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Volatile composition and sensory characteristics of Chardonnay wines treated with American and Hungarian oak chips

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Abstract

Toasted or non-toasted chips of oak woods of different geographical provenances were macerated in Chardonnay wines (4 g/l) during a period of 25 days. Oak lactones were detected in significant quantities in wines treated with American oak. Only trace amounts of oak lactones were detected in the wines treated with Hungarian oak. Toasting of the oaks increased the quantities of the compounds derived from the thermal degradation of lignin: vanillin, eugenol, guaiacol and its derivatives and the pyrolysis of cellulose and hemicellulose: furfural and 5-methyl furfural, and decreased the concentrations of the two isomers of oak lactones. The concentrations of the majority of the volatile compounds did not present statistically significant differences between 15 and 25 days. However, the wines preferred by the tasters and with maximum intensity of the sensory attributes acquired were those treated with oak chips for 25 days. Chemical and sensorial analyses of wines revealed that the effect of the toasting of oak chips on wine characteristics was greater than the type of oak used. All wines studied were positively evaluated by the panellists.

Keywords: Oak chips; Volatile compounds; Sensory analysis

1. Introduction

White oak barrels have long been used in fine wine making, initially for easy product handling during production, storage and transport. Later the positive effects of oak wood on wine development became appreciated, namely the ceding of pleasant aromas, and the regulation of red wine tannins and colour.

Oak species frequently used for barrel production are *Quercus alba* from North America, and *Quercus petraea* and *Quercus robur* from Europe, French oak being the most famous. Oak from other areas in the centre of Europe (Hungaria, Russia, Bulgaria) are suitable for aging or fermenting, but there is little information about these kinds of oak (Chatonnet, 1998).

The quantities of potentially extractable volatile compounds in oak barrels are determined by a number of factors that include: oak species and geographical provenance of the oak (Chatonnet & Dubourdieu, 1998; Fernández-de-Simón, Cadahia, & Galocha, 2003; Mosedale & Ford, 1996; Pérez-Coello, Sanz, & Cabezudo, 1999), type of seasoning or drying (Doussot, de Jéso, Quideau, & Pardon, 2002; Masson, Baumes, Moutounet, & Puech, 2000; Sefton, Francis, Pocock, & Williams, 1993), the intensity of toasting (Cadahia, Fernandez de Simon, & Galocha, 2003; Chatonnet, 1999; Hale, McCafferty, Larmie, Newton, & Swan, 1999), the length of the contact time between the oak

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barrel and wine, as well as the age of the barrel (Pérez Prieto, López Roca, Martínez Cutillas, Pardo Mínguez, & Gómez Plaza, 2002; Singleton, 1995).

Many volatile compounds in natural oak wood have been described but only a few of them have significant impact on the sensory characteristic of wines. *cis*- and *trans*-β-methyl-γ-Octalactones (oak lactones) have been described as responsible for the oak flavour, having low perception thresholds (Abbott, Puech, Bayonove, & Baumes, 1995; Maga, 1996). Vanillin is the only aldehyde derivative of lignin that can have a significant effect on the aroma of wines aged in oak barrels, while small free phenols, such as eugenol and guaiacol, can influence the spice and smoke attributes, respectively (Singleton, 1995) if present in appreciable quantities.

Toasting increases the quantities of some of these compounds and also leads to the formation of other new compounds. Furanic aldehydes, caused by carbohydrate degradation and responsible for the "toasty" aromas, and lignin degradation compounds (vanillin, siringaldehyde, guaiacol) tend to be formed during the toasting process. Other compounds produced by Maillard reactions, such as maltol, cyclotene and furaneol, have been correlated with descriptors, such as toasty, burnt sugar and fruity-caramel (Chatonnet, 1998; Cutzach, Chatonnet, Henry, & Dubourdieu, 1997).

To impart the woody character to white wines, barrel fermentation or aging have been practised (Aleixandre et al., 2003; Moutounet, Rabier, Puech, Verette, & Barillière, 1989; Towey & Waterhouse, 1996a), although the former presents challenges, such as limited fermentation capacities, difficulties in the control of fermentation temperatures and the cleaning and sanitization of the barrels. Maceration of oak chips in wines could be an alternative to barrel aging or barrel fermentation. This could have economic and vinification management interests since oak barrels are expensive and wine oak barrel aging is a long process.

In the case of white wines, the use of oak chips could avoid the oxidation aromas and colour changes produced during barrel aging, and impart oak notes to wines without decreasing the fresh and fruity characteristics.

The amount of chips, oak wood type and treatment and sensory characteristic of the wines obtained must be investigated in order to obtain quality wines with good acceptability (Pérez-Coello et al., 2000). With short contact times, results similar to those obtained during barrel aging were obtained (Wilker & Gallander, 1988). Wines treated with oak chips matured more quickly than wines aged in barrels and more colour and oak volatile extraction were observed (Alamo Sanza, Nevares Dominguez, & García Merino, 2004; Arapitsas, Antonopoulos, Stefanou, & Dourtoglou, 2003).

The objectives of this study were defining the chemical and sensory characteristics of Chardonnay wines treated with oak wood chips of different geographical provenances and treatment with the aim of determining the suitability of the quantity of the chips used, the effect of the type of the wood and its treatment (toasting) and the selection of an appropriate contact time.

2. Materials and methods

2.1. Samples

Chardonnay grapes from the 2002 vintage were harvested at their optimal moment in the La Mancha region (Spain). Microvinification was performed by the traditional method for white wines, using selected *Saccharomyces cerevisiae cerevisiae* yeasts (CECT No. 10835). 3 L of a well homogenised young Chardonnay wine, together with 12 g (dry weight) of oak chips (4 g/L) were placed in 5 L glass flasks. Four types of oak chips (sized 1 cm × 0.5 cm × 0.1 cm) were tested in duplicate: toasted and non-toasted American (*Quercus alba*) and Hungarian (*Quercus petraea*) oaks. Chips were obtained from a Spanish cooperage (Magreñan, La Rioja, Spain) (average annual temperature, 13.9 °C; total precipitation, 370 mm^3/year; sun hours, 2800/year), that follows a strict quality and traceability process (ISO 9001/2000 and ISO 14001), that assures the origin and representativity of the samples. The wood was seasoned and toasted before making the chips. Natural seasoning in the open air was carried out for 36 months in the case of *Q. alba* and 18 months for *Q. petraea*. Each oak wood was toasted over a flame of the same wood type to a medium toast intensity level (45–50 min; temperature at the wood surface 160–170 °C).

The flasks were placed in a cool dark room (temperature of about 20 °C) to allow the oak wood compounds to leach out from the chips into the wine. The maceration was stopped after 4, 8, 15, and 25 days from the beginning of the process. The wines were stored for one day at 5 °C prior to their analysis.

2.2. Isolation and analysis of volatiles

The oak wood volatiles were extracted from the test wines by continuous liquid–liquid extraction with *n*-pentane:dichloromethane (60:40) as extracting solvent, adding 40 μl of a γ-caprolactone solution (1 g/l) as internal standard to 200 ml of wine. Previous to a concentration step with a Vigreux column, the extracts were analyzed by GC–MS.

A Hewlett-Packard G 1800 B GCD System equipped with a gas chromatograph and a quadrupole mass detector (Hewlett-Packard, Palo Alto, CA) was used. The column was a BP-21 capillary column (60 m × 0.25 mm i.d.; 0.25 μm film thickness). The injector temperature was 250 °C and the oven temperature programmed as

initial, 70 °C (5 min) ramp 1 °C/min to 90 °C ramp 2 °C/min to 200 °C (40 min). Carrier gas was He (0.7 ml/min). Injection volume was 1 μl in splitless mode (0.3 min). Mass acquisition range was 40–450 amu, ionization energy, 70 eV, solvent delay, 5 min.

Table 1
Volatile compound concentrations (mg/l) of Chardonnay wine without oak chips

	Mean ($n = 2$)	RSD (%)
Esters		
Ethyl butyrate	0.81	2.3
Ethyl lactate	2.43	0.4
Ethyl pyruvate	0.14	4.9
Ethyl caproate	0.73	9.9
Ethyl caprylate	0.86	3.6
Ethyl caprate	0.06	3.9
Ethyl dec-9-enoate	0.32	5.2
Ethyl monosuccinate	3.87	7.0
Diethyl succinate	0.25	1.7
OH-butanedioic acid diethyl ester	0.31	1.9
3-OH-hexanoic acid ethyl ester	0.04	3.3
Isoamyl acetate	3.64	9.6
Hexyl acetate	0.05	
2-Phenylethyl acetate	0.35	6.4
1,4-Butanodiol diacetate	0.24	13.8
Alcohols		
1-Hexanol	1.15	8.5
trans-3-Hexen-1 -ol	0.16	5.8
cis-3-Hexen-1-ol	0.08	5.7
trans-2-Hexen-1-ol	0.01	8.0
3-(Methylthio)-1-propanol	0.84	9.1
Benzyl alcohol	0.05	9.0
2-Phenylethanol	20.73	3.5
Terpenic compounds		
Linalool	0.10	6.7
Geraniol	0.02	5.0
Acids		
Butyric acid	0.58	5.0
Isobutyric acid	2.59	5.9
Isovaleric acid	0.98	4.1
2-Hexenoic acid	0.05	11.6
Caproic acid	3.75	3.3
Heptanoic acid	0.05	4.8
7-Octenoic acid	0.11	8.4
Caprillic acid	4.90	3.0
Capric acid	1.48	2.8
Furfurylic acid	0.01	3.8
Benzoic acid	0.04	9.8
Lactones		
γ-Butyrolactone	1.06	1.0
γ-Decalactone	0.01	9.9
4-OH-3-methyl decalactone	0.01	6.3
Pantolactone	0.03	1.9
Carbonyl compounds (aldehydes and ketones)		
3-OH-butanone	0.93	1.8
Furfural	0.01	5.4
Benzaldehyde	Tr	
Cyclopentanone	0.04	10.3
1-[3-Methoxy phenyl]-ethanone	0.18	4.5
l-[4-OH-3,5-dimethoxyphenyl]-ethanone	0.02	2.2

Tr, traces; RSD, relative standard deviation.

The identification of the volatile compounds was based on the comparison of their GC retention times and mass spectra with those of authentic standards from Sigma–Aldrich. The tentative identification of compounds, for which it was not possible to find reference volatiles, was carried out by comparison of their mass spectra with spectral data from the Wiley G 1035 A library. For quantification purposes, calibration curves were used when standards were available; otherwise semi-quantitative analyses were done, assuming a response factor equal to one.

2.3. Sensory descriptive analysis

Wines were evaluated by a panel of nine judges, comprising members of staff of the Food Technology and Analytical Chemistry Department, aged between 25 and 40 years and experienced in wine tasting. The assessment took place in a standard sensory analysis chamber (ISO 8589, 1988) equipped with separate booths.

The training of panellists was done using labelled references for wine aromas, and commercial Chardonnay wines. During the training sessions, the generation of consistent terminology for wine attributes by consensus, the proper use of the scale, and the adequate and consistent quantification of attribute intensities were emphasized (Noble et al., 1987).

Thirteen aroma and ten gustatory attributes were chosen to describe the wines. The formal evaluation consisted of two sessions that were held on different days. The panellists used a 10 cm unstructured scale, from 0 to 10, to rate the intensity of each attribute, previously selected. The left-hand (low) end of the scale was "attribute not perceptible" and the right-hand (high) end of the scale was "attribute strongly perceptible". The overall impression was also evaluated by each panellist, bearing in mind visual, olfactory and gustatory aspects, as well as lack of defects, and using unstructured 10 cm line scales, bounded at the ends by the terms "poor" and "very good".

2.4. Statistical analysis

The results from both chemical and sensorial analyses of wines were analyzed statistically by the Student-Newman Keuls test and principle component analysis (PCA). Statistical processing was carried out using the SPSS 11.0 for Windows statistical package.

3. Results and discussion

3.1. Chemical analysis of wines

Table 1 displays volatile compound concentrations of Chardonnay wine without oak chip treatment. The vol-

atile composition was similar to that of wines of the same variety cultivated in the La Mancha region, Spain (Castro Vázquez, Pérez Coello, & Cabezudo, 2002; Sánchez-Palomo, Díaz-Maroto Hidalgo, González-Viñas, & Pérez-Coello, 2005). Compounds that can play a major sensory role are terpenes (linalool and geraniol), C_6 alcohols (1-hexanol, *cis*- and *trans*-3-hexen-l-ol, and *trans*-2-hexen-1-ol) and short-and medium-chain fatty acid ethyl esters and acetates that present fruity aromas, especially ethyl butyrate, ethyl caproate and isoamyl acetate (Arrhenius, McCloskey, & Sylvan, 1996).

Tables 2–5 show data for the evolution of oak wood compounds extracted from wines treated with oak chips during the periods of 4, 8, 15 and 25 days. Results of the Student-Newman Keuls test showed the existence of significant differences among the measurements of certain volatile compounds.

The relative standard deviations (RSD%) of some compounds were low (<15%). Variability was generally lower for volatiles extracted from wines treated with non-toasted chips than for samples treated with toasted chips. This variability could be due to different toasting levels of chips, since some of them appeared over-toasted (charred) (Towey & Waterhouse, 1996b).

In general, the accumulation profiles of oak volatile compounds analyzed in wines displayed an ascending tendency with maceration time, but in some cases differences were not statistically significant mainly after 15 days of treatment.

It is interesting to note that the two oak lactones appeared in trace concentrations in wines treated with both toasted and non-toasted Hungarian oak chips. There is very little information about Hungarian oak composition, but Towey and Waterhouse (1996a) found

Table 2
Volatile oak-related compound concentrations (μg/l) of Chardonnay wines macerated with non-toasted American oaK chips

Compound	4 days		8 days		15 days		25 days	
	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)
trans-Oak lactone	43.1	18.0	37.8	2.8	49.3	7.8	43.4	2.2
cis-Oak lactone	300	21.0	292	6.0	336	4.8	319	6.3
Eugenol	7.5[a]	11.0	12.5[b]	11.9	15.0[b]	6.0	13.8[b]	3.5
cis-Isoeugenol	Tr	–	Tr	–	Tr	–	Tr	–
trans-Isoeugenol	0.85[a]	2.9	1.0[a]	2.8	2.2[b]	15.2	2.2[b]	8.3
Guaiacol	2.9	10.5	4.4	26.9	3.9	6.4	4.3	8.3
4-Vinyl guaiacol	193	12.2	183	2.5	190	6.1	152	11.2
4-Methyl guaiacol	2.5	13.0	1.7	13.7	2.5	31.0	2.0	4.4
Syringol	4.3[a]	8.8	3.9[a]	5.0	6.2[ab]	1.9	10.2[b]	13.0
(*Z*)-4-(l-propenyl) syringol	Tr	–	Tr	–	0.7	50.0	0.6	50.0
(*E*)-4-(1-propenyl) syringol	0.3	22.0	0.2	12.0	1.5	23.5	0.9	33.0
Vanillin	5.9	40.0	6.0	29.1	9.3	15.0	9.7	10.1
Furfural	23.2	25.3	23.1	0.7	26.1	5.0	27.9	33.9
Furfurylic acid	27.9	34.0	20.3	62.0	30.1	59.0	32.3	61.0

Tr, traces; RSD, relative standard deviation.

Table 3
Volatile oak-related compound concentrations (μg/l) of Chardonnay wines macerated with toasted American oak chips

Compound	4 days		8 days		15 days		25 days	
	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)
trans-Oak lactone	10.2	23.5	12.5	28.0	13.8	32.1	16.5	3.4
cis-Oak lactone	90.7	6.7	97.2	15.5	97.8	33	111	2.4
Eugenol	2.7[a]	5.0	4.4[b]	6.6	4.1[b]	16.4	6.2[c]	4.4
cis-Isoeugenol	0.7	3.6	0.7	28.1	0.8	40.5	0.8	19.2
trans-Isoeugenol	7.0[a]	1.6	9.9[ab]	4.5	10.1[ab]	18.9	11.9[b]	0.7
Guaiacol	12.5[a]	25.7	15.1[a]	12.9	18.6[ab]	7.0	20.0[b]	8.9
4-Vinyl guaiacol	161[a]	3.7	149[a]	8.9	116[ab]	24.9	70.6[b]	22.6
4-Ethyl guaiacol	2.7[a]	6.8	3.0[a]	0.2	3.3[a]	7.7	4.1[b]	0.4
4-Methyl guaiacol	8.8[a]	7.8	10.0[ab]	6.0	12.1[bc]	6.3	13.5[c]	3.9
Syringol	52.9	7.8	57.4	9.2	62.4	26.5	66.5	13.9
(*Z*)-4-(1-propenyl) syringol	3.3	7.7	3.6	39.8	6.1	45.0	5.8	34.6
(*E*)-4-(1-propenyl) syringol	3.7[a]	18.3	3.4[a]	18.1	6.0[b]	13.6	4.5[ab]	1.3
Vanillin	28.3[a]	8.4	47.3[a]	2.4	67.3[b]	9.5	89.0[b]	24.9
Furfural	130	10.3	115	29.3	109	44.8	117	70.7
Furfurylic acid	18.1	33.7	17.0	36.4	26.9	69.5	51.7	13.1
Maltol	25.5	8.1	25.2	12.5	25.5	4.7	23.0	1.4

RSD, relative standard deviation.

Table 4
Volatile oak-related compound concentrations (μg/l) of Chardonnay wines macerated with non-toasted Hungarian oak chips

Compound	4 days		8 days		15 days		25 days	
	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)	$\bar{x}$	RSD (%)
Eugenol	1.1[a]	8.1	1.5[b]	7.9	2.2[c]	0.8	2.9[d]	5.1
cis-Isoeugenol	Tr	–	Tr	–	Tr	–	Tr	–
trans-Isoeugenol	0.8[a]	13.6	1.5[ab]	11.1	2.1[bc]	6.0	2.7[c]	19.8
Guaiacol	2.7	38.9	1.6	13.4	2.2	23.0	1.9	18.0
4-Vinyl guaiacol	169	20.3	185	0.9	196	2.4	140	11.8
4-Ethyl guaiacol	0.2	19.0	Tr	–	0.2	37.0	0.3	38
Syringol	4.0	36.0	4.6	10.0	4.5	15.6	4.1	4.0
(*Z*)-4-(1-propenyl) syringol	0.4[a]	33.0	0.1[a]	19.0	0.7[b]	27.0	0.8[b]	4.8
(*E*)-4-(1-propenyl) syringol	Tr		1.03	35.0	1.3	42.0	2.3	35.0
Vanillin	6.8	7.4	6.6	26.5	10.5	16.9	9.6	10.4
Furfural	1.7	32.0	1.0	6.8	1.9	20.9	2.7	12.9
5-Methyl furfural	Tr	–	Tr	–	Tr	–	Tr	–
Furfurylic acid	16.3	13.2	27.1	6.7	33.1	61.0	50.5	3.5

Tr, traces; RSD, relative standard deviation.

Table 5
Volatile oak-related compound concentrations (μg/l) of Chardonnay wines macerated with toasted Hungarian oak chips

Compound	4 days		8 days		15 days		25 days	
	$\bar{x}$	RSD	$\bar{x}$	RSD	$\bar{x}$	RSD	$\bar{x}$	RSD
Eugenol	2.1[a]	6.6	2.3[a]	10.8	2.2[a]	3.4	3.0[b]	1.6
cis-Isoeugenol	Tr	–	Tr	–	Tr	–	Tr	–
trans-Isoeugenol	8.3	12.1	7.3	25.2	6.8	9.8	7.9	2.2
Guaiacol	17.4[a]	35.0	25.0[a]	1.3	34.2[b]	2.4	39.5[b]	0.7
4-Vinyl guaiacol	179[a]	2.1	143[b]	0.4	88.9[c]	2.0	136[b]	9.8
4-Methyl guaiacol	15.5[a]	0.4	16.5[ab]	2.7	17.7[b]	6.2	21.9[c]	0.1
4-Ethyl guaiacol	3.0[a]	4.1	4.4[b]	3.0	4.1[b]	1.8	5.8[c]	12.0
Syringol	69.0[a]	9.9	57.3[a]	12.6	58.7[a]	10.6	89.4[b]	7.8
(*Z*)-4-(1-propenyl) syringol	4.1	2.5	4.8	4.6	3.9	37.0	9.5	44.0
(*E*)-4-(1-propenyl) syringol	3.5	7.9	4.5	19.8	4.6	36.9	4.9	48.0
Vanillin	65.3[a]	1.7	88.6[a]	1.4	56.9[a]	52.7	135.4[b]	3.3
Vanillic acid	35.1	9.7	29.8	20.0	30.7	34.6	48.7	6.8
Furfural	83.5[a]	4.2	179[a]	27.1	156[a]	36.2	374[b]	8.1
5-Methyl furfural	24.5	11.9	19.5	11.3	22.4	67.2	37.5	43.0
Furfurylic acid	21.7[a]	6.7	26.1[a]	32.0	37.0[ab]	29.0	52.2[b]	9.9
Maltol	51.7	0.6	40.7	0.27	44.6	6.6	44.4	5.9
Cyclotene	5.4	1.9	5.9	9.5	6.0	4.0	6.1	7.5

Tr, traces; RSD, relative standard deviation.

similar concentrations of oak lactones in wines aged in French and Hungarian oak barrels.

As already reported by other authors for most oak species, *cis*-β-methyl-γ-octalactone was found at higher concentrations than *trans*-β-methyl-γ-octalactone (Masson, Guichard, Fournier, & Puech, 1995; Pérez Coello, Sanz, & Cabezudo, 1997; Towey & Waterhouse, 1996b).

Non-toasted oak chips released more oak lactones to wines than did toasted, probably due to the thermo-degradation of these heat-sensitive compounds or their loss by volatilization when the oak wood is subjected to very high temperatures or even charring (Singleton, 1995).

Volatile phenols, such as eugenol and *iso*-eugenol, guaiacol and some of its derivatives, showed an increasing tendency with increasing maceration time, they also occurred in greater quantities in samples treated with American oak chips than with Hungarian oak chips. Toasted chips ceded more eugenol, guaiacol and syringol derivatives than the non-toasted chips. It is well know that thermal degradation of the phenolic aldehydes produces a large number of volatile phenols (Chatonnet, 1999; Singleton, 1995).

Vanillin was the only phenolic aldehyde detected in measurable quantities in the studied wines and, as expected, occurred in greater quantities in wines treated with toasted oak due to degradation of lignin (Chatonnet, 1998; Singleton, 1995). Tables 3 and 5 show that the wines treated with toasted Hungarian oak chips contained more vanillin than those treated with toasted American.

Furfural was found in very small quantities in control wine but this compound increased on adding toasted oak chips to wines. Furfural and other furans, such as 5-methyl furfural and 5-(OH-methyl)furfural are formed

in large quantities from the thermo-degradation of oak wood polysaccharides during the toasting of oak wood. Toasted Hungarian oak ceded more furfural to wines than did to toasted American oak.

Maltol and cyclotene are products of complex carbohydrate thermolysis. They were only detected in wine treated with toasted oak chips in concentrations similar to those found in wines aged in American and French medium toasted barrels (Chatonnet, 1998).

The results of principal component analysis (PCA) of oak wood volatiles from wines treated with oak chips are shown in Fig. 1. Table 6 shows the variables that presented the greatest correlations with each principal component, as well as the corresponding calculated component loadings. The first three principal components accounted for 74% of the total explained variance among the samples.

Fig. 1 clearly shows the distribution of samples into four groups according to type of oak wood used, irrespective of the maceration time of the oak chips in wine. Principal component 1 separated samples treated with toasted oak chips from those treated with non-toasted oak wood chips. Variables highly correlated with this component are compounds derived from the thermal pyrolysis of the major constituents of oak wood (guaiacol and its derivatives, furfural, and vanillin). These compounds were found in larger quantities in wines treated with all toasted oaks. This revealed that the effect of toasting on the oak chemical composition was greater than either geographical provenance or the variety of the oak.

Principal component 2, accounting for 17% of the explained variance, separated samples treated with American oak chips from those treated with Hungarian oak.

Table 6
Calculated component loadings of variables highly correlated with the three first principal components

Principal component	Cumulative variance (%)	Variables	Loading[a]
PC1	44	Guaiacol	0.959
		4-Methyl guaiacol	0.959
		4-Ethylguaiacol	0.918
		Furfural	0.915
		Vanillin	0.903
PC2	61	*trans*-Oak lactone	0.969
		cis-Oak lactone	0.968
		Eugenol	0.950
PC3	74	*cis*-Isoeugenol	0.938

[a] Only those volatiles with absolute correlation coefficient values greater than 0.900 have been included.

The principal difference between the two groups of samples was due to the two isomers of the oak lactones and eugenol which occurred in greater quantities in American than in Hungarian oak. Principal component 3 separated samples treated with toasted American oak from the rest by its content of an isomer of iso-eugenol which occurred in trace quantities in the rest of the samples.

3.2. Descriptive sensory analysis

Figs. 2 and 3 show "spider web" diagrams for the average scores of the olfactory attribute intensities of the control wine versus wines treated with American and Hungarian oak chips during 25 days. The oak treated wines presented the maximum intensity of the sensory attributes acquired, and they were preferred by the tasters.

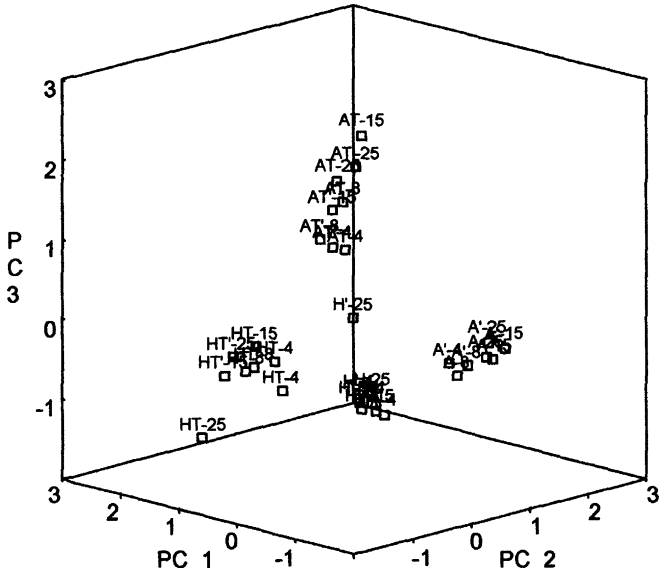

Fig. 1. Scatter diagram for the wine samples in the space formed by the first three principal components: (A) American oak chips; (AT) toasted American oak chips; (H) Hungarian oak chips; (HT) toasted Hungarian oak chips.

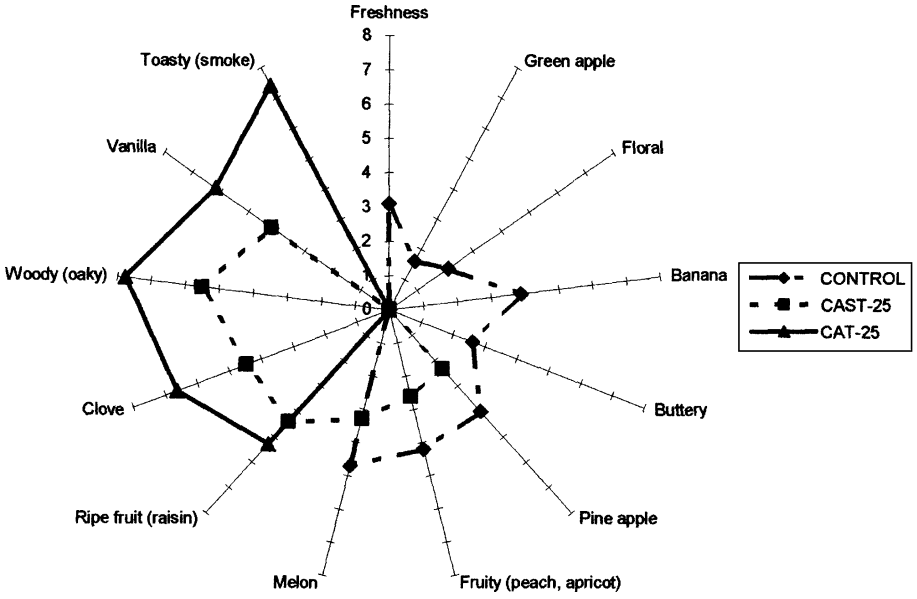

Fig. 2. Olfactory attribute scores of the control wines and wines macerated with toasted (CAT) and non-toasted (CAST) American oak chips during 25 days.

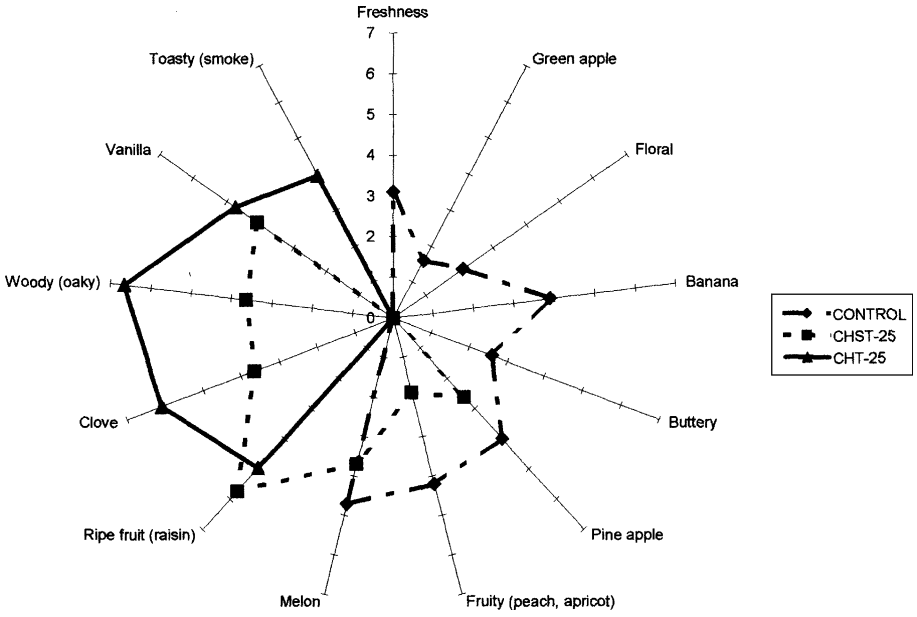

Fig. 3. Olfactory attribute scores of control wines and wines macerated with toasted (CHT) and non-toasted (CHST) Hungarian oak chips during 25 days.

The young Chardonnay wine presented moderate intensity, and pleasant fresh, floral, and fruity (pine apple, banana, melon, peach, and apple) odours, that are correlated with C_6 alcohols, terpenes, and fatty acid ethyl esters and acetates, respectively. Tasters also noted a light buttery hint typical of Chardonnay wines.

Wines treated with non-toasted American and Hungarian oak wood chips during 25 days, lost some of the control wine characteristics whilst others, such as melon, fruity and pineapple were greatly attenuated. They also presented attributes imparted by oak wood-derived components, such as vanilla, clove, and woody (oak), that were not detected in control wine (Pérez-Coello et al., 2000).

Toasted oak wood chips produced such pronounced sensorial differences in wines that the olfactory characteristics of control wine completely disappeared. The resultant wines presented a high intensity of attributes of oak-derived compounds, and a new attribute (toasty-smoke odour), not manifested by wines treated

with non-toasted chips. Smoke aroma could have been produced by volatile phenols, such as guaiacol and its derivatives, and toasty aroma by furan derivatives or compounds formed by Maillard reaction (Chatonnet & Dubourdieu, 1998).

Wines treated with different oaks of the same heat treatment, revealed similar characteristics (Francis, Sefton, & Williams, 1992). The only difference was a greater woody sensation perceived in wines treated with American oak than those treated with Hungarian oak chips, a fact consistent with the chemical content of oak lactones (Gutierrez Alonso, 2002).

Figs. 4 and 5 show the graphical representations of the average intensities of each gustatory attribute of the control wine versus those of the same wine treated with oak wood during 25 days.

Wines treated with non-toasted oak wood (American and Hungarian) presented very similar gustatory characteristics. The woody flavour was outstanding in wines treated with oak during 25 days. Comparing these wines

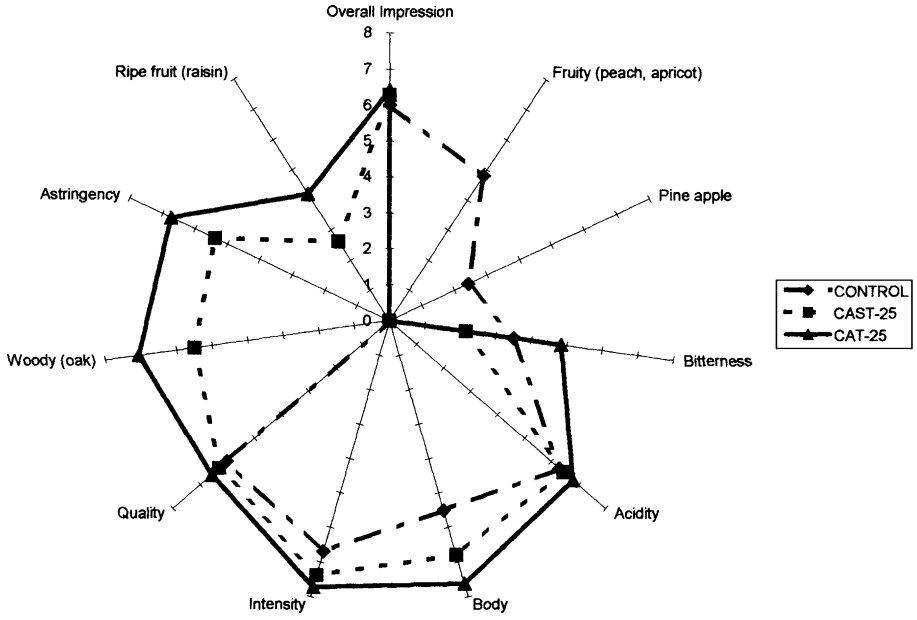

Fig. 4. Gustatory attribute scores of the control wines and wines macerated with toasted (CAT) and non-toasted (CAST) American oak chips during 25 days.

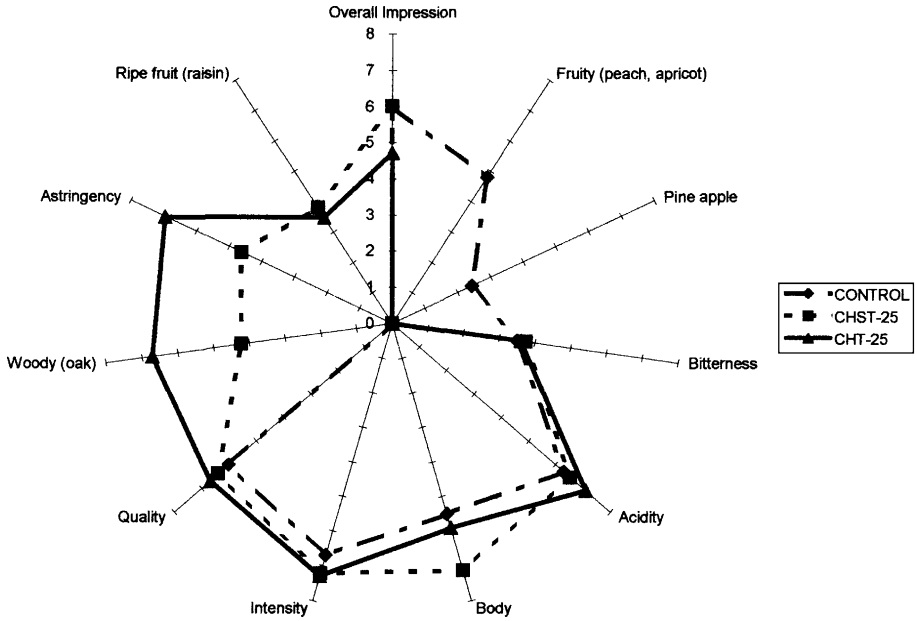

Fig. 5. Gustatory attribute scores of control wines and wines macerated with toasted (CHT) and non-toasted (CHST) Hungarian oak chips during 25 days.

with the control wine, it could be observed that fruity notes decreased, whilst the typical characteristics of oak wood-derived compounds dominated. Also, in the same wines, a moderate astringency, due to the ellagitannins ceded by the chips and ripe fruit flavour appeared.

Wines treated with toasted oak chips, were generally more astringent and with stronger bitterness, body, woody, and ripe fruit flavours than the rest.

In conclusion, the toasting of the oak wood had a greater influence on the sensory characteristics of wines than the type of the oak wood used, the same observation made in chemical analysis.

Differences among the wines treated with American and Hungarian oak were not appreciated. Wines treated with Hungarian oak presented woody-oak notes of considerable intensities. This fact suggests that there are compounds other than oak lactones that play an active role in the oaky sensations in wines (Sauvageot & Feuillat, 1999). Similarly, vanillin contents were below the compound odour threshold (Chatonnet, Dubourdieu, & Boidron, 1992) but all the tasters appreciated the attribute "vanilla" in all samples, so other compounds, besides vanillin, probably influence the perception of this attribute (Diaz-Plaza, Reyero, Pardo, Alonso, & Salinas, 2002; Spillman, Pollnitz, Liacopoulos, Skouroumounis, & Sefton, 1997).

Wines treated with French oak are generally preferred to those treated with American oak (Diaz-Plaza et al., 2002; Ferreras, Fernández, & Flaqué, 2002; Pérez-Coello et al., 2000). In our case, all the wines studied were positively evaluated by all panellists since all the overall impressions were good. The differences between oak woods did not affect preferences. On the other hand, the amount of chips used in this study (4 g/l) was selected in order to avoid a excessive impact of the wood character in wines that could produce a negative effect in the taster (Pérez-Coello et al., 2000).

This means that white wines treated with oak chips might have promising market prospects and can present an alternative to the young varietal wines presently in existence.

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