Influence of Aging Conditions on the Quality of Red Sangiovese Wine

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A red Sangiovese wine was stored in barrels of different woods (oak and chestnut) and types (225-L “barriques” and 1000-L barrels) at 12 and 22 °C for 320 days to evaluate the effects of different aging conditions on wine quality. Chestnut barrels led to wines richer in phenolics, and which were more tannic, colored, and fruity. Oak barrels gave wines with more monomeric phenolics, but less astringent, with higher vanilla smell, and more harmonious. The type of barrel could be used as a parameter to regulate the extraction of wood components and the polymerization of monomeric phenolics. Storage at 22 °C favored the formation of polymerized phenolics and the increase of color density and color hue. The temperature produced less pronounced effects on aroma and taste, even if wines stored at 12 °C showed more harmony.

Keywords: *Red wine; oak; chestnut; aging; sensorial profile; phenolics*

INTRODUCTION

Many red wines owe part of their quality to aging in wooden barrels (*1, 2*). Today there is a great interest toward wines matured in wood barrels: consumers are attracted to their particular and peculiar sensorial characteristics, and the market for these products is growing. In Italy, wine aging in large wooden barrels is a traditional operation in the production of some wines (e.g., Barolo and Brunello di Montalcino), but the use of small oak barrels (“barriques”) is rapidly increasing. The maturation of wine in wood barrels modifies its smell and taste and reduces its astringency, while many physical and chemical transformations are favored (*3*). Generally, the sensorial characteristics improve, increasing the worth and agreement of the product, even if many parameters can influence the results of this process.

The importance of gaseous exchanges through oak barrel walls during maturation were underlined in some studies (*3*−*6*). However, it is not clear whether wood is permeable to oxygen or the oxygen penetrates just through the bung and fissures existing between the staves (*7, 8*). Anyway, the slow dissolution of oxygen involves several redox reactions and leads to the formation of unstable compounds (peroxide) more oxidant than molecular oxygen. Acetaldehyde, which derives from ethanol oxidation (*1*), is involved in the copolymerization of flavonoids and anthocyanins, increasing stable red polymer (*9*−*13*). A direct condensation of anthocyanin flavylium ions with (+)-catechin, (−)-epicatechin, or tannins may also occur, improving the blue-red color (14). On the other hand, oak influences the sensorial and chemical characteristics of wine, because many constituents can be extracted from staves during aging in barrels: ellagitannins (*15, 16*); tannins; gallic, ferulic, vanillic, syringic, and ellagic acids; vanillin; coumarins; and volatile compounds (*6, 17*−*21*). The physical and chemical differences between oak and chestnut woods were put in evidence (*3, 15, 16, 20, 21*). However, with exception of the comparative study of Climaco and Borralho (*22*) about the aroma profile of wines aged in oak or chestnut barrels, no studies are available showing the effects of chestnut barrels on the quality of red wines.

Our objective was to assess the influence of temperature, kind of wood, and barrel capacity on the evolution of some compositional parameters and the sensorial profile of a red Sangiovese wine after 320 days of aging. The effects of the storage conditions were considered with particular attention to the evolution of color parameters and phenolics.

MATERIALS AND METHODS

Wine. Sound and ripe Sangiovese red grapes (30000 kg) were destemmed, crushed, added with 80 mg/L SO_2 and 150 mg/L dry selected yeast (*Saccharomyces cerevisiae* 404 IMIA, DI.PRO. V.AL.; University of Bologna strain collection). Fermentation was carried out on skins for 7 days at 28 °C in stainless steel tanks. Pressed and free-run musts were assembled and fermented to dryness in stainless steel tanks. Wine finished the alcoholic and malo-lactic fermentation within 60 days and then was racked, filtered with diatomaceous earth, and adjusted to 80 mg/L of total sulfites. The wine main characteristics were the following: ethanol 12.2% (v/v), pH 3.40, total dry extract 26.8 g/L, total SO_2 80 mg/L, titratable acidity 5.9 g/L, volatile acidity 0.38 g/L, malic acid 0.09 g/L, and lactic acid 1.53 g/L.

Storage Conditions. A factorial design was carried out considering two storage temperatures (12 and 22 °C), two kinds of wood (oak and chestnut), and two types of barrels (225-L barriques and 1,000-L barrels). For each of the 8 combinations three replicates were considered. Moreover, 50-L stainless steel tanks were stored under nitrogen at 12 °C ($n = 3$) and 22 °C ($n = 3$). Wood barrels were furnished by Garbellotto (Conegliano Veneto, TV, Italy) using homogeneous lots of Italian chestnut or French oak (Allier). Barrique staves were curved with a medium degree of heating (10 min at 200 °C), whereas 1000-L barrel staves were preheated by steam and curved with a medium degree of heating (10 min at 200

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Table 1. Wine Characteristics Before (control) and After 320 Days of Maturation in Stainless Steel Tanks or Wooden Barrels

	before aging	after 320 days of aging									
		stainless steel		oak				chestnut			
	control	50-L		225-L barriques		1000-L barrels		225-L barriques		1000-L barrels	
		12 °C	22 °C	12 °C	22 °C	12 °C	22 °C	12 °C	22 °C	12 °C	22 °C
total phenolics (mg/L)	2111de	2003^{b}	1949^{a}	2065^{cd}	2062^{c}	2050^{bc}	2068^{cd}	2212^{f}	2362^{g}	2119^{e}	2254^{f}
tannic phenolics (mg/L)	1151^{e}	953^{b}	886^{a}	983^{bcd}	878^{a}	971^{bc}	881^{a}	1024^{d}	986^{bcd}	950^{b}	1004^{cd}
polymerized phenolics (mg/L)	952^{ab}	943^{ab}	934^{a}	995^{cd}	1029^{c}	943^{ab}	970^{bc}	1008de	1108^{f}	966^{bc}	1032^{e}
color density (AU)	6.66^{e}	6.05^{d}	6.06^{d}	5.58^{a}	5.86^{bc}	5.47^{a}	5.58^{a}	6.08^{d}	5.99^{cd}	5.57^{a}	5.78^{b}
color hue	0.597^{a}	0.728^{bc}	0.783^{def}	0.740^{c}	0.792^{ef}	0.734^{bc}	0.774^{de}	0.718^{b}	0.772^{d}	0.726^{bc}	0.802^{f}
OD 620 nm (AU)	0.752^{f}	0.687^{bc}	0.684^{b}	0.680^{b}	0.710^{cd}	0.650^{a}	0.650^{a}	0.740^{ef}	0.730^{de}	0.670^{ab}	0.680^{b}
PPC (AU)	1.22^{a}	1.89^{b}	2.00^{de}	1.96^{c}	2.11^{f}	1.88^{b}	1.98^{cd}	1.98^{cd}	2.13^{f}	1.89^{b}	2.01^{e}
gallic acid (mg/L)	35.6^{a}	34.0^{a}	34.9^{a}	34.6^{a}	40.5^{ab}	36.3^{ab}	43.4^{b}	69.3^{d}	93.9^{f}	60.0^{c}	81.5^{e}
(+)-catechin (mg/L)	70.2^{e}	26.2^{d}	20.1^{ab}	24.7^{cd}	18.3^{a}	27.3^{d}	21.8^{bc}	19.8^{ab}	17.6^{a}	21.8^{bc}	19.1^{ab}
(−)-epicatechin (mg/L)	34.9^{e}	20.0^{d}	17.5^{b}	18.6^{bcd}	17.4^{ab}	19.1^{cd}	18.3^{bc}	17.4^{b}	15.8^{a}	18.5^{bcd}	17.6^{bc}
quercetin (mg/L)	14.1^{bc}	13.1^{abc}	13.9^{abc}	16.1^{c}	15.3^{bc}	12.6^{ab}	10.6^{a}	14.0^{bc}	13.8^{abc}	14.1^{bc}	12.7^{ab}
delfinidin 3-glucoside (mg/L)	32.6^{d}	17.4^{bc}	10.1^{a}	18.2^{bc}	10.0^{a}	19.5^{c}	11.7^{a}	16.6^{b}	10.0^{a}	18.6^{bc}	10.7^{a}
cyanidin 3-glucoside (mg/L)	11.9^{e}	6.0^{cd}	3.4^{a}	6.0^{cd}	3.3^{a}	6.3^{d}	4.1^{b}	5.5^{c}	3.5^{ab}	6.1^{cd}	3.5^{ab}
petunidin 3-glucoside (mg/L)	47.1^{d}	22.4^{b}	13.0^{a}	24.7^{bc}	12.9^{a}	25.5^{c}	15.1^{a}	22.2^{b}	12.7^{a}	24.1^{bc}	13.1^{a}
peonidin 3-glucoside (mg/L)	24.2^{c}	12.7^{b}	7.1^{a}	13.1^{b}	7.3^{a}	13.6^{b}	8.1^{a}	12.1^{b}	7.0^{a}	12.8^{b}	7.2^{a}
malvidin 3-glucoside (mg/L)	163.2^{f}	83.5^{cd}	44.6^{a}	91.2^{e}	46.6^{ab}	91.7^{e}	52.1^{b}	80.0^{c}	46.4^{ab}	87.4^{de}	48.2^{ab}
total anthocyanins (mg/L)	279.1^{e}	142.1^{bc}	78.3^{a}	153.2^{cd}	80.3^{a}	156.5^{d}	91.0^{a}	136.5^{b}	79.7^{a}	149.1^{bcd}	82.7^{a}

[a–f] Different letters on the same line indicate a mean separation at $p < 0.05$ (LSD test). Each value is the mean of three replicates analyzed in duplicate ($n = 6$), except control ($n = 3$ replicates of analysis).

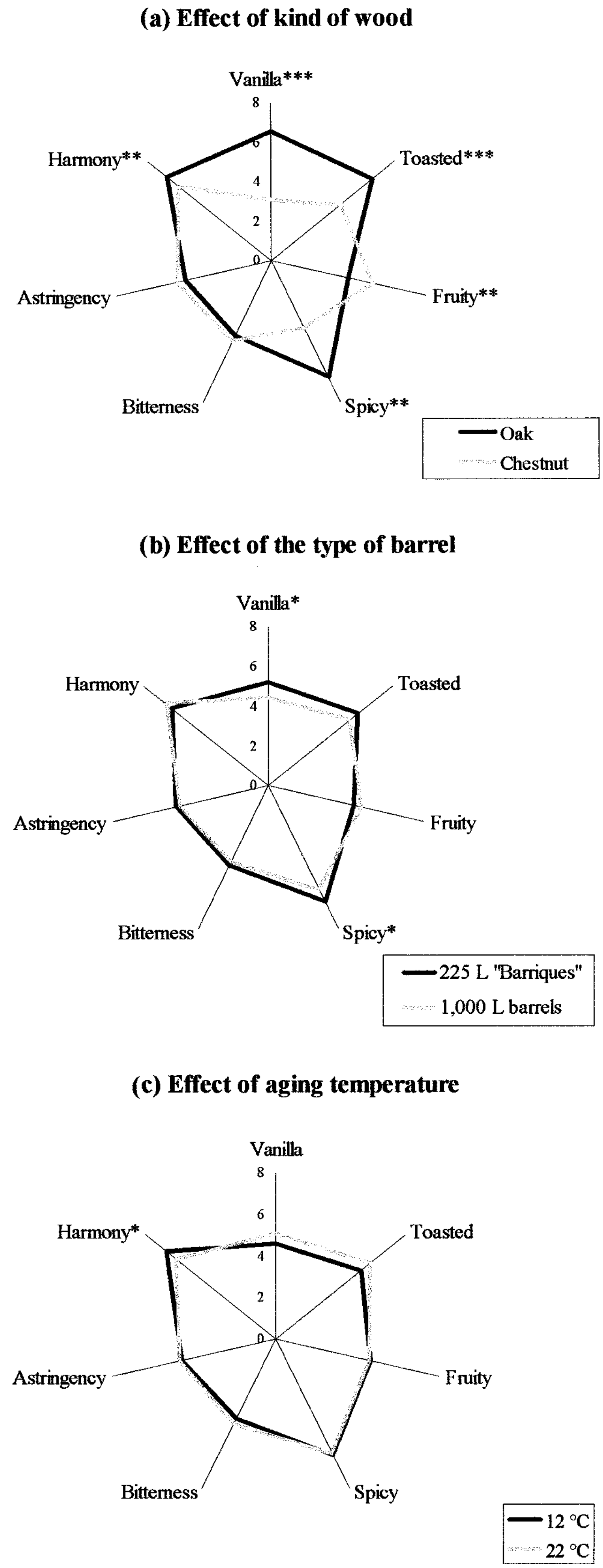

Figure 1. MANOVA results for the descriptive sensorial analysis of red Sangiovese wines after 320 days of aging in wooden barrels. Spider webs represent the mean values ($n = 20$ for each level of the variable) for (a) kind of wood; (b) type of barrel; and (c) aging temperature. Asterisks indicate the separation of means at $p < 0.05$ (*), $p < 0.01$ (**), or $p < 0.001$ (***).

Table 2. MANOVA Results[a]

	wood (a)	type of barrel (b)	temperature (c)	(a*b)	(a*c)
total phenolics	<0.0001	<0.001	<0.0001	<0.001	<0.0001
tannic phenolics	<0.0001	n.s.	<0.0001	n.s.	<0.0001
polymerized phenolics	<0.0001	<0.0001	<0.0001	n.s.	<0.01
color density	<0.0001	<0.0001	<0.01	n.s.	n.s.
color hue	n.s.	n.s.	<0.0001	<0.001	<0.05
OD 620 nm	<0.001	<0.0001	n.s.	n.s.	n.s.
PPC	<0.01	<0.01	<0.01	n.s.	n.s.
gallic acid	<0.0001	n.s.	<0.0001	<0.01	<0.01
(+)-catechin	<0.001	<0.01	<0.0001	n.s.	<0.05
(−)-epicatechin	<0.05	<0.05	<0.05	n.s.	n.s.
quercetin	n.s.	<0.01	n.s.	<0.01	n.s.
delfinidin 3-glucoside	<0.05	<0.01	<0.0001	n.s.	n.s.
cyanidin 3-glucoside	<0.05	<0.01	<0.0001	n.s.	n.s.
petunidin 3-glucoside	<0.05	<0.05	<0.0001	n.s.	n.s.
peonidin 3-glucoside	<0.01	<0.05	<0.0001	n.s.	n.s.
malvidin 3-glucoside	<0.01	<0.05	<0.0001	n.s.	n.s.
total anthocyanins	<0.01	<0.01	<0.0001	n.s.	n.s.

[a] Significant effects of independent variables are shown with p level.

°C). Barrels were stored in two conditioned cells maintained at different temperatures (12 ± 0.5 °C or 22 ± 0.5 °C), but with the same degree of relative humidity (90 ± 1%). Barriques were stopped by a silicone stopper, and 1000-L barrels had glass stoppers. Monthly, the level of total SO_2 was checked in every barrel and adjusted to 80 mg/L. After 320 days of storage, samples of wine were taken off from each barrel and submitted to chemical and sensorial analyses.

Chemical Analysis. Ethanol, pH, total dry extract, titratable acidity, volatile acidity, total and free SO_2, optical densities (OD), total phenolics, and lactic and malic acids were measured according to the European Official Methods (*23*). Polymerized phenolics (molecular weight > 3500 Da) were evaluated as described previously (*24*), using a membrane dialysis with a nominal molecular weight cutoff of 3500 (Cellu-Sep T1, Membrane Filtration Products, Inc., San Antonio, TX). Polymeric pigment color (PPC) was evaluated as stated by Jackson et al. (*25*), and phenolics reacting with gelatin (tannic phenolics) were quantified as proposed by Glories (*26*). Monomeric anthocyanins, phenolic acids, (+)-catechin, (−)-epicatechin, and quercetin were quantified by HPLC following Castellari et al. (*24*). All analyses were made in duplicate.

Sensorial Evaluation. The three replicates of each sample were reunified and stored at 4 °C before analysis. Evaluations were performed at 21−23 °C in an isolated room under green lights. At each session 30-mL samples were presented in coded, clear, 150-mL tulip glasses covered with glass dishes. Five expert judges of the Center for the Enological Research of Bologna University performed descriptive analyses. Quality evaluations were carried out using descriptors [vanilla, toasted, fruity, spicy, bitterness, astringency, and harmony (equilibrium between aroma and taste)] chosen by the panel in preliminary sessions. The wines were evaluated two times with a full-randomized order and judges were not allowed to discuss their evaluations. At each session the judges were asked to evaluate the samples on a 0−10 points quality scale (0 less intense, 10 more intense) for each characteristic, according to their sensory knowledge, training, and experience.

Statistical Procedures. Statistical treatments of data were made using Statistica 5.0 for Windows (StatSoft, Inc., Tulsa, OK). A three-way MANOVA and a LSD test were conducted to put in evidence the effects and interactions of the independent variables (kind of wood, type of barrel, and storage temperature) on the chemical and sensorial data. For the results of the descriptive analysis, scores were normalized for each judge and descriptor (*27*). The level of significance was set at $p < 0.05$.

Principal component analysis (PCA) was carried out considering the chemical data, to illustrate the relationship among the analytical variables and the wines stored under different conditions. Two principal components (PC) were extracted and were the only significant ones that resulted, according to the Kaiser criterion (eigenvalue > 1). A Varimax rotation of axes was carried out in order to explain the loadings of components in the reduced space with respect to the significant eigenvalues.

RESULTS AND DISCUSSION

Aging in Stainless Steel Tanks. Table 1 shows the composition of Sangiovese wines before storage (control) and after 320 days of storage in 50-L stainless steel tanks.

Significant influences of the storage temperature were evident for anthocyanins, (+)-catechin, (−)-epicatechin, tannic phenolics, and total phenolics, which were higher in wines stored at 12 °C. On the contrary, color hue and PPC were higher in wines stored at 22 °C. These results are in accord with those reported in the literature (*28*−*31*), and state that temperature is an important factor influencing phenolics and color during maturation under anaerobic conditions.

Effect of Wood in Wine Aging. Table 1 shows the composition of wines after 320 days of storage in wooden barrels. The use of chestnut caused a significant increase (Table 2) of total phenolics and gallic acid in wines compared to those of wine aged in oak. On the other hand, wines stored in oak barrels showed less tannic and polymerized phenolics, and contained more (+)-catechin, (−)-epicatechin, and anthocyanins than wines aged in chestnut barrels. These results could reflect the different compositions of the woods, and it is possible that the considerable chestnut permeability (*3*) could have speeded up the polymerization of monomeric compounds [(+)-catechins, (−)-epicatechin, and anthocyanins]. The effects on PPC (mean values, chestnut, 2.00; oak, 1.98), polymerized phenolics (mean values, chestnut, 1028; oak, 984), and OD at 620 nm (mean values, chestnut, 0.705; oak, 0.672) seem to confirm that chestnut improved the formation of pigmented and polymerized phenolics. The phenolics extracted from chestnut staves appeared more tannic than those of oak wood, and this did not seem to be compensated by the polymerization reactions occurring in the maturation phase. The descriptive analysis (Figure 1a) showed some significant differences between the sensorial profiles of wines aged in different wood barrels. Vanilla, toasted, and spicy were more intense in oak wines, which were also perceived as more harmonious. On the contrary, chestnut wines resulted in more fruity. These results indicate the use of chestnut barrels could be very interesting to differentiate and to improve thesensorial complexity of red wines aged in wooden barrels.

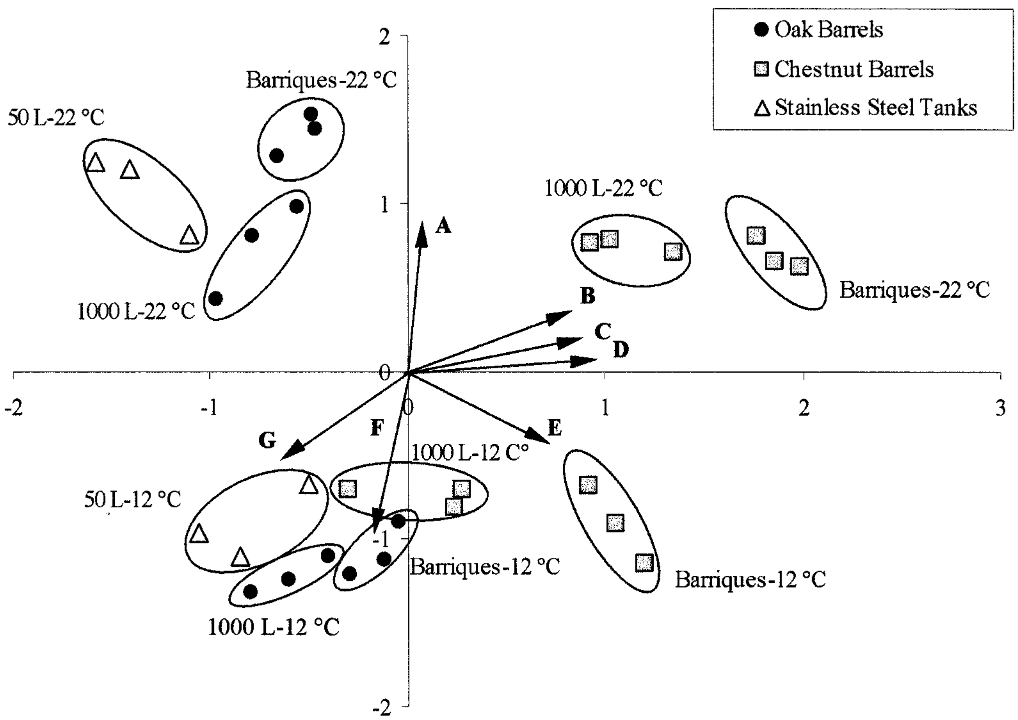

Figure 2. PCA of red Sangiovese wines after 320 days of storage. Factorial weights higher than 0.70 are represented as vectors. A = Color hue; B = polymerized phenolics; C = gallic acid; D = total phenolics; E = tannic phenolics; F = total anthocyanins; G = (+)-catechin.

Effect of the Type of Barrel. Storage in barriques seemed to improve the concentrations of some phenolics as indicated by total phenolics and quercetin. Furthermore, wines stored in barriques showed lower contents of anthocyanins, (+)-catechin, and (−)-epicatechin, and higher values of PPC and polymerized phenolics (Tables 1 and 2), indicating a more rapid polymerization of monomeric phenolics than in wine stored in 1000-L barrels. The favorable rate of surface/volume of 225-L barriques may be considered the origin of the easier extraction and polymerization of phenolics if compared to that in 1000-L barrels, because both the contact between wood and wine and the oxygen dissolution in wine may be improved (*32*). On the other hand, our results show that wines stored in barriques improved the color density and the OD at 620 nm, if compared to those of wines from 1000-L barrels, while color hue was not influenced (Tables 1 and 2). Furthermore, the type of barrel influenced the perception of vanilla and spicy descriptors which were evaluated as more intense in barriques than in the 1000-L containers (Figure 1b). Consequently, the selection of an appropriate type of barrel could adjust some wine characteristics regulating the interactions between wine and wood.

Effect of Storage Temperature. The extraction of wood phenolics increased at 22 °C if compared to that at 12 °C, as demonstrated by the levels of total phenolics and gallic acid in wines (Tables 1 and 2). Furthermore, storage at 22 °C raised the concentration of PPC and color hue, while it decreased the value of anthocyanins, (+)-catechin, (−)-epicatechin, and tannic phenolics if compared to those stored at 12 °C. These results are in agreement with those reported previously for the wines stored in stainless steel tanks. Polymerized phenolics and color density were higher in wines kept at 22 °C, while OD at 620 nm was not significantly influenced. Some authors (*31, 33*) reported that low storage temperature gave wines with a more stable color. Actually, under our conditions, the increase of temperature seemed to accelerate the evolution of the phenolic fraction, but also increased browning, as shown by the color hue (Tables 1 and 2). The sensorial profiles (Figure 1c) showed that the temperature of storage influenced significantly just harmony, which was higher in wines stored at 12 °C. Hence, the temperature produced many significant effects on color parameter and phenolic compounds, but, unexpectedly, the effect on aroma and taste was less pronounced.

Effect of Aging Conditions on Wine Characteristics. The MANOVA showed some significant interaction between the factors considered in the current study (wood, type of barrel, and temperature) (Table 2). The interaction between the factors wood and type of barrel is underlined by the release of total phenolics and gallic acid which appeared more intense for chestnut wines than for oak ones when aging was carried out in 225-L barriques (Table 1).

On the contrary, oak wines were richer in quercetin than chestnut wines when aged in barriques. Moreover, the color hue of oak wines was higher in 225-L barriques, while in chestnut wines the color hue was increased in 1000-L barrels (Table 1). Furthermore, the interaction between wood and temperature (Table 2) showed that an increase of temperature improved the concentration of total phenolics, gallic acid, and tannic phenolics more in chestnut than in oak wines (Table 1). On the other hand, the values of polymerized phenolics and color hue indicate that oxidative and polymerization phenomena were more intense in chestnut than in oak when the temperature increased (Table 1).

Figure 2 shows the results of the principal component analysis (PCA). The plot of the scores in the coordinate plane defined by the two canonical components of the functions showed a satisfactory discrimination for the wine aged under different conditions. These first two principal components (PC) together accounted for 86%

of the total variance. The first PC contrasted the wines' high total, tannic, and polymerized phenolics, and gallic acid with those high in (+)-catechin. The second PC separated wines higher in anthocyanins versus those with greater values of color hue. If we consider the particular aging conditions, the first PC discriminates between wines stored in barrels of different material or type, whereas the second PC classifies the wines on the basis of the temperature of storage. The separation between wines aged at different temperatures always appeared complete, confirming the significant effects of this parameter. On the other hand, the differentiation of wines stored in chestnut barrels from wines stored in stainless steel tanks underlines the capacity of this wood to induce specific and distinctive attributes to wines. Conversely, results for wines stored in oak barrels, for color and the phenolic parameters considered in this work, were more similar to those aged in stainless steel tanks (Table 1).

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