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Review Article

Influence of oak wood on the chemical and organoleptic profile of white wines

Tatyana Yoncheva[1]✉*, Nikolay Stoyanov[2], Dimitar Dimitrov[1]

[1]*Department of Vine Selection, Enology and Chemistry, Institute of Viticulture and Enology, Pleven, Agricultural Academy, Bulgaria*
[2]*Department of Wine and Beer Technology, Technological Faculty, University of Food Technologies, Plovdiv, Bulgaria*

Abstract

The use of oak wood in various forms for the production of white wines has become an increasingly popular practice among winemakers. As a result of extraction, condensation and other processes, their chemical composition and sensory profile were modified. Phenolic compounds and volatile aromatic substances passed from the wood to the wine improving the aroma and taste and enhancing its antioxidant activity. Their quantity has depended on the botanical type and origin of the wood and the method of its heat treatment. In the production of white wines several technologies have been applied - conducting the alcoholic fermentation and aging on lees in barrels, completing the fermentation in tanks and racking the wine to the barrels, starting the fermentation in tanks but in the middle of the process racking the fermenting juice to the barrels. Into the wine, of phenols mainly passed gallotannins and ellagitannins and of aromatic substances – eugenol, isoeugenol, vanillin, furan derivatives, lactones, etc. Further to the use of barrels, the application of alternative oak forms has become more and more popular, which in the case of white wines allowed avoiding the volatile components oxidation. The result was a quality product with better technological properties. The wines acquired hints of wood without losing their freshness and fruity character.

Keywords

oak wood, white wines, chemical composition, organoleptic profile

✉*Corresponding author: Assoc. Prof. Tatyana Yoncheva, PhD, Department of Vine Selection, Enology and Chemistry, Institute of Viticulture and Enology, 1 "Kala tepe"str., 5800 Pleven, Agricultural Academy, Bulgaria, tel.: 00359 64 822161; E-mail: t_ion@abv.bg*

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Introduction

The use of oak wood in winemaking has been a traditional practice, due to the positive effect on the chemical composition and organoleptic qualities of the wine. Knowing of the wood composition and structure was related to its rational use, which lead to the intensification of aging processes, improvement of the quality of drinks and reduction of their cost price. In contact with the wood, various physical and chemical processes took place, during which a number of volatile aromatic compounds and phenols passed into the liquid, which improved its color, taste and aroma (Marinov 2004; Navojska et al. 2012; Dumitriu et al. 2019). The main ongoing processes were extraction, i.e. extraction of new compounds from the wood to the liquid (polysaccharides, polyphenols, volatile substances) and oxidative, under the influence of oxygen diffusion through the wood pores. As a result, transformations occurred in a number of components of the wine composition, giving it a specific color, aroma and taste (Abrasheva et al. 2008; Kyraleou et al. 2016; Botha et al. 2020; Zamora 2022).

Red wines aging in wooden casks have been traditional and practiced for centuries due to its beneficial effect on their qualities. Their color became tile red and more stable, the aroma was richer, and the astringency in the taste decreased (Abrasheva et al. 2008; Dharmadhikari 2016; Gonzalez-Centeno et al. 2021). Recently, an increasingly popular and frequently used practice among winemakers has been the contact of white wines from different varieties with oak wood, in various forms. That influenced and modified their composition and characteristics, which favorably affected their organoleptic profile (Nunes et al. 2017; Naranjo et al. 2021; Stegarus et al. 2021a, b; Zamora 2022).

Composition, characteristics and processing of oak wood used in winemaking

The oak wood species has a significant influence on the quality characteristics of aging wines. The oak wood used in winemaking belonged to the botanical genus *Quercus*, spread in Europe, Asia, America and Africa. Over 150 species have been known however for enological purposes mainly the American species *Quercus alba* and the European *Quercus robur* and *Quercus petraea* have been used (Marinov 2004; Tagareva-Delcheva et al. 2015; Herrero et al. 2016; Alañon et al. 2018; Dumitriu et al. 2019; Zamora 2022).

The various regions of wood origin have determined the differences in its characteristics. Its quality was influenced by the weather conditions, the soil composition of the terrain, the age and height of the tree. Depending on this, the chemical composition of oak wood has been complex and varied widely - 23-50% cellulose, 19-30% hemicellulose, 17-30% lignin, 2-10% tanning substances and 0.3-0.6% resinous substances (Marinov 2004; Herjavec et al. 2007; Gilby 2020; Petrozziello et al. 2020a). The physical and mechanical parameters of the wood (porosity, grain size, flexibility, etc.) could have an important impact on the transfer of substances between wine and wood (Alañon et al. 2018).

The processes taking place during its processing (drying and toasting) also modified its characteristics. These processes were accompanied by the occurrence of chemical and physical changes from the degradation of various polymers, mainly hemicellulose and lignin. Thus the content of extractable components from the wood (non-volatile and volatile compounds) was changed. Phenols and tannins (gallotannins and ellagitannins) belonged to the non-volatile group, which were easily hydrolyzed. Ellagitannins represented the main group of components in oak wood and were available in all varieties of the *Quercus* species, constituting up to 10% of the dry matter. The volatile compounds group included aromatic substances such as eugenol, isoeugenol, vanillin, furan derivatives, lactones, etc. The different species of wood have various composition and structure. The European species (*Quercus petraea*, *Quercus robur*) contained higher levels of extractable aromatic components such as eugenol, vanillin. The American oak (*Quercus alba*) had more lactones, mainly the *cis* isomer. The French oak contained lower concentrations of whiskey lactones and was more suitable for aging white wines. The American woods were the poorest in ellagitannins, the French ones contained more, and the Bulgarian woods were the richest (Marinov 2004; Herjavec et al. 2007; Jordao et al. 2012; Herrero et al. 2016; Botha et al. 2020; Zamora 2022).

The various structure of the wood has determined the differences in the color of the aged white wines. Recamales et al. (2007) studied the color development of white wines from the Spanish variety Zalema when aged in American and Spanish oak barrels. Wines aged in American oak had weaker color intensity. The reason was that American wood let through less oxygen from the air, therefore the oxidation condensation processes were weaker, there was less evaporation of the liquid, a lower rate of extraction of substances such as phenolic compounds from the wooden casks.

Oak drying for enological purposes might be natural or artificial, with the aim of reducing excessive humidity, undesirable aldehydes and rough ellagitannins (Pambianchi 2022). Under natural conditions, it usually took place over a period of 18 - 36 months and had a highly positive effect on its tannic and volatile aromatic profile. Drying in natural conditions significantly reduced the amount of lipids (Cabrita et al. 2012; Navojska et al. 2012). During two or three years of natural wood drying, the concentration of desired aromatic components such as eugenol, syringic and vanillic aldehydes, methyloctalactone went up multiple times depending on the oak species. The ratio of whiskey lactones also changed. Drying would increase their amount and change the *cis*- and *trans*- forms of β-methyl-γ-octolactone correlation (Stoyanov et al. 2013; Tagareva-Delcheva et al. 2015).

The artificial drying of the wood was a faster and more economical, but less efficient method, as it did not remove unwanted components from the wood. It was performed in ovens, at a temperature of up to 50℃ and duration of about 1 month. Kiln-dried wood had high content of astringent tannins and bitter coumarins and contained less eugenol, vanillin and methyloctolactone. That type of drying could cause cracks to appear in the wood, which might later be associated with problems in the use of the casks (Pambianchi 2022).

The applied heat treatment had a strong effect on the wood qualities, as a result of which the qualitative and quantitative composition of the extractable substances changed. Heat treatment strongly modified the wood composition. Not toasted wood contained significantly less volatile aromatic substances compared to the treated one. According to the applied temperature regime, the duration and degree of toasting, it could be (Chira and Teissedre 2014; Fiacco 2015; Pambianchi 2022): lightly toasted (the wood was toasted for a period of about 5 minutes at temperature of 120-180℃), medium toasted (toasting took place for a period of about 10 minutes at temperature of 200℃), heavily toasted (the wood was heated briefly at high temperature, followed by medium toasting for 15 minutes, at temperature of 230℃).

During toasting, a number of structural, physical and chemical changes occurred in the composition of the wood, due to the thermal degradation of the high molecular components. Heating operation modified the macromolecular structure of wood. The process led to a significant increase in volatile compounds, resulting from changes in substances such as cellulose, hemicellulose, lignin, polysaccharides, polyphenols and lipids. For most of them, with the increase in the degree of toasting the concentration also went up, reaching the highest values in heavily toasted woods. Volatile phenols, phenolic aldehydes and ketones, as well as some phenolic alcohols, were formed during the thermal degradation of lignin. The degree of toasting also greatly affected the amount of guaiacol, eugenol, syringol and 4-allyl-syringol (Cabrita et al. 2012; Herrero et al. 2016; Baron et al. 2018; Loupassaki et al. 2016; Zamora 2022). Jordao et al. (2005) observed an increase in the values for volatile phenols (guaiacol, eugenol, isoeugenol, methyl guaiacol) in all oak species studied after medium toasting but the concentrations of these compounds in general decrease after strong toasting. Pambianchi (2022) said that while guaiacol and syringol levels increased with more toasting, 4-methylguaiacol, 4-allylsyringol, phenolic aldehyde and eugenol decreased from medium to heavy toasting. Heavy toasting also resulted in some cresol, 4 ethylguaiacol, 4-propylguaiacol, responsible for bacon, spice, clove or smoky aromas. Toasting also increased the amount of oak lactones. During the polysaccharides and hemicelluloses degradation, furan derivatives were formed – furfural and furfuryl alcohol by means of Maillard reaction during the toasting process. These compounds contributed to cocoa, nut and smoky aromas. Furfural was produced when pentoses were heated and furfuryl alcohol was formed by enzymatic reduction of its analogous aldehyde during aging in oak barrels. The quantity of furfural

in the wine depended on the age of barrel and the degree of wood toasting (Herrero et al. 2016; Naranjo et al. 2021).

The substances that the different woods could release to the wine depended a lot on the toasting level. As the toasting level increased the structure, tannicity and coconut notes that the wood brought to the wine decreased, while the vanilla and toasty aromas increased. The higher toasting level meant the higher vanilla, furanic compounds and volatile phenol concentration, and the lower content of ellagitannins and whisky lactones (Zamora 2022).

Herrero et al. (2016) studied the effect of toasting level and aging time on the volatile composition and sensory quality of Chardonnay and Sauvignon Blanc wines, aged in French oak barrels. The volatile compounds released by the oak wood into wines increased with the aging time except methylvanillate and vinylphenols. The concentration of vanillins, furfurals, guaiacols, eugenols and lactones increased over time. The maximum concentrations of furfurals, guaiacols and vanillins were found in medium toasting level barrels.

Forms of use of oak wood and stages of application in winemaking

The traditional storage and aging of wines was done in barrels. The main processes taking place in winemaking could be successfully carried out in a cask. In most cases, however, they had been used to age the wine after fermentation was complete (Chira 2018). When white wines were fermented in barrels, the oak-derived compounds would impact on the olfactory and gustatory perception of the wines, which would be dependent on the type of species and geographical origin of oak, size and toasting of the barrel, barrel age, time of aging, etc. (Naranjo et al. 2021). Oak had remained the preferred material for their making, as the wood was softer, required minimal processing, and oak forests were prevalent in Europe.

To obtain a high quality aged wine, barrel choice had been of great importance. Transfer of wood compounds into wine and micro-oxygenation that took place during barrel aging had a significant effect on phenolic composition and organoleptic perception of the final product. White wine was gradually aged in oak barrels to enhance its stability, aromatic complexity and organoleptic properties (Gonzalez–Centeno et al. 2020).

The duration of contact with the barrel had depended on a number of factors such as the period of use, the potential of the variety and the style of the final product that the producer wanted to achieve. The size of barrels, the type of wood and the aging time had an impact on the wine composition and wine color. More intense extraction of components from the wood into the wine was observed when new barrels were used, and these wines were richer in volatile compounds, especially vanillin. The majority of them passed into the wine in the initial stages of contact with the wood (Recamales et al. 2007; Nunes et al. 2017). The size of the barrel was also of importance – in barrels with a larger volume, the wine received less oxygen, due to the lower degree of contact surface with the liquid. Gonzalez–Centeno et al. (2020) studied the chemical and sensory differences in Sauvignon Blanc wines linked to barrel size. They found that the color, total phenols and fruity aroma were not generally impacted by barrel size. The smaller the barrel, the higher the extraction of oak woody volatiles due to the higher surface of wine-wood interaction per unit of wine volume and the greater the transfer of whiskey lactones and vanillin from wood to wine.

The classical method of aging wines in barrels was slow and expensive and associated with disadvantages. Premises and barrels were needed, there were evaporation losses, more difficult cleaning (Dharmadhikari 2016; Carpena et al. 2020). Therefore, accelerated methods had been successfully applied to improve the wines' quality (Table 1).

Table 1. Oak wood forms used in winemaking

Aging method	Wood forms
Classical	barrels
	casks
Accelerated	staves
	planks
	sticks
	granules
	chips

For this purpose, in practice, wood was widely used in various shapes with different sizes and toasting levels. The use of oak wood in such forms was accepted by the OIV in 2001 and was widely used in winemaking in the USA, Australia, South Africa and South America (Kyraleou et al. 2016; Rubio-Breton et al. 2018). The application of this enological practice was officially permitted in the European Union by Regulation 1507/2006. The current European legislation provided for the use in winemaking only of wood from the genus *Quercus* (Kyraleou et al. 2016; Dumitriu et al. 2019; Galdo et al. 2019; Gonzalez-Centeno et al. 2021).

All oak alternatives could be added at a different stages of winemaking and in different doses (Table 2). The effect of their use depended on the type, age, origin and treatment of the wood, the shape and size of the fragments, the temperature, the time of application and the duration of the contact. The wines acquired different nature due to the different type and amount of extractable substances that had passed through. The main goal was to improve the volatile aromatic and phenolic composition, as well as their olfactory properties (Baron et al. 2018; Galdo et al. 2019; Petrozziello et al. 2020a).

Oak chips had been the most commonly used in practice, due to the ease of use. EU Regulation 934/2019 defined the main requirements for it when used for enological purposes. It should be small pieces of wood with dimensions of at least 2 mm to 20 mm with different degrees of toasting. The doses for white wines ranged from 0.5 to 4 $g.l^{-1}$. The small size of the chips provided a good contact surface and a quick effect of the application – from 4-6 weeks to several months, depending on the size of the particles (Dharmadhikari 2016; Kyraleou et al. 2016; Alañon et al. 2018; Loupassaki et al. 2018; Petrozziello et al. 2020a).

Table 2. Stage of application of oak chips and doses (Alañon et al. 2018)

Stage of application	Doses, $g.l^{-1}$
During alcoholic fermentation	1 - 10
After alcoholic fermentation	2 - 15
Storage	2

The main advantage of applying alternative oak forms was obtaining a quality product with improved technological characteristics, achieving the same effect and benefit as using barrels, but for a shorter period of time, as well as an easier way of use (Loupassaki et al. 2018).

Chemical composition and organoleptic profile of white wines in contact with oak wood

The role of wood in the aging of wines had been versatile – components were extracted from it that changed the wine aroma and taste. At the same time, there were interactions between wood-extractable compounds and wine substances (especially phenols), as well as slow oxidation of certain wine compounds by atmospheric oxygen which passed through wood pores, resulting in wines with less astringency and particular color properties (Nunes et al. 2017). As consequence of the wood contact all aged white wines had increased polyphenol content due to phenols transfer from wood to wine. The contact with wood reduced the browning potential index. The precipitation of oxidized phenols, the formation of phenolic polymers and the antioxidant properties of some phenolic compounds lead to increases in the stability of white wines to oxidation (Alañon et al. 2018).

Barrels may show a positive effect on white wines. Stored and aged in oak barrels gave them a specific taste and aroma. White wines had been, in general, fruitier and fresher than red ones. These descriptors depended on the grapes variety and winemaking technology. The use of oak played a significant role in winemaking process and had a deep effect on the resulting wine, affecting color, flavor, tannin profile and texture. Nowadays the use of wood barrels in the elaboration of quality white wines had become common in winemaking. Flavor notes that were common descriptions of wines exposed to oak included caramel, cream, smoke, spice and vanilla (Vilela et al. 2014; Baron et al. 2018).

Alañon et al. (2018) described Chardonnay wines aged in barrels for 3 and 4 months as nuttier (5 out of 7 points) and honeyed (5 out of 7 points) in their olfactory profile and more honeyed (5 out of 8 points), with more intense flavor (7 of 8 points), body flavor (6 of 8 points), and overall quality (7 of 8 points) in their flavor profile. The control wine was distinguished by more freshness (5.5 out of

7 points), peach/apricot (6 out of 7 points), tropical fruit (6 out of 7 points) in the aroma and more tropical fruit (6 out of 8 points) and acidity (6 out of 8 points) in the taste. Baron et al. (2018) found more vanilla (5 out of 8 points), caramel (4 out of 8 points) in the smell and more vanilla (6 out of 8 points), caramel (5 out of 8 points), hazelnut (5.5 out of 8 points) and spicy (5.5 out of 8 points) in the taste of wines with medium toasted chips.

Several practices had been used for the production of white wines in barrels.

The first possibility was conducting alcoholic fermentation and aging on lees in barrels. This had been a well spread enological practice used to achieve wines with an enriched woody aroma and rounder mouthfeel. This was due to the strong influence of yeast autolysis and components that were released from the cell degradation under the action of enzymes – proteinases and peptidases. Mannoproteins and polysaccharides, together with some proteins and peptides released by yeasts, played a positive role in improving wine mouthfeel. Lipids and amino acids had been aroma precursors and their presence could contribute to the aromatic complexity. The yeast lees express antioxidant activity and consuming oxygen protected the wine of oxidation. The yeast cells absorbed the ellagitannins from the wood, reducing the astringency of the wines. Some compounds extracted from wood such as furfural and vanillin could be metabolized by the yeasts decreasing their sensory impact (Rodrigues et al. 2012; Alañon et al. 2018; Zamora 2022).

The second possibility was racking the grape juice after settling to stainless steel tanks to perform the complete alcoholic fermentation inside these vats and then racking the wine to the barrels. That meant that the wine would not gain the mouthfeel associated with the release of mannoproteins and polysaccharides and would not be protected against oxidation by the lees and the impact of wood would probably be too intense (Alañon et al. 2018; Zamora 2022).

In the case of the third possibility the grape juice started alcoholic fermentation inside stainless steel tanks and in the middle of the process the fermenting juice was racking to the barrels to finish the fermentation there. This procedure allowed the presence of a part of the lees. That practice had been probably the most used one nowadays (Zamora 2022).

The contact with wood enriched the wine with various volatile substances that improved the intensity and complexity of its aroma. Wood also released phenolic compounds that contributed to texture sensations of the wine, increasing some sensory attributes such as body and mouthfeel (Zamora 2022). In white wines the major polyphenols were hydroxynamic acids, mainly p-coumaric and caffeic acid conjugated with tartaric acids. All of these phenolic compounds played an important role in white wine browning potential because they could be easily oxidized to quinones, which polymerized in turn (Nunes et al. 2017).

Fermentation in oak barrels lead to wines with much more complex sensory properties, largely attributed to the phenols extracted from oak wood which gave astringency and bitterness to wood-matured wines. Wines produced by fermentation and maturation in oak barrels had different flavor characteristics compared to those that had undergone barrel maturation only after fermentation in stainless steel. That was due to actively growing yeasts capable to transform volatile compounds extracted from oak wood into other volatile metabolites (Ibern–Gomez et al. 2001; Herjavec et al. 2007).

Lukic et al. (2015) investigated the phenolic and aroma composition of Malvazija istarska white wines produced by an unconventional technology comprising prolonged maceration during and after fermentation followed by aging in wooden barrels. The maceration had a stronger influence on phenols, and aging on volatile aromas. The investigated samples contained higher levels of dry extract, volatile acids, phenols, color intensity, antioxidant activity, monoterpenes, higher alcohols, esters, furans. Higher color intensity was a result of enzymatic and oxygen-assisted chemical reactions during fermentation, maceration and aging, as well as the extraction of different compounds from the wood into the wine.

Ibern-Gomez et al. (2001) evaluated the effect of oak fermentation in white wines Chardonnay and Picapoll. The presence of characteristic oak-wood phenols such as coniferaldehyde, sinapinaldehyde, syringaldehyde, scopoletin and volatile compounds 4-ethyl-guaiacol, 4-vinylphenol, eugenol, β-methyl-γ-octalactone were found in the samples fermented

in barrels but were not detected in the same wines fermented in stainless steel vats.

The chemical and sensorial characteristics of barrel-fermented and barrel-aged wines were modified due to the wood-derived compounds. The aromatic and phenolic composition of wines had improved by fermentation and aging in oak barrels on lees. This technology allowed increasing the content of volatile and phenolic compounds positively related to the quality of the wines' flavor. Verdejo wines fermented and aged in oak barrels showed greater amounts of eugenol and methyleugenol, and lower quantities of terpenes and esters compared to wines fermented in stainless steel tanks (Alañon et al. 2018).

The chemical and sensory attributes depended mainly on whether or not the wine fermented in barrel and the presence or absence of the lees. If the grape juice was fermented in barrel, the yeast could absorb some volatile substances and phenolic compounds or transform some of the compounds released by wood and thus achieving a lower sensory impact. Vanillin and furfural were partially reduced by yeast respectively to vanillic alcohol and furfuryl alcohol with significantly lower organoleptic impact. The wines aged in barrel without the presence of lees were greatly affected by wood – the intensity of vanilla, coconut, toasted/smoked notes were very high, the structure and tannicity were rather pronounced but the mouthfeel was relatively low (Zamora 2022).

Herjavec et al. (2007) described the differences in chemical composition and sensory properties of the Chardonnay and Sauvignon wines produced in new light and medium-toasted Croatian barrels. They observed a large decrease in syringic acid and syringaldehyde and confirmed the importance of vanillin as an indicator of keeping wines in oak barrels. Inox-fermented wines had no vanillin. Aging in medium-toasted barrels resulted in a smokier (10 out of 11 points), roasted (4.5 out of 11 points), hazelnut (7 out of 11 points) and raw oak flavor (7.5 out of 11 points), whereas light toasting resulted in a fruitier aroma (9.5 out of 11 points). Marked differences were observed in the aroma of Chardonnay wines. Barrel fermentation had a varying influence on varietal aroma which was more intensive in Chardonnay wines and less pronounced in Sauvignon wines.

Vilela et al. (2014) compared chemically and sensorially two white wines from Malvasia Fina and Gouveio grape varieties, produced in stainless steel tanks and oak wood barrels. The results showed that the wines produced in oak wood barrels, independently of the grape varieties, were more astringent and more pronounced in body character and spicy aroma. In all wines, esters were the largest group of volatile compounds identified, followed by alcohols and fatty acids. In the wines vinified in oak barrel, furfural and 5-methylfurfural were detected.

Naranjo et al. (2021) compared the aromatic and sensory profile of Maturana Blanca white wines produced using different technologies. A total of 33 volatile compounds were quantified. The wines made with pre-fermentative maceration showed the highest concentrations of ethyl esters and acetates, resulting in greater aromatic intensity and values of floral aromas, ripe fruit and tropical fruit. The aromatic profile of wines fermented in American oak barrels with medium toast showed higher complexity and they were also characterized by the presence of important amounts of furfural, whiskey lactone, and eugenol. These compounds came from wood and contributed to aromas of cocoa, coconut, nut, toast, smoky, spices and clove, increasing the aromatic complexity of the wines.

When aging white wines from the Portuguese variety Encruzado in French oak barrels for 180 days, an increase in the total phenolic index was observed during the first 90 days, thereafter it slightly went down. All wines showed a minor decrease in color intensity, which was most pronounced between 90 and 180 days, with an increase in yellow hues. When the process took place in new barrels it increased the total polyphenolic content, flavonoid and non-flavonoid phenols and color intensity. The extraction of some individual phenolic compounds such as gallic and ellagic acids also went up. That enhanced the potential resistance to the oxidation of wines when stored in new barrels compared to used ones. The wines aged in oak barrels showed a higher final polysaccharide concentration. The wine in oak barrels showed a deeper yellow coloration and rounder mouthfeel (Rodrigues et al. 2012; Jordao et al. 2016; Nunes et al. 2017).

The wines contact with the wood also had a positive effect on their antioxidant features, due to the

presence of more extracted polyphenols. The ratio of these compounds determined the antioxidant properties of wines. A correlation was found between the content of ellagitannin in oak wood and its antioxidant characteristics. The heat treatment process significantly lowered the amount of ellagitannin and the wood antioxidant capacity. On the other hand, toasting enhanced the total phenolic content. The amount of extractable total phenols and ellagitannins strongly depended on the size and shape of the wood used and therefore this factor also affected their concentration and the antioxidant properties of the wines (Jordao et al. 2012; Bartkovsky et al. 2020).

Romanet et al. (2023) investigated the change in antioxidant activity of 14 Chardonnay wines during aging in oak barrels. They found that the duration of barrel aging had a greater impact on wine composition than the size of the vessel and the antioxidant capacity of wines was increasing during on-lees barrel aging.

Nikolantonaki et al. (2019) indicated that wine oxidative stability went up during aging of Sauvignon Blanc and Chardonnay wines. The wines aged under medium toasted oak showed better antioxidant stability. A positive correlation was demonstrated between the tannin potential of the oak wood and the concentration of total ellagitannin in the wine – the higher tannin potential of the barrel, the greater the ellagitaninns content in the wine.

Baron et al. (2018) presented the results of a study on the application of toasted oak chips on parameters of white wine Malverina. The experimental variants differed on the time of chip application and the degree of toasting. The moment when the chips were applied played an important role on the antioxidant activity. In variants with addition of chips into the must the antioxidant activity was lower by 50% than in the control samples. Variants with chips added into the wine showed a higher tendency in the antioxidant activity. It increased depending on the duration of the contact period. The highest antiradical activity was recorded in samples containing medium-toasted chips. The lowest values were found in variant without chips. If chips were added to wine samples the antiradical activity increased due to the presence of alcohol because it supported the extraction of phenolic substances (antioxidants) from oak wood.

In terms of sensory impact, the main volatile substances released by oak wood were phenolic aldehydes and ketones, volatile phenols, furanic compounds and β-methyl-γ-octalactones. Phenolic aldehydes and ketones contributed to the characteristic vanilla aroma of aged wines. The group of volatile phenols included guaiacol, methylguaiacol, ethylguaiacol, vinylguaiacol and eugenol. Eugenol gave a pleasant spicy aroma of clove whereas all the others contributed with smoked/toasted notes. The influence of volatile phenols on the quality of the wine depended on their concentration. Normally furanic compounds were below their perception threshold and their involvement in wine aroma was not important. Their group comprised furfural, methylfurfural, hydroxyl methylfurfural and furfuryl alcohol. β-methyl-γ-octalactones were responsible for the coconut flavor. They were also known as whiskey lactones and were available in the form of two isomers. The perception threshold of the *cis* form was much lower than that of the *trans* form (Zamora 2022).

Loupassaki et al. (2016) studied the evolution pattern of some selected wood-related volatiles and their impact on the aromatic profile of the wines produced by different aging techniques – barrel aging and use of wooden chips. Furfural was predominant substance and its concentration peaked after six months of aging, irrespective of the technique used. *Cis*-β-methyloctalactone tended to accumulate towards the end of the aging period. Its concentration was higher in the samples aged in the barrel made of American oak. Guaiacol and vanillin concentrations were low. The samples that received aging in barrels made of American oak had more intense aromatic profile. The samples treated with oak chips were more balanced.

Stegarus et al. (2021a) examined the effects of two types of oak and short aging periods on Chardonnay white wine composition, focusing on the identification of the volatile profile. The time and method of aging significantly influenced the concentrations of alcohols in the samples. During aging the concentration of most ester increased only hexyl acetate and trimethylene acetate decreased. For white Chardonnay wine, the use of oak could

prevent the oxidation of aromatic volatile compounds, inducing oak notes to the wine without reducing the fresh and fruity characteristics.

The contact of wine with wood had a favorable effect on its organoleptic indicators. As a result of the ongoing processes and transformations, the clarity was improved, the flavor and taste became more developed and complex. That depended to a significant extent on the type of wood and the way it was processed.

The American oak added rounded vanilla and coconut flavors, while the French oak added hazelnut and smokiness. American wood may provide popcorn and toffee flavors to white wines, notably Chardonnay, while French wood imparted a mild nuttiness and a hint of smoke. In American oak, greater toast levels accentuated butterscotch flavors, whereas, in French oak, higher toast levels enhanced smokiness. American oak contributed luscious flavors of coconut and cinnamon, while French oak contributed spicy undertones of clove and cedar. The higher the toast level, the more it resembled mocha or espresso (Moore 2021).

Botha et al. (2020) investigated the influence of medium-toasted French oak barrels and staves on the sensory profile of South African white Chenin Blanc wines fermented and aged in contact with wood for 4 and 9 months. The control preserved the fruitiness in the aroma, while the samples in contact with the wood lost it and acquired an aroma associated with vanilla, oak, marmalade, dried apple and quince, coffee, caramel, toffee, honey, tobacco, smoke. The roasted coffee and tobacco notes were due to furfurylthiol and the board aroma came from the concentration of trans-2-nonenal, trans-2-octanal and 1-decanal.

Important for the chemical and organoleptic profile of the wines was not only the wood species and type of processing, but also the form under which it was used, the dose and the time of application and contact. When using alternative oak forms, the shape and size of the contact surface had been of significance. In white wines, the application of oak chips could avoid the oxidation of aromatic volatile components that were formed during aging. The wines would acquire hints of wood without losing their freshness and fruity character (Stegarus et al. 2021b).

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 (Alañon et al. 2018).

The oak chips had a stronger impact on the increased polyphenols content in wines. The samples of Chardonnay wine in the barrel and with addition of chips had a significantly high amount of total polyphenols. The concentration of flavonoids increased in the barrel and with chips during the storage. The antioxidant activity was higher in both wines than in the control. The most important ingredients extracted from the barrels into wine included *cis*- and *trans*- β-methyl-γ-octolactone and volatile polyphenols such as guaiacol, 4-methylguaicol and eugenol. Oak wood mainly enriched wine with furfural, guaiacol and vanillin (Bartkovsky et al. 2020).

Petrozziello et al. (2020b) determined the compositional differences between 200 wines aged using oak chips or wood barrels. Several factors were considered including degree of oak wood toasting, wood origin and the type of wine. These factors influenced the amount of aromatic compounds extracted from chips and barrels with regards to methylvanillate, ethylvanillate and furan derivative compounds. Wines aged in barrels had a higher concentration of ethylvanillate, 4-ethylphenols, eugenol and whisky lactones than wines aged with chips, which were characterized by a generally higher concentration of furanic compounds and hydroxybenzaldehyde derivatives. In Verdejo white wines, a different effect was observed when using medium-toasted oak chips during the alcoholic fermentation or during aging. Compared to the control, in wines exposed to wood, descriptors such as freshness, green apple, fruitiness, tropical and fruit were reduced, and the intensity of notes such as dried fruit, coconut, sweet spices, toastiness was enhanced. Wines in which chips were added during the alcoholic fermentation showed a lower content of volatile components extracted from oak and a higher concentration of volatile fermentative compounds compared to wines in which chips were added during storage. The degree of toasting the chips and the dose to put in had been of importance. In the case of

Chardonnay wines, the effect of the degree of toasting was stronger than the oak origin. The sensory profile of Listan blanco white wines was influenced more by the dosage than by the geographical origin of the wood.

Stegarus et al. (2021b) studied the influence of the addition of oak chips and barrel aging on basic wine parameters and volatile compounds of Chardonnay wines. Oak chips (non-toasted and light toasted) were added at the final stage of the winemaking process for aging. The reduction of the alcohol content was the result of evaporation and ethanol losses. An increase in titratable and volatile acidity was observed. In the initial stages, the extraction of carboxylic, phenolic and volatile acids from the wood was accelerated. The extraction of furan aldehydes, oak lactones, phenol aldehydes and alcohols depended mainly on the alcohol content of the wine and less on its pH. Of the higher alcohols, isobutanol, isopentanol and 2-phenylethanol were found in the largest amount. After 3 months of aging the amount of isobutanol became lower, and the other two higher alcohols were increased. Of the esters, the main ones were the ethyl esters, with a predominance of ethyl lactate, ethyl caproate and ethyl octanoate. Of the acetate esters, isoamyl acetate was predominant. During aging, most of the esters increased in concentration. Of the lactones, the highest ratio belonged to butyrolactone. When aging in contact with toasted wood, the amount of volatile phenols in the wine was higher - p-vinylguaiacol, acetovanillone.

Galdo et al. (2019) conducted a comparative study on the influence of different blends of wood chips from oak species *Quercus alba*, *Quercus petraea* and cherry *Prunus avium* on the phenolic composition, color characteristics and sensory parameters during aging of Encruzado white wines. During the aging time the use of wood chips induced an increase of wine phenolic content and color intensity, particularly in wines aged in contact with cherry wood chips alone or in blends with oak wood chips. The significantly highest total phenolic content was found in the wine aged in contact with a blend containing wood chips from cherry and American oak. The wine aged in contact with single French oak wood chips showed a significantly lower value. The favorable porosity of cherry woods could be considered a potential reason for an easier extraction of flavonoid phenolic compounds from these wood chips. Regarding the sensorial results, the use of French and American chips increased of "woody aroma" for the wines aged with chips and also an increase of "body" and "astringency" descriptors for the wines aged with oak chips alone or blended with cherry chips.

Conclusions

Traditionally, the carrying out of alcoholic fermentation, storage and aging in contact with oak wood had been characteristic of red wines. The present review had summarized the application and technological significance of wood in the production of white wines. As a result of the ongoing extraction, oxidation-reduction, condensation and other processes, their chemical composition and sensory profile was changed. From the wood to the wine, mainly polyphenolic and volatile aromatic substances passed, which improved the wines aroma and taste, increased their antioxidant activity. Into the wine, of phenols mainly passed gallotannins and ellagitannins and of aromatic substances – eugenol, isoeugenol, vanillin, furan derivatives, lactones, etc. In addition to using barrels, the application of alternative oak forms was becoming increasingly popular. Oak chips were the most often used in practice at different stages of winemaking and in different doses. When used during the alcoholic fermentation, the dose would be 1-10 $g.l^{-1}$, then after the end of the alcoholic fermentation – at a dose of 2-15 $g.l^{-1}$, and during wine storage – at a dose of 2 $g.l^{-1}$. Its application ensured a more complex effect on the wine, opportunities to control the extraction processes and to reduce the cost of the finished product. In white wines, the oxidation of the extracted volatile aromatic components could be avoided by using chips. The wines acquired hints of wood without losing their freshness and fruity character. The result was a quality product with improved technological characteristics.

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