

Sustainable use of wood in wine spirit production

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14.1 Introduction

The aged wine spirit (WS), a spirit drink derived from the wine, holds a prominent position worldwide owing to its production, trade (IBISWorld, 2010), and consumption (Grigg, 2004) together with a long history and a relevant socioeconomic role, particularly in traditionally wine-producing countries (Belchior et al., 2015; Garreau, 2008).

Considering the WS production process, the aging stage stands out for its remarkable contribution to drink refinement given the specific physicochemical and related sensory characteristics imparted by the wood. In many wine-producing countries, tradition and legislation impose the use of wooden barrels at this stage. However, this technology has some drawbacks. Actually, economic, social, and environmental issues are associated with low production efficiency, high cost, and high demand for wood, which is a natural resource with limited availability. Besides, in the face of a global and more competitive market with more informed and demanding consumers, product differentiation based on innovation (Mitry & Smith, 2009) and sustainable processes (Whelan & Kronthal-Sacco, 2019) are increasingly relevant. This context supports the search for alternatives toward a more sustainable wood-based aging technology.

Sustainability is a comprehensive approach that involves environmental, social, and economic dimensions and their linkages aiming to balance ecology and prosperity in a lasting way (Purvis et al., 2019). This concept emerged in the late 20th century (Purvis et al., 2019) and has been gradually adopted by several economic sectors, including the beverages one. For this sector, particularly in

Europe, this challenge has been addressed together with food security, quality, nutrition and health, and consumer satisfaction, implying commitments in three main areas: sustainable supply, resource efficiency, and sustainable production and consumption patterns (FoodDrinkEurope, 2012). Regarding the subsector of spirit beverages, the European strategy for achieving sustainable production by 2050 should be highlighted given that the main WS production regions are located in Europe. For this purpose, the main focuses are: farming practices, water, energy, reuse of by-products, packaging; and transport (spiritsEUROPE). Interestingly, the wood, which is a pivotal resource for the aging of spirits, was not included because “In Europe, only oaks of at least 150 years can be used to make barrels. Coopers optimize the use of the raw material so that the entire tree is used, and waste is reduced. For instance, in France, the leading producer of barrels in the EU, wine and spirits producers work hand-in-hand with barrel producers to ensure oak used for casks is sourced from certified, sustainably managed forests which meet the Forest Stewardship Council standard. According to Forest Europe, the forest area in the EU increased over the last 25 years, due to sustainable management practices, such as those seen with French oak. Sustainable management means, amongst others, that cut trees will be replaced by new ones, which store more CO₂ than the 150-year-old trees used to make barrels” (spiritsEUROPE, 2020). However, such an assumption does not reflect the European forest situation reported by Ceccherini et al. (2020), which show an abrupt rise in the harvested forest area (49%) and biomass loss (69%) over EU26 countries for the period of 2016–2018 vs. 2011–2015. The increase in the rate of forest harvest is mainly ascribed to the wood demand. In addition, according to the European Green Deal (European Commission, 2019), an expansion of EU’s forested area and related quality (biodiversity and management) are imperative to reach the intended environmental improvement. Lastly, it should be stressed that many other countries exist in which the forest, the cooperage industry, and the WS industry are not so interconnected as in France, and the wood from many forest species other than oaks are increasingly used in WS’ aging.

Taking these facts into account, the amount of wood used in WS’ aging is a matter of concern, and, therefore, it is a mandatory topic in sustainability strategies.

In this scenario, sustainability of wood-based WS aging implies the production of high-quality and differentiated aged beverage through a process that increases the producer’s profitability, based on the efficient use of wood and its reuse to obtain new products (circular economy)—Fig. 14.1.

This chapter provides an overview of these topics and the research conducted over the last 30 years on WS aging technologies. The studies have been focused on the phenomena underlying aging, the factors that govern them, and their impact on physicochemical and sensory characteristics of the aged WS. In this approach, they will be examined in the light of their contribution to the aging’s sustainability.

14.2 The aged wine spirit and its production process

14.2.1 Wine spirit definition

According to the International Organisation of Vine and Wine (OIV), whose guidelines are applicable at the international level, the WS is defined as “a spirit beverage obtained exclusively by the distillation of wine, fortified wine or wine added with wine distillate, or by re-distillation of a wine distillate whose final product retains the aroma and the flavour of the raw materials. The alcoholic strength of the end product must not be less than 37.5% v/v” (OIV, 2020). Nevertheless, more restrictive conditions are imposed by some producing regions, such as the European Union (Reg. EU 2019/787).



FIGURE 14.1

Main components of a sustainable wood-based technology for the aging of WS.

14.2.2 Technological process of aged wine spirit production

The production process of aged WS includes four main stages: winemaking, distillation, aging, and finishing. At the end, the aged WS is bottled (Fig. 14.2). Each stage may comprise some variations according to the production region and the producer in order to afford specific characteristics to the final product.

Hence, the quality of the final product is related to the characteristics of the wine, imparted by the grapes and by the winemaking stage, and to the characteristics of the WS before and especially after aging.

The main objective of winemaking is to obtain a suitable wine for distillation without any particular differentiation (Belchior et al., 2015).

The distillation has a comprehensive role based on the concentration of ethanol and volatile compounds, the formation of new volatiles and the elimination of other volatiles (Léauté, 1990). Despite the research performed aiming to improve the distillation systems to save energy, time, and ameliorate the WS quality (Cantagrel, 1992), few technological changes have been done on the traditional distillation (in alembic or in column still).

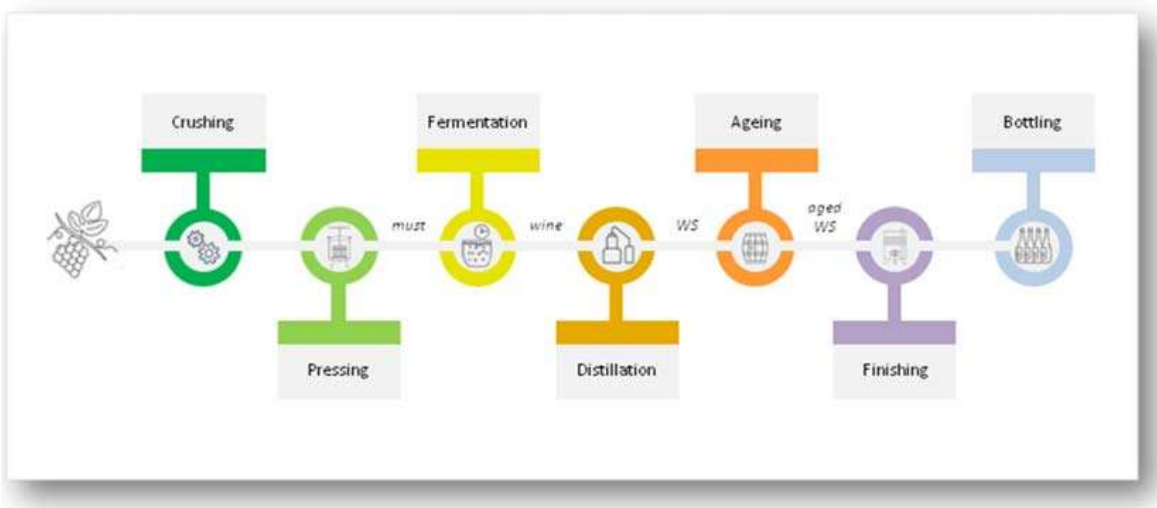


FIGURE 14.2

Technological diagram of the aged WS production.

After distillation, the WS has high concentration of ethanol and richness of volatile compounds, such as esters, terpenes, acids, aldehydes, alcohols, and acetals, proceeding from the raw material, fermentation, and distillation, but is devoid of phenolic compounds other than some volatile phenols (Caldeira et al., 2010). It also presents some metals such as copper and iron (Canas et al., 2020; Catarino et al., 2003). Consequently, the nonaged WS is colorless, has specific flavor attributes, and low sensory complexity.

The aging stage plays a crucial role in enhancing sensory properties and refining the beverage.

The finishing stage comprises blending, dilution, and filtration operations (Belchior et al., 2015).

14.2.3 Main production regions worldwide

WS production exists in many countries, however, the main designations of origin (DOs) are found in the traditionally wine-producing countries, located in Europe (Regulation EC 110/2008)—Fig. 14.3.

Among the European countries, it is worth mentioning the French regions of “Armagnac” and “Cognac,” which are exclusive DOs for aged WS and that date back to the 15th and 16th centuries, respectively (Cantagrel, 2008; Garreau, 2008), producing the most prestigious and top-selling products. Similarly, the Portuguese DO “Lourinhã,” whose historical references on WS production date back to the early 20th century, was delimited in 1992 as an exclusive DO for aged WS (Belchior et al., 2015). Indeed, these three regions assign DO only to aged WS while the others assign DO to several vitivinicultural products, such as WS and wines.

14.2.4 Regulations

The aging time stipulated for WS by the regulations of the main producing regions is shown in Table 14.1.



FIGURE 14.3
WS producing regions.

Producing region	Minimum aging time	Regulation
Europe	Wine spirit: General At least one year in wood containers with a capacity of at least 1000 L or for at least six months in wood containers with a capacity of less than 1000 L DOs “Armagnac”: “Cognac” and “Lourinhã”:	Reg UE 2019/787 Décret n° 2009-1285 Décret n° 2009-1146, Dec.-Lei n° 323/94
Canada	“Brandy”:	FDR (2020)
USA	“Grape brandy”:	CFR (2020)
South Africa	“Pot still brandy”:	Liquor Products Act 60 (1989)
Australia	“Brandy”:	Wine Australia Compliance Guide (2016)
Chile	“Aged Pisco”:	Decreto 521 (2000)
Peru	Not mentioned	NTP 211.001 (2006)

The term “brandy” used in many countries outside Europe means WS; it does not correspond to the definition of “brandy” prevailing in Europe (Reg UE 2019/787).

14.3 The aging stage

Aging “means the storage of a spirit drink in appropriate receptacles for a period of time for the purpose of allowing that spirit drink to undergo natural reactions that impart specific characteristics to that spirit drink” (Reg UE 2019/787).

As aforementioned, after distillation the WS has low sensory complexity. For this reason, the wood contact during the aging stage is pivotal to trigger several physicochemical phenomena that make the aged WS a complex mixture with hundreds of compounds (Canas, 2017) leading to sensory fullness and remarkable improvement of its quality.

14.3.1 Main physicochemical phenomena and determining factors

The physicochemical phenomena underlying the WS aging involve the wood, the wine distillate, and the environment surrounding the barrel or the tank:

- (i) Direct extraction of wood constituents;
- (ii) Decomposition of wood biopolymers (lignin, hemicelluloses, and cellulose) followed by the release of derived compounds into the distillate;
- (iii) Chemical reactions involving only the wood extractable compounds, involving only the distillate compounds, involving both of them;
- (iv) Evaporation of volatile compounds and concentration of volatile and nonvolatile compounds;
- (v) Formation of a hydrogen-bonded network between ethanol and water.

Among these phenomena, the most studied are the direct extraction of compounds and the decomposition of wood biopolymers, which are responsible for the enrichment of WS in wood compounds, influencing its color, aroma, and flavor (Caldeira et al., 2006; Canas, 2017).

Regarding the reactions occurring in the liquid medium, evidence exists on the oxidation of wood compounds (Cernîsev, 2017), in which some mineral elements such as iron may be involved (Canas et al., 2020). In addition, several reactions involving the distillate compounds have been described such as the oxidation of alcohols to aldehydes and aldehydes to carboxylic acids followed by esterification with ethanol giving rise to esters and acetals (Puech et al., 1984). These reactions point out the remarkable role of oxygen in the aging of WS, which is supplied by the air surrounding the barrel and diffuses slowly and continuously through the wood and the space between staves (del Álamo-Sanza et al., 2017) or by micro-oxygenation (MOX) (*vide* 3.5.2).

Evaporation of volatile compounds through the barrel, including ethanol and water, causes a noticeable loss of WS (Canas et al., 2002), which is called the “Angel’s share” and is closely related to the cellar conditions and the wood porosity (Roussey et al., 2021). Considering only “Cognac,” it represents a waste estimated at about 22 million bottles per year (BNIC, 2009).

The aforementioned phenomena depend on the following factors (Belchior et al., 2015):

- The wood features—botanical species, toasting level, size, among others;
- The cellar conditions—temperature, relative humidity, and air circulation;
- The technological operations performed during the aging period such as the refilling, the addition of water, and the stirring.

14.3.2 The wood

14.3.2.1 Botanical species used in cooperage

Several oak species have been used in cooperage to make barrels for the aging of alcoholic beverages. Oak wood from *Quercus robur* L. species is traditionally used in the aging of WS (Puech et al., 1998), while other kinds of oak wood, from *Quercus sessiliflora* Salisb., *Quercus alba* L., and *Quercus pyrenaica* Willd. species, are mainly aimed at wine aging (Martínez-Gil et al., 2018). Chestnut wood (*Castanea sativa* Mill.) has also been exploited for these purposes (Canas et al., 2018).

Despite their differences, oak and chestnut wood present adequate anatomical characteristics (Table 14.2) and chemical composition (Fig. 14.4) that make them suitable for barrel making and for the production of wood fragments for WS' aging (Anjos et al., 2013; Canas et al., 2018; Keller, 1987).

Regarding the chemical composition, the wood is best characterized as a composite of three-dimensional biopolymers (high molecular weight compounds) consisting of an interconnected cellulose, hemicelluloses, and lignin network with limited amount of extractives and inorganics. Water is the main chemical component of a living tree, but all wood cell walls, on a dry weight basis, consist mostly of carbohydrates (sugar-based polymers, including holocellulose, cellulose, hemicelluloses, and minor polysaccharides) that are combined with lignin (Higuchi, 1990; Pettersen, 1984)—Fig. 14.4.

Low molecular weight compounds and hydrolysable tannins are the main extractives. In particular, this fraction of wood will decisively determine its oenological quality, as aforementioned (vide 3.1). In oak heartwood, hydrolysable tannins (ellagitannins) constitute ca. 10% of the dry weight and are responsible for astringency at relatively low threshold concentrations ranging from 0.2 to 6.3 $\mu\text{mol/L}$, whereas at threshold concentrations between 410 and 1650 $\mu\text{mol/L}$, bitter taste is perceived (Glabasnia & Hofmann, 2006). *Trans* and *cis* isomers of β -methyl- γ -octalactone, phenolic aldehydes, such as vanillin and syringaldehyde, and volatile phenols, such as eugenol, guaiacol, ethyl- and vinylphenols, furfural and its related compounds, are the major volatile compounds susceptible to migration from oak wood to WS (Caldeira et al., 2006; Canas, 2017). In general, due to the heterogeneity within the species (influenced by many other factors such as geographical origin, silviculture practices, and the tree), the ranges observed for ellagitannins and low molecular weight compounds in

Table 14.2 Anatomical characteristics of oak wood (*Quercus robur*) and chestnut wood.

<i>Quercus robur</i>	<i>Castanea sativa</i>
Ring-porous	Ring-porous
Earlywood ring with one-to-many rows of pores	Large growth rings
Latewood pores solitary or radially oriented in dendritic groups	Latewood pores radially oriented in flame-like groups
Pore density in latewood sparse to dense	Pore density in latewood sparse
Earlywood vessels with tyloses	Earlywood vessels with thin-walled tyloses
Apotracheal parenchyma either diffuse or in uniseriate diagonal and tangential bands	Apotracheal parenchyma both diffuse and in short, indistinct uniseriate tangential bands
Uni- and multiseriate rays	Uniseriate rays, rarely biseriate

Adapted from Schoch, W., Heller, I., Schweingruber, F. H., & Kienast, F. (2004). Wood anatomy of central European species. <http://www.woodanatomy.ch>. (Accessed on 29 December 2020).

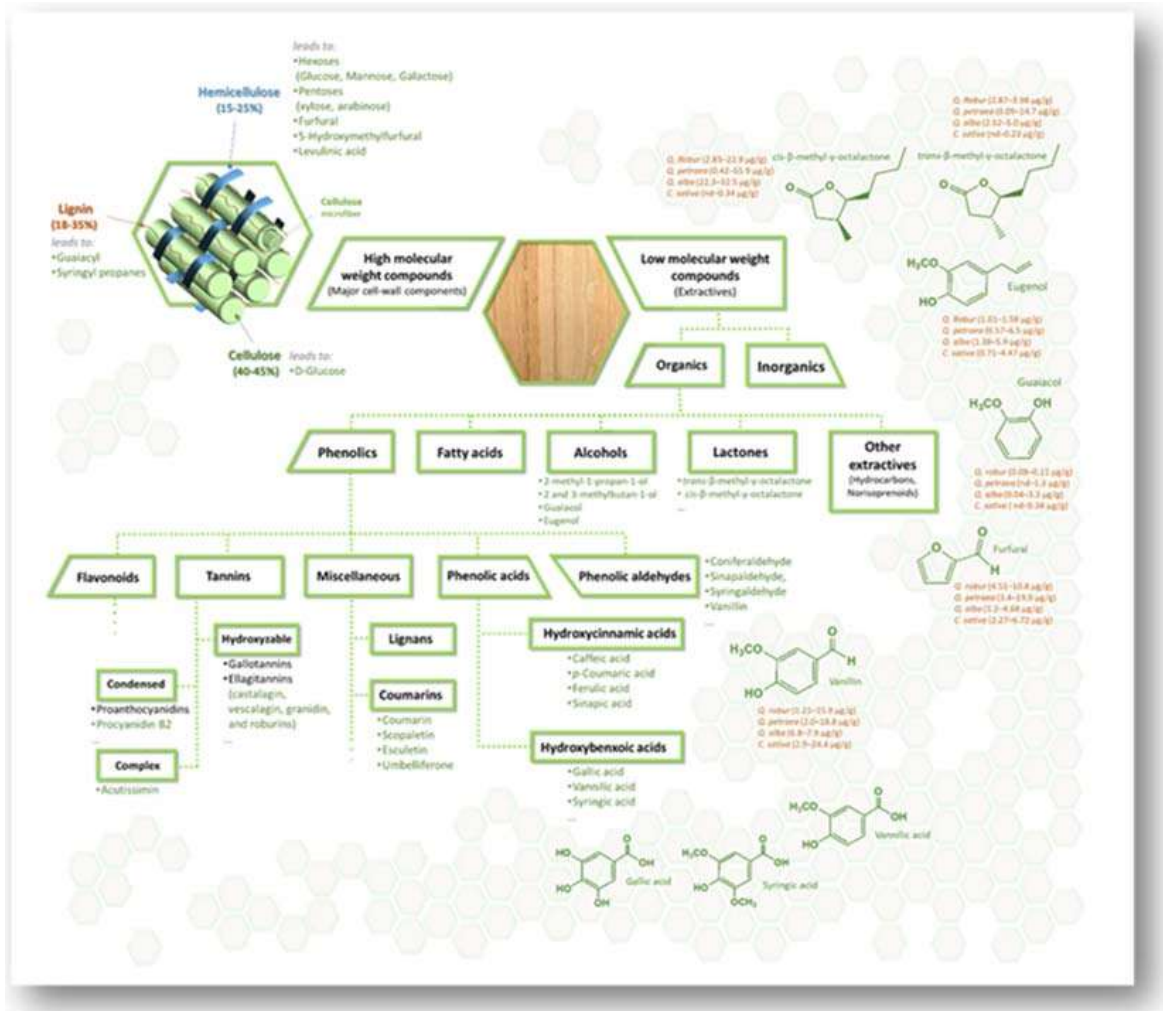


FIGURE 14.4

Wood chemical constituents' classification with structures of molecules addressed in the text. On the left side: schematic representation of lignocellulosic biomass cell walls highlighting the structure of cellulose (dark green), hemicelluloses (blue), and lignin (orange).

the same species are wide (Alañón et al., 2011; Flamini et al., 2007); as an illustration, the concentration ranges of some representative volatile compounds present in wood species are shown in Fig. 14.4.

The chemical composition of the aged WS has a strong dependence on these conditions as well as on those imparted by the cooperage operations (vide 3.2.3) and the aging process (vide 3.1).

14.3.2.2 Main forest ecosystems producing wood for cooperage and their sustainability

The main forests producing wood for cooperage are located in the northern hemisphere, especially in Europe and North America (Keller, 1987). Several oak species (white oaks) are grown in the USA and Canada, including *Q. alba*, *Quercus bicolor* Willd., *Quercus stellata* Wangenh., and *Q. lyrata* Walt

(Solomon, 1983). The greatest area in Europe is occupied by the native species *Quercus robur* and *Q. sessiliflora* (Leuschner & Ellenberg, 2017), and the most iconic forests are located in France (Chatonnet, 1995); Eastern Europe (Russia, Ukraine, Romania, among others) forests are also relevant suppliers of wood from these species. *Q. pyrenaica* is mainly found in the Iberian Peninsula (Martínez-Gil et al., 2018). The Mediterranean basin and southern Central European comprise the main chestnut (*C. sativa*) forest ecosystems (López-Sáez et al., 2017).

Some studies reflect the current concern with these forests management toward sustainability to overcome the pressure caused by the supply of wood and other threats. Molder et al. (2019) present an approach to sustain both the ecological value and the economic viability of silviculture in Central European forests of *Q. robur* and *Q. sessiliflora*. Integrative management is proposed including several measures such as the development of forest regeneration techniques, retention forestry, and adapted historical management techniques (coppicing and wood pasture). Tkach et al. (2019) address the importance of natural regeneration processes to assure a new generation of valuable *Q. robur* forests and to optimize the age structure of Ukrainian forest. Prada et al. (2016) show that carbon sequestration by chestnut coppices can increase by reducing the number of thinning and lengthening the rotation period.

Indeed, certification of sustainable forest management practices already exists through the “Program for the Endorsement of Forest Certification” or the “Forest Stewardship Council” (Paluš et al., 2018).

14.3.2.3 Cooperage process and sustainability

The wooden barrel dates back to antiquity, and has been used by Asian, European, and American civilizations. It is believed that in Europe, the Celts and the Romans played a key role in its manufacture (Twede, 2005). Nowadays, the barrel making process in cooperage comprises several steps from cutting the logs to testing the integrity and strength of the barrel (Puech et al., 1998). Among them, the wood seasoning and especially the heat treatment of the barrel are of remarkable importance for the aging result due to the changes made on the structure and chemical composition of the wood (Caldeira et al., 2006; Canas, 2017).

From the sustainability point of view, some particularities of this process should be highlighted: (i) energy consumption, especially for the manufacture of staves and heads, has a high environmental impact (Flor et al., 2017); (ii) higher waste of wood is associated with barrels made from European oaks than from American oaks and chestnut due to the need to split (instead of sawn) the logs because of their anatomical features (Carpena et al., 2020); (iii) a considerable waste of wood results from the entire process (Smailagić et al., 2019), including staves with defects and those broken during heat treatment.

Taking into account that millions of barrels are produced/exported annually worldwide (more than 90,000 t in 2019; Trade Map, 2020), several cooperages reflect a growing awareness of the need for sustainable production (e.g., <https://www.iscbarrels.com>; <https://www.worldcooperage.com>), developing strategies that involve the use of wood from sustainably managed forests, internal reuse of wood waste (e.g., to meet energy needs and to manufacture pieces of wood for alternative aging technologies), and sale of wood waste to external reuse.

14.3.2.4 Contribution of the wood reuse to a more sustainable process

The wood waste from cooperage can be externally reused by many ways, making circular economy a reality. Several works show the potential interest of wood compounds for other industrial applications. Tannins can be used in leather, inks, and dyestuffs production (Krisper et al., 1992). Lignin can be a source of several products, such as adhesives, dispersants, and animal feed additives (Abdelaziz et al., 2016). Obtaining vanillin, which is one of the most appreciated and sought natural food flavorings worldwide, is also an appealing option (Gallage & Moller, 2018). In addition, the wood and the bark are remarkable sources of bioactive compounds (especially phenols) of growing interest in the replacement of synthetic ones that are widely used in food, cosmetics, and pharmaceutical industries (Burlacu et al., 2020). Pellets, pallets, and composites for the furniture industry can also be obtained from wood residues.

14.3.3 The aging technology

The aging of WS is traditionally performed in oak barrels. Besides its mechanical strength, easy handling and versatility of shape (Twede, 2005), the barrel is not a simple vessel but an active interface between the liquid contained therein and the environment (*vide* 3.1).

In this aging technology, the WS is first lodged in new barrels for several months. Thereafter, the aged WS is transferred to used barrels in which the aging progresses, from one year to several decades according to the producing region regulation (*vide* 2.4) and the intended quality.

Thus, despite the high quality attained by the WS through this aging technology, the process is time-consuming and costly, resulting in low production efficiency and low profitability for the producer (the invested capital in WS and wood returns over the long term). In addition, barrels take up a lot of space in the cellar and their lifetime is limited, and there is a great loss of WS by evaporation (described above as “Angel’s share”). For these reasons, new approaches to a more sustainable aging using barrels have been studied. Besides, in recent years, special attention has been devoted to alternative aging technologies to meet the sustainability criteria (Fig. 14.1).

14.3.4 How to assure a more sustainable aging using wooden barrels?

As aforementioned, the traditional aging of WSs using barrels presents some economic and environmental drawbacks. Furthermore, the regular replacement of barrels is required, being a common practice, as after a number of uses, the barrels are no longer capable of providing an adequate contribution of extractable compounds to the beverage because of the exhaustion of their transfer capacity. In this context, different strategies to extend the life of barrels for the aging of beverages or for other purposes can be followed. The most traditional one is the regeneration of the inner surfaces of the barrels, often involving retoasting. More recent options involve the insert of oak fragments through the bunghole of exhausted barrels to prolong their useful life (Flor-Montalvo et al., 2020; García-Alcaraz et al., 2020), taking advantage of air diffusion through the barrel and the consequent oxygen supply. In apparent contradiction to the detrimental effects of reuse, barrels can be reused and go from the aging of one beverage to another. Also, barrels can be reused for purposes other than beverage aging, such as crafting furniture and accessories as a best practice example of circular economy. Furthermore, specific technological options, such as barrel size, wood species, and toasting level, are relevant factors for the use of barrels to achieve more sustainable aging.

14.3.4.1 Alternative woods, toasting level, and barrel size

A more sustainable aging using barrels can be achieved by exploring alternative woods. Specifically, chestnut wood, of particular significance in the countries bordering the Mediterranean Sea, has been proved to be an interesting choice for the aging of WSs as summarized by [Canas et al. \(2018\)](#). More recently, chestnut wood was used for the aging of “Brandy de Jerez” ([Garcia-Moreno et al., 2020](#)), promoting a faster and cheaper aging and affording high quality and differentiated spirits. Using barrels with higher toasting intensity (heavy vs. medium and light levels) is also an available option to accelerate the aging process resulting from a faster extraction (higher pool of extractable compounds in the wood together with greater anatomical changes) ([Caldeira et al., 2006](#); [Canas, 2017](#)). Another technological factor ruling the aging process is barrel size (*vide* 3.1). The use of barrels of higher size reduces the quantity of wood with the advantage of environmental sustainability to be developed. In addition, higher size barrels can be reused more often because of the slower exhaustion of their transfer capacity, as indicated by a comparative study on WS aging in barrels of 250 and 650 L ([Canas et al., 2008](#)). Indeed, the surface area to volume ratio decreases with barrel size (85 m²/L in 250 L barrels, 57 m²/L in 650 L), resulting in different extraction kinetics and explaining the comparative extended life of higher size barrels ([Canas et al., 2016](#); [Nocera et al., 2020](#)).

14.3.4.2 Barrels regeneration

Decline in barrels has led to several methods of rejuvenation/regeneration. A frequently used method involves scraping the inner surface of barrels, typically removing several millimeters of the wood layer, possibly in conjunction with retoastings ([Mosedale, 1995](#)). Scraping is an effective method for rejuvenation, as it exposes new unextracted wood to the distillate to be aged. However, this technology of mechanical working of inner surface causes thinning of the wall, and sometimes results in loss of its mechanical strength, thus cannot be repeated frequently. A number of oak barrels become rejected for reuse because they are not subject to regeneration with the help of such technology. Hence, alternative technologies for treatment and regeneration of inner surface of the oak barrels have been proposed. Most of them are aimed to barrels used for fermentation or wine aging, in which coloring matter, tartrate crystals and other deposits/contaminations, such as those of microbiological origin (e.g., *Brettanomyces*), on/inside the wood ([García-Alcaraz et al., 2020](#)). However, having in mind the WS aging, these technologies are expected appropriated for regeneration of barrels for this purpose.

A curious technology without any mechanical working, by using oak extracts, is claimed to enable multiple use of the oak barrels ([Sula et al., 2011](#)). According to the authors, the extract components are absorbed in the inner surface of the oak staves, causing full reproduction of basic chemical, physicochemical, and biochemical transformations.

The so-called “Barena method” consists of spraying an abrasive (of mineral origin) against at least a portion of the inner surface of the barrel, and preferably the entire surface, so as to remove the area of wood spoiled by deposits and microorganisms ([Brunateu et al., 2012](#)).

A number of treatments are used to regenerate barrels in terms of microbiological contamination, such as chemical agents (sulfur dioxide, ozone) or physical agents, with UV radiation, hot water, microwaves, and ultrasounds, showing varying levels of efficiency ([Breniaux et al., 2019](#)). The ability of these treatments to ensure both wood sterilization and wood structure preservation is of utmost importance.

14.3.4.3 Barrels reuse for the aging of other beverages

The barrels can be reused and go from the aging of one beverage to another. For instance, Scotch whisky production resorts to woods previously used in other beverages' aging such as Bourbon or Sherry, being also reported the reuse of Port or Madeira wine barrels for the finishing steps (Mosedale, 1995; Russell, 2003). Beer aging also resorts to the reuse of wood from other beverages, as the example of Lambic beers which reuse barrels previously used in wine aging (Coelho, 2020). The previous use changes the composition of extractives by removing compounds but also promoting the sorption of compounds in the wood [namely terpenes, alcohols, esters, aldehydes, norisoprenoids and acids (Coelho, 2020), monomeric anthocyanins, catechins, gallic acid, and *trans*-resveratrol (Barrera-García et al., 2007)], which may then be available for later extraction during a different beverage aging (Coelho, 2020).

14.3.4.4 Barrels reused for other purposes

Barrels can be reused for other purposes, e.g., decoration, whether keeping the barrels intact or deconstruct, using the staves and metal hoops to create something totally new as shown in Fig. 14.5. Furniture and accessories, crafted from used barrels can be structurally sound, aesthetically appealing and highly functional. It allows incorporating salvaged wood with a story, being at the same time a rustic trend.

14.3.5 Innovative technologies for wine spirit's aging

Different approaches have been developed in the searching of alternative technologies for the aging of alcoholic beverages. Several studies are devoted to wood fragments or wood extracts applied to the alcoholic beverages kept in stainless steel tanks, in order to shorten the aging period (economic and social advantage) and also to reduce the quantity of wood used (environmental sustainability). Another research line lies in physical treatments applied in the barrels to accelerate the aging process. Finally, wood fragments combined with the application of physical treatments have also been investigated.

14.3.5.1 Wood fragments

The application of wood fragments has been widely studied in wines (Gómez-Plaza & Bautista-Ortín, 2019), and less often in other alcoholic beverages such as cider brandies (Rodríguez Madrera et al., 2013), apple spirit (Coldea et al., 2020), grape marc spirits (Rodríguez-Solana et al., 2017; Taloumi & Makris, 2017), and sugar cane spirits (Bortoletto & Alcarde, 2015). Regarding the use of wood fragments in the aging of WSs, several works have been performed in the last decade. The effect of wood fragments with different shapes/sizes and from different kinds of wood (oak vs. chestnut), in comparison with the aging in barrels, on the physicochemical and sensory properties of the aged WSs was assessed (Caldeira et al., 2010, 2013, 2016, 2017; Canas et al., 2009, 2013, 2016; Cruz et al., 2012). These authors showed that the aged WSs obtained by such alternative technologies had very different chemical composition, resulting from different extraction kinetics during the aging process; the kinetics depended both on the compound nature and on the aging technology. Besides, the results obtained were closely related to the shape/size of fragments and the kinds of wood. In all studies, it was always possible to discriminate chemically the WSs based on the aging technology, although their sensory differentiation was not so evident.



FIGURE 14.5

Examples of barrels reuse. Photos by Despina Galani (a), Mike Bergmann (b), Vamvouras (c), and redcharlie (d) on Unsplash.

In addition, other species like acacia (*Robinia pseudoacacia* L.), mulberry (*Morus alba* L. and *Morus nigra* L.), ash (*Fraxinus excelsior* L.), and cherry (*Prunus avium* L.) are increasingly regarded for wine aging (Fernández de Simón et al., 2009; Tavares et al., 2017), thus being admitted its interest for the WSs aging.

14.3.5.2 Wood fragments combined with micro-oxygenation

The use of wood fragments is often associated with MOX, which consists of directly applying small quantities of oxygen to the beverage, simulating the slow and continuous diffusion of this gas through the barrel (del Álamo-Sanza et al., 2017). Several studies made on red wine showed that the limited amounts of oxygen supplied have beneficial effects on wine quality, and namely on color stabilization (Gómez-Plaza & Bautista-Ortín, 2019).

Regarding the aging of WSs with wood fragments combined with MOX, recent works have been done using chestnut and oak wood (Canas et al., 2019; Granja-Soares et al., 2020); staves combined with MOX were compared with barrels. The WSs aged through the alternative technology presented significantly higher total phenolic content and low molecular compounds contents (phenolic compounds and several odorant compounds) extracted from the wood. These results, which were ascribed to a faster extraction, were more pronounced in the WSs aged with chestnut wood. Accordingly, significantly higher antioxidant activity was found in the aged WSs resulting from alternative technology than from barrels (Nocera et al., 2020). Besides, the WSs resulting from these aging technologies were discriminated by FTIR-ATR spectroscopy combined with FDA and by NIR (Anjos, Caldeira, Roque et al., 2020; Anjos, Martínez Comesaña et al., 2020). From the sensory point of view, for the same aging time, the WSs proceeding from the alternative technology were more evolved and presented significantly higher overall quality (Granja-Soares et al., 2020). In addition, higher amounts of acetaldehyde, 1-butanol, methanol, and alcoholic strength found in WS aged in stainless steel tanks with staves and MOX than in barrels suggest lower evaporation of WS promoted by the alternative technology (Anjos, Caldeira, Pedro, et al., 2020).

More recently, our team started to study the influence of MOX level on the physicochemical and sensory characteristics of the aged WS under the Project POCI-01-0145-FEDER-027819 (<https://projects.iniav.pt/oxyrebrand>). The first results revealed that the behavior of most of the low molecular weight compounds was significantly influenced by the aging time and the oxygenation level (Canas et al., 2020).

14.3.5.3 Wood extracts

A South African team (van Jaarsveld et al., 2009a,b,c) reported another technological option that consists of obtaining liquid extracts by macerating different kinds of wood chips in water and ethanol solution at different concentrations. After, these macerates, distilled and concentrated by different processes, were mixed with unaged distilled beverages and the chemical composition and sensory acceptability after the aging period was evaluated. They noticed that the best conditions for obtaining the extracts were the use of ethanol at higher concentrations. Influence of oak origin and toasting level on the sensory quality of the beverages was also found. Despite the interesting results achieved, there is a lack of comparison with the aging in barrels.

14.3.5.4 Physical treatments

Given the knowledge about physical and chemical reactions taking place during aging (*vide* 3.1), some physical methods have been explored. Most of them were applied to wine and other alcoholic beverages; little research on WSs has been done.

14.3.5.4.1 Electric field

Zhang, Zeng, Lin, et al. (2013) and Zhang, Zeng, Sun, et al. (2013) studied the application of an electric field (EF) of 1 kV/cm to small barrels of 2 and 5 L filled with the same WS. This treatment increased the extraction of several phenolic compounds from the wood. After the EF treatment for up to 14 months, the amount of phenolic compounds in the WSs was higher than in those aged in barrels without EF treatment.

This kind of physical treatment has also been applied to other alcoholic beverages such as red wine (during aging and in winemaking stages). The main results are summarized by Puértolas et al. (2020).

14.3.5.4.2 Ultrasonic waves combined with wood fragments

Some researcher groups have been applied ultrasounds combined with oak chips to accelerate the aging of “Brandy de Jerez” (Delgado-González et al., 2017; Schwarz et al., 2014, 2020). The best aged spirits were produced in absence of light, in presence of oxygen, at room temperature and with high flow rates (Delgado-González et al., 2017). The authors applied this process to five varietal WSs, whose sensory quality increased with this technical procedure. Recently, it was applied and compared with results of traditional “Brandy de Jerez” aging (Schwarz et al., 2020). The multidimensional analysis of the results showed discrimination between the brandies proceeding from the two aging technologies (barrels vs. oak chips and ultrasounds). On the contrary, Schwarz et al. (2014) concluded that the brandies obtained by the accelerated method attained in one month sensory characteristics and acceptability close to those of brandies aged in barrels for 6–18 months.

The influence of the ultrasound application to accelerate the aging process of other alcoholic beverages, such as fermented rice and maize beverages, plum brandies and grape marc spirit, was examined in some works (Balcerek et al., 2017; Chang & Chen, 2002; Taloumi & Makris, 2017); its effect on the beverages’ quality was differentiated. Ultrasounds have also been applied in several stages of winemaking, and the main results summarized by García Martín & Sun (2013) showed variable effects on the wine quality.

14.3.5.4.3 Other physical treatments

Other physical treatments, such as gamma irradiation, nanogold photocatalysis, high pressure, and microwave irradiation, applied to some alcoholic beverages are described in the literature (Pielech-Przybylska & Balcerek, 2019), thus admitting the interest of their study in the aging of WSs.

14.4 Concluding remarks

Despite the economic, social, and environmental issues underlying the traditional aging in barrels, many alternatives exist that can concur to ensure the sustainability of WS aging. Indeed, greater achievements can be reached based not only on specific measures related to the WS’ aging but rather on those involving the entire value chain (from the forest to the final product), thus implying commitment of all players (forest owners, foresters, cooperers, WS producers). The information provided in this chapter points out interesting and promising resources to support such a comprehensive strategy: (i) the use of wood in cooperage from sustainably managed forests, an efficient use of production factors, such as energy and water, and the reuse of wood waste from cooperage in internal and external processes; (ii) a wise and judicious exploring of barrels for WS aging, by extending their useful life, their reuse, and by a proper selection of technological options such as barrel size, different

wood species, and toasting level; (iii) the use of innovative technologies, based on wood fragments (from different wood species and sizes/shapes) combined with MOX, on wood extracts and on physical treatments (EF, ultrasounds, among others).

Further studies on the aging chemistry may provide meaningful clues for the development of new technologies toward a more sustainable wood-based aging of this spirit drink.

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