Peer-reviewed version available at *Beverages* **2018**, *4*, 91; doi:10.3390/beverages4040091

New Strategies to Improve Sensorial Quality of White Wines by Wood Contact

M. Elena Alañón [a*], M. Consuelo Díaz-Maroto [a] and M. Soledad Pérez-Coello [b]

[a] Area of Food Technology, Regional Institute for Applied Scientific Research (IRICA), University of Castilla-La Mancha, Avda. Camilo José Cela, 10, 13071 Ciudad Real, Spain.

[b] Area of Food Technology, Faculty of Chemical Sciences and Technologies, University of Castilla-La Mancha, Avda. Camilo José Cela, 10, 13071 Ciudad Real, Spain.

*Corresponging author

Tlf.: [34] 926295300

Fax: [34] 926295318

e-mail: mariaelena.alanon@uclm.es

Abstract

Ageing wine is a commonly practice used in winemaking since the quality and sensory profile increase due to the extractable compounds coming from wood by means of barrels or chips. The quantitative and qualitative compounds from wood depend on the species, its origins and the treatments applied in cooperages. Traditionally, oak wood species are most often used in cooperage, specifically *Quercus alba*, Known as American oak and *Q. robur* and *Q. petraea* both known as French oak. However, although this stage is very common for red wines, its use is still restricted in the case of white wines. However, this topic is particularly interesting, since due to the sensorial benefits of wood contact, the option for ageing white wines in barrels or chips is increasingly and widely chosen by winemakers. This review compiles the novel strategies applied to white wines by means of wood contact in the last years with the aim to increase wine quality and sensorial features.

Keywords: white wine; volatile compounds; sensorial characteristics; oak; alternative woods; barrels; chips

1. Introduction

White wine market has been monopolized for many years by young varietal wines, which should be consumed in a short period after bottling to avoid the loss of freshness and fruity character, mainly due to the detriment of the compounds of varietal origin. Different oenological practices were used to enhance varietal aromas in slightly aromatic or neutral white grape varieties such as the prefermentative skin-contact treatment or the use of glycosidic enzymes, obtaining more aromatic wines with a low content of phenolic compounds [1-3].

Wood ageing in the case of white wines has only been used occasionally, mainly by fermentation in barrels or by ageing on lees [4, 5]. The yeast cells absorb the ellagitannins from the wood reducing the astringency of the wines, while some compounds extracted from wood such as furfural and vanillin can be metabolized by the yeasts decreasing their sensory impact [6].

Recently, these techniques have been recovered together with other alternative practices in white vinification. Fermentation and/or ageing in wooden barrels or amphorae, accelerated ageing with wood chips, ageing in barrique on lees [5, 7-9] and the use of other types of wood such as acacia [10] have been used to improve the quality of white wines.

All these innovations have contributed to increase and improve the variety of white wines in contact with wood in the market, adapting to the new tastes of the consumer and the demands of the international market. However, it is important to look for the best combination between type of wood, ageing process and grape variety in order to obtain a quality wine with new sensory sensations but without masking the primary and secondary aromas specific to each grape variety.

2. Sensorial quality improvement of white wines by contact with oak wood

In recent years, oenological research has not only focused on the ageing of red wines. There are more and more studies on the contact between white wine and wood, either during the ageing stage and / or during alcoholic fermentation. In this sense, the selection of type wood is fundamental. The barrels traditionally used are those of American oak (*Quercus alba*) and French (*Q.robur* and *Q. petreaea*), the latter having the most prestige in the market and, therefore, also higher price. Both species are not exclusive to France, but extend across Eastern Europe and the North of the Iberian Peninsula, so lately Hungarian, Russian or Spanish oak barrels have been introduced into the market.These new oak woods present a similar volatile composition to that of French ones, and they are a good alternative in the ageing of wines [11, 12].

The knowledge of the chemical composition of oak wood, especially its content in volatile compounds and ellagitannins, is of great importance to select the most suitable oak for the ageing of a particular wine. During ageing time, a transfer of several chemical substances take place from the wood to the wine that will condition the sensory characteristics of the final product.In different studies, it has been shown that there are very few chemical characteristics of a single oak species. On the contrary, there is a great variability within each species, and even, within each geographical area [11, 13], since the climatic and forest conditions have a great influence on chemical composition of oak wood [14]. Moreover, the physical and mechanical parameters of the wood (porosity, grain size, flexibility, etc.), can have an important influence on the transfer of substances between wine and wood, for that reason the most appreciated species are those commonly known as "porous ring" woods, such as the oak.

To provide the woody character to white wines, fermentation or ageing in oak barrels have been carried out. However, compared to red wines, there are few studies on the effect of the interaction between oak wood barrels and white wine. Although, one of the most suitable white grape variety to ferment the must or to age the wine in oak barrels is

Peer-reviewed version available at Beverages 2018, 4, 91; doi:10.3390/beverages4040091

Chardonnay [5, 15-18],in the literaturedifferent studies about the influence of oak maturation on the quality of white wines from other varieties can be found, such as Verdejo [19], white Listán [20], Muscatel [21],Sauvignon blanc [16; 18], Encruzado [22]or Malvazija istarska [9].

Herrero et al. [18] studied the effect of toasting level and ageing time on the volatile composition and sensory quality of two white wines, Chardonnay and Sauvignon blanc, aged in oak barrels. The differences observed in the content in wood-extractable volatile compounds of wines were dependent on the toasting level and ageing time, as well as on the grape variety. The volatile compounds released by the oak wood into wines increased with the ageing time, except methyl vanillate and vinylphenols, which decreased, although the authors found a high variability among replicates, which has been previously reported in other works [17]. From a sensory point of view, Chardonnay and Sauvignon blanc wines 12-month aged in French barrels did not show an homogeneous aroma quality among judges [18].Previous studies that had evaluated the impact of ageing in oak barrels in Chardonnay wines are Spillman et al. [15] and Herjavec et al.[16], among other. The first one established correlations between the volatile composition and the olfactory profile of wines aged in new oak barrels and confirmed the role of some oak wood-extractable compounds in aged Chardonnay wine aroma, such as the strong correlation between “smoky” aroma and volatile components produced by barrel toasting. While Herjavec et al. [16] observed a positive influence of the fermentation in new Croatian oak barrels on the quality of Chardonnay and Sauvignon blanc wines, in comparison with those fermented in steel tanks.

The aroma quality of Chardonnay wines has also been tried to improve by fermentation and ageing in oak barrels on lees. This technology allowed increasing the content of volatile compounds positively related to the quality of the wines' flavour. However, no significant differences were observed in the aroma of the wines compared to the

Peer-reviewed version available at Beverages 2018, 4, 91; doi:10.3390/beverages4040091

fermented and aged wines in stainless steel, probably due to the stronger influence of lees in the aroma of the wines compared to oak wood [5].

On the other hand, Rodríguez-Nogales et al. [19] classified Verdejo wines obtained through different winemaking techniques based on their volatile composition and sensory characteristics. Verdejo wines fermented and aged in oak barrels shown greater amounts of eugenol and methyleugenol and lower quantities of terpenes and esters compared to those young wines fermented in stainless steel tanks. More recently, Lukic et al. [9] increased the aromatic composition complexity of white wines by prolonged maceration followed by maturation in wooden barrels. While, the utilisation of new oak wood barrels induced changes for some aroma descriptors, such as “wood aroma” and “aroma intensity” in Encruzado white wines [22]. These authors showed the important role of ageing time and barrel capacity on the quality of oak barrel-aged white wines.

However, these oenological practices have some drawbacks such as the limited capacity of the barrels, mainly when they are used for wine fermentation, the difficulty to control the temperature of fermentation or the cleaning of the barrels. Also, not all wines are suitable for ageing in oak barrels since the micro-diffusion of oxygen through wood pores could oxidize the wine and the release of chemicals into the wine could completely masks its organoleptic characteristics [23]. In the case of white wines, oxidation causes a decrease in pleasant sensory levels along with the appearance of off-flavours as “honey-like” or “cooked vegetables”and the brown coloration of wine [24]. In this sense,oak wood chips are presented as a good alternative to the use of barrels for the ageing of white wines. Their price is less than that of the barrels, however, the different behaviour of the chips has made the evolution of this technique slower than it might seem.

Like barrels, chips can be used during fermentation or during wine ageing. Various authors have revealed the advantages of the fermentation of white wines in the presence of oak chips [20, 25, 26]. Airén wines were fermented with untreated chips from the most

Peer-reviewed version available at *Beverages* **2018**, *4*, 91; doi:10.3390/beverages4040091

common oak varieties, American and French, at different doses, 4, 7 and 14 g/L. Wines best valued by the tasters were those treated with 7g/L of American oak chips [25].

On the other hand, Gutiérrez Alfonso [20] compared from the sensorial point of view two *Listánblanco* white wines fermented with oak chips and in barrels. Chips from American and French oaks were added in two doses, 4 and 8 g/L, while new barrels of 225 L were made from same type of oak.The variable with the greatest effect on the sensory profile of the wine was the amount of oak chips used, while the geographical origin of the oak was more noticeable in chips than in barrels. In this sense, wines fermented with the higher quantities of American oak chips shown the greater intensities of vanilla and coconut aromas, together a greater astringency than in barrels.

Recently, Sanchéz-Palomo et al. [26] tried to improve the quality of Verdejo white wines by using oak chips during the alcoholic fermentation of the must or during the ageing of the wine. Wines aged in the presence of chips showed the highest quantities of volatile oak-extractable compounds, such as oak lactones and furanic compounds, while wines fermented with chips had higher concentrations of fermentative volatile substances, as alcohols, acetates and ethyl esters of straight-chain fatty acids.

Respect to the use of oak chips during ageing, the volatile composition and the sensory characteristics of Chardonnay wines treated with chips of different oak species and toasting degree have been studied [7]. Table 1 shows the odour activity values (OAV) of volatile oak-related compounds in Chardonnay wines aged with non-toasted and toasted American (*Q. alba*) and Hungarian (*Q. petraea*) oak chips during 25 days, together the odour perception thresholds and odour descriptions of each compound found in the literature [12, 27-33]. Volatile oak-related compounds with higher OAVs were those quantified in wines treated with American oak chips. Compounds with OAVs > 1 and with possible impact on the aroma of the aged Chardonnay winewere cis-oak lactone, eugenol and 4-vinylguaiacol in wines treated with non-toasted American oak chips, and cis-oak lactone, eugenol, isoeugenol, guaiacol and vanillin in wines treated with toasted

American oak chips. These results show the important effect that toasting process has on the aromatic potential of oak.Thus, in the case of wines aged in contactwith Hungarian oak chips, only compounds with OAVs > 1 were obtained in those treated with toasted wood.

Peer-reviewed version available at *Beverages* **2018**, *4*, 91; doi:10.3390/beverages4040091

Table 1. Odour perception thresholds, odour descriptions and odour activity values (OAV) of volatile oak-related compounds in Chardonnay wines macerated with non-toasted and toasted Hungarian and American oak chips during 25 days.

Compounds	Odour perception threshold (µg/L)	Odour description	OAV			
			NTA	TA	NTH	TH
trans-Oak lactone	122[b]	Vanilla, oaky, clove, coconut [a]	0.36	0.14	0.00 *	0.00
cis-Oak lactone	35[b]	Vanilla, oaky,clove, coconut[a]	9.11	3.17	0.00	0.00
Eugenol	5[b]	Spicy, clove, cinnamon [a]	2.76	1.24	0.58	0.60
Isoeugenol	6 [e]	Spicy, clove, woody/oak [a]	0.37	1.98	0.45	1.32
Guaiacol	15[d]	Spicy, toasty, smoky/burnt [a]	0.29	1.33	0.13	2.63
4-Vinylguaiacol	141[d]	Smoky [d]	1.08	0.50	0.99	0.96
4-Ethylguaiacol	46[b]	Toasted bread, smoky, clove [b]	-	0.09	0.01	0.13
Syringol	570 [f]	Smoky [c]	0.02	0.12	0.01	0.16
Vanillin	60 [g]	Sweet, vanilla [a]	0.16	1.48	0.16	2.26
Furfural	15000 [b]	Slightly toasty, caramel [a]	0.00	0.01	0.00	0.03
5-Methylfurfural	16000 [b]	Spicy, toasty, sweet [a]	-	-	0.00	0.00
Maltol	5000[h]	Caramel[h]	-	0.05	-	0.01

NTA: non-toasted American; TA: toasted American; NTH: non-toasted Hungarian; TH: toasted Hungarian

* Those compounds with OAV equal to zero were detected in trace amounts in wines and could not be quantified.

[a][12] [b] [27], [c] [28], [d] [29], [e] [30], [f] [31], [g] [32], [h] [33]

3. Sensorial quality improvement of white wines by contact with alternative woods to oak

Although, oak is by far, the wood most used to carry out the ageing process, in the last years several studies have been published relating to the effects of other woods such as chestnut, cherry and acacia in wine ageing [34-43]. However, the scientific researchers have been focused on the impact of the use of alternative wood species exclusively on the quality of red wines and not of white wines. Therefore, there is a restricted knowledge about the impact of alternative woods to oak wood on white wine quality during ageing process.

Recently, the effect of chips from different types of woods such as acacia and cherry on the ageing process of traditional Portuguese Encruzado wines was evaluated in comparison with the traditional chips from American and French oak woods [44]. As consequence of the wood contact, all aged white aged wines increased the polyphenol content due to phenols transfer from wood to wine. However, those wines aged with acacia chips exhibited the highest total phenolic content (342.94 mg/L) in comparison with the rest of wines aged with cherry and oak wood (328.59 mg/L and 319.86 mg/L respectively) [44]. The particular richness of some phenolic compounds in acacia wood and consequently in wines aged in contact with this wood species had already been reported by other authors [38, 41]. However, contrary to this fact, other authors evidenced a pronounced enrichment of model wines in polyphenolic substances in those wines treated with oak chips compared to those treated with acacia or cherry due to the significantly higher amounts of total extractable polyphenols of oak wood [45].

It is worthy to note that the contact of wood by means of chips with white wines implied a decrease on the browning potential index due to the release of phenolic compounds from wood to wines. Phenomena such as the precipitation of oxidized phenols, the formation of phenolic polymers and the antioxidant properties of some phenolic compounds lead to increase the stability of white wines to oxidation [44]. This

Peer-reviewed version available at Beverages 2018, 4, 91; doi:10.3390/beverages4040091

fact should be also confirmed in case of the use of barrels where a gentle flow of oxygen is produced through the wood pores since no references regarding to this have been found. Among all type of wood tested, those wines aged with cherry chips exhibited the higher browning potential values which pointed it out as the most sensible to oxidation [44]. This fact was in consonance to low content of oxidizable polyphenols that characterized cherry heartwood [38, 47].

From a sensorial point of view, it seems that white wines aged with acacia chips showed major color intensity than those wines treated with cherry or American and French oak wood. Indeed, comparing the values of color difference (ΔE) between control wine and wines aged in contact with different wood chips species, only white wine aged with acacia wood chips showed values higher than two CIELAB units which is detectable by human eyes [44].

On the other hand, the use of cherry and acacia wood seemed to impart to white wines less aggressiveness and less woody character than oak wood. Furthermore, contrary to oak wood, acacia barrels appeared to enhance the sweetness and honey tasted and pronounce the vanilla and spicy character of Malvazija wines. These facts resulted in a better overall appreciation scores for white wines aged with acacia than for those aged with oak or other woods [44, 47]. However, the typical aged flavours described as spicy or vanilla were not detected in Chardonnay wines, a more international grape variety, aged in both acacia barrels and acacia chips [10]. The reasons of these facts were the low content of volatile phenols such as eugenol and guaiacol, the low level of vanillin and the lack of other substances contributing to vanilla flavour such as *cis*- and *trans*-*β*-mehtyl-*γ*-octalactone detected in wines aged with acacia. On the other hand, the sweetness character of wines aged in acacia was also confirmed by other authors who found new aged flavours coming from the contact with acacia wood described as nutty, honeyed and toasted [10]. Based on bibliography, the responsible compounds for these new aromas seem to be 2-acetyl pyrazine, 2-acetyl-3-

Peer-reviewed version available at Beverages 2018, 4, 91; doi:10.3390/beverages4040091

methylpyrazine and 2-acetylthiazole which were identified as distinctive of acacia wood due to their powerful sensorial features described as toasty, popcorn and nutty [48].

However, despite the fact that it seems that there is a clear preference of acacia wood against oak or other woods to carry out the ageing of white wines, crucial aspects related to ageing treatment (barrels or chips) and ageing time have not elucidated yet. Therefore, our research group compared the traditional ageing technique of a Chardonnay wine by means of acacia barrels with the alternative practice of use acacia chips obtained from manufacturing acacia barrels. Both assays were performed in duplicate and acacia wood was undergone a lightly toasting process. Sensorial properties of aged wines were monitored along four timing points, monthly and weekly for barrels and chips respectively. Wine control without acacia contact and all aged wines were submitted to a descriptive sensorial analysis to assess the best condition of maturation process with acacia wood based on the organoleptic properties.

In general terms, characteristics sensorial attributes of Chardonnay wines such as fresh, peach/apricot, tropical fruit and citrus character diminished drastically as consequence of the long contact with acacia wood by means of barrels or chips. Wines aged in barrels during one month and those wines macerated with acacia chips, especially those with less contact time, preserved better the freshness, fruity and varietal character. The better retention of fruity characteristics of the original wine by the use of chips than barrels had been previously reported by other authors [34, 49]. Simultaneously, the emergence of new sensory features described as acacia wood, nutty, honeyed and toasted appeared as a consequence of the acacia ageing of wines. These new sensorial features were imperceptible for wines with one month of stay in barrels and one week macerated with chips and clearly accentuated in wines aged in barrels during three and four months [10].

Among wine samples treated with acacia chips, those macerated during three weeks obtained higher scores by the panelists. Meanwhile, wines in contact with acacia

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 November 2018 doi:10.20944/preprints201811.0056.v1

Peer-reviewed version available at Beverages 2018, 4, 91; doi:10.3390/beverages4040091

during three and four months were the most regarded samples aged in barrels. Average values of each descriptor from sensorial analysis of most scored aged wines in comparison with control are shown by means of spider web diagrams in Figure 1. Compared to the use of barrels, the treatment with chips was less scored by the panelists. The use of chips led to a higher acidity and the attributes from acacia wood were timidly increased implying lower scores of taste intensity, taste quality and global quality. On the other hand, wines aged in barrels during three and four months exhibited a sensory profile different from control. They resulted in a highly complexity due to the good balance between the varietal features from Chardonnay wine and the emergence of new clearly perceptible sensory notes described as acacia wood, nutty, honeyed, and toasty as consequence of the contact with acacia barrels.

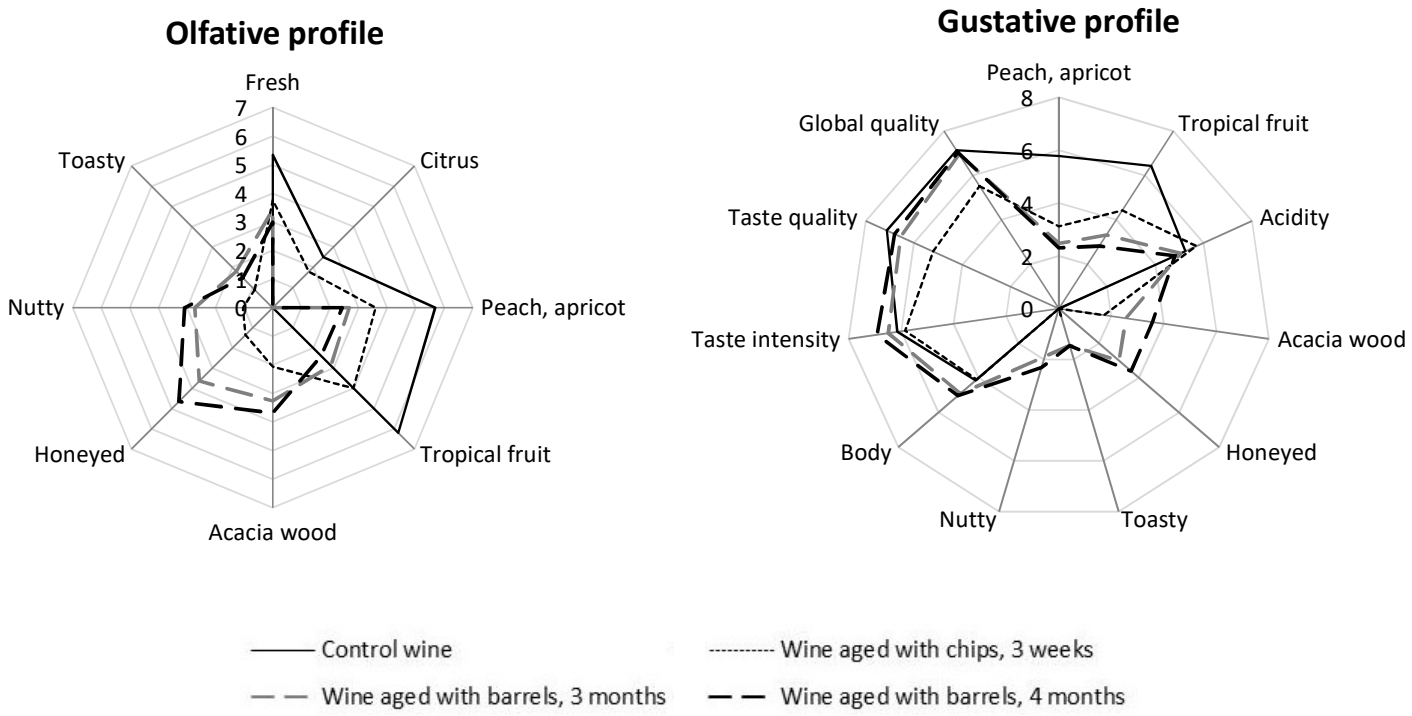

Figure 1. Olfative and gustative profiles of aged wines with the acacia treatments best scored in comparison with sensorial profiles of control wines.

With the aim of looking for other alternative woods to carry out the ageing processes that might create unique flavours, an exploratory survey evaluated 12 wood species from New Zealand in comparison with American oak wood [50]. These wood species never before used as flavourants in wine: Matai, Feijoa, Macrocarpa, Pohutukawa, Radiata pine, Totara, Kahikatea, Rimu, Cherry beech, Silver beech and Manuka were light and dark toasted in the manner of oak barrels and then infused in Chardonnay wines. Each wood showed different behaviors in terms of sensorial properties. In general terms, typical oaked wine descriptors such as woody, smoky, vanilla and buttery were provided by these woods. However, other unattractive sensorial features described as earthy, sappy, resin, paint stripper or pencil sharpenings were detected in one of the wood treatments. Based on a hedonic consumer trial, it was concluded that each wood could generate a flavour liked by some consumers, so wood species as yet untested may be useful in conferring unique flavours from a particular geographical region.

On the other hand, the production of high quality wine spirits also implies an ageing period in wood barrels during several phenomena occur and contribute to the acquisition of desired chemical characteristics and sensory properties. These changes are closely related to wood botanical species. Therefore, the study and characterization of other species different from oak wood traditionally used were also carried out for the ageing of spirit drinks.

One of the alternative wood to oak wood most commonly evaluated to carry out the ageing of wine spirits has been chestnut (*Castanea sativa*). Chemical composition, chromatic characteristics, sensory properties and antioxidant activities of wine spirits aged in chestnut have been studied in comparison with oak wood. In general terms, wine spirits aged in chestnut wood presented higher content of compounds of great importance due to their influence on the color, aroma and flavours such as phenolics and low molecular weight compounds than those wine spirits aged in oak wood. Compounds

such as gallic acid, vanillic acid, syringic acid, ellagic acid, eugenol, 4-ethylphenol and 4-allyl syringol were found in greater amounts in wine spirits aged in chestnut wood that those aged in oak wood barrels [51]. This fact also lead to the major antioxidant activity observed in wine spirits aged in chestnut than those aged in oak or other type of wood barrels due to the greater amount of phenolic compounds released by chestnut wood [46, 51, 52].

The use of chestnut also provided more evolve chromatic characteristics, more complex sensory profile and higher overall quality that made spirits look older. Wine spirits aged in chestnut wood exhibited higher intensities of topaz color while the yellow-straw decreased contrary to wine spirits aged with oak wood indicating a faster evolution induced by chestnut wood [53, 54]. Furthermore, sensorial attributes such as vanilla, woody, caramel, toasted, coffee and sweet were more pronounced in wine spirits aged in chestnut barrels than in oak wooden barrels [51, 54]. These sensorial properties seem to be attributable to the highest content of vanillin and other compounds like 4-proylguaiacol, syringol and its derivatives (4-methyl- and 4-allylsyringol) in chestnut wood as it has been reported by several authors [55, 56]. Indeed, the average overall quality was significantly higher in wine spirits aged in chestnut barrels than in those aged in oak barrels owing to the highest scores related to maturation [51, 54].

On the other hand, released compounds from chestnut, beech, ash, cherry and alder wood were compared with those provided by oak wood in spirits models (55 % of ethanol) [52]. Alcoholic extracts macerated with chestnut exhibited great amounts of gallic acid in comparison with other woods according to the high presence of this compound in chestnut wood previously reported [46, 57]. Under moderate toasting conditions (185 ºC, 60 min), chestnut and cherry woods provided similar quantities of benzoic, cinnamic acid derivatives and furanic compounds than those found in American and French oak wood. However, alder, ash and beech woods seemed to be less proned to the lignin degradation. Consequently, longer toasting time or higher temperature are

required for alder, ash and beech woods to achieve a suitable lignin degradation to carry out ageing processes.

4. Conclusions

Although the ageing stage has been exclusively for red wines, in the last years the effects of wood contact on white wines have been addressed by several scientific researchers. New white winemaking techniques such as fermentation with oak chips and barrels or the ageing on lees entail sensorial advantages due to the highest quantities of volatile oak-extractable compounds. On the other hand, new wood species alternative to traditional oak wood spices offer the possibility to flavour white wines in different manner in which oak wood does. Therefore, the treatment of white wines with wood by means of technological innovations or the use of alternative woods from oak, not only might drive to an added-value on quality but also to the acquisition of unique flavours in white wines leading to diversification market opportunities. However, in the majority of cases the scientific studies have been done with minority grape varieties, so further studies should be conducted with more international varieties to address the effects of wood contact with white wines deeply.

Author Contributions: The three authors contributed to the writing and correction of the paper.

Funding: The Spanish National Institute for Agricultural and Food Research and Technology (INIA) supported this work with theProject RTA2014-00055-C03-02.

Acknowledgments: M. Elena Alañón thanks to University of Castilla-La Mancha for the postdoctoral contract (Access to the Spanish System of Science, Technology and Innovation (SECTI)).

Conflicts of Interest: Authors declare no conflict of interest.

References

1. Sánchez-Palomo, E.; Díaz-Maroto, M.C.; González Viñas, M.A.; Pérez-Coello, M.S. Aroma enhancement in wines from different grape varieties using exogenous glycosidases. *Food Chem.* **2005**, *92*, 627-635.
2. Sánchez-Palomo, E.; Pérez-Coello, M.S.; Díaz-Maroto, M.C.; González Viñas, M.A.; Cabezudo, M.D. Contribution of free and glycosidically-bound volatile compounds to the aroma of muscat “a petit grains” wines and effect of skin contact. *Food Chem.***2006**, *95*, 279-289.
3. Sánchez-Palomo, E.; González Viñas, M.A.; Díaz-Maroto, M.C.; Soriano-Pérez, A.; Pérez-Coello, M.S. Aroma potential of Albillo wines and effect of skin-contact treatment. *Food Chem.***2007**, *103*, 631-640.
4. Jiménez Moreno, N.; Ancín Azpilicueta, C. Binding of oak volatile compounds by wine lees during simulation of wine ageing. *LWT-Food Sci. Technol.*, **2007**, *40*, 619-624.
5. Liberatone, M.T.; Pati, S.; Del Nobile, M.A.; La Notte, E. Aroma quality improvement of Chardonnay White wine by fermentation and ageing in barrique on lees. *Food Res. Int.***2010**, *43*, 996-1002.
6. Chatonnet, P.; Dubourdieu, D.; Boidron, J.N. Incidence des conditions de fermentation at d´elevage des vinsblanc secs en barriques sur leur composition in substances cèdèes par le bois de chêne. *Sci. Aliments*, **1992**, *12*, 665-685.
7. Guchu, E.; Díaz-Maroto, M.C.; Pérez-Coello, M.S.; González Viñas, M.A.; Cabezudo, M.D. Volatile composition and sensory characteristics of Chardonnay wines treated with American and Hungarian oak chips. *Food Chem.* **2006**, *99*, 350-359.
8. Baiano, A.; Varva, G.; De Gianni, A.; Viggiani, I.; Terracone, C.; Del Nobile, M.A. Influence of type of amphora on physico-chemical properties and antioxidant capacity of “Falanghina” white wines. *Food Chem.***2014**, *146*, 226-233.

9. Lukic, I.; Jedrejcic, N.; KovacevicGanic, K.; Staver, M.; Persuric, D. Phenolic and aroma composition of white wines produced by prolonged maceration and maturation in wooden barrels. *Food Tech. Biotech.***2015**, *53*, 407-418.
10. Alañón, M.E.; Marchante, L.; Alarcón, M.; Díaz-Maroto, I.J.; Pérez-Coello, S.; Díaz-Maroto, M.C. Fingerprints of acacia aging treatments by barrels or chips based on volatile profile, sensorial properties, and multivariate analysis. *J. Sci. Food Agric.* **2018**, DOI:10.1002/jsfa.9129.
11. Guchu, E.; Díaz-Maroto, M.C.; Díaz-Maroto, I.J.; Vila-Lameiro, P.; Pérez-Coello, M.S. Influence of the species and geographical location on volatile composition of Spanish oak wood (*Quercus petraea* Liebl. and *Quercus robur* L.). *J. Agric. Food Chem.***2006**, *54*, 3062-3066.
12. Díaz-Maroto, M.C.; Guchu, E.; Castro-Vázquez, L; de Torres, C.; Pérez-Coello, M.S. Aroma-active compounds of American, French, Hungarian and Russian oak Woods, studied by GC-MS and GC-O. *Flavour Fragr. J.* **2008**, *23*, 93-98.
13. Prida, A.; Puech, J.L. Influence of geographical origin and botanical species on the content of extractives in American, French, and East European oak woods. *J. Agric. Food Chem.***2006**, 54, 8115-8126.
14. Díaz-Maroto, I.J.; Vila-Lameiro, P.; Guchu, E.; Díaz-Maroto, M.C. A comparison of the autecology of *Quercus robur* L. and *Q. pyrenaica* Wild. present habitat in Galicia, NW Spain. *Forestry***2007**, *80*, 223-239.
15. Spillman, P.J.; Sefton, M.A.; Gawel, R. The contribution of volatile compounds derived during oak barrel maturation to the aroma of a Chardonnay and Cabernet Sauvignon wine. *Aust. J. Grape Wine Res.***2004**, *10*, 227-235.
16. Herjavec, S.; Jeromel, A.; Da Silva, A.; Orlic, S.; Redzepovic, S. The quality of white wines fermented in Croatian oak barrels. *Food Chem*. **2007**, *100*, 124-128.
17. Prida, A.; Chatonnet, P. Impact of oak-derived compounds on the olfactory perception of barrel-aged wines. *Am. J. Enol. Vitic.***2010**, *61*, 408-413.

18. Herrero, P.; Sáenz-Navajas, M.P.; Avizcuri, J.M.; Culleré, L.; Balda, P.; Antón, E.C.; Ferreira, V.; Escudero, A. Study of chardonnay and Sauvignon blanc wines form D.O.Ca Rioja (Spain) aged in different French oak wood barrels: chemical and aroma quality aspects. *Food Res. Int.***2016**, *89*, 227-236.
19. Rodríguez-Nogales, J.M.; Fernández-Fernández, E.; Vila-Crespo, J. Characterisation and classification of Spanish Verdejo young white wines by volatile and sensory analysis with chemometric tools. *J. Sci. Food Agric.***2009**, *89*, 1927-1935.
20. Gutiérrez Afonso, V.L. Sensory descriptive analysis between white wines fermented with oak chips and in barrels. *J. Food Sci.* **2002**, *67*, 2415-2419.
21. Aleixandre, J.L.; Padilla, A.I.; Navarro, L.L.; Suria, A.; García, M.; Álvarez, I. Optimisation of making barrel-fermented dry Muscatel wines. *J. Agric. Food Chem.***2003**, *51*, 1889-1893.
22. Nunes, P.; Muxagata, S.; Correia, A.C.; Nunes, F.M.; Cosme, F.; Jordao, A.M. Effect of oak Wood barrel capacity and utilization time on phenolic and sensorial profile evolution of an Encruzado white wine. *J. Sci. Food Agric*. **2017**, *97*, 4847-4856.
23. Ortega-Heras, M.; González-Sanjosé, M.L.; González-Huerta, C. Consideration of the influence of ageing process, type of wine and oenological classic parameters on the levels of wood volatile compounds present in red wines. *Food Chem.***2007**, *103*, 1434-1448.
24. Karbowiak, T.; Gougeon, R.D.; Alinc, J.B.; Brachais, L.; Debeaufort, F.; Voilley, A.; Chassagne, D. Wine oxidation and the role of cork. Crit. Rev. Food Sci. Nutr. **2009**, *50*, 20-52.
25. Pérez-Coello, M.S.; González-Viñas, M.A.; García-Romero, E.; Cabezudo, M.D.; Sanz, J. Chemical and sensory changes in white wines fermented in the presence of oak chips. *Int. J. Food Sci. Technol.***2000**, *35*, 23-32.

26. Sánchez-Palomo, E.; Alonso-Villegas, R.; Delgado, J.A.; González-Viñas, M.S. Improvement of Verdejo white wines by contact with oak chips at different winemaking stages. *LWT-Food Sci. Technol.***2017**, *79*, 111-118.
27. Zea, L.; Moyano, L.; Moreno, J.A.; Medina, M. Aroma series as fingerprints for biological ageing in fino sherry-type wines. *J. Sci. Food Agric.***2007**, *87*, 2319-2326.
28. Cadwallader, K.R. Potent odorants in hickory and mesquite smokes and liquid smoke extracts. Annual Meeting of the Institute of Food Technologies, New Orleans, LA, 1996, June 22-26, 34-36.
29. Sunao, M.; Ito, T.; Hiroshima, K.; Sato, M.; Uehara, T.; Ohno, T.; Watanabe, S.; Takahashi, H.; Hashizume, K. Analysis of volatile phenolic compounds responsible for 4-vinylguaiacol-like odor characteristics of sake. *Food Sci. Technol. Res.* **2016**, *22*, 111-116.
30. Escudero, A.; Campo, E.; Fariña, L.; Cacho, J.; Ferreira, V. Analytical characterization of the aroma of five Premium red wines. Insights into the role of odor families and the concept of fruitiness of wines. *J. Agric. Food Chem.* **2007**, *55*, 4501-4510.
31. López, R.; Aznar, M.;Cacho, J.; Ferreira, V. Determination of minor and trace volatile compounds in wine by solid-phase extraction and gas chromatography with mass spectrometric detection. *J. Chromat. A***2002**, *966*, 167-177.
32. Etievant, P.X. *Wine. In: Volatile Compounds in foods and Beverages.* Marse H. (ed.), Marcek Dekker Inc., New York, 483-587, 1991.
33. Cutzach, I.; Chatonnet, P.; Dubourdieu, D. Study of the formation mechanisms of some volatile compounds during aging of sweet fortified wines. *J. Agric. Food Chem.* **1999**, *47*, 2837-2846.
34. Alañón, M.E.; Schumacher, R.; Castro-Vázquez, L.; Díaz-Maroto, M.C.; Pérez-Coello, M.S. Enological potential of chestnut wood for aging Tempranillo wines Part I: Volatile compounds and sensorial properties. *Food Res. Int*. **2013**, *51*, 325-334.

35. Alañón, M.E.; Schumacher, R.; Castro-Vázquez, L.; Díaz-Maroto, M.C.; Hermosín, I.; Pérez-Coello, M.S. Enologial potential of chestnut wood for aging Tempranillo wines Part II: Phenolic compounds and chromatic characteristics. *Food Res. Int*. **2013**, *51*, 536-546.
36. Chinnici, F.; Natali, N.; Bellachioma, A.; Versari, A.; Riponi, C. Changes in phenolic composition of red wines aged in cherry wood. *LWT-Food Sci. Technol*. **2015**, *60*, 977-984.
37. Chinnici, F.; Natali, N.; Sonni, F.; Bellachioma, A.; Riponi, C. Comparative changes in color features and pigment composition of red wines aged in oak and cherry wood casks. *J. Agric. Food Chem*. **2011**, *59*, 6575-6582.
38. De Rosso, M.; Paniguel, A.; Dalla Vedova, A.; Stella, L.; Flamini, R. Changes in chemical composition of a red wine aged in acacia, cherry, chestnut, mulberry and oak wood barrels. *J. Agric. Food Chem*. **2009**, *57*, 1915-1920.
39. Fernández de Simón, B.; Martínez, J.; Sanz, M.; Cadahía, E.; Esteruelas, E.; Muñoz, A.M. Volatile compounds and sensorial characterization of red wine aged in cherry, chestnut, false acacia, ash and oak wood barrels. *Food Chem*. **2014**, *147*, 346-356.
40. Fernández de Simón, B.; Sanz, M.; Cadahía, E.; Martínez, J.; Muñoz, A.M. Polyphenolic compounds as chemical markers of wine ageing in contact with cherry, chestnut, false acacia, ash and oak wood. *Food Chem.* **2014**, *143*, 66-76.
41. Sanz, M.; Fernández de Simón, B.; Esteruelas, E.; Muñóz, A.M.; Cadahía, E.; Hernández, T.; Estrella, I.; Martínez, J. Polyphenols in red wine aged in acacia (*Robinia pseudoacacia*) and oak (*Quercus petraea*) wood barrels. *Anal. Chim. Acta*. **2012**, *732*, 83-90.
42. Gortzi, O.; Metaxa, X.; Mantanis, G.; Lalas, S. Effect of artificial ageing using different wood chips on the antioxidant activity, resveratrol and catechin concentration, sensory properties and color of two Greek red wines. *Food Chem*. **2013**, *141*, 2887-2895.

43. Kyraleou, M.; Kallithraka, S.; Chira, K.; Tzanakouli, E.; Ligas, I.; Kotseridis, Y. Differentiation of wines treated with wood chips base don their phenolic content, volatile composition, and sensory parameters. *J. Food Sci*. **2015**, *80*, C2701-C2710.

44. Delia, L.; Jordão, A.M.; Ricardo Da Silva, J.M. Influence of different wood chips species (oak, acacia and cherry) used in a short period of aging on the quality of encruzado white wines. *Mitt. Klosterneuburg*, **2017**, *67*, 84-96.

45. Psarra, C.; Gortzi, O.; Dimitirs, P.M. Kinetics of polyphenol extraction from wood chips in wine models solutions: effect of chip amount and botanical species. *J. Inst. Brew.* **2015**, *121*, 207-212.

46. Alañón, M.E.; Castro-Vázquez, L.; Díaz-Maroto, M.C.; Hermosín-Gutiérrez, I.; Gordon, M.H.; Pérez-Coello, M.S. Antioxidant capacity and phenolic composition of different woods used in cooperage. *Food Chem*. **2011**, *129*, 1584-1590.

47. Kozlovic, G.; Jeromel, A.; Maslov, L.; Pollnitz, A.; Orlic, S. Use of acacia barrique barrels – influence on the quality of Malvazija from Istria wines. *Food Chem*. **2010**, *120*, 698-702.

48. Culleré, L.; Fernández de Simón, B.; Cadahía, E.; Ferreira, V.; Hernández Orte, P.; Cacho, J. Characterization by gas chromatography-olfactometry of the most odor-active compounds in extracts prepared from acacia, chestnut, cherry, ash and oak woods. *LWT-Food Sci Technol*. **2013**, *53*, 240-248.

49. Pérez-Coello, M.S.; Sánchez, M.A.; García, E.; González-Viñas, M.S.; Sanz, J.; Cabezudo, M.D. Fermentation of white wines in the presence of wood chips of American and French oak. *J. Agric. Food Chem*. **2000**, *48*, 885-889.

50. Young, O.A.; Kaushal, M.; Robertson, J.D.; Burns, H.; Nunns, S.J. Use of species other than oak to flavor wine: an exploratory survey. *J. Food Sci.* **2010**, *75*, S490-S498.

51. Canas, S.; Caldeira, I.; Belchior, A.P.; Spranger, M.I.; Clímaco, M.C.; Bruno Sousa, R. Chestnut wood: A sustainable alternative for the aging of wine brandies. In book: Food Quality: Control, Analysis and Consumer Concerns. Chapter 4. Publisher:

Nova Science Publishers, Inc. Editors Daniel A. Medina, Laine A.M. **2011**, pp 181-228.

52. Rodríguez Madrera, R.; Suárez Valles, B.; Diñeiro García, Y.; Del Valle Argüelles, P.; Picinelli Lobo, A. Alternative Woods for aging distillates – An insight into their phenolic profiles and antioxidant activities. *Food Sci. Biotechnol*. **2010**, *19*, 1129-1134.
53. Canas, S.; Belchior, A.P.; Caldeira, I.; Spranger, M.I.; Bruno de Sousa, R. La couleur et son evolution dans les eaux-de-vie Lourinha pendant les trois premiéres années du vieillissement. *Ciência e Téc. Vitiv*. **2000**, *15*, 1-14.
54. Caldeira, I.; Anjos, O.; Portal, V.; Belchior, A.P.; Canas, S. Sensory and chemical modifications of wine brandy aged with chestnut and oak wood fragments in comparison to wooden barrels. *Anal. Chim. Acta*, **2010**, *660*, 43-52.
55. Alañón, M.E.; Castro-Vázquez, L.; Díaz-Maroto, M.C.; Pérez-Coello, M.S. Aromatic potential of *Castanea sativa* Mill. compared to *Quercus* species to be used in cooperage. *Food Chem*. **2012**, *130*, 875-881.
56. Caldeira, I.; Bruno de Sousa, R.; Belchior, A.P.; Clímaco, M.C. A sensory and chemical approach to the aroma of wooden aged Lourinha wine brandy. *Ciência e Téc. Vitiv*. **2008**, *23*, 97-110.
57. Canas, S.; Leandro, M.C.; Spranger, M.I.; Belchior, A.P. Low molecular weight organic compounds of chestnut wood (Castanea sativa L.) and corresponding aged brandies. *J. Agr. Food Chem*. **1999**, *47*, 5023-5030.