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ScienceDirect
Food Chemistry 108 (2008) 213–219
Food Chemistry
www.elsevier.com/locate/foodchem

Concentration of volatile compounds in Chardonnay wine fermented in stainless steel tanks and oak barrels

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Received 15 May 2007; received in revised form 23 October 2007; accepted 23 October 2007

Abstract

The influence of the type of container used in alcoholic fermentation on the formation of volatile compounds in wine from Chardonnay variety was studied. To do so, must from Chardonnay variety was fermented in both stainless steel tanks and in new Nevers oak barrels. The results obtained showed that wine fermented in barrels had a greater concentration of higher alcohols and esters than wine fermented in tanks. Concentration of isoamyl acetate, ethyl hexanoate, ethyl octanoate and ethyl decanoate was four times higher in wine fermented in oak barrels than in wine fermented in stainless steel tanks. With regard to the concentration of acids, a greater concentration of medium-chain fatty acids (C6:0–C10:0) was noticeable in wine fermented in oak barrels. Given that these acids are toxic for the yeasts, they may be responsible for the slower fermentation rate of wine fermented in oak barrels.

Keywords: Chardonnay wine; Alcoholic fermentation; Oak barrel; Stainless steel tanks; Volatile compounds

1. Introduction

Wine aroma depends on the balance of several hundred volatile compounds, whose individual concentrations vary between 10^{-1} and 10^{-10} g/l (Rapp & Mandery, 1986). Some volatile compounds are formed during alcoholic fermentation by the yeasts. These compounds constitute the *fermentation bouquet* of wine and they have a large influence on the final aroma of the product. The main groups of compounds formed during alcoholic fermentation are organic acids, higher alcohols, esters and, to a lesser extent, aldehydes (Lambrechts & Pretorious, 2000). *Fermentation bouquet* of wine is influenced by many factors among which yeast specie and yeast strain may be highlighted (Fraile, Garrido, & Ancín, 2000; Patel & Shibamoto, 2003; Romano, Fiore, Paraggio, Caruso, & Capece, 2003; Garde & Ancín, 2006), as well as the nitrogen demand of yeasts (Torrea, Fraile, Garde, & Ancín, 2003), oxygenation of grape must (Valero, Moyano, Millan, Medina, & Ortega, 2002) and fermentation temperature (Bardi, Koutinas, Psarianos, & Kanellaki, 1997; Torija et al., 2003). Nitrogen compounds influence the production of esters, as amino acids and ammonia determine the pool of intracellular nitrogen that regulates the metabolic pathways of esters formation (Henschke & Jiranek, 1993). The formation of alcohols is also influenced by the pool of intracellular nitrogen (Large, 1986). In this sense, Torrea et al. (2003) found that there existed a negative correlation between the nitrogen assimilated by yeasts and the total concentration of alcohols in wine.

Alcoholic fermentation can be carried out in different types of containers, such as stainless steel tanks, plastic tanks and oak barrels. The use of oak barrels to ferment wine could have an important influence on the aromatic composition of the product. Wood is a porous material which can bind and release compounds unlike the stainless steel tank which is a material that does not interact with wine. Burgundy white wines have traditionally been fermented in barrel and, worldwide, it is becoming more and more common to use barrel in the elaboration of

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doi:10.1016/j.foodchem.2007.10.067

quality white wines. Several studies have described the influence of wood compounds on the aroma of white wine (Pérez-Coello et al., 2000; Chatonnet, Dubordieu, & Boidron, 1991; Herjavec, Jeromel, Da Silva, Orlic, & Redzepovic, 2007). However, few studies exist on the influence that the type of container has on the *fermentation bouquet* of wine. Yokotsuka, Matsunaga, and Singleton (1994) compared the composition of Koshu white wines fermented in oak barrels and plastic tanks and found a larger formation of esters, especially ethyl acetate, in wines fermented in oak barrel. For all these reasons, the aim of this work was to study the influence of the type of container used for alcoholic fermentation in the formation of volatile compounds in quality white wines. To do so, a Chardonnay must was used and it was fermented both in stainless steel tanks and in new French oak barrels from the Nevers region.

2. Materials and methods

2.1. Samples and vinification

The must used was *Vitis vinifera* var. Chardonnay. The must was obtained by pressing at 0.5 atm and was treated with SO_2 (60 mg/l). Clarification was carried out by natural settling with the must in repose for 24 h at 10 °C. The sample was divided in four aliquots. Two aliquots of 60 l were fermented in stainless steel tanks of 70 l. Two other aliquots of 225 l of wine were fermented in new barrels, made from Nevers French oak (*Quercus sessilis*). All the fermentations were carried out by traditional method that is without inoculation of *Saccharomyces cerevisiae*. The fermentations in stainless steel tanks were carried out at a controlled temperature of 17 ± 2 °C, while fermentations in oak barrels were carried out at temperatures in the range of 19 ± 2 °C. In order to control the fermentation temperature stainless steel tanks with cooling jacket were used. In the case of the barrels, the temperature was controlled by introducing a heat exchanger bar inside the barrel with circulating cold water in the interior. Alcoholic fermentation lasted seven days in stainless steel tanks and 10 days in oak barrels. Samples were taken at 50% of consumed sugars and at the end of alcoholic fermentation.

2.2. Preparation of sample and analysis by FID and GC–MS of volatile compounds

It was necessary to use two methods of analysis because volatile compounds of wine have different volatilities and they are found in a very wide range of concentrations. In order to analyse high-range volatility and high concentration compounds (acetaldehyde, ethyl acetate, *n*-propanol, isobutanol, *n*-butanol, isoamyl alcohols and 2,3-butanediol) the method outlined by Clemente-Jimenez, Mingorance-Cazorla, Martínez-Rodriguez, Las Heras-Vázquez, and Rodríguez-Vico (2005) was used. These compounds were analysed by direct injection of 1 μl of sample in a gas chromatograph Shimadzu GC-17A (Shimadzu, Kyoto, Japan) with a flame ionization detector (FID). A DB-WAX capillary column (30 m × 0.25 mm i.d. and 0.25 μm film thickness) with stationary phase of polyethylene glycol bonded and cross-linked (Cromlab, Barcelona, Spain) was used. Chromatographic conditions were as follow: He (purity = 99.000%) as carrier gas (40 cm/s); injector and detector temperature, 220 °C. The high volatile compounds were separated using a temperature program with initial oven temperature of 40 °C for 2 min, a temperature gradient of 3 °C/min to a temperature of 120 °C, maintained during 10 min. The standards were prepared with reagents from Aldrich (Gillingham, England) at concentrations between 0.5 and 500 mg/l. Two chromatographic analyses were made of each sample.

The compounds of middle-range volatility were, isoamyl acetate, ethyl hexanoate, acetoin, ethyl lactate, *n*-hexanol, ethyl octanoate, ethyl 3-hydroxybutyrate, γ-butyrolactone, butyric acid, ethyl decanoate, diethyl succinate, 3-(methylthio)-1-propanol, 2-phenylethyl acetate, hexanoic acid, benzyl alcohol, 2-phenylethanol, diethyl malate, octanoic acid, decanoic acid, mono-ethyl succinate, dodecanoic acid, tetradecanoic acid, hexadecanoic acid, tyrosol, octadecanoic acid, 9,12-octadecadienoic acid and tryptophol. These compounds that in general are present in lesser concentrations than the former ones, were extracted and analysed by GC–MS. To extract these middle-range volatile compounds the method outlined by Lopez, Aznar, Cacho, and Ferreira (2002) was used. For this extraction prepacked cartridges (3 ml total volume) filled with 200 mg LiChrolut EN resins (Merck, Darmstadt, Germany) were placed in the extraction system (Vac Elut 20 station from Varian, Harbor City, CA, USA) and conditioned by rinsing with 4 ml of dichloromethane HPLC quality (Panreac, Barcelona, Spain), 4 ml of methanol HPLC quality (Scharlau, Barcelona, Spain) and finally, with 4 ml of water ethanol mixture (12%, v/v). An amount of 50 ml of wine previously centrifuged at 2750 g for 30 min, were passed through the SPE (solid-phase extraction) cartridge at 2 ml/min. Afterwards, the sorbent was dried by letting air pass through it for 20 min. Analytes were recovered by elution with 1.3 ml of dichloromethane of HPLC quality (Panreac). An amount of 100 μl of the internal standard solution (heptanoic acid) was added after the SPE of the samples. The mixture was then sealed and stored at −30 °C until analysis.

The analyses of the extract were carried out, following the method described by Garde and Ancín (2006), using a Shimadzu QP 5000 GC–MS (Kyoto, Japan). A DB-WAX capillary column (30 m × 0.25 mm i.d. and 0.25 μm film thickness) with stationary phase of polyethylene glycol bonded and cross-linked (Cromlab) was used. The chromatographic conditions were: He as carrier gas (30.9 cm/s); injector temperature, 240 °C; temperature of the transfer line, 240 °C. The middle-range volatile compounds were separated using a temperature program with initial oven temperature of 40 °C for 5 min, a temperature gradient of 2 °C/min to a temperature of 50 °C, maintained during

10 min, followed by a gradient temperature of 2 °C/min to a final temperature of 240 °C, and a final time of 30 min. The sample volume injected was 2 μl, using a splitless mode. The ionization was produced by electronic impact at 70 eV. Operation mode was Full Scan, between 35 and 300 amu. The dissolutions of the standards were prepared in dichloromethane HPLC quality (Panreac). To examine the accuracy of the method, the recovery index was used. A known amount of each volatile compound was added to a previously analysed wine sample and all the volatile compounds were quantified. The recovered quantity was calculated from the difference between the measured concentration after adding the volatile compounds and the initial, endogenous concentration. The recovery values were always >78%.

2.3. Preparation of samples and analysis of free amino acids

Amino acids were quantified according to the Pico·Tag method outlined in Ancín, Ayestarán, and Garrido (1996). To do so a Waters high-pressure liquid chromatograph (Waters Chromatography Div., Milford, Mass., USA) equipped with two 510 pumps, a 717 Plus autosampler, and 996 photodiode array detector was used. A Pico·Tag reverse-phase column (300 mm × 3.9 mm i.d.) with a stationary phase of dimethyloctadecylsilyl bonded to amorphous silica was used. Amino nitrogen was quantified by the addition of the concentration of the free amino acids.

2.4. Enological parameters and statistical analysis

Enological parameters are described by the Office International de la Vigne et du Vin (1990). Data were statistically analysed by one-way ANOVA. The software used was SPSS v. 12 (Chicago, Ill., USA).

3. Results and discussion

3.1. Enological parameters and assimilable nitrogen

The wine fermented in oak barrels showed a higher quantity of residual sugar than the wine fermented in stainless steel tanks (Table 1), although in both kinds of vinification, fermentation reached dryness (residual sugar < 2.5 g/l). Volatile acidity of wine fermented in stainless steel tanks was slightly higher to that found in wine fermented in oak barrels. In all cases, the values were inferior to the limits found by Peynaud (1993) as undesirables for wine aroma (0.6 g HAc/l). At the end of alcoholic fermentation, the alcoholic degree reached by both samples was similar (Table 1).

The consumption of nitrogen was similar in both types of wine during the first half of alcoholic fermentation (Fig. 1). During the second half of this fermentation the assimilable nitrogen continued to be consumed in wine fermented in stainless steel tanks while in wine fermented in oak barrels the concentration of assimilable nitrogen remained constant. At the end of alcoholic fermentation, the concentration of assimilable nitrogen was 38% higher in wine fermented in oak barrel than in wine fermented in stainless steel tanks. Yokotsuka et al. (1994) also found that Koshu white wines fermented in barrel showed a higher concentration of amino acids at the end of alcoholic fermentation than the same wine fermented in plastic tanks.

Table 1
Enological parameters in Chardonnay must and wines

	Must	Wine	
		Stainless steel tank	Barrel
Sugar (g/l ± s)	150 ± 10	0.08 ± 0.01	0.49 ± 0.06
pH ± s	3.40 ± 0.01	3.59 ± 0.02	3.57 ± 0.03
Total acidity (g/l[a] ± s)	4.4 ± 0.2	4.9 ± 0.3	4.9 ± 0.2
Volatile acidity (g/l[b] ± s)	nd	0.22 ± 0.02	0.12 ± 0.01
Free SO_2 (mg/l ± s)	12.0 ± 0.0	2.3 ± 0.3	1.8 ± 0.4
Alcohol (vol%)	nd	12.2 ± 0.2	12.0 ± 0.1

nd: Not detected.
[a] Expressed as tartaric acid.
[b] Expressed as acetic acid.

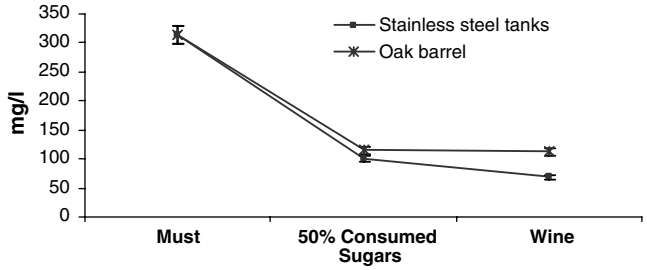

Fig. 1. Evolution of assimilable nitrogen (mg N/l) during Chardonnay must fermentation in stainless steel tanks and in oak barrels.

3.2. Evolution of acids during alcoholic fermentation

The concentration of short-chain and medium-chain fatty acids (C4:0–C12:0) increased in both types of wines during the first half of alcoholic fermentation; although this increase was significantly greater ($p < 0.05$) in wine fermented in oak barrels than in wine fermented in stainless steel tanks (Table 2). The concentration of octanoic and decanoic acids stands out as being much higher in the sample fermented in oak barrels ($p < 0.001$) than in the sample fermented in tanks. In the second half of fermentation, the concentration of medium-chain saturated fatty acids (C6:0–C10:0) continued to increase, especially in wine fermented in oak barrels. The concentration of these compounds was practically four times higher in wine fermented in oak barrels than in wine fermented in stainless steel tanks. The synthesis of medium-chain fatty acids by the yeasts is mainly due to the fact that they are intermediate products in biosynthesis of long-chain fatty acids (Taylor & Kirsop, 1977). In our samples, these compounds

Table 2
Concentration of acids (μg/l) in must, at 50% of consumed sugars and in wines samples

	Must	50% Consumed sugars			Wine		
		Stainless steel tank	Oak barrel	*F*	Stainless steel tank	Oak barrel	*F*
Butyric acid	247 ± 3	331	431	32.293*	307	542	72.786**
Hexanoic acid	234 ± 9	508	894	38.715*	865	3377	199.502**
Octanoic acid	315 ± 4	679	1720	71.379**	1008	6046	254.074**
Decanoic acid	418 ± 3	546	1353	71.379**	565	2474	258.884**
Dodecanoic acid	nd	965	1062	9.343*	958	989	2.083
Tetradecanoic acid	nd	1056	1076	2.190	nd	nd	
Hexadecanoic acid	1204 ± 10	1240	1372	4.202	1206	nd	
Octadecanoic acid	781 ± 14	820	826	0.020	814	nd	
9, 12-Octadecadienoic acid	1147 ± 48	1151	nd		1155	nd	
Total acids	4346 ± 52	7297	8733	16.376*	6878	13428	121.753**

nd: Not detected.
* Significant differences $p < 0.05$.
** Significant differences $p < 0.001$.

could also be extracted by wine during its fermentation in barrel, since oak wood (*Q. sessilis*) contains saturated fatty acids with an even number of carbons in the chain (C2:0–C26:0) (Nishimura, Ohnishi, Masuda, Koga, & Matsuyama, 1983; Nykänen, Nykänen, & Moring, 1985; Wiessmann, Kubel, & Lange, 1989). The extraction of this type of acids would be favoured by the use of new barrels for the fermentation of Chardonnay must. The higher concentration of hexanoic, octanoic and decanoic acids in the sample fermented in oak barrels could have affected the alcoholic fermentation rate, because these medium-chain fatty acids affect cell membrane permeability and intensify alcoholic toxicity. This would explain why the wine fermentation in oak barrels lasted two days longer than the fermentation in tanks.

Tetradecanoic acid (C14:0) was synthesized in the first half of fermentation and it was consumed at the end of fermentation in both types of wine (Table 2). This coincides with that found by Fraile et al. (2000) for this same acid. Neither hexadecanoic acid (C16:0) nor octadecanoic acid (C18:0) were found in the wine fermented in oak barrels, unlike the case of the wine fermented in stainless steel tanks. It is likely that the yeasts, during fermentation in oak barrels, would have incorporated these long-chain fatty acids from the medium as a response mechanism to the toxicity of ethanol, CO_2 and medium-chain fatty acids. 9,12-Octadecadienoic acid (C18:2) was consumed from the beginning of fermentation in oak barrels but not in the case of wine fermented in tanks. This compound is important for the fluidity of the plasmatic membrane and cannot be synthesized by the yeasts, in absence of oxygen, so that they must take it from the medium (Ratledge & Evans, 1989).

3.3. Evolution of higher alcohols, methanol and 3-(methylthio)-1-propanol during alcoholic fermentation

The evolution of these compounds during alcoholic fermentation and their concentration in wine are displayed in Table 3. Total alcohols correspond to the sum of *n*-butanol, *n*-hexanol, *n*-propanol, isobutanol, isoamyl alcohols, tyrosol, tryptophol, benzyl alcohol and 2-phenylethanol. In no case the sum of total alcohols exceed the concentration of 400 mg/l described by Rapp and Mandery (1986) as the threshold where they would contribute in a negative way to wine aroma. At the half-way stage of alcoholic fermentation, total concentration of alcohols in wine fermented in oak barrels was approximately half of that found in wine fermented in stainless steel tanks (Table 3). At the end of alcoholic fermentation, the concentration of total alcohols was 42% higher in wine fermented in oak barrels than in wine fermented in tanks. The greater quantity of alcohols in wine fermented in barrels would seem to be related to the lower consumption of assimilable nitrogen (Fig. 1). Torrea et al. (2003) found that there existed a negative correlation between the nitrogen consumed by yeasts and the total concentration of alcohols in wine.

Aromatic alcohols, 2-phenylethanol, benzyl alcohol, tyrosol and tryptophol, were the ones that showed the greatest differences ($p < 0.001$) between both types of vinification at the end of alcoholic fermentation, with the higher concentration being found in wine fermented in oak barrels. The concentration of *n*-hexanol and *n*-propanol was also significantly higher ($p < 0.001$) in wine fermented in oak barrels than in wine fermented in tanks, just as had occurred with the aromatic alcohols. Isoamyl alcohols, which made up the majority of the alcohols, did not show any significant differences between the two types of wines. *n*-Butanol which is not formed by the catabolism of amino acids (Ehrlich pathway) and *n*-propanol, were the two higher alcohols which showed the least differences ($p < 0.05$), although their concentration was also higher in the wine fermented in oak barrels.

3-(Methylthio)-1-propanol was mainly produced during the first half of alcoholic fermentation in both fermentations. Garde and Ancín (2006) also found that this compound is mainly produced at the beginning of fermen-

Table 3
Concentration of alcohols (μg/l) at 50% of consumed sugars and in wines samples

	50% Consumed sugars			Wine		
	Stainless steel tank	Oak barrel	*F*	Stainless steel tank	Oak barrel	*F*
n-Butanol	nd	nd		1610	1720	44.536*
n-Hexanol	545	710	14.519*	502	1078	65.705**
n-Propanol	13960	7410	46.410**	21910	32077	25.473*
Isobutanol	7350	3780	41.497*	17790	37321	81.482**
Isoamyl alcohols	33410	14600	75.792**	87090	102933	4.146
Tyrosol	116	142	5.589	604	2068	123.985**
Tryptophol	111	248	67.692**	213	1020	107.441**
Benzyl alcohol	nd	nd		12	56	119.889**
2-Phenylethanol	554	907	18.861*	930	6564	161.331**
Total alcohol	56055	27815	64.955**	130671	185504	28.310*
3-(Methyltio)-1-propanol	51	95	139.821**	40	96	138.827**
Methanol	38950	22750	65.763**	53710	66952	10.964*

nd: Not detected.
* Significant differences $p < 0.05$.
** Significant differences $p < 0.001$.

tation in Parellada wines and that its concentration could decrease at the end of the fermentative process. Methanol was synthesized throughout the fermentation in both types of wines. The concentration of these two compounds was significantly higher in the wine fermented in oak barrels than in the wine fermented in stainless steel tanks ($p < 0.001$ and $p < 0.05$ for 3-(methylthio)-1-propanol and methanol, respectively), just as had occurred with the majority of the higher alcohols. Methanol did not exceed the limit described as toxic at any time.

3.4. Evolution of esters during alcoholic fermentation

Total esters correspond to the sum of all the quantified esters except ethyl acetate because this one makes a different contribution to wine aroma due to the fact that it does not present flowery or fruity aromas as the rest of the esters do. The total concentration of esters (Table 4) was significantly higher ($p < 0.001$) in wine fermented in oak barrels (17.6 mg/l) than in wine fermented in stainless steel tanks (4.7 mg/l). Isoamyl acetate, ethyl hexanoate, ethyl octanoate and ethyl decanoate were found in concentrations four times higher in wine fermented in oak barrels than in wine fermented in stainless steel tanks.

At the half-way stage of fermentation, ethyl acetate was the only ester that was found in higher concentration in wine fermented in stainless steel tanks than in wine fermented in oak barrels. Ethyl octanoate was the ester that showed the greatest difference ($p < 0.001$) between the two types of wines. During the second half of alcoholic fermentation, the concentration of total esters increased 36% in wine fermented in tanks and 77% in wine fermented in oak barrels. This high increase in ester concentration in wine fermented in oak barrels during the second half of

Table 4
Concentration of esters (μg/l) at 50% of consumed sugars and in wines samples

	50% Consumed sugars			Wine		
	Stainless steel tank	Oak barrel	*F*	Stainless steel tank	Oak barrel	*F*
Isoamyl acetate	542	562	0.134	1260	5170	76.756**
2-Phenylethyl acetate	21	22	8.058*	92	235	189.531**
Ethyl hexanoate	423	560	11.957*	899	3962	341.780**
Ethyl octanoate	384	764	64.716**	667	2871	116.400**
Ethyl decanoate	154	221	24.151*	101	496	260.103**
Ethyl 3-hydroxybutyrate	199	197	2.529	217	249	8.643*
Diethyl malate	105	105	0.609	107	110	0.600
Diethyl succinate	69	124	27.108*	108	1186	221.555**
mono-Ethyl succinate	528	635	37.237*	716	2568	78.965**
Ethyl lactate	578	811	11.957*	539	911	26.886*
Total esters	3004	4005	24.162*	4710	17758	864.864**
Ethyl acetate	16370	9800	29.837*	51002	67476	7.762*

nd: Not detected.
* Significant differences $p < 0.05$.
** Significant differences $p < 0.001$.

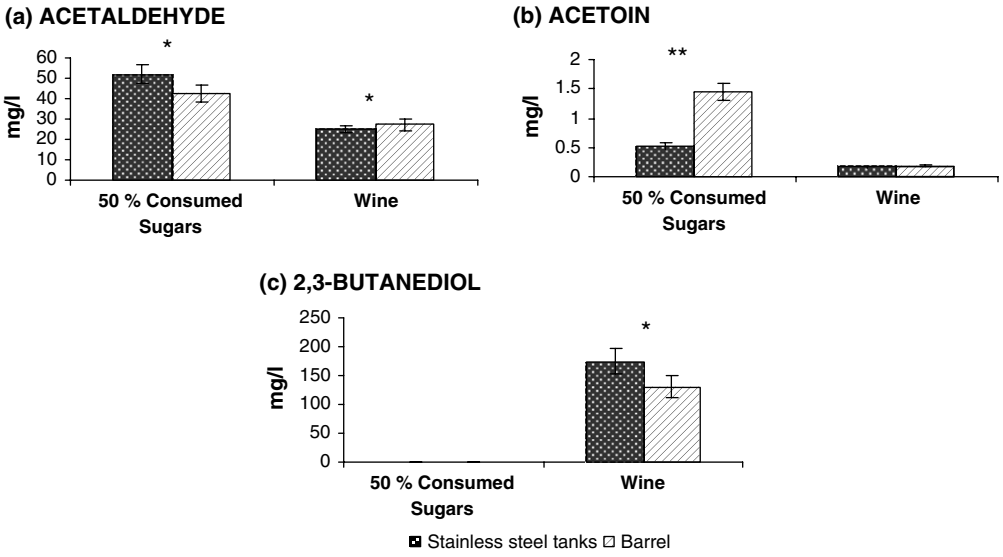

Fig. 2. Concentration of acetaldehyde, acetoin and 2,3-butanediol (mg/l) at 50% of consumed sugars and in wines fermented in stainless steel tanks and in oak barrels (significant differences: $^{*}p < 0.05$ and $^{**}p < 0.001$).

alcoholic fermentation could be due to different factors. The lower presence of unsaturated fatty acids in the must fermented in oak barrels during the second half of alcoholic fermentation could lead to a diminution of cellular growth and an increase in the production of short-chain fatty acids and their corresponding ethyl esters (Thurston, Quain, & Tubb, 1982). Furthermore, the porosity of the new wood could have favoured that some yeasts remained immobilized in the wood pores, thus producing an increase in the production of esters. In this sense, Mallouchos et al. (2003) and Mallouchos et al. (2007) found that fermentations carried out by immobilized cells in different kind of supports, produced more aromatic wines. Yokotsuka et al. (1994) also found a greater concentration of total esters in Koshu wines fermented in oak barrels than in these wines fermented in plastic tanks, and more particularly, of ethyl acetate. Ethyl esters of succinic acid (diethyl succinate and mono-ethyl succinate) were also found in greater concentration in wine fermented in oak barrels than in wine fermented in tanks.

3.5. Evolution of acetaldehyde, acetoin and 2,3-butanediol during alcoholic fermentation

Acetaldehyde (Fig. 2a) was formed during the first half of fermentation both in wine fermented in stainless steel tanks as well as in wine fermented in oak barrels, and during the second half of fermentation the concentration of this compound decreased. The concentration of acetaldehyde was higher in wine fermented in oak barrels than in wine fermented in tanks. This compound gives grass-like or apple-like aromas to the wine when it is found in concentration higher than 0.5 mg/l (Henschke & Jiranek, 1993). All wines studied surpassed this perception threshold.

Acetoin was formed mainly during the first half of alcoholic fermentation and in a greater quantity in wine fermented in oak barrels (Fig. 2b). In wine fermented in tanks, the concentration of this compound was higher than in wine fermented in oak barrels, although in both cases the concentration was lower than that reached at the half-way stage of fermentation. The decrease of this compound at the end of fermentation has also been observed by other authors (Fraile et al., 2000; Garde & Ancín, 2006) and this could be due to its reduction to 2,3-butanediol (Ribéreau-Gayon, Dubourdieu, Donéche, & Lonvaud, 2000). In Fig. 2c it may be seen that this compound was formed at the end of alcoholic fermentation in both types of wine. Yeasts can irreversibly reduce diacetyl to acetoin and afterwards to 2,3-butanediol (Bayonove, Baumes, Crouzet, & Günata, 2003). A greater concentration of this compound was found in wine fermented in tanks than in wine fermented in oak barrels. Although this compound is odourless, as its perception threshold is very high (668 mg/l) (Moreno, Zea, Moyano, & Medina, 2005), it does contribute to the sweet taste in wine.

4. Conclusions

Results of this work reveal that the type of container used for Chardonnay wine fermentation influences the *fermentation bouquet* of wine to an important extent. It is very likely that this could be due to the fact that the wood from new oak barrels is a porous material which interacts with must during fermentation, unlike what happens with stainless steel tanks which is a wholly stable and inert material. The concentration of fermentation volatile compounds was higher in wine fermented in oak barrels than in wine fermented in stainless steel tanks. In wine fermented in oak barrels, the concentration of total alcohols was 42% higher

than in wine fermented in tanks. This difference in concentration was correlated with the lower consumption of assimilable nitrogen in wine fermented in oak barrels. In addition, the greater concentration of ethyl esters of medium-chain fatty acids and of isoamyl acetate in wine fermented in oak barrels stands out. Finally, in this wine the concentration of medium-chain fatty acids was higher to that of wine fermented in stainless steel tanks.

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