significantly lower b^* values. For the remaining fined rosé wines no significant differences were obtained. In addition, for c^* values (chroma), no significant differences were obtained among all wines.

Finally, for total color differences (ΔE) between control rosé wines and wines aged in contact with the different wood chip species, two different tendencies were obtained. Thus, for unfined rosé wine samples, wines aged in contact with American oak and acacia wood chips showed significantly higher ΔE values, while for fined rosé wine samples, wines aged in contact with cherry and French oak wood chips showed significantly higher ΔE values. All of these values were higher than two CIELab units, indicating that the color difference could be detected by human eyes according to the work described by Spagna *et al.*[28]

Volatile composition

The results for the volatile composition of the rosé wines obtained after 20 aging days in contact with the different wood chips are presented in Tables 3 and 4. For the total esters group, no significant differences were obtained between all fined rosé wines. However, for unfined rosé wines, the aging process in contact with cherry wood chips induced significantly higher value of total esters as a result of the higher concentration of ethyl lactate. In addition, in particular also for unfined rosé wines aged in contact with acacia and cherry wood chips, significantly higher values of hexyl acetate and significantly lower values for ethyl acetate were found (Table 3).

For the great majority of individual alcohols quantified, similar values were found between all rosé wine samples. However, for unfined rosé wines (Table 3), significantly higher values of isobutanol were detected for rosé wine aged in contact with cherry wood chips, while for the rosé wine aged in contact with American oak wood chips significantly lower values of isobutanol were detected. A similar trend was also found for the fined rosé wines (Table 4). Unfined rosé wine aged in contact with French oak wood chips showed significantly higher values of *trans*-3-hexen-1-ol, while the remaining unfined rosé wines showed similar values between them. Finally, from a global point of view, and being the result of the differences obtained for isobutanol content, unfined rosé wine aged in contact with cherry wood chips stood out from the others with a significantly higher value of total alcohols, while unfined rosé wine aged in contact with American oak wood chips showed a significantly lower value. A similar trend was also found for fined rosé wines.

In terms of total amounts of aldehydes, for both rosé wine samples used in this work, rosé wines aged in contact with oak wood chip species showed a significantly higher value of total aldehydes content. The control rosé wines, as expected, showed significantly lower values.

Concerning the terpene compound group, after the aging time considered, no significant differences were detected between all wines.

For lactones group, in terms of total amounts, no significant differences were detected in rosé wines. This result was fundamentally a consequence of γ-butyrolactone content found with similar

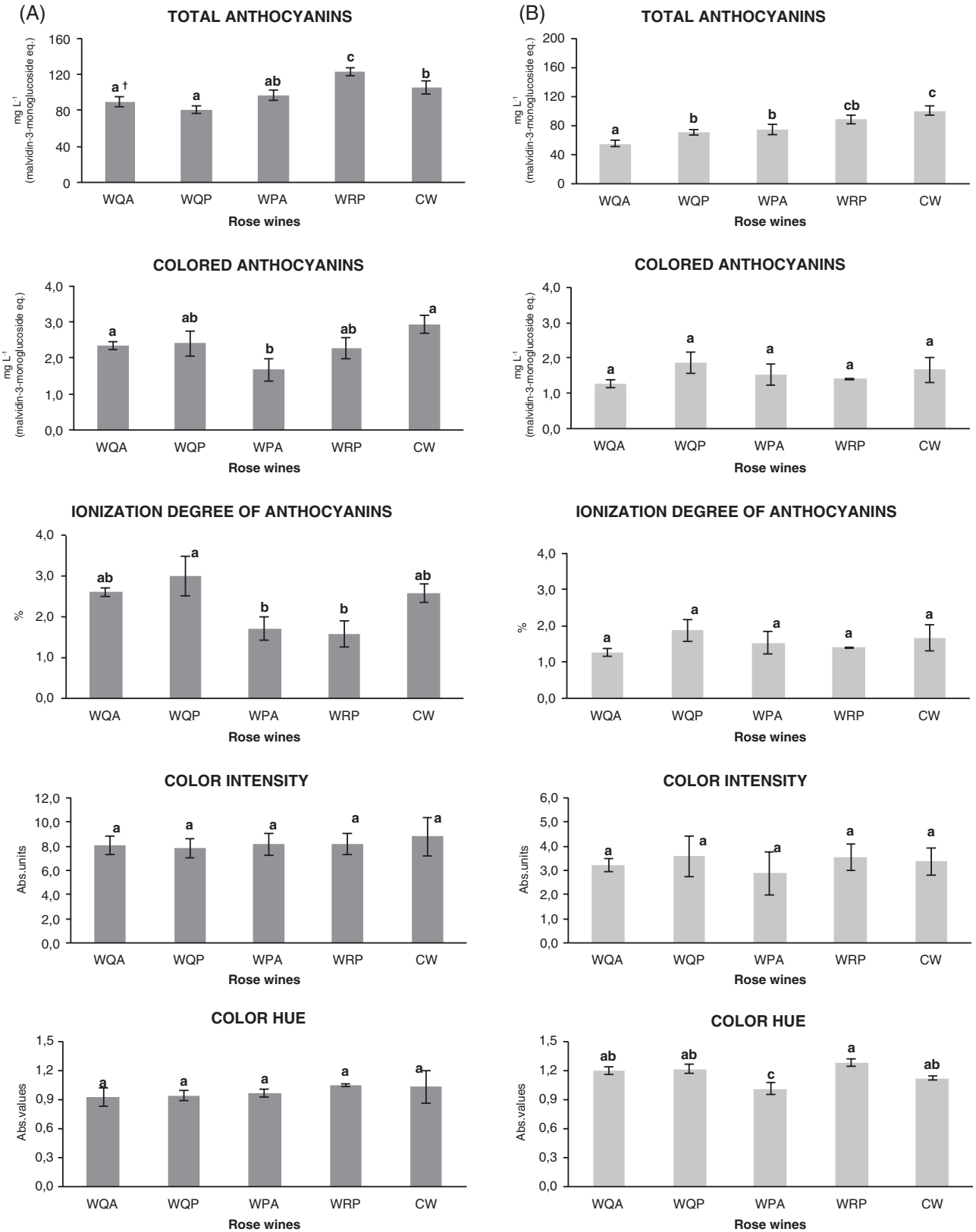

Figure 2. Anthocyanin content and color properties from unfined (A) and fined (B) rosé wines aged in contact with different wood chip species with the concentrations of 1.5 and 1.0 g L^{-1}, respectively, and obtained after 20 aging days. CW, control wine; WQA, wine aged with *Quercus alba* wood chips; WQP, wine aged with *Quercus petraea* wood chips; WRP, wine aged with *R. pseudoacacia* wood chips; WPA, wine aged with *Prunus avium* wood chips. †Values with same letters for each parameter and for the same rosé wine are not significantly different (Tukey test, $P < 0.05$); average values of three replicates.

Table 2. Chromatic characteristics using CIELab method coordinates of unfined and fined rosé wines aged in contact with different wood chip species with the concentrations of 1.5 and 1.0 g L^{-1}, respectively, and obtained after 20 aging days

CIELab coordinate	Unfined rosé wine					Fined rosé wine				
	CW	WQA	WQP	WRP	WPA	CW	WQA	WQP	WRP	WPA
L^*	41.28^{a} † ± 1.43	48.45^{b} ± 0.93	41.67^{a} ± 2.12	46.14^{b} ± 1.32	42.54^{a} ± 1.03	54.20^{a} ± 1.21	53.25^{a} ± 0.76	51.79^{a} ± 1.23	53.95^{a} ± 0.98	46.76^{b} ± 1.03
a^*	11.77^{a} ± 0.32	12.31^{a} ± 0.58	12.22^{a} ± 0.21	11.21^{a} ± 0.12	12.05^{a} ± 0.73	5.03^{a} ± 0.25	5.49^{a} ± 0.10	5.73^{a} ± 0.32	4.98^{a} ± 0.32	6.69^{a} ± 0.55
b^*	12.87^{b} ± 0.12	8.59^{a} ± 0.08	13.42^{b} ± 0.21	12.69^{b} ± 0.62	12.68^{b} ± 0.34	3.54^{a} ± 0.10	3.24^{a} ± 0.05	2.70^{ab} ± 0.03	4.57^{c} ± 0.13	2.01^{d} ± 0.10
c^*	17.44^{a} ± 1.21	15.02^{a} ± 0.87	18.15^{a} ± 1.04	16.93^{a} ± 0.98	17.49^{a} ± 0.76	6.15^{a} ± 0.43	6.37^{a} ± 0.19	6.33^{a} ± 0.36	6.76^{a} ± 0.12	6.98^{b} ± 0.21
ΔE^*	–	8.35^{a} ± 0.45	0.81^{b} ± 0.02	4.89^{c} ± 0.12	1.30^{b} ± 0.10	–	1.09^{a} ± 0.02	2.64^{b} ± 0.03	1.06^{a} ± 0.01	7.77^{c} ± 0.02

L^* (%; lightness); a^* (from green to red); b^* (from blue to yellow); c^* (chroma); ΔE^* total color difference; the values corresponding to ΔE^* were obtained taking as a reference each control rosé wine studied (CW).
CW, control wine; WQA, wine aged with *Quercus alba* wood chips; WQP, wine aged with *Quercus petraea* wood chips; WRP, wine aged with *R. pseudoacacia* wood chips; WPA, wine aged with *Prunus avium* wood chips.
† Values with same letters for each CIELab coordinate and for the same rosé wine are not significantly different (Tukey test, $P < 0.05$); ± standard deviation; average values of three replicates.

values in all rosé wines. In fact, this compound represented about 99% of the total of lactone group quantified. In terms of individual lactone compound group, *trans*-3-methyl- γ-octalactone was only quantified in very small amounts in unfined rosé wine aged in contact with French oak wood chips, while *cis*-3-methyl-γ-octalactone was quantified in unfined rosé wine aged in contact with oak wood chips followed by the unfined rosé wine aged in contact with cherry wood chips. A similar trend was also found for fined rosé wines (Table 3). However, fined rosé wine aged in contact with cherry wood chips showed a very low amount of *cis*-3-methyl-γ-octalactone (Table 4).

With respect to acids group, similar values were detected between all wines in terms of total acids content and in general also for individual acid compounds. However, it is important to note that dodecanoic acid was only detected in unfined rosé wine aged in contact with American oak wood chips, while decanoic acid was quantified in higher amounts in fined rosé wine aged in contact with French oak wood chips.

Finally, a last volatile compound group (designated other volatile compounds) was considered and which included five different phenols (eugenol, 6-methoxyeugenol, 4-vinylguaiacol, 3,4-dimethylphenol and acetovanillone). In terms of total amounts of this compound group, for unfined and fined rosé wine samples, no significant differences were found between all wines. However, 6-methoxyeugenol was only detected in unfined rosé wine aged in contact with American oak wood chips (Table 3).

Sensory profile evaluation

Figure 3 shows the spider web diagrams obtained from average values of each descriptor from sensorial analysis of wines after 20 aging days. For color and aroma descriptors of unfined rosé wines (Fig. 3(A)), significantly higher scores for 'floral aroma' descriptor were obtained for unfined rosé wines aged in contact with acacia, cherry and French oak wood chips, and also for control wine in relation to the rosé wine aged in contact with American oak wood chips that showed the lowest score for 'floral aroma' descriptor. A similar tendency was also found for the 'aroma quality' descriptor. For the remaining color and aroma descriptors, there were no significant differences between the different unfined rosé wines. For fined rosé wines and also for color and aroma parameters (Fig. 3(B)), rosé wines aged in contact with oak wood chips showed significantly higher scores for 'wood aroma' in relation to the remaining wines. In addition, according to the panel test, the rosé wines aged in contact with the two oak wood chip species used and also control wine showed significantly higher scores for 'aroma intensity' descriptor in relation to the other fined rosé wines. For the remaining color and aroma descriptors, there were no significant differences between the different fined rosé wines. In respect of the taste parameters and overall appreciation of unfined rosé wines (Fig. 3(C)), all rosé wines aged in contact with the different wood chip species showed significantly higher scores for 'astringency' descriptor in relation to the control wine. However, for overall appreciation, unfined rosé wine aged in contact with cherry wood chips showed a significantly higher score in relation to the remaining unfined rosé wines. In addition, rosé wines aged in contact with oak wood chip species showed the significantly lowest scores for overall appreciation. Finally, for the taste descriptors and overall appreciation results of fined rosé wines, no significant differences were found among all wines (Fig. 3(D)).

Table 3. Volatile composition from unfined rosé wines aged in contact with different wood chip species (1.5 g L^{-1}) obtained after 20 aging days

	Rosé wines				
Compound[†]	CW	WQA	WQP	WRP	WPA
Esters					
Isobutyl acetate	$0.049^{b} \pm 0.004$	$0.049^{b} \pm 0.000$	$0.024^{a} \pm 0.000$	$0.046^{b} \pm 0.002$	$0.048^{b} \pm 0.001$
Ethyl butyrate	$0.400^{a} \pm 0.040$	$0.354^{a} \pm 0.024$	$0.387^{a} \pm 0.060$	$0.369^{a} \pm 0.034$	$0.471^{a} \pm 0.008$
Ethyl-2-methylbutyrate[‡]	$0.009^{a} \pm 0.001$	$0.008^{a} \pm 0.001$	$0.006^{a} \pm 0.002$	$0.009^{a} \pm 0.001$	$0.009^{a} \pm 0.001$
Ethyl isovalerate	$0.015^{a} \pm 0.001$	$0.013^{a} \pm 0.000$	$0.012^{a} \pm 0.003$	$0.014^{a} \pm 0.000$	$0.018^{a} \pm 0.000$
Isoamyl acetate	$1.868^{a} \pm 0.195$	$1.634^{a} \pm 0.146$	$1.863^{a} \pm 0.081$	$1.822^{a} \pm 0.024$	$2.074^{a} \pm 0.065$
Ethyl acetate	$0.856^{b} \pm 0.082$	$0.812^{b} \pm 0.029$	$0.503^{a} \pm 0.087$	$0.163^{c} \pm 0.023$	$0.190^{c} \pm 0.013$
Hexyl acetate	$0.202^{b} \pm 0.027$	$0.195^{b} \pm 0.014$	$0.041^{a} \pm 0.009$	$0.773^{c} \pm 0.071$	$0.883^{c} \pm 0.057$
Ethyl lactate	$29.68^{ab} \pm 3.47$	$28.94^{ab} \pm 2.32$	$26.27^{a} \pm 4.1$	$29.58^{ab} \pm 3.11$	$38.48^{b} \pm 3.83$
Ethyl octanoate	$1.200^{a} \pm 0.017$	$1.195^{a} \pm 0.043$	$1.256^{a} \pm 0.060$	$1.304^{a} \pm 0.020$	$1.303^{a} \pm 0.003$
Ethyl 3-hydroxybutyrate	$0.318^{a} \pm 0.045$	$0.241^{a} \pm 0.018$	$0.410^{a} \pm 0.108$	$0.232^{a} \pm 0.055$	$0.321^{a} \pm 0.030$
Ethyl 2-furoate	$0.009^{a} \pm 0.001$	$0.009^{a} \pm 0.001$	$0.009^{a} \pm 0.001$	$0.009^{a} \pm 0.000$	$0.010^{a} \pm 0.000$
Ethyl decanoate	$0.309^{a} \pm 0.015$	$0.378^{a} \pm 0.046$	$0.330^{a} \pm 0.043$	$0.322^{a} \pm 0.013$	$0.280^{a} \pm 0.018$
Diethyl succinate	$1.332^{a} \pm 0.016$	$1.214^{a} \pm 0.006$	$1.624^{a} \pm 0.209$	$1.307^{a} \pm 0.136$	$1.218^{a} \pm 0.010$
Benzyl acetate[§]	$0.020^{a} \pm 0.002$	$0.022^{a} \pm 0.005$	$0.019^{a} \pm 0.000$	$0.019^{a} \pm 0.000$	$0.019^{a} \pm 0.000$
β-Phenylethyl acetate[¶]	$1.774^{a} \pm 0.108$	$1.931^{a} \pm 0.099$	$1.834^{a} \pm 0.341$	$1.761^{a} \pm 0.230$	$1.625^{a} \pm 0.029$
Ethyl vanillate[††]	$0.070^{a} \pm 0.004$	$0.091^{ab} \pm 0.008$	$0.130^{b} \pm 0.020$	$0.072^{a} \pm 0.001$	$0.053^{a} \pm 0.004$
Methyl vanillate[††]	$0.028^{ab} \pm 0.001$	$0.049^{bc} \pm 0.005$	$0.071^{c} \pm 0.015$	$0.032^{ab} \pm 0.001$	$0.020^{a} \pm 0.002$
Total average value	38.139 [a¶¶]	37.135 [a]	34.796 [a]	37.841 [a]	47.022 [b]
Alcohols					
Isobutanol	$180.12^{ab} \pm 25.61$	$140.93^{a} \pm 9.52$	$167.14^{ab} \pm 16.456$	$169.98^{ab} \pm 0.882$	$216.77^{b} \pm 13.583$
3-Methyl-1-pentanol	$0.284^{ab} \pm 0.055$	$0.243^{ab} \pm 0.011$	$0.178^{a} \pm 0.050$	$0.267^{ab} \pm 0.011$	$0.342^{b} \pm 0.014$
2,3-Butanediol	$1.005^{ab} \pm 0.108$	$0.854^{a} \pm 0.076$	$0.587^{a} \pm 0.006$	$1.104^{ab} \pm 0.031$	$1.251^{b} \pm 0.025$
1-Hexanol	$1.696^{a} \pm 0.203$	$1.387^{a} \pm 0.123$	$1.190^{a} \pm 0.255$	$1.526^{a} \pm 0.034$	$1.823^{a} \pm 0.042$
Trans-3-hexen-1-ol	$0.110^{a} \pm 0.013$	$0.102^{a} \pm 0.002$	$1.173^{b} \pm 0.406$	$0.087^{a} \pm 0.007$	$0.151^{a} \pm 0.024$
Cis-3-hexen-1-ol	$0.305^{b} \pm 0.027$	$0.286^{b} \pm 0.007$	$0.146^{a} \pm 0.000$	$0.258^{b} \pm 0.033$	$0.306^{b} \pm 0.009$
Benzyl alcohol	$0.080^{a} \pm 0.005$	$0.073^{a} \pm 0.001$	$0.087^{a} \pm 0.011$	$0.081^{a} \pm 0.002$	$0.089^{a} \pm 0.005$
β-Phenylethyl alcohol	$32.38^{a} \pm 1.577$	$28.60^{a} \pm 3.949$	$31.53^{a} \pm 5.429$	$31.09^{a} \pm 1.859$	$34.42^{a} \pm 0.562$
Total average value	215.987 [a]	172.480 [b]	202.041 [a]	204.409 [a]	255.158 [c]
Aldehydes					
Furfural[‡‡]	$1.357^{a} \pm 0.127$	$2.715^{a} \pm 0.277$	$1.722^{a} \pm 1.288$	$1.557^{a} \pm 0.078$	$2.233^{a} \pm 0.020$
5-Methyl furfural[‡‡]	$0.281^{a} \pm 0.00$	$1.919^{b} \pm 0.267$	$1.439^{b} \pm 0.259$	$0.400^{a} \pm 0.168$	$0.413^{a} \pm 0.006$
Vanillin	$0.019^{a} \pm 0.004$	$0.748^{b} \pm 0.086$	$0.722^{b} \pm 0.105$	$0.039^{a} \pm 0.006$	$0.016^{a} \pm 0.001$
Syringaldehyde	$0.054^{a} \pm 0.006$	$1.110^{b} \pm 0.139$	$0.860^{b} \pm 0.255$	$0.117^{a} \pm 0.019$	$0.072^{a} \pm 0.008$
Total average value	1.711 [a]	6.492 [b]	4.743 [b]	2.113 [c]	2.734 [c]
Terpenes					
Linalool	$0.018^{a} \pm 0.002$	$0.018^{a} \pm 0.001$	$0.016^{a} \pm 0.001$	$0.017^{a} \pm 0.002$	$0.018^{a} \pm 0.001$
α-Terpineol	$0.011^{a} \pm 0.002$	$0.011^{a} \pm 0.001$	$0.007^{a} \pm 0.002$	$0.011^{a} \pm 0.001$	$0.011^{a} \pm 0.001$
Geraniol	$0.005^{a} \pm 0.001$	$0.005^{a} \pm 0.001$	$0.005^{a} \pm 0.000$	$0.005^{a} \pm 0.000$	$0.007^{a} \pm 0.003$
Total average value	0.034 [a]	0.034 [a]	0.028 [a]	0.033 [a]	0.036 [a]
Lactones					
γ-Butyrolactone	$8.475^{a} \pm 0.153$	$7.482^{a} \pm 1.517$	$7.326^{a} \pm 0.483$	$8.302^{a} \pm 0.216$	$8.432^{a} \pm 0.130$
Trans-3-methyl-γ-octalactone	n.q.	n.q.	0.013 ± 0.010	n.q.	n.q.
Cis-3-methyl-γ-octalactone	n.q.	$0.070^{c} \pm 0.004$	$0.029^{b} \pm 0.004$	$0.007^{a} \pm 0.000$	$0.020^{d} \pm 0.001$
γ-Undecalactone	$0.004^{a} \pm 0.001$	$0.004^{a} \pm 0.002$	$0.004^{a} \pm 0.001$	$0.004^{a} \pm 0.001$	$0.004^{a} \pm 0.001$
Total average value	8.479 [a]	7.556 [a]	7.372 [a]	8.313 [a]	8.456 [a]
Acids					
Hexanoic acid	$6.604^{ab} \pm 0.218$	$6.885^{ab} \pm 0.859$	$5.077^{a} \pm 0.438$	$6.086^{ab} \pm 0.657$	$7.589^{b} \pm 0.402$
Octanoic acid	$7.638^{a} \pm 0.072$	$8.135^{a} \pm 1.017$	$8.796^{a} \pm 0.854$	$7.264^{a} \pm 0.950$	$7.885^{a} \pm 0.157$
Decanoic acid	$2.261^{a} \pm 0.344$	$2.919^{a} \pm 0.297$	$2.729^{a} \pm 0.349$	$2.158^{a} \pm 0.126$	$2.137^{a} \pm 0.026$
Geranic acid	$0.172^{ab} \pm 0.035$	$0.284^{b} \pm 0.048$	$0.191^{ab} \pm 0.027$	$0.164^{ab} \pm 0.021$	$0.141^{a} \pm 0.001$
Dodecanoic acid	n.q.	0.223 ± 0.004	n.q.	n.q.	n.q.
Total average value	16.675 [a]	18.446 [a]	16.793 [a]	15.672 [a]	17.752 [a]
Others (phenols)					
Eugenol	$0.003^{a} \pm 0.001$	$0.005^{a} \pm 0.002$	$0.005^{a} \pm 0.001$	$0.003^{a} \pm 0.001$	$0.003^{a} \pm 0.001$

Table 3. Continued

Compound†	Rosé wines				
	CW	WQA	WQP	WRP	WPA
6-Methoxyeugenol	n.q.	0.004 ± 0.001	n.q.	n.q.	n.q.
4-Vinylguaiacol	1.680^{a} ± 0.013	1.914^{a} ± 0.129	1.819^{a} ± 0.046	1.704^{a} ± 0.035	1.734^{a} ± 0.066
3,4-Dimethylphenol	0.180^{a} ± 0.022	0.202^{a} ± 0.028	0.176^{a} ± 0.043	0.185^{a} ± 0.017	0.193^{a} ± 0.000
Acetovanillone (apocyanin)††	0.024^{a} ± 0.002	0.041^{ab} ± 0.006	0.074^{b} ± 0.019	0.026^{a} ± 0.004	0.017^{a} ± 0.001
Total average value	1.887 ^{a}	2.166 ^{a}	2.074 ^{a}	1.918 ^{a}	1.947 ^{a}

†Values expressed in ppm.
‡Expressed in ethyl butyrate equivalents.
§Expressed in benzyl alcohol equivalents.
¶Expressed in *β*-phenylethyl alcohol equivalents.
¶¶Values with same letters for each volatile compound are not significantly different (Tukey test, $P < 0.05$); average values of three replicates.
††Expressed in vanillin equivalents.
‡‡Expressed in 5-hydroxymethylfurfural equivalents.
CW, control wine; WQA, wine aged with *Quercus alba* wood chips; WQP, wine aged with *Quercus petraea* wood chips; WRP, wine aged with *R. pseudoacacia* wood chips; WPA, wine aged with *Prunus avium* wood chips; n.q., not quantifiable.

Table 4. Volatile composition of fined rosé wines aged in contact with different wood chip species (1.0 g L^{-1}) obtained after 20 aging days

Compound†	Rosé wines				
	CW	WQA	WQP	WRP	WPA
Esters					
Isobutyl acetate	0.015^{a} ± 0.004	0.028^{a} ± 0.003	0.029^{a} ± 0.006	0.028^{a} ± 0.005	0.029^{a} ± 0.001
Ethyl butyrate	0.317^{a} ± 0.032	0.383^{a} ± 0.019	0.347^{a} ± 0.018	0.361^{a} ± 0.016	0.385^{a} ± 0.036
Ethyl 2-methylbutyrate‡	0.005^{a} ± 0.000	0.009^{a} ± 0.001	0.008^{a} ± 0.001	0.007^{a} ± 0.001	0.008^{a} ± 0.000
Ethyl isovalerate	0.010^{a} ± 0.001	0.015^{bc} ± 0.001	0.018^{c} ± 0.002	0.014^{abc} ± 0.001	0.014^{ab} ± 0.001
Isoamyl acetate	1.411^{a} ± 0.162	1.726^{a} ± 0.235	1.532^{a} ± 0.238	1.646^{a} ± 0.132	1.702^{a} ± 0.125
Ethyl acetate	0.157^{a} ± 0.046	0.180^{a} ± 0.001	0.176^{a} ± 0.006	0.161^{a} ± 0.042	0.163^{a} ± 0.021
Hexyl acetate	0.738^{a} ± 0.082	0.818^{a} ± 0.053	0.770^{a} ± 0.027	0.749^{a} ± 0.079	0.738^{a} ± 0.041
Ethyl lactate	23.74^{a} ± 2.68	26.22^{a} ± 4.36	20.82^{a} ± 1.25	26.59^{a} ± 4.73	24.94^{a} ± 4.55
Ethyl octanoate	1.145^{a} ± 0.055	1.083^{a} ± 0.017	1.054^{a} ± 0.033	1.304^{a} ± 0.162	1.132^{a} ± 0.064
Ethyl 3-hydroxybutyrate	0.219^{a} ± 0.049	0.138^{a} ± 0.011	0.236^{a} ± 0.044	0.174^{a} ± 0.028	0.176^{a} ± 0.028
Ethyl 2-furoate	0.007^{a} ± 0.001	0.008^{a} ± 0.000	0.008^{a} ± 0.000	0.008^{a} ± 0.001	0.008^{a} ± 0.001
Ethyl decanoate	0.272^{a} ± 0.034	0.295^{a} ± 0.035	0.293^{a} ± 0.035	0.279^{a} ± 0.045	0.275^{a} ± 0.015
Diethyl succinate	1.210^{a} ± 0.197	1.225^{a} ± 0.09	1.171^{a} ± 0.019	1.284^{a} ± 0.131	1.072^{a} ± 0.051
Benzyl acetate§	0.034^{b} ± 0.007	0.019^{a} ± 0.000	0.019^{a} ± 0.001	0.019^{a} ± 0.000	0.019^{a} ± 0.001
β-Phenylethyl acetate¶	1.667^{a} ± 0.233	1.609^{a} ± 0.119	1.718^{a} ± 0.112	1.813^{a} ± 0.125	1.519^{a} ± 0.078
Ethyl vanillate††	0.087^{a} ± 0.020	0.048^{a} ± 0.000	0.059^{a} ± 0.002	0.080^{a} ± 0.005	0.052^{a} ± 0.011
Methyl vanillate††	0.037^{a} ± 0.006	0.034^{a} ± 0.002	0.043^{a} ± 0.003	0.037^{a} ± 0.007	0.027^{a} ± 0.004
Total average value	31.072 ^{a¶¶}	33.847 ^{a}	28.304 ^{a}	34.550 ^{a}	32.261 ^{a}
Alcohols					
Isobutanol	130.72^{a} ± 15.94	162.13^{c} ± 2.62	130.36^{a} ± 36.13	145.83^{a} ± 11.31	167.85^{d} ± 18.06
3-Methyl-1-pentanol	0.260^{a} ± 0.018	0.228^{a} ± 0.003	0.279^{a} ± 0.021	0.203^{a} ± 0.029	0.247^{a} ± 0.021
2,3-Butanediol	0.961^{a} ± 0.123	0.983^{a} ± 0.108	0.919^{a} ± 0.060	0.837^{a} ± 0.089	0.816^{a} ± 0.074
1-Hexanol	1.376^{a} ± 0.235	1.429^{a} ± 0.064	1.437^{a} ± 0.036	1.220^{a} ± 0.211	1.283^{a} ± 0.121
Trans-3-hexen-1-ol	0.076^{a} ± 0.025	0.088^{a} ± 0.027	0.117^{a} ± 0.010	0.099^{a} ± 0.032	0.086^{a} ± 0.010
Cis-3-hexen-1-ol	0.265^{a} ± 0.020	0.278^{a} ± 0.027	0.302^{a} ± 0.012	0.277^{a} ± 0.037	0.273^{a} ± 0.023
Benzyl alcohol	0.069^{a} ± 0.012	0.082^{a} ± 0.006	0.070^{a} ± 0.002	0.083^{a} ± 0.000	0.071^{a} ± 0.008
β-Phenylethyl alcohol	31.57^{a} ± 5.42	29.45^{a} ± 0.24	27.89^{a} ± 0.69	30.49^{a} ± 1.10	27.24^{a} ± 2.30
Total average value	165.30 ^{a}	144.677 ^{b}	161.387 ^{a}	179.049 ^{a}	197.876 ^{c}
Aldehydes					
Furfural‡‡	1.046^{a} ± 0.017	1.788^{b} ± 0.135	2.403^{b} ± 0.089	1.350^{b} ± 0.417	1.746^{b} ± 0.392
5-Methylfurfural‡‡	0.286^{a} ± 0.000	1.265^{b} ± 0.035	1.435^{c} ± 0.015	0.281^{a} ± 0.000	0.329^{a} ± 0.068
Vanillin	0.035^{a} ± 0.010	0.309^{b} ± 0.053	0.392^{b} ± 0.007	0.039^{a} ± 0.007	0.002^{a} ± 0.006
Syringaldehyde	n.q.	0.489^{ab} ± 0.110	0.572^{b} ± 0.150	0.074^{c} ± 0.019	n.q.

Table 4. Continued

Compound†	Rosé wines				
	CW	WQA	WQP	WRP	WPA
Total average value	1.367 [a]	3.851 [b]	4.802 [c]	1.744 [a]	2.077 [a]
Terpenes					
Linalool	0.015[ab] ± 0.000	0.015[ab] ± 0.001	0.016[ab] ± 0.001	0.015[b] ± 0.004	0.015[a] ± 0.001
α-Terpineol	0.007[a] ± 0.002	0.008[a] ± 0.001	0.009[a] ± 0.001	0.009[a] ± 0.002	0.008[a] ± 0.001
Geraniol	0.005[a] ± 0.001	0.004[a] ± 0.002	0.005[a] ± 0.001	0.005[a] ± 0.001	0.005[a] ± 0.000
Total average value	0.027 [a]	0.027 [a]	0.030 [a]	0.029 [a]	0.028 [a]
Lactones					
γ-Butyrolactone	6.925[a] ± 0.806	7.312[a] ± 0.028	7.308[a] ± 0.321	7.873[a] ± 0.518	6.139[a] ± 1.131
Trans-3-methyl-γ-octalactone	n.q.	n.q.	n.q.	n.q.	n.q.
Cis-3-methyl-γ-octalactone	n.q.	0.049[b] ± .008	0.013[c] ± 0.001	0.001[a] ± 0.000	0.003[a] ± 0.000
γ-Undecalactone	0.004[a] ± 0.000	0.004[a] ± 0.001	0.012[b] ± 0.002	0.004[a] ± 0.001	0.004[a] ± 0.001
Total average value	6.929 [a]	7.365 [a]	7.333 [a]	7.878 [a]	6.146 [a]
Acids					
Hexanoic acid	5.19[a] ± 0.88	6.17[a] ± 0.54	6.50[a] ± 0.22	5.87[a] ± 1.70	5.60[a] ± 0.24
Octanoic acid	7.40[a] ± 1.00	7.86[a] ± 0.82	7.46[a] ± 0.99	7.67[a] ± 1.37	7.49[a] ± 0.77
Decanoic acid	2.374[ab] ± 0.263	2.023[a] ± 0.233	3.778[b] ± 0.769	2.664[ab] ± 0.229	2.094[a] ± 0.31
Geranic acid	0.177[a] ± 0.029	0.168[a] ± 0.028	0.242[a] ± 0.073	0.191[a] ± 0.042	0.167[a] ± 0.026
Total average value	15.152 [a]	16.233 [a]	17.985 [a]	16.410 [a]	15.360 [a]
Others (phenols)					
Eugenol	n.q.	0.004[b] ± 0.001	0.004[b] ± 0.001	0.002[a] ± 0.001	0.002[a] ± 0.001
4-Vinylguaiacol	1.503[a] ± 0.190	1.347[a] ± 0.160	1.484[a] ± 0.171	1.485[a] ± 0.080	1.295[a] ± 0.090
3,4-Dimethylphenol	0.159[a] ± 0.047	0.168[a] ± 0.020	0.241[a] ± 0.088	0.195[a] ± 0.038	0.171[a] ± 0.015
Acetovainillone (apocyanin)††	0.030[a] ± 0.005	0.022[a] ± 0.005	0.031[a] ± 0.002	0.034[a] ± 0.001	0.023[a] ± 0.006
Total average value	1.692 [a]	1.541 [a]	1.760 [a]	1.716 [a]	1.491 [a]

†Values expressed in ppm.
‡Expressed in ethyl butyrate equivalents.
§Expressed in benzyl alcohol equivalents.
¶Expressed in β-phenylethyl alcohol equivalents.
¶¶values with same letters for each volatile compound are not significantly different (Tukey test, $p < 0.05$); average values of three replicates.
††Expressed in vanillin equivalents.
‡‡Expressed in 5-hydroxymethylfurfural equivalents.
CW, control wine; WQA, wine aged with *Quercus alba* wood chips; WQP, wine aged with *Quercus petraea* wood chips; WRP, wine aged with *R. pseudoacacia* wood chips; WPA, wine aged with *Prunus avium* wood chips; n.q., not quantifiable.

PCA applied to rosé wine characterization

To better understand the relationship between rosé wines aged in contact with different wood chips concerning the phenolic parameters, volatile composition and sensorial profile, a PCA was performed. The corresponding loading plots that established the relative importance of each variable are shown in Fig. 4. This figure shows the relationship between the unfined (Fig. 4(A I)) and fined (Fig. 4(B I)) rosé wines and the most relevant independent phenolic, volatile and sensorial parameters evaluated. For unfined rosé wines (Fig. 4(A I)), the PCA showed that the first two PCs explained 71.69% of the total variance, while for fined rosé wines (Fig. 4(B I)), the PCA showed that the first two PCs explained 63.19 % of the total variance.

In Fig. 4(C II), it is possible to visualize the spatial distribution of the unfined rosé wines aged in contact with different wood chips evaluated concerning the different parameters considered. Thus, after a cluster analysis, one group is formed by two unfined rosé wines (control rosé wine and rosé wine aged in contact with acacia wood chips); these rosé wines were positively related with color intensity and hue, total anthocyanins, total pigments and 'aroma intensity' descriptor and negatively related with degree of polymerization of pigments and two sensorial descriptors ('acidity' and 'limpidity'). Another group is formed by unfined rosé wine aged in contact with cherry wood chips. This rosé wine was positively related with polymeric pigments, 'vegetal aroma' descriptor and two volatile compound groups (total esters and total terpenes), and negatively related with non-flavonoid phenols. The third group is formed by unfined rosé wine aged in contact with French oak wood chips and was positively related with degree of ionization of anthocyanins and negatively related with 'overall appreciation' descriptor. Finally, a last group is formed by unfined rosé wine aged in contact with American oak wood chips. This rosé wine was positively related with degree of polymerization of pigments, 'wood aroma' descriptor and two volatile compound groups (total aldehydes and total other volatile compounds).

For fined rosé wines, the spatial distribution of the rosé wines aged in contact with different wood chips evaluated concerning the different parameters considered is shown in Fig. 4(D II). Three different groups are formed: one group formed by fined rosé wines aged in contact with oak wood chips; another group formed by fined rosé wine aged in contact with cherry wood chips and control fined rosé wine; and the third group formed exclusively by the rosé wine aged in contact with acacia wood chips. The group formed by fined rosé wines in contact with oak wood chips

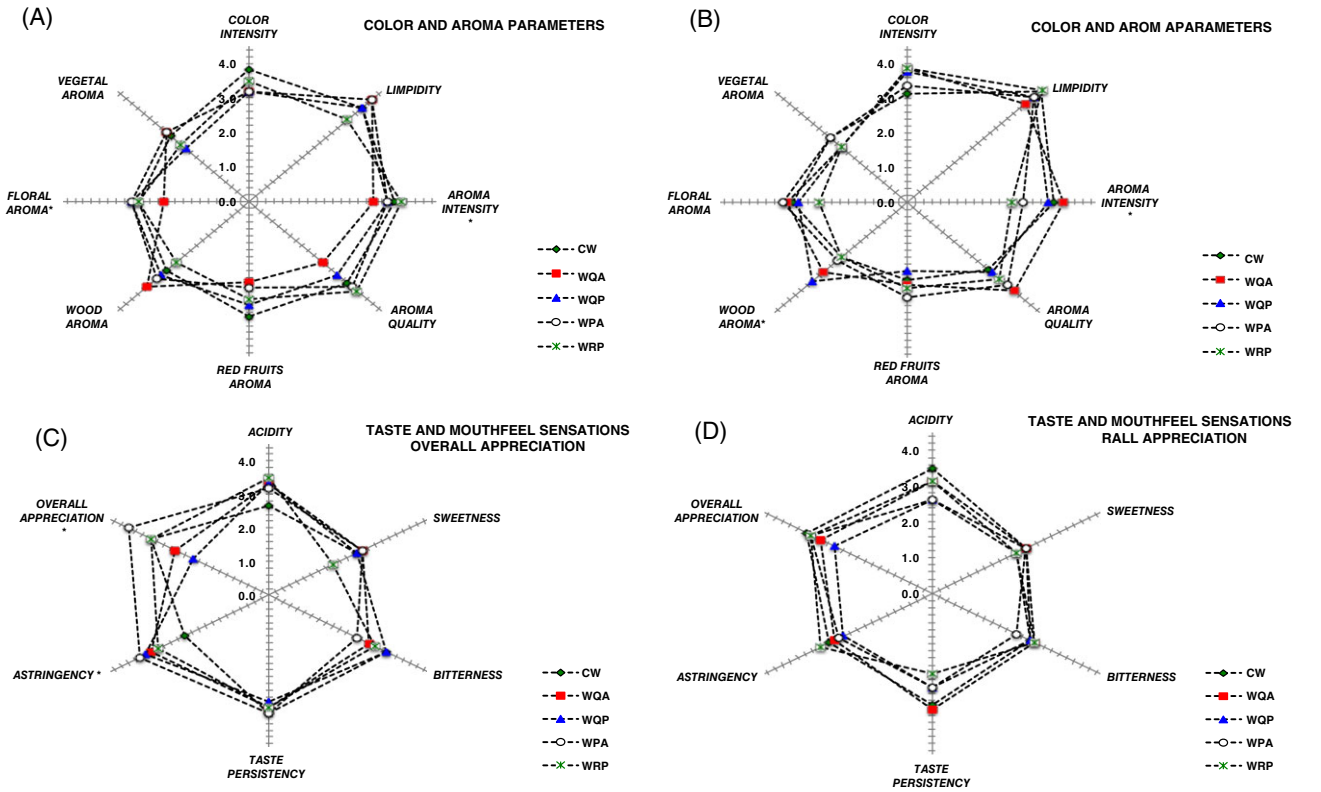

Figure 3. Sensory profile from unfined (A and C) and fined (B and D) rosé wines aged in contact with different wood chip species with concentrations of 1.5 and 1.0 g L^{-1}, respectively, and obtained after 20 aging days. CW, control wine; WQA, wine aged with *Quercus alba* wood chips; WQP, wine aged with *Quercus petraea* wood chips; WRP, wine aged with *R. pseudoacacia* wood chips; WPA, wine aged with *Prunus avium* wood chips. *Sensory parameters where there is significantly differences between the rosé wines (Tukey test, $P < 0.05$).

was positively related with three phenolic parameters (degree of polymerization of pigments, color intensity and hue), two sensorial descriptors ('aroma intensity' and 'wood aroma') and also with total aldehydes. In addition, this group was negatively related with total anthocyanins, total pigments and total alcohols. The group formed by fined rosé wines aged in contact with cherry wood chips and control rosé wine was positively related with total alcohols and two sensorial descriptors ('vegetal aroma' and 'red fruits aroma'), and negatively associated with total phenols, color hue and two volatile compound groups (total lactones and total acids). Finally, the group formed by fined rosé wine aged in contact with acacia wood chips was positively related with non-flavonoid phenols and negatively related with three sensorial descriptors ('taste persistency', 'floral aroma' and 'aroma intensity').

DISCUSSION

The majority of the published works related to the impact of different wood chip species, especially oak wood, on wine quality are related to red wines,[8,14,29] and in recent years also a few studies have been published relating to white wines.[10,11,16] Thus, the use of different wood chip species (oak, acacia or cherry) in a short aging period of rosé wines is not usual and consequently it is not possible to have a real perception of the potential impact on rosé wine properties and also the wood chip concentration usually used. Therefore, this novelty implies a difficulty to make a comparative analysis with previous works, with different woods, wines, chip concentrations and contact times.

Phenolic content and color properties of rosé wines studied

In general, the majority of the published works reported a higher phenolic composition of red and white wines aged in contact with wood, in particular in contact with different oak wood species,[8,11,15,28] but also in contact with other non-oak wood species, namely acacia wood.[10,16] This increase in total phenol content is an evident consequence of phenol transfer from wood to wine. Recently for white wines, Delia *et al.*[16] reported that 20 aging days were sufficient for the extraction of phenolic compounds from different wood chip species. Thus, the results obtained in our experimental work for both of the rosé wine samples used (unfined and fined) confirmed also the tendency for higher total phenolic content of wines aged in contact with wood chips.

Concerning the potential impact of the individual wood chip species used, the results obtained demonstrated that, in general, the use of acacia wood induced a higher increase of phenolic content of rosé wines studied, in particular when the wood chips were added to unfined rosé (Fig. 1). These results could reflect the large quantities of potentially extractable phenolic compounds from acacia wood extracts previously reported by other authors.[30]

The high flavonoid and non-flavanoid content of rosé wines aged in contact with acacia wood chips could correspond to a higher extraction of several individual phenolic compounds, for example gallic acid, ellagitannins and ellagic acid. Previously, several authors[31,32] reported high flavonoid compound content in seasoned acacia wood. On the other hand, the high porosity of acacia wood also promotes phenolic compound extraction from this wood species. Recently, Delia *et al.*[16] reported for a short aging period an increase of total phenols, non-flavonoid and flavonoid

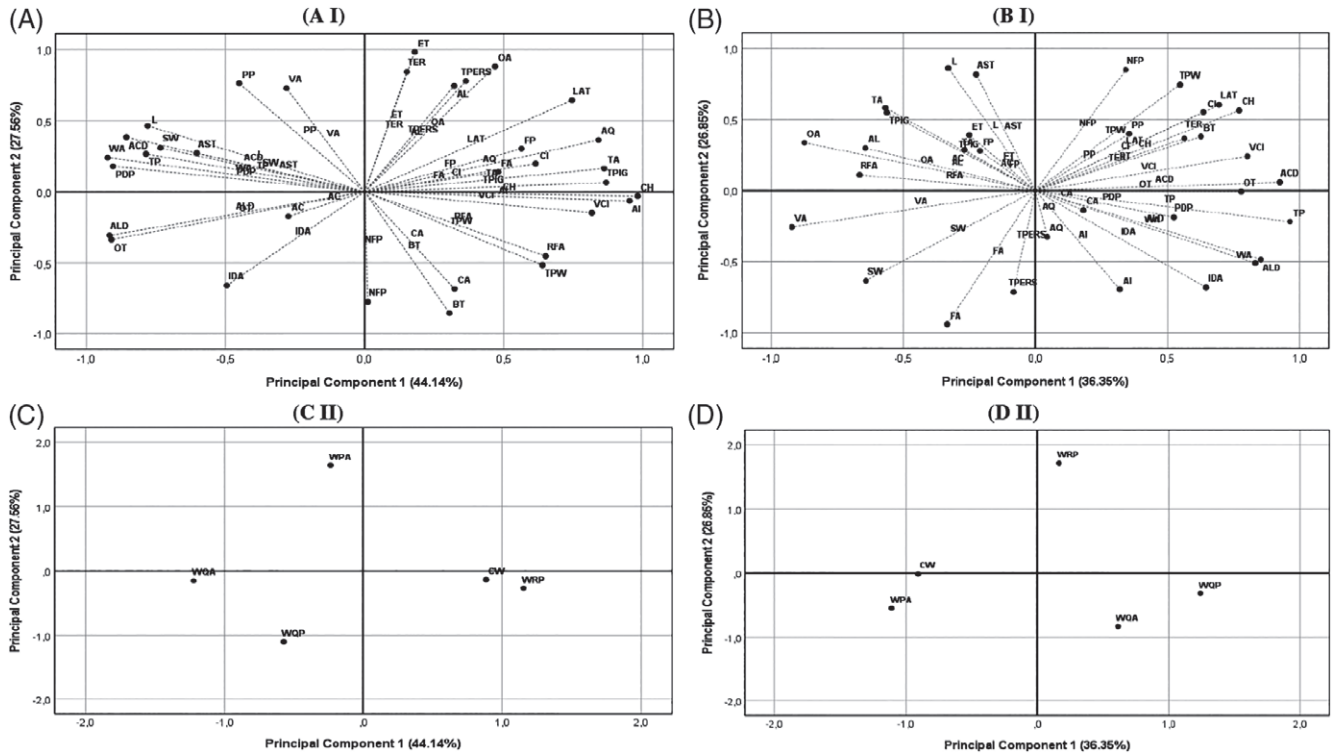

Figure 4. PCA (PC1 and PC2) for different sensorial attributes and phenolic and aromatic parameters from unfined (A and C) and fined (B and D) rosé wines aged in contact with different wood chip species (concentrations of 1.5 and 1.0 g L^{-1}, respectively) after 20 aging days. I, projection of sensorial attributes and phenolic and aromatic parameters; II, projection of rosé wine samples. Sensorial attributes: VCI, color intensity; L, limpidity; AI, aroma intensity; AQ, aroma quality; RFA, red fruits aroma; WA, wood aroma; FA, floral aroma; VA, vegetal aroma; AC, acidity; SW, sweetness; BT, bitterness; TPERS, taste persistency; AST, astringency; OA, overall appreciation. Phenolic parameters: TP, total phenols; FP, flavonoid phenols; NFP, non-flavonoid phenols; TPIG, total pigments; PP, polymeric pigments; PDP, degree of polymerization of pigments; TPW, tannin power; TA, total anthocyanins; CA, colored anthocyanins; IDA, degree of ionization of anthocyanins; CI, color intensity; CH, color hue. Aromatic parameters: ET, total esters; AL, total alcohols; ALD, total aldehydes; TER, total terpenes; LAT, total lactones; ACD, total acids; OT, total others. Rosé wines samples: CW, control wine; WQA, wine aged with *Quercus alba* wood chips; WQP, wine aged with *Quercus petraea* wood chips; WRP, wine aged with *R. pseudoacacia* wood chips; WPA, wine aged with *Prunus avium* wood chips.

compounds of white wines from 'Encruzado' grape variety aged in contact with acacia wood chips. According to Férnandez de Simón *et al.*,[33] each type of wood and piece size have shown a particular composition and extraction kinetics. Thus, the phenolic compound extraction from wood to wine will be dependent on the level of wine penetration into the wood, the concentration gradient between wine and wood and also the natural phenolic richness of the different wood species.

The results obtained for polymeric pigments showed a tendency for higher values in the unfined rosé wines aged in contact with cherry wood chips (Fig. 1). However, the differences obtained were not statistically different between the other remaining unfined rosé wines. This tendency for higher polymeric pigments in unfined rosé wines aged in contact with cherry wood chips allows us to consider that the use of these chips could induce a potential faster evolution of wine phenolic compounds and consequently a development of derived and polymeric compounds. This trend is in accord with the results reported previously by other authors for red wines.[12,15] De Rosso *et al.*[34] also reported that barrels from cherry wood provide a favorable environment for oxidative reactions, making it less suitable for longer aging periods.

In our study, for fined rosé wines, no significant differences were detected for polymeric pigments. However, only a slight tendency for higher values in the rosé wines aged in contact with American oak and acacia wood chips was found. It is also important to note that the wood chip concentrations used in our research (1.5 and 1.0 g L^{-1}) are much lower than that used generally in the published works (from 3 to 40 g L^{-1}), in particular for red wines.[8,15,35] Therefore, this fact could contribute to explain the low differentiation obtained in our work among the rosé wines aged with different wood chip species and control wine for some phenolic parameters, such as polymeric pigments.

After 20 aging days, degree of polymerization of pigments quantified in the different rosé wines was characterized by significantly higher values for the unfined rosé wines aged in contact with French oak and cherry wood chips, while for fined rosé wines, the samples aged in contact with American oak and acacia wood chips showed significantly higher values (Fig. 1). These results showed, in general, the same tendency obtained for polymeric pigments; however, for the degree of polymerization of pigments the differences between the wines were more evident.

Tanning power represents the expression of the 'potential tannins' of a wine, namely the capacity of some proanthocyanidins with particular degree of polymerization to interact with proteins, influencing the astringent characters of the wine during tasting. All rosé wines aged in contact with acacia wood chips showed significantly higher tanning power results. It is important to note that the rosé wines aged in contact with acacia wood chips showed a higher total phenolic content. Thus, probably the phenolic compounds extracted from acacia wood showed high level of interactions with saliva proteins which may explain the significantly high tanning power quantified in wines aged with acacia wood chips.

Consequently, this may also induce a potential higher level of wine astringency. However, for the sensorial panel test, this difference was not totally detected, in particular for fined rosé wines (Fig. 3).

Previous work[12] reported that the use of wood promotes pigment stabilization, namely anthocyanin pigments, and induces a higher color intensity and the best chromatic attributes of red wines. The results obtained in our work are in agreement with this previous work, because, in general, rosé wines aged in contact with wood chips showed higher values for the majority of phenolic and chromatic parameters studied (Fig. 2 and Table 2). In particular, for unfined rosé wines, contact with acacia wood chips led to the highest values of total anthocyanins, lightness (L^*) and color difference (ΔE) in relation to the control wine, while the aging process with American oak wood chips induced a smaller increase of b^* values in relation to the control wine. Instead, the use of cherry wood chips induced a greater decrease of anthocyanin content and red color content of the unfined rosé wine. However, these differences did not induce a significant color difference (ΔE) in relation to the unfined control rosé wine.

The impact of cherry wood chips used during the aging process was more evident for fined rosé wines. Although all of these differences have been verified, it cannot be considered that there has been a clear tendency to differentiate the color properties studied of all rosé wines according to the different wood chip species used. Probably the short storage time and/or wood chip concentration used were not enough to lead to marked differences between the rosé wines. Previous authors[13] have also reported clear evident differences in wine characteristics only after several months of storage.

Volatile composition of rosé wines analyzed

The scientific literature contains a large amount of data related to volatile composition of different wood species, in particular of oak,[4,5,33] and in the last few years also of other species, such as cherry and acacia.[36,37] Consequently, the use of different wood species will have a potential impact on the volatile composition of aged wines.

Most wine esters are enzymatically synthesized by yeasts during alcoholic fermentation and can also be modulated by lactic acid bacteria during malolactic fermentation.[38] Other authors[39] reported that red wine ester profiles could be strongly influenced by grape composition and, in particular, grape nitrogen and lipid metabolism, and also by the must clarification and temperature used during the fermentation process. However, it is important to note that that wood aging of wines produces complex interactions between wood-derived compounds and pre-existing components in wine. Thus, wood contributes several aroma volatiles; but the whole volatile fraction, including the volatiles extracted from grape or produced during fermentation, such as esters, could be involved in interactions with the non-volatile fraction. In this case, several authors reported an increase of acetic acid and acetate esters on contact with wood.[40]

Esters are an important volatile compound group for aroma of wines as they contribute to their 'fruity' character. In our work, unfined rosé wine aged in contact with cherry wood chips showed the highest total ester content as a result of higher level of ethyl lactate, which contributes specifically to raspberry aroma. This individual ester occurs after malolactic fermentation from the formation of lactic acid. However, this ester is found naturally in a wide range of foods such as grape and cherry. Niu *et al.*[41] quantified this individual ester in 'cherry fruit wine' as the major volatile compound. Also, hexyl acetate (that contributes to fruity aroma) was detected in higher content in unfined rosé wines aged in contact with cherry and acacia wood chips, while unfined rosé wine aged with French oak wood showed the lowest value. Escalona *et al.*[40] reported also an increase of hexyl acetate and isoamyl acetate of red wines after wood contact. Those authors consider that the increase of these compounds could be related to a change in the equilibrium for increasing levels of acetic acid and the high concentration of isoamyl alcohol and hexanol. Also in our work, for unfined rosé wine aged in contact with cherry wood chips, a slight increase of isoamyl acetate (responsible for odors of melon and banana) occurred. Just like in our work for unfined rosé wine aged with French oak wood chips, Ferreras *et al.*[42] reported for white wines from 'Treixadura' grape variety that contact with oak wood caused a reduction in hexyl acetate with respect to the initial wine.

In our work, probably the use of a longer aging time could induce clearer evolution of the content of these compounds as a result of an increase of the interactions between wood components (volatile and non-volatile) and wine components. However, the wines with lower phenolic content, such as rosés wines, should have a reduced contact time with the wood chips.

After 20 aging days, unfined rosé wines (control wine, and wines aged with oak wood chips) showed important values of ethyl acetate, while the rosé wines aged with cherry and acacia wood chips showed a tendency for lower values. Several authors[43] reported an increase of ethyl acetate during wood maturation and it may be that this compound comes both from the wine oxidation process and also from the wood. The low content of ethyl acetate in unfined rosé wines could be a consequence of potential interactions between cherry and acacia wood components with some individual esters, such as ethyl acetate, inducing a decrease of this compound during the wine aging process.

Ethyl and methyl vanillate were quantified in all unfined rosé wines, including in control wine; however, they were found with higher values for the rosé wines aged in contact with French oak wood chips. In fact, these individual compounds were previously detected in wines without addition of oak wood chips,[14,44] but also in red wines macerated with different oak wood chips.[14,45] In addition, methyl vanillate has been detected and quantified directly in different woods, in particular from different oak species, acacia and cherry woods.[37,46] Thus, the increase of these compounds in wines could be related to the contact with wood chips.

Alcohols are a wine compound group which are formed during the fermentation process. In wines, the alcohol content also depends on different technological factors, such as maceration, fermentation temperature and clarification.[18,47] According to Câmara *et al.*,[48] the potential increase of alcohols during wine aging in contact with wood could be a result of hydrolysis of esters. This probably contributed to the higher isobutanol values founded in all rosé wines aged in contact with cherry wood chips. These results for isobutanol also confirm previous data reported by Lukić *et al.*[49] in white wines aged in barrels.

Based on the results obtained, it was possible to detected a significantly higher content of total aldehydes in the unfined and fined rosé wines aged in contact with oak wood chips in relation to the other rosé wines. In general, this higher aldehyde content is attributable to the presence of greater amounts of furfural, 5-methylfurfural, vanillin and syringaldehyde. Furfural and 5-methylfurfural are formed in considerable quantities by the thermal degradation of wood polysaccharides or by Maillard reaction during the toasting process, particularly in oak woods.

Furfural was the most abundant individual aldehyde quantified in all rosé wines aged in contact with all wood chip species. This result confirms also the results previously reported.[10,36] Nevertheless, those authors also reported a slight increase of furfural after toasting in cherry wood, probably due to a different structure of the polysaccharides which have a higher resistance to thermodegradation. However, in our experimental work, unfined and fined rosé wines aged in contact with cherry wood chips also showed higher furfural values. Probably the toasting process used in the manufacture of cherry wood chips was more intense and consequently furfural was produced to a greater extent.

Vanillin is the most important phenolic aldehyde due its vanilla flavor. A higher content was detected in rosé wines aged with oak wood chips. A similar result was also obtained for syringaldehyde (contributing to pepper and spice notes). According to several authors,[34–36] these results are expected since oak wood shows the highest levels of these compounds compared to cherry and acacia woods. However, other authors[10] also reported different tendencies, with higher values of vanillin in wines aged in contact with acacia than oak wood after three months of aging in barrels. For those authors, wines aged in acacia barrels showed a higher vanilla character. In addition, according to De Rosso *et al.*,[31] acacia wood is also generally characterized by higher content of aromatic aldehydes, such as vanillin, than oak wood. Other authors[32] also detected significant vanillin values in seasoned and toasted acacia samples. Acuña *et al.*[50] reported for different wood species with enological use that solvent impregnation (such as wine) changes significantly with the toasting process, and these changes are more pronounced in oak wood than in acacia wood. Thus, each specific toasting process induces structural changes in the wood which will then influence the greater or lesser extraction of the different extractable components, such as vanillin.

Finally, in control unfined and fined rosé wines, all of these aldehydes were detected in a small amounts (except for syringaldehyde in fined rosé wine). Previous works[44,49] also reported small quantities of these compounds in wines without oak wood chips or barrel treatment.

Concerning the lactones group, no significant differences were detected between all unfined and fined rosé wines for total lactones. However, as reported broadly by other authors,[44,49] the different contents were evident in rosé wines aged with oak wood chips in particular for *cis*- and *trans*-3-methyl-γ-octalactone. *Cis*- and *trans*-lactones are products of the dehydration of 2-methyl-3-(3,4-dihydroxy-5-methoxybenzo)octanoic acid. Despite the small concentration achieved, these compounds are involved in the characteristic aroma of wines aged in contact with oak wood, namely for coconut nut and woody aroma. This is particularly important for *cis* form, which is the most important form of methyl-γ-octalactones.[29,36] Furthermore, American oak wood species are also characterized by higher values of these compounds.[4,42]

As expected, very low values of lactones were detected in all rosé wines aged in contact with acacia and cherry wood chips. This is an expected result because for seasoned and toasted wood extracts from acacia and cherry, previously other authors[36] did not find any forms of methyl-γ-octalactones. However, Kozlovic *et al.*[10] detected notably low values of *cis*- and *trans*-3-methyl-γ-octalactones in white wines aged in acacia barrels during 12 months, while Jordão *et al.*[51] also detected low values of 3-methyl-γ-octalactones in toasted cherry wood extracts.

The concentrations of total fatty acids in the unfined and fined rosé wines with and without wood chip contact were very similar. However, for dodecanoic acid, this acid was only quantified in the unfined rosé wine aged in contact with American oak wood chips. For toasted cherry wood chips, Setzer[52] only detected traces of dodecanoic acid in extracts made from this wood chip species. Ferreras *et al.*[42] in white wines aged in contact with American and French oak wood reported similar values of dodecanoic acid in all wines, including in control wine. In addition, Mangas *et al.*[53] detected constant values of this fatty acid during the aging process of ciders in contact with American oak wood.

According to Snakkers *et al.*,[54] glyceride forms of wood in contact with ethanol are hydrolyzed and the fatty acids released are esterified. Also, according to those authors, for certain fatty acids and in relation to the heating temperature used during wood toasting, there is a thermal degradation of the most extractable forms at the lowest temperatures and a thermal degradation of the less accessible non-extractable combined forms at higher temperatures. Thus, this behavior can be determinant for the variability of acid contents extracted from the wood during the wine aging process.

Finally for the last volatile compound group studied (which included eugenol, 6-methoxyeugenol, 4-vinylguaiacol, 3,4-dimethylphenol and acetovanillone), and as an overview, the use of different wood chip species did not induce changes in the concentration of this compound group. However, 6-methoxyeugenol (contributing to clove aroma) was only detected in unfined rosé wines aged in contact with American oak wood chips. A similar tendency was previously reported by Schumacher *et al.*[44] in white wines aged in contact with American oak wood. All of these phenol compounds included in 'other compounds' are produced due to the thermal degradation undergone by lignin during the toasting treatment of woods at the cooperage stage.

Sensory characterization of rosé wines

Despite the several changes obtained for the different chemical parameters studied, in sensorial terms the differences were not totally evident for the majority of sensorial descriptors (Fig. 3). The use of a reduced contact time between wines and wood chips, and also the low wood chip concentration used, may have contributed to the low sensory differences detected between wines by the tasting panel. However, the sensorial evaluation of all wines for 'floral aroma' and 'quality of aroma' descriptors, in relation to the rosé wine aged in contact with American oak chips, may indicate a potential lower ability of this wood for the aromatic component of unfined rosé wines. Instead, for fined rosé wines, the aging process induced a clear differentiation of the rosé wines aged with oak wood chips for 'wood aroma' and 'aroma intensity' descriptors. This will certainly be a result of the significantly higher values of *cis*-3-methyl-γ-octalactone quantified in these rosé wines in relation to the other wines. According to several authors,[8] the presence of higher levels of β-methyl-γ-octalactone (especially the *cis* form) had an important role in several wine aroma descriptors such as 'vanilla', 'coconut' and 'wood' aroma descriptors.

The high total phenolic content quantified in unfined rosé wines aged in contact with wood chips had certainly an important impact on higher scores detected for 'astringency' sensation descriptor in relation to unfined control rosé wine. A similar trend was previously reported by other authors.[10,15,16] In addition, according to Chira and Teissedre,[29] wood ellagitannin concentration and other extractable phenolic wood components are closely

correlated with several wine sensory descriptors, namely 'complexity', 'persistency', 'astringency' and 'round tannins'.

Finally, it was only possible to find a clear differentiation between rosé wines for overall appreciation in unfined rosé wines. In that case, the panel test indicated that the rosé wine aged in contact with acacia wood chips showed significantly higher overall appreciation scores in relation to the other rosé wines, while the rosé wines aged in contact with oak wood chips showed the lowest overall appreciation scores. Recently, Delia *et al.*[16] also reported higher preference for global assessment of white wines aged in contact with acacia wood chips. In this context, other authors[10] also reported that acacia barrels are less 'aggressive' compared to oak and add less wood character to the wines.

CONCLUSIONS

This experimental work demonstrates that, in general, the use of acacia wood chips compared with the other wood chip species used had a slight impact on the increase of phenolic content of rosé wines. In addition, for the different volatile compounds analyzed, the addition of wood chips had a greater impact especially for aldehyde compounds. This impact was mainly detected in particular for rosé wines aged in contact with oak wood chips that induced an increase of these volatile compounds. From a sensorial point of view, despite the several changes obtained for the different chemical parameters studied, the differences were not totally clear. However, the possibility of the use of acacia wood chips could be a potential good option for the rosé aging process. All of these points were, in general, more obvious when the wood chips were added to unfined rosé wines and less so when added to fined rosé wines. Thus, the possible addition of wood chips to rosé wines to produce wines with 'wood character' will be more obvious before the stabilization operations to which wines are submitted.

Finally, the evidences obtained in our work are interesting from a practical point of view, especially when the option for aging rosé wines by the use of wood chips may be an option for winemakers to produce wines with potential new profiles. However, 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 rosé wine quality. In addition, the use of a more extended aging time, different wood chip concentrations and the possibility of wood chip addition at different steps of rosé winemaking will also be other points to be considered in future research.

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