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Various types of wood used in the whisky industry

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About the Author

Born and raised in Jonava (Lithuania), in 2001 completed MSc in Chemical Engineering at the University of Technology in Kaunas, where research and dissertation were in binding materials. After graduating worked in Secondary school in the home town teaching pupils Maths and helping in the Chemistry and Physics labotaries . Then in 2004 moved to Wales were worked for a pharmaceutical company "Alzeim" in Brecon. "Alzeim" had a fantastic project to create production line extracting Galantamine from the Daffodils. In 2012 joined the team at Penderyn distillery, as a trainee distiller & blender. Over the years honed skills working alongside the master distiller, "Einstein" in whisky industry" - Dr Jim Swan, and now after 12 years responsible for producing all of the award-winning Welsh Single Malt Whisky produced at the distillery. As the custodian of Penderyn bulk whisky stocks, responsible for the selection of new casks, the management of our bulk inventories, and the development of new and innovative single malt bottles.

In 12 years working in whisky industry got involved in the creation of the final product from the begging to the finish. From being trainer to General Manager Blending and Maturation.

Having background in chemical engineering, working in the research project author continuing being innovating and creative. Working in Distillery play a role in driving innovation and bringing creative ideas to the production of spirits. Development of new products and unique flavour profiles.

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Declaration Statement

I, Aista Phillips, declare that this dissertation, entitled " Different type of wood in whisky industry," submitted in partial fulfillment of the requirements for the degree of MSc, is entirely my own original work, except where explicitly stated otherwise. I have appropriately acknowledged all sources, whether quoted, paraphrased, or summarized, and I have cited them following the guidelines provided by University of Wales Trinity Saint David.

I further declare that:

This dissertation has not been submitted for any other degree or qualification at any other university.

Where I have used the work of others, it is fully acknowledged in the text and listed in the references.

I understand that any act of plagiarism or academic misconduct may result in severe penalties, including the possible expulsion from the academic institution. I am aware of the consequences of such actions and have taken all necessary steps to ensure the originality of this work.

Date: 08/03/2024

Signature: ___________________________

Aista Phillips

Contents

Abstract:

Its rich history, craftsmanship and meticulous process of aging spirits characterize the whisky industry. Central to this process is the choice of wood for cask maturation. This dissertation delves into the various types of wood used, examining their distinct characteristics and influences on the maturation process and final flavour profiles of whiskies. The exploration encompasses traditional oak varieties, such as American and European oak as well as unconventional choices, different wine casks and wood types. It explores the intricate interplay between wood, climate, and regional nuances.

This dissertation aims to contribute to a comprehensive understanding of the intricate relationship between wood types and the whisky maturation process, offering valuable insights for distillers, researchers and enthusiasts in the ever-evolving world of whisky production.

Note: The term ***Whiskey*** usually refers to the Irish and American product. The general term, especially the Scotch variety is ***Whisky*** *(without the "e").* For clarity, the term *Whisky* is used throughout this dissertation.

Chapter 1: Introduction

1.1 Background

The art of creating fine whisky is a harmonious blend of science, tradition and the environment in which it matures. One of the most influential factors in shaping the character and flavour profile of whisky is the type of wood used in the aging process. Distillers carefully select different types of wood, primarily oak, to impart distinct qualities to their spirits. (Smailagić et al., 2021)

Whisky is known as the "water of life" in Gaelic, referring to the water that permeates every part of our bodies. In the spirit business, whisky has been around for centuries. Historically there are signs that early Christian Missionaries introduced distilling as a craft to the nation and Scottish farmers thought to have distilled for hundreds of years. Mr J Marshall Robb explains in his book 'Scotch Whisky', that the earliest references to whisky are much later. According to a record discovered in the Scottish Exchequer Rolls, Friar John Cor received 'eight bolls of malt for the purpose of brewing aqua vitae' in 1494.

September 1506, while King James IV was in Inverness, is recorded in his Treasurer's Accounts as follows: "For aquavite to the King...." and "For ane flacat of aquavite to the King..." (www.britannica.com, n.d.) In this instance, the aqua vitae most likely consisted of a drinkable spirit. Back then, the alcohol they drank was direct from the stills, unaged, and oftentimes sweetened with honey or herbs to make it less harsh and potent.

Whisky production and maturation have a rich and diverse history, deeply intertwined with the cultural and economic development of various regions.

According to history, the wooden barrels used to mature whisky happened by fortunate coincidence. Distilling greater spirit that they could immediately put to use, it needed to be stored and this achieved using oak barrels. After sometime when finally ready to use the spirit came the realization that the spirit became softer, had more flavour and a far nicer character than the initial beverage. The use of oak barrels and ageing began a crucial part of the process.

Whisky maturation was once as simple as filling barrels with alcohol and letting them sit for a period, today far more involved. The maturation outcome varies depending on a number of factors, including size, climate, freshness, history, wood type, maturation period, and whisky finishes. While each of those elements has the potential to alter the flavour of whisky and is significant, wood is the most crucial element for maturing.

Whisky has been transported in casks since ancient times. Greeks and Romans during their many invasions, used barrels secured with hoops for shipping and storing their wines. The word cooper is thought to have originated from the Latin word "cupa," which meant vessel. The profession for which a barrel-building and repair specialist is qualified.

Casks were initially used to hold whisky in the early 1800s when distillers discovered the barrels helped the spirits mature. Oak makes an excellent vessel because it can be made waterproof. Because it can be waterproofed by skilled coopers, oak makes an ideal container. Additionally, because of its porous nature, which permits the exchange of wood tannins and spirit, it builds and enhances taste as it matures.

Scotland was the first country to implement regulations governing the maturation of barrels during World War I. The Immature Spirits Act was established in 1915, with David Lloyd George serving as its steward. This stipulated that a spirit cannot be called whisky unless it has matured in casks for at least three years. This was to prevent harsh, strong New-Make Spirit entering the market and so restrict the supply of alcohol to the nation.

Lloyd George did not want alcohol interfering with military recruitment and vital munition production. As Minister of Munitions he wanted full prohibition famously stating, 'Drink is doing more damage in the war than all of the German submarines put together.' (Jeffreys, 2023)

He did not get his way but other strict controls introduced; Beer watered down and reduced licencing hours. However, by 1917 many distilleries closed due to lack of labour and restrictions on Barley consumption. It is ironic Lloyd George and the anti-alcohol lobby had the effect of regulating and improving quality. Whisky would become a premium product recognised around the world.

American oak barrels were encouraged to be used by Scotch whisky distillers by new laws passed in the US in the 1930s. Due to the Coopers' strong labour union and to help the American timber industry recover from the Great Depression, a legislation was established in 1935 that restricted the maturation of bourbon to only virgin, recently-picked oak barrels. Because distilleries could only use barrels once, this created a barrel oversupply. In an attempt to partially offset their costs, they began selling the barrels to Scotland, which at the time was the world's biggest whisky manufacturer. The distilleries in Scotland were happy to buy the barrels at a significant discount. (Plappert, 2020)

The three-step process of whisky maturing in wood must occur in three different ways. These procedures are, in order, Additive, Subtractive, and Interactive. To elaborate, the cask will provide additional flavour and individuality to the spirit as an **additive**. Wood sugars, oaky scents, tannins, and colour (a result of the last filling cask) are among the additions made to this.

Subtractive: Spirit is cleaned of some volatiles and chemicals by the cask, improving its accessibility, mellowing, and softness. Casks that are used in the beverage industry are frequently burned; the charred wood acts as a natural filter to remove undesirable materials like sulphur.

Interactivity: This is how creativity works. Certain chemical and molecular reactions occur between the wood, the alcohol, the residue from previous fills, and most importantly, oxygen, to produce new flavours and smells. The casks breathe, the spirits oxidise, and the spirits transform the oak. This interactive mechanism may result in different effects for different species of oak. The spirit is affected differently by the wood's many qualities, including its density, permeability, hemicellulose, lignins, tannins, oils, lipids, and other constituents. Even though the modern Scotch Whisky industry has been around for more than 250 years, professionals and industry insiders like Dr. Bill Lumsden of Glenmorangie argue that scientific understanding of the third interaction process is still in its early stages. (FINE + RARE, n.d.)

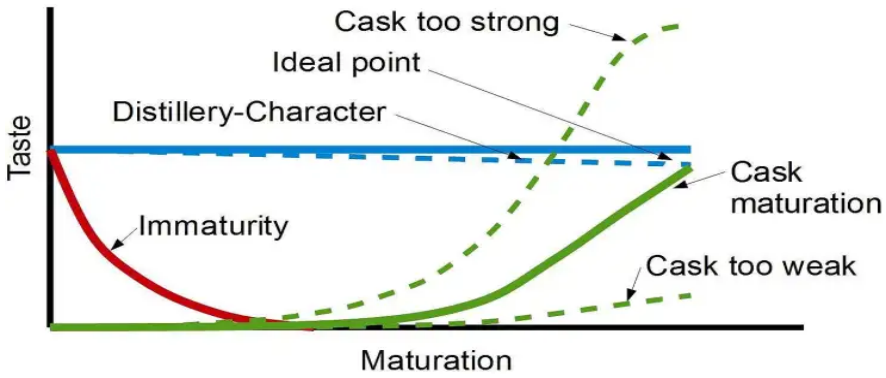


Figure 1 Optimal flavour profile of whisky (AUGUST 22, 2017 BY WHISKY WONDER)

Significance of wood in shaping the character and quality of whiskies.

Throughout its history, whisky production has evolved, adapting to changes in technology, regulation and consumer preferences while retaining its character as a complex and diverse spirit. Wood plays a crucial role in shaping the character and quality of whiskies during the maturation process. (Li, Zhang and Sun, 2023) The interaction between the spirit and the wooden cask contributes to various aspects of the final product including flavour, aroma, colour and overall complexity. Here are some key points highlighting the significance of wood in whisky maturation, development and production:

1. Flavour Development- Compounds such as vanillin, lignins, and tannins extracted from the wood during maturation influence the taste profile. These flavours can include notes of vanilla, caramel, spice, and various fruit or nut undertones.
2. Colour Enhancement- Whisky's natural colour is an interaction between the spirit and wood. As whisky ages, it takes on hues from pale gold to deep amber. The compounds leached from the wood, along with the charred layer inside the cask, contribute to the final colour.
3. Aroma Complexity- A significant portion derived from the wood. Compounds from the cask, combined with the aging process, create a complex bouquet of scents. This can include woody notes, as well as hints of spices, toffee, and other aromatic elements.
4. Maturation Process- The porous nature of wood allows the whisky to interact with air, promoting oxidation and the development of new compounds. This process contributes to a mellowing of the spirit, smoothing out harsh notes and enhancing the overall balance.
5. Tannin Influence- Tannins from the wood contribute astringency, affecting its mouthfeel and texture. While excessive tannins can result in bitterness, a moderate amount can provide structure and complexity.
6. Cask Size and Type- Can influence the final product. Smaller casks have a higher surface area relative to volume, leading to faster maturation and greater wood influence. Different types of wood, such as oak from various regions, also contribute distinct characteristics.
7. Previous Contents of the Cask- Whisky casks are often reused having previously held other spirits like sherry, bourbon or wine. Residual flavours from the previous contents absorbed by the wood and transferred to the whisky during maturation, adding layers of complexity.
8. Balance and Harmony- The art of whisky maturation achieves a harmonious balance between the spirit and the wood. Distillers carefully monitor the aging process ensuring the wood imparts desirable qualities without overwhelming the inherent character of the whisky.

1.2 Objectives

The choice of wood for whisky maturation plays a crucial role in shaping the final flavour, aroma and character of the whisky. (Li, Zhang and Sun, 2023) Distillers often use a variety of wood types to achieve specific objectives.

The impact of different wood types on the aging process.

The choice of wood, size and style of cask and length of whisky aging all play critical roles in shaping the unique character and quality of whiskies. The interplay between the spirit and the wooden vessel is a delicate and intricate dance that distillers carefully orchestrate to create a final product that reflects both tradition and innovation.

The impact of different wood types on the aging process is a fascinating aspect of whisky production. Distillers carefully select the type of wood for cask construction and the choice can significantly influence the final flavour, aroma and overall profile of the whisky. The most commonly used wood for maturation is oak but the specific type of oak and any previous use of the cask play crucial roles. Here are some key factors to consider:

Type of oak often used in the whisky industry

The common name for **Quercus Alba** is "American White Oak." It smells strongly like coconut, vanilla, and sweet spices. This particular sort of cask is only used by the Bourbon industry. American oak is by far the most productive kind of wood when it comes to ageing. But most was originally used to age Bourbon, and then it was sold to other parties to age everything from tequila to single malt Scotch Whisky, often adding notes of vanilla and fresh fruit. New American oak has a slightly different but distinctive taste profile. The main flavour is sweet vanilla, with undertones of woodsy and spicy spices. There's a chance that any fruitiness will meld with a certain vegetal bitterness**.**

The European or Spanish oak, **Quercus Robur**. Generally speaking, "European Oak" describes wood from France or Spain. Sherry barrels are commonly used to age spirits such as Armagnac and Cognac, but the influence of these barrels is often felt by whisky drinkers. European oak has a grain that is frequently much more compact than American oak, which makes it less porous and takes longer to impart the necessary flavours, despite the fact that the taste is very different. Because European Oak tends to lean more towards tannins, stewed citrus notes, a woody spicy character, and softer dried fruit aromas than vanilla and fresh fruit, it is commonly regarded with giving alcoholic beverages a "Darker," "Deeper" flavour profile.

Provenance is important because there are many different varieties of European oak that can be found across the continent. Because Spanish oak is very porous, for example, its impact on the distillate is greater. Russian or Ukrainian oaks grown in frigid climates may have little to no porosity and little flavour impact.

French Oak is known for its unique combination of savoury and sweet tastes, with frequent descriptions including tobacco, cedar, nuttiness, coffee, and chocolate. probably, more whisky is completed, in whole or in part, in French oak barrels these days, and this is also probably the case in other whisky-producing countries. Because it adds more muted aromas to the wine, the wine business favours French oak (quercus petraea) over American oak. When considering additive and interaction processes, French oak is thinner than American oak. That being said, it gives the wine more tannins. The tannin content of French Oak used wine casks that are subsequently used in the whisky industry must be properly evaluated and controlled.

Should the French Oak's tannins mix with any remaining tannin soak from an earlier wine filling, it could result in a "double whammy" of tannins that overpower the whisky and throw the balance off.

When it comes to the maturing of alcohol, **Scotch Oak** is particularly rare because the tree itself is rare due to years of slow deforestation. It is often wild rather than cultivated, making it difficult to work with and construct barrels. Scotch Oak is considered to impart a fiery and spicy flavour to the whisky. European oak offers a more comparable product than American oak.

Similar to Scotch Oak, **Irish oak** is infrequently used in the manufacture of barrels. Mostly because of the dearth of this wood type. However, recent Midleton Distillery research suggests that this specific type imparts sweet flavours of vanilla, caramel, and chocolate coupled with a fair dosage of woody spices, setting itself out significantly from its Scottish sibling. (Qureshi, 2018)

Particularly uncommon is **Hungarian Oak**, whose effect on the distillate strikes an unusual spice mix, with subdued wild berry flavours and a greater depth than the more conventional European oak.

Mizunara wood is indigenous to the Japanese islands and frequently mentioned in relation to the unique aroma of Japanese whisky. Mizunara Oak barrels are challenging to build and particularly rare because they are a protected and a slow growing tree. In the whisky community, their use is frequently the subject of much enthusiasm and discussion. A lot of the time though, such excitement is really just marketing hype. The tree is typically at least 200 years old and commercially difficult to work. The wood is porous with leaks and evaporative stability perpetual issues. Mizunara barrels of exceptional quality are particularly pricey due to their scarcity. The high cost of whiskies matured or finished with Mizunara wood is due to a few factors that most consumers are probably unaware. According to expert opinion, Japanese and Scotch whiskies need to age in Mizunara casks for at least 15 years before the genuine characteristics, flavours and properties of the wood become apparent. Younger whiskies or those that were only briefly finished do not benefit from or have the capacity to exhibit the specific qualities that Mizunara oak can add. (www.wineenthusiast.com, n.d.)

Among the less well-known woods used to age whisky is **amburana**, a native of the Brazilian jungle. Strong tonka bean flavour, strong vanilla undertones, and overtones of fragrant coconut and cinnamon are imparted to whisky by the Amberana, which is commonly used to age cachaça, a Brazilian spirit manufactured from sugarcane. (RD1 Spirits, n.d.)

The market for whisky is changing. The demand for whisky is continuously rising worldwide, and distillers are trying new things more than before. Nations lacking a history of whisky production have joined the global market without encountering obstacles from regulations or laws. This gives certain distillers who are searching for unusual or rare varieties of oak/wood options. Here are some examples: -

Garry Oak, a collection of derived Garryana Native Oak, was used by the Westland Distillery in Seattle, which took home the Washington State Distillery of the Year award at the 2017 NY International Spirits Competition. Pacific Northwest natives, or Garry Oaks, are located between British Columbia and California. Roasted coffee, cocoa, and a deep, black spice are among its notes. The issue is that wood is so rare and its use in the maturing of whisky is so recent that there is no dependable method for obtaining it. The Westland crew is still searching the West Coast in spite of this for even a single stave of the oak. They are careful to use only fallen trees so as not to add to the species' extinction.

As the nation's first distillery, Mackmyra has spearheaded the Swedish whisky trend by using ingredients that are sourced within a 75-mile radius of the distillery. Taking the term "local" a step further, Mackmyra uses **Swedish oak** barrels that are sourced from the southern part of the country. This oak was once used in the building of ships. Angel D'Orazio, the master distiller of Mackmyra states, "Swedish Oak (Quercus Robur) is very slowly cultivated here thus its taste derives from that gradual growth." (WhiskySpeller, 2014) It has less vanilla than Quercus alba and imparts a more peppery, spicy side when compared to its American brethren.

Different types of wood are already in use in whisky industry

The goal of The Cleveland Underground Select is to highlight the various unique flavours that each sort of wood can offer by using a variety of woods.

Since 2014, research into whisky maturation in various wood types has tested knowledge and methodology, none more so than experiments with wild cherry casks, according to Kevin O'Gorman, Master of Maturation at Midleton Distillery. (Magazine, 2023) The outcome is a ginger and coconut fiber-scented Irish whisky that tastes of fresh green herbs and black tea—a first for the globe. Blended with distinct pot still spices and a prolonged, crisp finish including prickly spices and hazelnuts. Achieving the ideal balance of flavour has been made possible by the uncommon and permeable wood.

Acacia wood purchased from France and usually matured between one and four years. Matured for a while in a mix of ex-bourbon and ex-sherry casks, with a tight grain. As a result, the whisky developed a deep mahogany hue and gradually acquired rich, chocolatey, and nutty tastes.

It has long been known to players in various countries. Teeling and Midleton are just two of the producers who have long been pushing the boundaries in Ireland, where regulations are looser than they are in Scotland. Upon sampling new offerings, like whiskies matured in casks that had held pineapple rum, ginger beer, and other wines, Campbell says that Teeling is really one of his go-to whiskies of interest. (Williams, 2021) His favourite is their Sommelier Selection Margaux Cask.

Midleton has played around with **French Chestnut** finishes. Banana, hints of cinnamon, and sweet, delicate fruit are all present in the whisky. For its Method and Madness line, Mulberry uses a small batch that is finished there.

Yoshino Sugi **(Japanese Cedar**). Japanese cedar is used to mature and finish the blended whisky Kamiki. It includes whiskies from both imports and Japan. Osaka is where the first of its kind, Kamiki, is matured and blended. Japanese spring water was added to the whisky to make it strong enough to be bottled and then distributed in batches. The cedar from Japan, which is most commonly used for buildings and temples, adds subtle notes of ginger, sandalwood, and honey to the finished product. (Nakayama, 2021)

Both distillers and customers are realising that there are still many tastes to explore. Understanding the impacts of maturation in unique woods is developing, influenced by the myriad types of wood found worldwide. Even if the barrels themselves could be more challenging to manufacture and leak more, the companies indicated above are reaping the benefits of their extra labour.

Daniel Szor, the founder of Cotswolds Distillery, intends to experiment with different woods for the brand's experimental collection, such as cherry, acacia, and chestnut, but he primarily employs oak casks. Szor, who enjoys a little more leeway than his Scottish colleagues, is eager to point out that the focus will still be on preserving the DNA of the spirit that flows from the stills in the English countryside. “I think it’s important to describe the effect of these ‘exotic’ casks on whisky as being exactly what it is – flavouring – as such they can be successful in drawing in new consumers who might be looking for sweeter or more novel flavours.”- says Mr. D. Szor. (spiritsbeacon.com, n.d.)

The diversity of flavour profiles resulting from various wood choices

Commonly used in bourbon production, American white oak imparts flavours of vanilla, caramel and sometimes coconut. The wood often charred, contributes a sweetness and richness in the whisky. Additionally, the porous nature of American oak allows for greater interaction between spirit and wood.

European oak, often used in Scotch whisky production, imparts different characteristics compared to American oak. It can contribute more tannic and spicy notes, as well as flavours of dried fruits, nuts, and sometimes a hint of earthiness.

Mizunara oak unique to Japan contributes distinctive flavours such as sandalwood, coconut and a pronounced spiciness. The wood is porous, giving higher evaporation rates and flavour concentration.

Casks previously used for aging sherry contribute rich and sweet flavours. This can include notes of dried fruits (raisins, figs), nuts (almonds, walnuts) and a deep fortified wine sweetness.

Bourbon casks, typically made of new charred American white oak, impart sweet and robust flavours. This can include vanilla, caramel and sometimes a touch of charred oak.

Casks previously used for aging wine (such as red wine or port) can introduce fruity, tannic, and sometimes spicy notes to the whisky.

Some distillers use casks that have held multiple types of spirits or wines, creating a complex interplay of flavours. This approach can result in a multi-layered and nuanced whisky.

The diversity of flavour profiles in whisky is testament to the art and science of whisky maturation. The choice of wood significantly shapes the final product, allowing for a rich tapestry of aromas and tastes that cater to a wide range of preferences among whisky enthusiasts. Distillers continue to experiment with different wood types and cask treatments, contributing to the ever-evolving landscape of whisky flavours.

The influence of environmental factors on wood maturation.

Environmental factors have a significant part in the whisky aging, affecting the interaction between the spirit and the wooden cask. These factors can influence the rate of maturation, the extraction of flavours from the wood and the overall character of the final product. Here are some key environmental factors that affect wood maturation:

1. The temperature of the maturation environment influences the rate at which the whisky interacts with the wood. In warmer climates such as Kentucky for bourbon or parts of Japan for whisky, the expansion and contraction of the wood occur more rapidly. This leads to increased interaction between the spirit and the wood, resulting in faster maturation compared to cooler climates.
2. Humidity levels also play a role. In humid environments, casks may breathe more, allowing the whisky to penetrate deeper into the wood and extract flavours. Conversely, in drier climates, evaporation rates may be higher, concentrating flavours and potentially leading to greater wood influence.

The atmospheric pressure at different altitudes can affect the maturation process. Distilleries located at higher altitudes experience lower atmospheric pressure, which could affect the rate at which the spirit interacts with the wood. The reduced pressure might lead to slower maturation.

Seasonal temperature variations can influence the rate of expansion and contraction of the cask. During warmer seasons, wood expands allowing the spirit to penetrate deeper. In cooler seasons, wood contracts, releasing the absorbed compounds back into the whisky. Diurnal temperature variations where significant differences between daytime and nighttime temperatures occur can contribute to the complexity of the maturation process. These swings promote more interaction between the whisky and the wood. Similar to wine the concept of *terroir* applies to whisky maturation. (Whisky 300, 2023) The specific geographic location including soil composition and local flora can influence the flavours imparted by the wood. For example, water sources with unique mineral content can change the whisky style. The location of the maturation warehouse within a distillery can also be a factor. Warehouses on higher floors may experience different temperature and humidity conditions than those on lower floors, leading to variations in maturation.

Movement of the cask, whether intentional (e.g., turning or rotating casks) or due to environmental factors (e.g., seismic activity), can influence the extraction of flavours. Agitation promotes more contact between the whisky and the cask interior. Microorganisms present in the maturation environment (moulds and fungi) can interact with the wood affecting the maturation process. Although some microbial activity is undesirable, certain interactions contribute to whisky complexity

Understanding and managing environmental factors is a delicate art for distillers. Combinations of these elements contribute to the unique characteristics of whiskies from different regions and distilleries. As a result, environmental factors are an integral part of the *terroir* of whisky, influencing the final flavour, aroma and overall profile of the matured spirit.

Chapter 2: The main types of Wood Used in Whisky Maturation

2.1 American Oak (Quercus alba)

Most commonly used is American oak predominantly Quercus alba, but may include wood from 10 or more other species of American white oak (Singleton 1974). American oak is a species native to North America and commonly used in the production of whisky, particularly bourbon. It is the primary species used in the construction of barrels for aging whisky in the United States and is known for its relatively wide and porous grain. The wide grain allows for greater interaction between the whisky and the wood imparting distinct flavours during the maturation process. Some of the common flavour characteristics associated with **American oak include**:

Vanilla: A noticeable sweetness often derives from compounds like vanillin present in the wood.

Caramel: The charring process contribute caramelized sugars, adding a rich sweetness to the whisky.

Coconut: Some barrels can contribute coconut-like notes enhancing its complexity.

Spice: Introduction of spicy notes, including hints of cinnamon and nutmeg.

Tannins: American oak tends to have moderate levels of tannins contributing to the structure and mouthfeel of the whisky. Tannins can add a subtle astringency to the spirit.

American oak barrels are often charred or toasted. Charring involves briefly exposing the interior of the barrel to an open flame creating a layer of charcoal. Toasting is a gentler process that involves heating the wood to different temperatures. Both processes influence the flavours extracted from the wood and contribute to the colour of the whisky. (Ferreras, Fernández and Falqué, 2002)

Table 1 Summary of effects of cooperage treatment on wood properties (Thesis & Mosedale, n.d.)

Treatment	Treatment Effects			
	Tannins	Oak lactones	Other Extractives	Anatomical Properties
Seasoning	Decrease in soluble tannins during wood ageing widely reported.	Lactones reported to increase during wood ageing.	Conditions of drying reported to influence volatile constituents.	Decrease in moisture content to approximately 14% of dry weight.
Toasting	Decreases levels of ellagitannins through oxidation or hydrolysis reactions.	Heating may increase synthesis, but there will be loss through volatilising from the wood surface	Degradation of lignin leads to the formation of lignin derived compounds available for extraction. Levels of volatiles reported to increase.	At high temperatures physical degradation of the wood may occur. Effects will vary through the depth of the stave.
Charring	Decreases ellagitannins through the same reactions as occur in toasting	Conflicting reports about the effect on lactones.	Large amounts of furan and lignin derived compounds formed. Charred layer may also remove undesirable sulphur compounds.	Break up of wood structure near surface may allow easier penetration of new wood and extraction of compounds.

American oak contributes to the colour of the whisky, imparting compounds from the wood to the spirit. The barrels' charred layer enhances a deep amber colour associated with matured whiskies.

American oak is widely available and is often less expensive than some other types of oak. This availability makes it a popular choice for American whisky production and is a legal requirement for aging bourbon in the United States. Bourbon must be aged in new charred oak barrels. (www.govinfo.gov, n.d.) The regulation contributing the distinctive flavour profile associated with bourbon. American oak is relatively porous, allowing for more interaction between the whisky and the wood. This porosity influences the rate of maturation, contributing to a faster aging process observed in warmer climates. American oak's influence on whisky production extends beyond bourbon. Other types of American whiskies even some Scotch whiskies utilizing this oak species. Its unique characteristics contribute to the diverse, recognizable flavour profiles of whiskies worldwide.

The legal use of new barrels distinguishes bourbon from other whiskies and contributes to the unique character of the spirit. (www.govinfo.gov, n.d.)

American oak contributes moderate levels of tannins, adding structure and a subtle astringency to the mouthfeel and overall balance of the spirit. Its porosity combined with warm climate in bourbon producing regions, facilitates a faster aging process.

Interaction between whisky and the wood accelerates, leading to a quicker maturation of flavours and a shorter aging period compared to some other types of oak. While bourbon must be aged in new charred oak barrels, the used barrels are not discarded. (www.govinfo.gov, n.d.) Many distilleries sell or exchange their used barrels to other spirit producers such as Scotch whisky or rum makers, contributing to the global influence of American oak in the world of spirits. Contributing to the consistency and recognizable character of bourbon as a distinct category of whisky.

American oak is a fundamental and defining element in bourbon production, imparting specific flavours that shape the identity of bourbon. The combination of wood influence, charring and the aging process in new barrels results in the rich, sweet and complex flavour profile that is synonymous with bourbon whisky.

The impact of American oak on the flavour profiles of whiskies is profound and distinctive. It is widely used in the production of various whiskies including bourbon, Tennessee whisky and whiskies from other countries.

American oak barrels after their initial use in producing bourbon, are repurposed for aging other types of whiskies, including Scotch. This global influence of American oak contributes to a diverse range of flavour profiles and allows for innovation in the whisky industry.

In conclusion, the taste profiles of whiskies are greatly influenced by the usage of American oak barrels, which offer a special blend of sweetness, spice, and complexity. It has come to be associated with particular flavour attributes that whisky connoisseurs recognise and value, whether it is mentioned in relation to bourbon, Tennessee whisky, or other whiskies matured in American oak.

2.2 European Oak (Quercus petraea and Quercus robur)

European Oak refers to two closely related species of oak trees found in Europe: These two species commonly known as English Oak and Sessile Oak respectively. While they have many similarities, there are differences between the two.

General Characteristics of European Oak (both species):

European Oak is highly valued for its wood, which is strong, durable and has a distinctive grain pattern. It is widely used in construction, furniture making, flooring and wine barrel production. These oaks exist in a variety of habitats, ranging from lowland forests to upland woodlands. They are important components of many European ecosystems. European Oaks provide habitat and food for various wildlife species. Their acorns are a crucial food source for animals such as deer, squirrels and birds. Oak is renowned for longevity, living for several centuries with some specimens reaching ages of 500 years or more. Oak trees have cultural significance in many European societies. They are often associated with strength, durability and longevity. Additionally, oak trees have been symbolically important in various mythologies and folklore. As with many other tree species, European Oaks face threats, such as habitat loss and climate change. Conservation efforts are important to ensure the continued health and sustainability of oak populations. These trees play a vital role in European ecosystems and used by humans for various purposes for centuries. Their significance extends beyond their ecological contributions to include cultural, economic and aesthetic aspects.

European Oak and American Oak are distinct species with differences, particularly in their wood characteristics. There is more to the distinction between American oak and European oak than just the botanical species. Both are associated with distinct environments and used in very different ways by different cooperage sectors. Historically in Europe, oak is grown, silvicultured and been used for generations. The traditional approach to the silviculture has been to produce wood with regular narrow annual rings by maintaining high stand densities. Slow-growing oak is considered to produce better quality wood (Weaver and Spiecker 1994), but attitudes have changed as it is realised that faster-growing oak can produce the same high-quality wood.

It was believed, the flavour associated with oak depends on the forest where it is grown. However, there is considerable uncertainty as to what distinguishes the different geographic types of oak. (Schahinger

1991), Wood from the same location, even if it is the same species may have grown under different climatic conditions or silviculture regimes. (Kenk 1994)

Table 2: Differences between American oak and European oak

	European Oak:	American Oak:
General	Typically, has a more pronounced and varied grain pattern. The growth rings can be wider and more irregular, resulting in a distinctive and attractive appearance. The texture is often coarse.	Generally, has a finer and a more uniform grain pattern. The growth rings are usually tighter, and the wood has a smoother texture compared to European Oak.
Colour	The colour of the heartwood in European Oak can range from light tawny to light yellow-brown. It may have pink or brown tones, and the sapwood is usually lighter in colour.	American White Oak, one of the most common species used, tends to have a light to medium brown colour with a pinkish hue. The sapwood is typically paler than the heartwood.
Tannins	Generally, contains higher levels of tannins compared to American Oak. This can contribute to astringency and a more complex flavour in wine and spirits aged in European Oak barrels.	Contains tannins as well, but in different concentrations and chemical forms. American Oak barrels often impart a smoother and sweeter flavour profile to beverages
Density and Hardness	Generally denser and harder than American Oak. This characteristic contributes to the durability and strength of European Oak wood	While still durable, American Oak is slightly less dense and not as hard as European Oak. This can influence its workability and susceptibility to wear.
Common Uses	Traditionally used for furniture, cabinetry, flooring and wine barrels. Its high tannin content makes it particularly suitable for aging wines and spirits.	Widely used in the construction of furniture, flooring, and barrels for aging whisky and wine. American White Oak in particular, is popular for its use in the wine and spirits industry
Geographical Distribution	Found predominantly in Europe, with species like Quercus robur and Quercus petraea being native to the region.	Various species are found across North America, with American White Oak (Quercus alba) being one of the most commonly used species in woodworking and cooperage.

Understanding these distinctions is important, especially in industries like winemaking and woodworking. Choice of oak significantly affects the final product. Each type brings its own unique qualities influencing the flavour, appearance and overall characteristics of the finished product.

European Oak, particularly English and Sessile Oak are commonly used in whisky maturation. The influence of European Oak is significant, imparting distinct characteristics to the final product.

European Oak tends to impart a different flavour profile to whisky than American Oak. It often contributes rich, complex and spicy notes, with hints of tannins, dried fruits and sometimes a touch of earthiness. The tannins from European Oak barrels can add astringency and structure to the whisky, influencing its mouthfeel and overall taste. Some whisky-producing regions, especially in Europe, have a long tradition of using European Oak casks for maturation. This is particularly true for Scotch whisky, where both English and Sessile oak utilized.

Other whisky-producing regions often use American Oak barrels. However, there is a growing trend among distillers worldwide to experiment with different types of oak, creating unique and diverse flavour profiles. European Oak sherry casks are highly sought after for whisky maturation. These casks, which previously held sherry, contribute additional flavours such as dried fruits, nuts, and sometimes a subtle sweetness to the whisky.

Whisky makers engage in a balancing act when selecting casks. The choice between American Oak and European Oak, as well as the history of the cask (whether it previously held sherry, wine, etc.), greatly influence the final flavour profile of the whisky. Many distilleries and master blenders experiment with different types of oak casks to create limited edition or experimental releases.

European Oak has higher tannin content than American Oak. Tannins are compounds found in wood that contribute astringency and structure to the beverage. They can impart a drying sensation and add complexity to the mouthfeel. European Oak often imparts rich and complex flavours to the beverage. This can include notes of dried fruits, dark chocolate, tobacco, and sometimes a hint of spiciness. These flavours contribute to the overall complexity and depth of the drink. The porous nature of oak allows the beverage to interact with the air during maturation. European Oak, with its distinctive grain and higher levels of compounds like lignin, can contribute aromatic compounds to the beverage, enhancing its bouquet.

European Oak casks allow for a variety of compounds to be extracted from the wood, including vanillin, lactones, and phenolic compounds. These compounds affect the flavour profile by adding sweet, creamy, and sometimes smoky or toasty notes. European Oak casks may be used for extended maturation periods, the wood imparting a gradual evolution of flavours, allowing for a complex interplay between the beverage and the cask. The porous nature of oak also allows for subtle microbial activity, which can promote the development of unique flavours. It holds true, especially in traditional cellaring environments.

In the context of whisky, for example, European Oak casks are highly prized for their ability to impart a broad spectrum of flavours that add depth and complexity to the spirit. The combination of tannins, aromatic compounds, and the influence of previous contents creates a harmonious and intricate flavour profile appreciated by enthusiasts and connoisseurs alike.

2.3 Other Oak and non-Oak Varieties

The use of non-traditional wood choices in whisky maturation has become a fascinating and innovative trend in the whisky industry. Distillers and blenders are experimenting with various types of wood to impart unique flavours and characteristics to their spirits.

Table 3 Sources of oak wood reported as used for the maturation of alcoholic beverages (MOSEDALE, 1995)

Wood origins	Species reported as being used for cooperage	Main cask uses	Comments
America	*Q. alba* and related white oak species (see Singleton 1974).	Bourbon and subsequently Scotch whisky. Wine and sherry.	Low tannic content but high levels of volatiles.
Western Europe (mostly France)	*Q. robur*, *Q. petraea*.	Wine and brandy.	Varies depending upon precise origins.
Eastern Europe	*Q. robur*, *Q. petraea*, *Q. cerris*.	Wine, brandy, beer.	Present state of oak forestry uncertain - but potentially a major source of cask wood.
Japan and Asia	*Q. dentata*, *Q. crispula*, *Q. mongolica*.	Whisky and brandy.	*Q. crispula* reported to release a sweet taste (Kanazashi pers. comm.).
Near East	*Q. mirbeckii* and possibly others.		Oak staves imported from Iran and Turkey during 1940-50's (Williams 1983b).
South America	probably *Q. copeyensis* (see Singleton 1974).	Sherry and Whisky casks.	Costa Rican oak reported to have been exported to Spain.

Table 3 lists and describes some past and present sources of oak cask wood. Wood other than oaks occasionally used to store alcoholic beverages are normally coated on the inside by paraffin or silicone to prevent leakage and the release of unpleasant odours (Lamfalussy 1953; Molnar et al. 1985)

While oak from the Quercus alba species (American White Oak) is traditional in whisky maturation, some distillers are experimenting with **French Oak** (Quercus robur and others). French Oak can contribute different flavours, such as pronounced tannins, spice, and sometimes floral and fruity notes. **Chestnut** wood used in some experimental cask maturation, imparts a different set of flavours, these include notes of earthiness, nuttiness, and a distinct aromatic quality.

Acacia wood is lighter and more porous than oak, and it has been used in whisky maturation to impart delicate flavours. It can contribute floral, herbal, and sometimes fruity notes to the whisky. **Mulberry wood** often used experimentally in maturation is known for its sweet and fruity characteristics its use can result in whiskies with unique flavour profiles. **Maple wood**, associated with syrup production, used in cask maturation imparts sweet and sometimes spicy flavours to the whisky. **Teak**, a tropical hardwood, has been associated with experimental cask maturation. It can contribute complex flavours, including a certain richness and depth. This « exotic wood family » (ash wood, pear wood, wild cherry wood, acacia, etc.) are really low in tannins concentration / tannins extractability potential. For this kind of wood, it is better to keep the wood untoasted or with a really light toast if you want get the full potential of the flavours.

Some distillers experiment with hybrid casks combining staves of different wood types. These casks may include a combination of oak, chestnut or other woods, providing a complex flavour profile.

These non-traditional oak choices add an exciting dimension to the world of whisky, providing enthusiasts with a diverse range of flavour experiences. However, it is important to note that these experiments often lead to limited-edition releases, as the outcomes can be unpredictable and may not conform to traditional expectations. The exploration of non-traditional oak choices highlights the creativity and willingness of distillers to push boundaries and create new and intriguing expressions.

The rare and expensive **Mongolian oak** used in the production of Japanese whisky can give aromas of incense, sandalwood, pineapple and coconut**. Mizunara oak** is a type of oak native to Japan. It imparts distinctive flavours of sandalwood, coconut, and a unique spiciness to whisky. The porous nature of Mizunara wood accelerates the maturation process, allowing for quicker interaction between the wood and the spirit. Although uncommon in the production of whisky, **Japanese cedar** has been studied to enhance the spirit's characteristics. By adding a distinct aroma, it brings heightened complexity to the taste of whiskies, creating hints of fresh fruitiness. By adding a distinct aroma, it brings heightened complexity to the taste of whiskies, creating hints of fresh fruitiness. **Cedarwood** casks can contribute resinous and aromatic qualities to whisky. This non-traditional wood choice may impart flavours of cedar, pine, and sometimes a subtle smokiness. **Juniper wood** used experimentally for cask maturation can impart herbal and piney notes to the whisky, providing a unique and aromatic character. **Cherrywood** casks can contribute fruity and sweet notes to whisky. The wood may impart flavours reminiscent of cherries, adding a layer of complexity to the spirit. **Plum wood** can contribute fruity and sometimes floral characteristics, providing a unique flavour profile to the spirit. **Peach wood**, another experimental wood, can impart subtle fruity and sweet notes, contributing to a nuanced flavour profile.

Oregon oak, specifically Quercus garryana, is native to the Pacific Northwest in the United States. Used by some distillers to impart unique flavours such as nutmeg, cinnamon, and a distinct spiciness to the whisky. Experimental **Redwood** casks contribute flavours of cedar, pine, and sometimes a mild sweetness. **Amburana** Wood, primarily used in South America for aging cachaça and rum. Imparts unique flavours like cinnamon, nutmeg, and tropical fruit. (John 2023).

It is important to note that the use of non-oak materials is often experimental and can result in limited-edition releases. The characteristics imparted by these non-traditional woods can vary and the outcomes sometimes unpredictable. Distillers may use a combination of different wood types or employ specific toasting and charring techniques to enhance or modify the flavour contributions. As the whisky industry continues to innovate, the exploration of non-oak materials adds an exciting dimension to the diversity of flavours available to whisky enthusiasts.

Chapter 3: Maturation Process and Flavour Development

3.1 Chemical Reactions during Maturation

Whisky is commonly produced from grain (wheat, barley, corn, rye.) in a plant performing varied processes (malting, milling, mashing, fermenting, distilling and maturation). However, it is acknowledged that maturation gives whisky its final character, recognizable all over the world. The compounds in the wooden barrel are responsible for the scent and colour in the final drink. By developing oak barrels in oak casks, the antioxidant content of whisky increases due to increased concentration of phenols and furans.

Traditional Pot Stills (Double Distillation) produce a consistent distillate that may alter little from still to still. The variety of flavours in the final product imparted by maturation. Modern Stills are capable of producing varied high-quality distillate so increasing the range of flavours and characteristics of the whisky. Indeed, at Penderyn Distillery, two Faraday Single Distillation stills produce product alongside a traditional Pot still. Distillate from a mixture of the two provide an additional range of flavours.

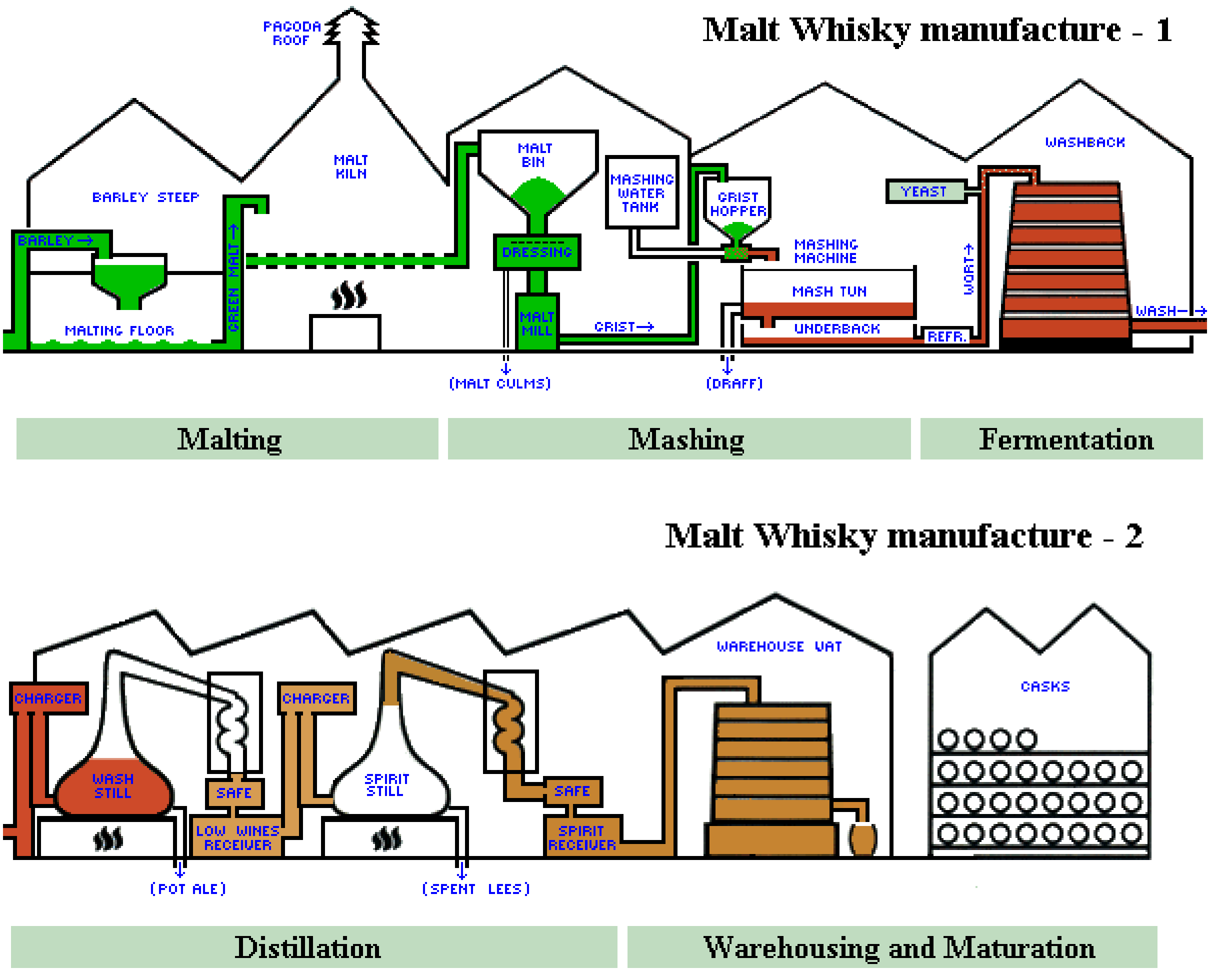


Figure 2 Whisky making process (Butler, n.d.)

However, it is without doubt, that the aging process in wood casks transforms the clear colour of the distillate and sometimes a sharp rough scent to a delicate, charming and brilliant colour.

The effect of maturation on whisky is quite distinct, with the unmatured spirit generally having few of the desirable properties sought in whisky taste and aroma. Therefore, the importance of the maturation process should not be underestimated. The following points are known about the maturation of whisky (Nishimura and Matsuyama, 1989):

1. Depending on the amount of time it takes to mature; maturity can range from 3 years to more than 10 years.

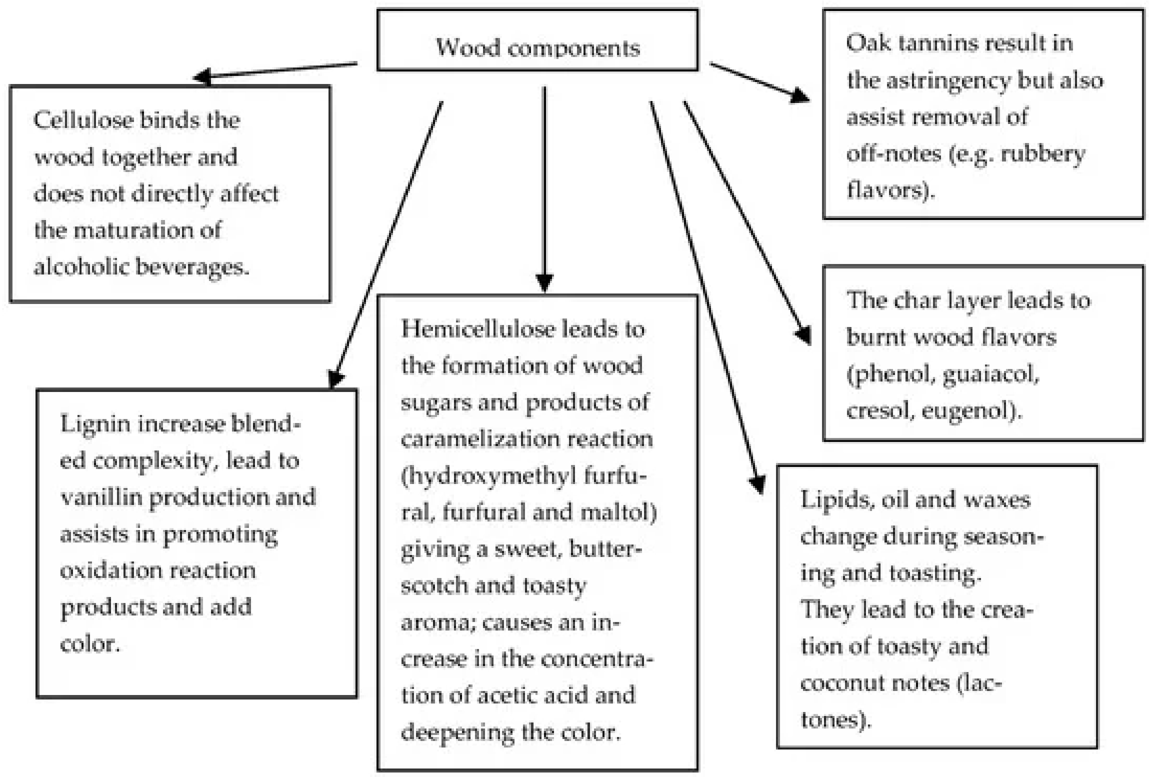
2. Old and unaged spirits tend to have a distinct flavour profile.

3. The barrels' porous wood is where water and alcohol vapor evaporate, leading to the loss of volume and strength.

4. The amount and length of time spent in barrels can affect the whiskies final quality, which may be influenced by various factors such as the type of barrel, size, wood species, prior processing, and surrounding conditions.

Whisky undergoes intricate chemical changes in wooden barrels. Taste, aroma, and colour are closely tied to these interactions. Some of the main chemical reactions that occur during whisky maturation are as follows:

Table 4: Major wood constituents and basic chemistry (Tarko, Krankowski and Duda-Chodak, 2023)



Lignins in the wood contribute to the colour of the whisky as they break down during maturation. They release phenolic compounds, adding depth and complexity to the flavour. This wood component breaks down and releases sugars and other compounds that contribute sweetness and body to the whisky. While cellulose itself is not directly soluble in alcohol, it can influence the overall texture and mouthfeel of the whisky as it interacts with other compounds. Lignins and tannins from the wood contribute to the astringency of the whisky. Over time, these compounds leach into the spirit, imparting structure and complexity to the flavour. The whisky extracts colour compounds, including tannins and polyphenols, from the wood. Tannins in particular, contribute to the development of a deeper colour.

Oxygen enters the cask through the porous wood, leading to oxidative reactions. This contributes to the mellowing of flavours and the development of subtle, aged characteristics. Oxidation can also influence the formation of esters and aldehydes contributing to fruity and nutty notes in the whisky. Oxygen entering the cask during maturation can also lead to oxidative reactions that influence the colour of the whisky. While some oxidation may lighten the colour, it can also contribute to the development of complex hues.

Esters formed through the interaction of alcohol with acids present in the wood, contribute fruity and floral aromas to the whisky.

Lactones, such as cis- and trans-oak lactones formed during maturation contribute coconut and woody notes to the whisky, enhancing its aromatic complexity. These esters provide complexity and nuance to the nose.

Phenols in the wood, including guaiacol and syringol, contribute smoky and spicy notes to the whisky. The breakdown of lignins releases these compounds into the spirit.

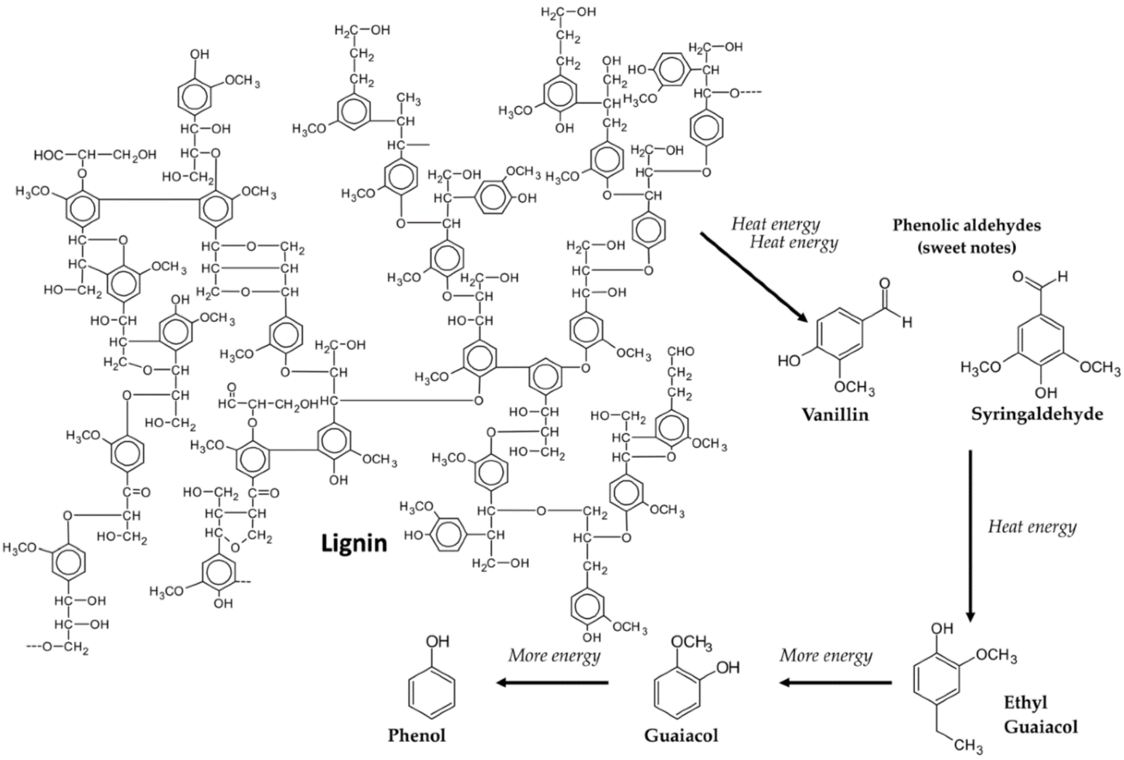


Figure 3 Thermal degradation of lignin (Tarko, Krankowski and Duda-Chodak, 2023)

The Maillard reaction is the result of the interaction between reducing sugars and amino acids, leading to the formation of complex flavour compounds. This reaction contributes to the development of rich, caramelized, and toasty flavours in the whisky.

Harsh and undesirable compounds such as acetaldehyde and fusel oils, may undergo chemical transformations during maturation, resulting in a smoother and more refined whisky.

If the cask previously held wine, sherry or another spirit, the residual compounds from the previous contents can interact with the whisky, introducing additional flavours and complexities.

The pH value of the wood and the whisky can influence the extraction of different compounds. Acidic conditions may enhance the extraction of certain flavour compounds.

It is essential to note that chemical reactions during maturation are highly dynamic and interrelated. The temperature, humidity, and environmental conditions of the maturation warehouse plays a role in influencing these reactions. The cumulative effect of these interactions over time results in the unique character and complexity of each whisky. The art of whisky maturation lies in understanding and managing these chemical processes to produce a well-balanced and flavourful final product.

Table 5 Main aroma compounds derived from wood (Tarko, Krankowski and Duda-Chodak, 2023)

Common Name	IUPAC Name	Aroma Notes	Olfactory Threshold
Volatile phenols			
Guaiacol	2-Methoxyphenol	smoke, sweet, medicine	9.5 µg/L
4-Ethylguaiacol	4-Ethyl-2-methoxyphenol	phenolic, smoked, leather	47 µg/L
4-Methylguaiacol	4-Methyl-2-methoxyphenol	spicy, phenolic, light green	20 µg/L
4-Vinylguaiacol	4-Vinyl-2-methoxyphenol	clove	40 µg/L
Eugenol	2-Methoxy-4-(prop-2-enyl) phenol	clove, honey, spicy, cinnamon	6 µg/L
Isoeugenol	1-Methoxy-4-(prop-2-enyl) phenol	floral, clove, woody	6 µg/L
Syringol	2,6-Dimethoxyphenol	smoke, burned, wood	570 µg/L
Furanic compounds			
Furfural	2-Furancarboxaldehyde	bread, almond, sweet	15 mg/L
5-Methylfurfural	5-Methyl-2-furancarboxaldehyde	almond, caramel, burnt, sugar	16 mg/L
Maltol	3-Hydroxy-2-methyl-4H-pyran-4-one	honey, toasty, caramel	5 mg/L
5-Hydroxy-methylfurfural	5-Hydroxymethyl-2-furaldehyde	caramel	100 mg/L
Lactones			
trans-β-Methyl-γ-octalactone	*trans*-4-Methyl-5-butyldihydro-2-(3H)-furanone	coconut, woody, vanilla	140–370 µg/L
cis-β-Methyl-γ-octalactone	*cis*-4-Methyl-5-butyldihydro-2-(3H)-furanone	coconut, woody, vanilla	20–46 µg/L
Phenolic aldehydes/Phenyl ketones			
Vanillin	4-Hydroxy-3-methoxybenzaldehyde	vanilla	1 mg/L
Syringaldehyde	4-Hydroxy-3,5-dimethoxybenzaldehyde	vanilla	50 mg/L
Acetovanillone	1-(4-hydroxy-3-methoxyphenyl)ethanone	vanilla	1 mg/L

New distillates matured for long periods in oak alter from a sharp and crude state, to mellow and wonderful notes. Clear distillates take on a golden tone demonstrating numerous changes within whisky and its aromatic components and hues. Maturing is a key figure giving distillates a proper quality and sensory profile. It fortifies the physical-chemical reaction with the wood and fluid changing in of colour and volume of the ethyl liquor.

Nevertheless, the ultimate taste of the drink depends primarily on the first composition of the distillate. The interaction of the whisky with the wood and its compounds during maturation helps balance the different flavour elements, including sweet, bitter and savoury notes. Microbial activity in the cask may contribute to the development of certain flavours and influence the overall taste profile of the whisky. The chemical reactions during maturation are dynamic and multifaceted, contributing to the complexity and uniqueness of each whisky. Interplay between the whisky and cask shapes its colour, aroma and taste. Resulting in a well-rounded and harmonious final product.

3.2 Factors Affecting Maturation

The duration of maturation or the length of time whisky spends aging is a crucial factor that significantly influences its final characteristics. In the early stages of maturation, the whisky interacts more actively with the wood. This can lead to rapid extraction of compounds from the cask, including colour, flavour, and aroma compounds. (www.hackstons.com, n.d.) Overtime the interaction with the wood continues at a slower rate. Extended maturation allows for more nuanced and subtle interactions, contributing to the development of complex flavours and aromas.

Whiskies matured for shorter durations may exhibit a lighter colour, with less time for the extraction of pigments and compounds from the wood. Longer maturation periods contribute to deeper and more intense colours as the whisky absorbs a greater amount of compounds, including tannins and lignins. Early in maturation, the whisky may display more prominent and youthful characteristics. This can include raw grain flavours and a stronger influence of wood-derived compounds. In the early stages, the removal of volatile compounds from the wood quickly results in an altered aromatic profile. It can exhibit raw and primary aromas.

With time the whisky undergoes a more balanced and gradual development of flavours. Complex interactions between the whisky and the wood lead to the emergence of nuanced and layered taste profiles. Longer aging allows for development of a sophisticated and multi-layered aromatic profile. Subtle and complex aromas may emerge, contributing to the overall whisky bouquet. Younger whiskies may have a more spirited aggressive mouthfeel, the alcohol presence more pronounced.

Over time, the texture becomes smoother and more refined. Tannins and other compounds from the wood contribute to a well-rounded and velvety mouthfeel. Evaporation loss, known as ‘angel's share’, is less significant during shorter maturation periods. With longer maturation the angel's share becomes higher, a greater portion of the whisky evaporates over time. This can result in a concentration of flavours and an change in alcohol content. Whiskies with shorter maturation periods are typically ready for market sooner, reducing production costs and allowing for a quicker return on investment. Longer maturation requires greater investment in storage space and resources. The cost of aging inventory for extended period may be higher, but can lead to premium and well-aged products.

The duration of maturation is a critical variable that distillers carefully manage to achieve the desired balance of flavours, aromas and overall character in their whiskies. Both short and extended maturation periods have their merits. The choice depends on the distiller's vision and the desired style of the final product.

Chapter 4: Regional and Climate Influences

Climate and environmental conditions

Climate and environmental conditions are very important in whisky aging. The interaction between the whisky and the atmosphere within the maturation warehouse can significantly influence the final characteristics of the spirit.

Temperature variations between seasons and day-night cycles cause the whisky to expand into the wood during warmer periods and contract during cooler periods. This promotes the extraction of flavours from the cask. In warmer climates, such as Kentucky in the United States or certain regions in Australia, higher temperatures can accelerate the maturation process. (Elise, 2024)

The whisky may interact more rapidly with the wood, leading to faster extraction of compounds and potentially more intense flavours. In cooler climates, such as Scotland, the maturation process is generally slower. The whisky has less interaction with the wood, allowing for a more gradual and nuanced development of flavours.

Higher humidity levels can prevent excessive evaporation (angles' share). This is important in regions with high temperatures to minimize losses during maturation. Lower humidity levels may contribute to higher evaporation rates. While this can lead to a higher angel's share, it may also concentrate the flavours in the remaining liquid, intensifying the overall character of the whisky.

Changes in barometric pressure can influence the movement of air into and out of the cask, affecting the rate of maturation. However, the impact of barometric pressure thought less significant than temperature and humidity. Coastal maturation warehouses may experience more moderate temperature fluctuations due to the influence of the sea, potentially resulting in a different maturation profile compared to inland warehouses. Maturation at higher altitudes may result in lower atmospheric pressure so affecting the maturation process and even resulting in unique environmental conditions. (Physics Stack Exchange, n.d.)

The environmental conditions within the warehouse can influence microbial activity. Microorganisms present in the air and wood may contribute to the development of certain flavours and characteristics in the whisky. The construction and insulation of the maturation warehouse can affect the internal environment. Well-ventilated warehouses with good insulation help maintain a stable environment and minimize temperature fluctuations. As we have seen wood type, quality and previous use influence how the whisky and wood interact. The environmental conditions can change the permeability of the wood and the extraction of compounds. Some whisky-producing regions have regulations that specify certain environmental conditions for maturation. For example, Scotch whisky must mature in Scotland, the climate having a distinct impact on the maturation process. (Walker and Hill, 2016)

In conclusion, the interplay between temperature, humidity, and other environmental factors contributes to the unique characteristics of whiskies from different regions. Distillers carefully consider these conditions when selecting maturation sites and managing their aging inventory to achieve the desired flavour profiles in their final products.

4.1 Whisky Regions

Whisky region refers to specific geographic areas known for producing whiskies with distinct characteristics influenced by factors such as climate, water source, local traditions and regulations. Different regions around the world have developed unique styles of whisky, each reflecting the local environment and production methods. Here are some prominent whisky regions:

Scottish Highlands: Known for a diverse range of whiskies. Highland malts can vary widely in flavour; some may be peaty and robust, while others are sweet and fruity.

Speyside: Recognized for its high concentration of distilleries, Speyside produces whiskies often characterized by their sweetness, maltiness, and complexity.

Islay: Famous for its heavily peated and maritime-influenced whiskies. Islay malt is favoured for their bold, smoky, and medicinal flavours.

Lowlands: Generally producing lighter and more approachable whiskies, Lowland malts often exhibit floral and grassy notes.

Irish Whisky: Known for its smooth and triple-distilled character, Irish whisky may display flavours ranging from light, floral, to rich, and complex. Key regions include Cork, Dublin, and Midleton.

Welsh whisky has gained recognition and popularity in recent years, and several distilleries in Wales are producing high-quality spirits. While the characteristics of Welsh whisky can vary depending on the specific distillery and production methods. Welsh whiskies often described as crisp and clean with a smooth and an approachable character, can be attributed to the use of fresh and clear Welsh water in the production process. Many Welsh whiskies exhibit fruity notes, including orchard fruits like apples and pears. These fruity characteristics influenced by the choice of yeast strains during fermentation, as well as the distillation and maturation processes. Welsh distillers' experiment with a variety of cask types for maturation, including ex-bourbon barrels, sherry casks, and even wine casks. Diversity in maturation contributes to a broad spectrum of flavours and aromas. As the Welsh whisky industry continues to evolve, individual distilleries may develop their own distinct characteristics, contributing to the diversity and richness of the global whisky landscape

American (Kentucky): Bourbon is an American whisky and Kentucky is particularly renowned for its production. Bourbon characterized by its sweet, corn-based mash bill and often features flavours of caramel, vanilla, and oak.

Tennessee (Jack Daniels): Similar to bourbon but distinguished by additional charcoal filtering known as the Lincoln County Process. Jack Daniels is a renowned Tennessee whisky.

Canadian Whisky: Often a blend of various grains, Canadian whisky tends to be smooth and light. Rye whisky from Canada may or may not contain a high percentage of rye grain.

Japanese Whisky: Inspired by Scotch whisky production methods, Japanese whisky has gained international acclaim for its quality and craftsmanship. Japanese distilleries produce a variety of styles from peated to delicate and floral.

Indian Whisky: India has a growing whisky industry with warm climates leading to faster maturation. Indian whiskies exhibit a range of flavours, often influenced by the use of local grains and cask types.

Australian Whisky: The Australian whisky industry has been gaining recognition for its diverse and innovative expressions. Climate conditions influence the maturation process, resulting in unique flavour profiles.

New Zealand Whisky: Similar to Australia, New Zealand's whisky industry is relatively young producing whiskies with distinctive characteristics influenced by local climates and production methods.

Taiwanese Whisky: Kavalan, a prominent Taiwanese distillery has gained international acclaim. The warm climate in Taiwan accelerates maturation, resulting in whiskies with rich and complex flavours.

Each whisky region has its own history, traditions and production methods. Contributing to the diversity of whiskies available globally. The unique characteristics of whiskies from different regions make exploring the world of whisky an exciting and rewarding journey for enthusiasts.

4.2 Global Perspectives

Wood choices in other whisky-producing regions.

While oak remains the predominant wood choice for whisky maturation globally, some whisky producing regions experiment with different types of wood or use unique cask treatments to impart distinct flavours to their spirits. Here are examples of regional wood choices or treatments:

Native to Japan, **Mizunara oak** is valued for its distinctive flavours of sandalwood, coconut, and a unique spiciness. Some Japanese whiskies for example Suntory and Nikka, use Mizunara casks to impart these unique characteristics.

Some Australian distillers' experiment with native woods such as **Tasmanian oak**, eucalyptus and other local species to create unique flavour profiles. Native woods contribute to the diversity of Australian whiskies.

Indian distillers' experiment with local wood varieties, including indigenous oak and other hardwoods. The warm climate in India accelerates maturation, influencing how the whisky interacts with different types of wood.

Taiwan: While American oak is commonly used, Taiwanese distillers like Kavalan also experiment with other wood types. These include ex-wine, sherry and port casks. This variety contributes to the unique flavour profiles of Taiwanese whiskies.

Swedish distillers, such as Mackmyra, primarily use oak casks for maturation. Additionally, they have experimented with other barrels, including ex-wine and small-sized casks to influence the flavour development of their whiskies.

In France, particularly in the Cognac region, **Limousin oak** traditionally used for maturing Cognac. Some French distillers use this oak for whisky maturation, contributing spicy and woody notes.

South African distillers often use **French oak** barrels for whisky maturation. These barrels may be ex-wine or brandy barrels, adding a layer of complexity to the final product.

New Zealand distillers' experiment with native woods, such as **rimu** and **totara**, alongside traditional oak. The use of native woods adds a unique and local touch to New Zealand whiskies.

English distillers may use **English oak** alongside traditional American oak. Additionally, some distillers experiment with casks that previously held wine, contributing to diverse flavour profiles.

Some German distillers use **German oak** for maturation, and the choice of wood may vary between distilleries. German oak can impart different flavours compared to other oak varieties.

While oak remains the primary choice, the specific characteristics of the wood whether sourced locally or internationally and the previous use of the cask (e.g. wine, sherry or port) contribute the diverse flavour profiles of whiskies from different regions. Distillers' experimentation with wood types and treatments is a key factor creating unique and innovative expressions of world whisky.

Chapter 5: Challenges and Future Trends

5.1 Sustainability and Sourcing

Sustainable wood practices in the whisky industry.

As environmental awareness increases, sustainable industry wood practices have become increasingly important. Distilleries recognize the need to manage wood resources responsibly.

Distilleries are increasingly focusing on sourcing wood from sustainably managed forests. This involves practices such as replanting trees to replace those harvested for cask production and ensuring the long-term health of the forests. Some distilleries seek wood from forests certified by organizations such as the Forest Stewardship Council (FSC). Their goal is to advance the sustainable, socially and economically profitable, and environmentally appropriate management of the world's forests. Since its establishment in 1994, FSC has developed into the most reputable and widely used forest certification scheme in the world. The certification confirms that wood from sustainably managed forests adheres to environmental and social guidelines. (FSC, 2022)

Distilleries may use reclaimed or repurposed wood for cask construction. Utilizing wood from old casks, furniture or other sources so reducing the demand for new timber and minimizing waste. Distilleries explore ways to recycle or repurpose casks that have reached the end of their useful maturation life. Reusing wood can help cut down on the quantity of wood that ends up in landfills. Utilising recovered wood also lessens the need for virgin wood, which saves deforestation. This wood doesn't need to be refined with chemicals that harm the environment because it has already been gathered and treated. (Theos Timber, 2018) Some distilleries opt for local wood species that are abundant and considered sustainable. Additionally, the use of invasive species for cask construction can contribute to ecological management by reducing the invasive impact on local ecosystems.

Smaller cask sizes have become popular for maturation. While this practice, often driven by the desire to accelerate the aging process, also reduces the amount of wood required for each cask making the process more resource-efficient. Experimentation with alternative wood types such as acacia or chestnut that are abundant and fast growing can contribute to sustainability. (Tao, García and Sun, 2013)

Distilleries work to optimize the use of wood during the barrel construction process, minimizing waste and maximizing the yield from each log. This includes the use of advanced technology and craftsmanship. The carbon footprint associated with the production and transportation of casks considered, with some distilleries sourcing wood locally to reduce the environmental impact of transportation. Ongoing research and innovation in cask construction techniques and alternative materials aim to develop more sustainable practices in the whisky industry. This includes exploring ways to extend the lifespan of casks and reduce environmental impact.

By adopting sustainable wood practices, the industry aims to balance the tradition of using wooden casks for maturation with a commitment to environmental stewardship. As consumer awareness of sustainability increases, distilleries continue to explore and implement practices that contribute to the long-term health of forests and ecosystems. The whisky industry faces several challenges related to wood sourcing for maturation. These challenges affect the availability, quality, and sustainability of wood. The global demand for whisky and other spirits is increasing, leading to a higher demand for wooden casks. This increased demand can put pressure on the supply chain, leading to challenges in securing a consistent and high-quality source of wood. Climate change can affect the growth and quality of trees.

The flavour profiles of the whiskies can be influenced by temperature fluctuations, rainfall patterns and extreme weather conditions that impact the growth rate and characteristics of trees.

Ensuring the sustainability of wood sourcing is a priority for the whisky industry. However, verifying and maintaining sustainable practices in forestry can be challenging, especially when dealing with complex supply chains and multiple suppliers. While certification programs like the FSC exist to promote sustainable forestry practices, verifying the certification of wood sources and ensuring compliance with sustainability standards throughout the supply chain can be logistically challenging.

Distilleries must adhere to various regulations and standards related to wood sourcing, such as restrictions on the use of certain types of wood or requirements for cask construction. Ensuring compliance with these regulations can be a complex task, particularly when sourcing wood internationally. Maintaining consistent wood quality is crucial for ensuring the desired flavour and maturation characteristics of whisky. Variability in wood quality, such as differences in grain tightness and chemical composition, can pose challenges for distilleries seeking consistency in their products.

Additionally, wood used for cask production competes with other industries, such as construction and furniture. High-quality wood suitable for whisky casks may become scarcer or more expensive due to increased demand from various sectors. Whisky maturation often requires several years sometimes decades. This long maturation time poses a challenge in forecasting future wood needs and ensuring a stable supply over extended periods, especially when demand for aged whiskies is high. The transportation of large and heavy wooden casks can be logistically challenging. Distilleries may face difficulties in transporting casks from the forest to the cooperage and then to the maturation warehouse, especially if located in remote or inaccessible areas. The spread of invasive species or diseases that affect trees impact the availability of suitable wood. Diseases like Dutch elm disease or invasive pests can devastate forests, affecting the quality and quantity of available wood. One of the most dangerous tree diseases in the world is Dutch elm disease. The disease is caused by a fungus that is dispersed by bark beetles. It causes leaf and tip dieback in all three of the principal native elms of Britain. (Forest Research, n.d.)

Addressing challenges require collaboration between distilleries, cooperages and forestry organizations. Sustainable and responsible wood sourcing practices, along with ongoing research and innovation are essential to ensuring the future success of the whisky industry and the quality of wood available to age.

5.2 Innovation and Experimentation

Trends in experimenting with new wood types.

Innovation and experimentation with new wood types have become prominent trends in the whisky industry as distillers seek to create unique flavour profiles and differentiate their products. Distilleries around the world are exploring a variety of wood types, including non-traditional options, to influence the maturation process and impart distinctive characteristics to their whiskies.

The raw distillate, and in particular the maturation conditions, play a significant role in the final flavour of the whisky. However, the type of wooden cask used for maturation appears to be the most important factor in determining the final flavour of a whisky. The type of wood used for maturation can affect the taste, colour, and aroma of the whisky. The effect of maturation depends on the nature of the whisky. In some cases, the wood contributes significantly to the flavour. In other cases, the whisky may have an already identifiable taste and the effect of maturation is less. The time needed to reach a satisfactory state of maturation is a financial and practical concern to the manufacturer and varies depending on the type of wood used. (MOSEDALE, 1995)

Acacia wood, has been experimented with for maturation. It is lighter and more porous than oak and has been used for sweet and white wines in France, Italy and Spain for many years. American winemakers have probably championed it the most, especially in white wines like pinot and sauvignon blanc. Some wineries also experiment with Riesling and Chardonnay. Apparently, Acacia emphasizes fruit and floral compositions without too much oak vanilla and tannins. Whiskies aged in acacia casks may display floral, herbal and sometimes fruity notes. Bushmills released a Distillery exclusive whisky matured in Acacia wood. (Anon, 2022)

Some distilleries have experimented with **chestnut** casks for maturation. Chestnut wood imparts earthy, nutty and aromatic qualities to the whisky, offering a distinct flavour profile. Released as part of the Defilement series, the 8-year-old whisky is finished in a new, charred chestnut octave cask. (Whisky Bargain, n.d.)

Cherry wood, known for imparting a subtle sweetness to the whisky can manifest as fruity and sometimes floral notes in the final product. It also contributes spicy and complex flavours.

These nuances can add depth and character to the overall flavour profile. Cherry wood may not have as much impact on the colour of the whisky as oak but can contribute to a rich and slightly reddish hue. More recently, distilleries such as Teeling and Mackmyra have a tendency to experiment with Cherry Wood. Teeling used it to make the ageing of the 15-year-old Irish Single Malt involved two stages: first in bourbon casks and then transitioning to virgin Cherry Wood casks. (Webbiz, 2021)

Ash wood is less common and generally considered to impart lighter flavours compared to oak. The wood may contribute more subtle and delicate notes to the whisky, making it an interesting choice for those seeking a different flavour experience. Ash wood has the potential to introduce herbal and nutty characteristics. These flavours can add complexity and a unique dimension to the overall taste. It allows a faster maturation process compared to oak and the porosity of the wood and interaction with the spirit can accelerate the extraction of flavours. While not as influential as oak in terms of colour, it can contribute to the whisky's appearance. The spirit may take on a lighter hue and interaction with ash result in a different visual aspect compared to traditional oak-aged whiskies.

Pear wood is uncommon in the whisky industry, primarily because it lacks certain characteristics that are desirable for aging and maturing whisky. The choice of wood for whisky casks is crucial, as it significantly influences the aroma, palate and overall standard of the whisky. Pear wood, is less porous limiting the ability to impart desirable characteristics to the spirit. Working together with the cooperage it came to the light that Pear wood barrels were not holding liquid the same way as other barrels. The experiment stopped and the conclusion was although the wood had very pleasant aroma it is not suitable for the whisky industry.

Innovative Toasting and Charring Techniques:

Table 6 : Summary of the effects of cooperage treatment on wood properties. (Thesis and Mosedale, n.d.)

Treatment	Treatment Effects			
	Tannins	Oak lactones	Other Extractives	Anatomical Properties
Seasoning	Decrease in soluble tannins during wood ageing widely reported.	Lactones reported to increase during wood ageing.	Conditions of drying reported to influence volatile constituents.	Decrease in moisture content to approximately 14% of dry weight.
Toasting	Decreases levels of ellagitannins through oxidation or hydrolysis reactions.	Heating may increase synthesis, but there will be loss through volatilising from the wood surface	Degradation of lignin leads to the formation of lignin derived compounds available for extraction. Levels of volatiles reported to increase.	At high temperatures physical degradation of the wood may occur. Effects will vary through the depth of the stave.
Charring	Decreases ellagitannins through the same reactions as occur in toasting	Conflicting reports about the effect on lactones.	Large amounts of furan and lignin derived compounds formed. Charred layer may also remove undesirable sulphur compounds.	Break up of wood structure near surface may allow easier penetration of new wood and extraction of compounds.

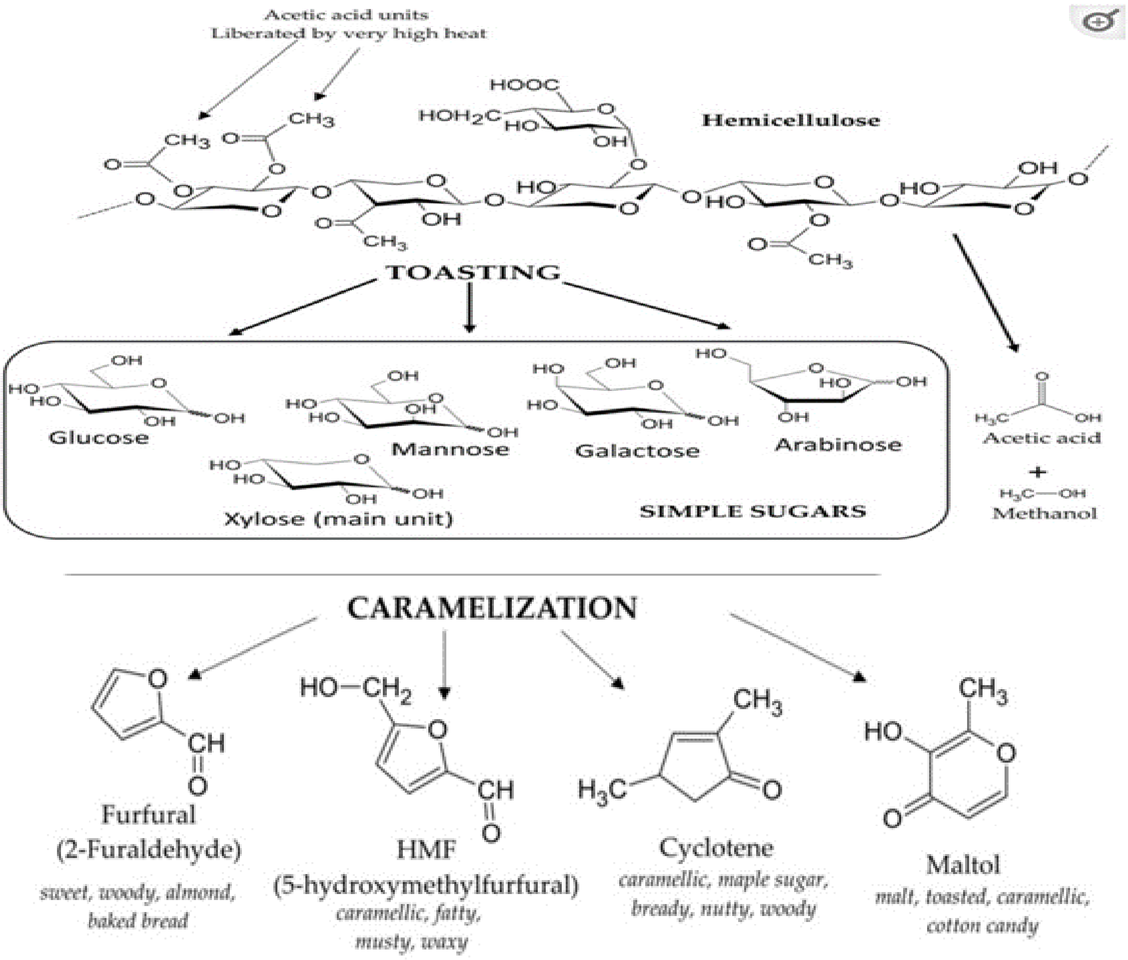


Figure 4 Structure of a hemicellulose molecule and the products liberated during toasting and caramelization processes (Tarko, Krankowski and Duda-Chodak, 2023)

Whisky derives primarily from barley in a process that includes mashing, fermentation, distillation and aging. It gets its final character from the compounds transferred from the wood into the spirit. Aging in oak barrels increases the antioxidant potential of whisky by increasing the concentration of phenols, furans and acid compounds. (Tarko, Krankowski and Duda-Chodak, 2023)

Distillers are exploring different toasting and charring techniques to enhance the influence of wood on the whisky. Variations in the intensity and duration of toasting and charring achieve specific flavour outcomes. (https://www.theglenlivet.com/en/, n.d.) It is important to mention that more you toast a barrel at high temperatures, more you will burn the wood, more colours you will extract. But it is also important depend of the wood and its concentration in total polyphenols (tannins, sugars from the wood: cellulose/hemicellulose, etc.) before the toasting. Large grains heavy toast will bring much more colour to the spirit than a tight grains heavy toast.

Some distilleries are experimenting with hybrid casks, combining different wood types or using casks made from staves of various woods. This approach allows for a multi-dimensional flavour profile resulting from the interaction of different wood influences. The KASC Project is a daring whisky-making project that bases its taste design and construction heavily on the provenance of wood. Portuguese oak, American oak, French oak, Hungarian oak, and chestnut are the five distinct tree varieties that go into making each hand-crafted 'hybrid' cask used to create whisky. This novel whisky has a multifaceted flavour and character that is enhanced by the distinct environment of each variety of tree, which contributes a totally new flavour variant. (kinahanswhiskey.com, n.d.) As well for example, **Cherry wood staves and American Oak tops**; this combination can create a whisky with a complex interplay of sweet, fruity, spicy, and vanilla notes.

The exploration of new wood types and maturation techniques are driven by the desire to create whiskies with diverse and unexpected flavour profiles. As consumers increasingly seek unique and distinctive expressions, distillers continue to push the boundaries of wood experimentation so contributing to the ongoing evolution of the whisky industry.

Collaborations between distillers and wood specialists have become a notable trend in the whisky industry. These partnerships aim to explore innovative maturation techniques and experiments with unique wood types, so creating distinctive flavour profiles.

The late Dr. Jim Swan, a respected whisky consultant, collaborated with Penderyn on various projects, including experiments with wood and maturation techniques. These contributing to the development of innovative expressions.

Collaborations between distillers and wood specialists continue to push the boundaries of what is possible in whisky maturation, resulting in a diverse array of unique and memorable expressions for consumers to explore. The **STR cask** is a style especially designed and optimised for maturation by the late Dr. Jim Swan. At the time, it was born from the need to re-use more wood from the abundance of old wine casks in Europe and America to produce single malt whisky. Originally used for the ageing of red wine (in our case, Spanish Rioja) and was coopered with American oak. After first application, our STRs are refurbished by J.Dias cooperage in Porto, Portugal (4th generation family business, now run by Sandra Dias). (Vaughan, 2022)

Wood specialists bring expertise in forestry, cooperage, and wood science. Their knowledge of different wood species, toasting and charring techniques and the impact of wood on whisky. They can advise distillers on sustainable wood practices, helping ensure responsible and environmentally friendly sourcing of wood for cask production. This may involve considerations such as replanting, forest management, and certification programs. The collaboration can innovate maturation techniques, including variations in temperature, humidity and airflow within maturation warehouses. These experiments aim to optimize the interaction between whisky and wood for unique flavour development.

Distillers benefit from the educational aspects of collaborations, gaining insights into wood science and maturation processes. The knowledge shared between distillers and wood specialists contribute to ongoing advancement of the industry. The Macallan collaborated with French cask maker Jean-Marc Paquet to create bespoke oak casks from the Vosges region in France so contributing to the distillery's Edition series. (Anon, n.d.) The craft of the cooper in opening up the wood is a vital component in accessing all of this valuable material.

It would be an interesting experiment to work closely with coopers to accumulate data to produce a comprehensive background of the capabilities of different wood types. At Penderyn, we are experimenting with wood types and their finishes. This is a fascinating creative process allowing distillers to explore unique flavour profiles and create distinctive expressions.

Focusing on Ash wood, Pearwood, Caucasian Oak, Carpathian Oak.

Ash trees are native to Europe. Certified wood from sustainable sources is used to make barrels. Light tones that range from yellowish to white-reddish are what define it. Having little tannins and powerful,honey-like aromas, it has a distinct tasting profile.

Figure 5 Ash Wood shavings

No unique volatile compounds were detected in the ash, because all the compounds in the ash were detected in at least one other tree, be it acacia, chestnut, cherry or oak. However, the quantitative differences can clearly be used to identify roasted ash, of which tyrosol is the most interesting because, although it is present in this wood and oak spice wood, after roasting it was found only in ash - 24.6 and 26.4 µg/g for oak species. In addition, this wood is quantitatively different and contains more certain volatile compounds than all reference woods (acacia, cherry, acacia), especially after roasting, including: catechol, 3-methylcatechol, homovanillyl alcohol, coniferaldehyde, 2-phenoxyethanol, 1 -hydroxyl. -2-butanone, 1-acetyloxy-2-butanone, γ-butyrolactone, solerone, 3,5-dimethylcyclotene, 4,5-dimethyl-2-cyclohexen-1-one, 2-furanmethanol, 3-ethylcyclotene, α-methylcrotonolactone , solerone and 3 -hydroxybenzaldehyde. Focusing on the volatile compounds desired by consumers, it was found that guaiacol, isoeugenol, syringol, and maltol, as well as vanillin, cystaldehyde, and acetovanillin were also abundant in ash wood at medium roast. Therefore, it is a wood with more volatile phenols after light and medium roasting (Figure 6c, d) and more phenolaldehydes/phenylketones after medium roasting (Figure 6d). However, furfural is quite low in wood and the concentration of furanic compounds is very low after all forest treatments (Figure 6 b-d). There are compounds that are not detected in ash wood but are present in traditional wood, such as trans- and cis-lactones, which are of great interest. Roasted ash seems more aromatic. (Martínez-Gil et al., 2022)

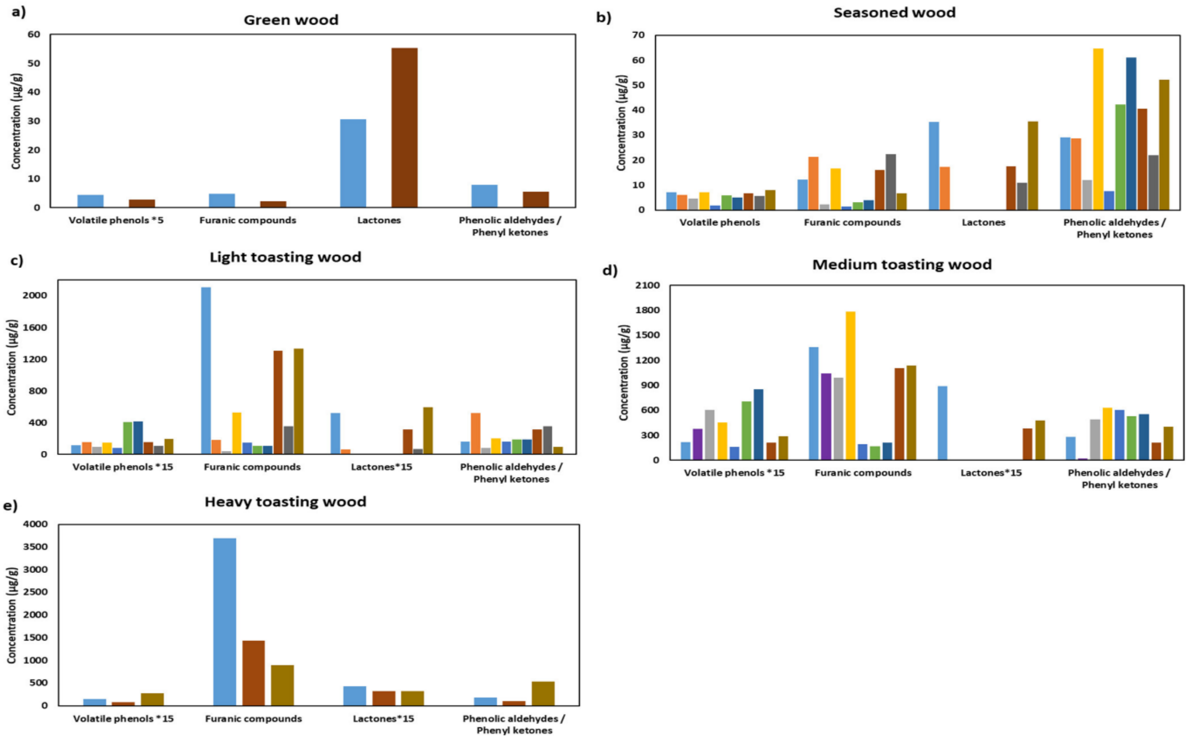


Figure 6 Graphical representation of the averages of the sum of the compounds in wood volatile phenols, furanic compounds, lactones and phenolic aldehydes/phenyl ketones by wood species, after the different cooperage treatments: (a) green, without treatment; (b) seasoned (carried out in oven and in open air); (c) light-toasted (light toasting, 190 °C for 10 min, 160–170 °C for 20 min and for 35 min); (d) medium-toasted (medium toasting, 180 °C for 45 min, 200 °C for 15 min and 35 min, 210 °C for 20 min and 45 min, and medium plus toasting); (e) heavy-toasted (heavy toasting and 250–260 °C for 27 min). (Martínez-Gil et al., 2022)

Ash wood in the industry is generally limited and often experimental specific releases or limited-edition expressions to explore the unique characteristics imparted by this wood type. It presents challenges, including potential brittleness and less flexibility compared to oak. These factors affect cask construction and the ability to shape it into traditional barrel forms.

As the whisky industry continues to embrace innovation and experimentation, some distillers may explore ash wood to create whiskies with distinct and unconventional profiles. Ash contributes a fresh, creamy floral profile with hints of spice. (nao-oak, n.d.) These experiments contribute to the diversity of offerings in the market. Ash wood may contribute to a sense of terroir, especially if the wood locally sourced. Distillers interested in highlighting the unique characteristics of a specific region explore the use of native wood types.

"Caucasian oak" typically refers to oak wood sourced from the Caucasus region, which includes countries such as Georgia, Armenia, Azerbaijan, and parts of Russia and Turkey. Oak from this region has gained attention in various industries, including the wine and spirits industry, for its distinct characteristics. The wood from Caucasian oak may have a unique pore structure, and the size and distribution of pores can impact its suitability for different applications, such as barrel making. Caucasian oak has been used in the wind industry, including brandies. The wood is valued for its potential to impart specific flavours and aromas to the beverages. Oaks from the Caucasus Mountains make excellent barrel wood with unique taste qualities. A protracted drying process ensures the highest quality prior to the start of the production process. These exceptional barrels shine because they have gentle tannins, unlike other oak, and they have fresh, fruity, and mineral tastes. (oakbarrels.shop, n.d.) The unique climate and soil conditions in the Caucasus region can influence the characteristics of the oak grown there. Factors such as terroir, similar to those influencing wine grapes, may play a role in the final profile of the wood.

Figure 7 Caucasian oak woodchips

The Carpathian Mountains span several countries in Central and Eastern Europe. The region is known for its diverse ecosystems and rich biodiversity. Historically, oak wood from the Carpathian region has been used in carpentry, construction, and furniture making. The region has a tradition of forestry, and oak is one of the hardwood species that grows in the area. Some distillers and producers may explore the use of oak from the Carpathian region for aging beverages. The unique terroir and climate of the region contribute distinctive characteristics to the wood. This variety of oak offers the wine or spirits a superb, well-balanced mouthfeel and flavour character. (nao-oak, n.d.) Oak trees on the foothills of the Carpathian Mountains yield a unique type of wood suitable for barrel manufacturing. Local specialists choose the wood for the casks very carefully. Aging in this wood improves the aromatic profile of all types of spirits and distillates.

Figure 8 Carpathian oak woodchips

Even if the Carpathian & Caucasian oak are the same varieties than the French oak; the profile is completely different, because of the impact of the « Terroir » (lowest temperature, with snow, different soils, climate & weather conditions different than in France…). Oak will always be less concentrate in tannins than the French oak but the profile is really interesting respecting much more the fruity notes from the alcohol.

Despite producing wonderful aromas and flavours, Apple and Pear wood are rarely used since they eventually lose their seal. Pearwood has a mild, round, acidic, and somewhat peppery fruitwood smoke taste. Although, flavours would contribute for the whisky, from the knowledge from the coopers about the lose their seal over time I decided not to include in the next step of the flavour experiment.

Figure 9 Pear wood shavings

Limited Use and Experiments:

Whisky enthusiasts seeking novel and unconventional flavours are intrigued by unique and experimental releases. It is essential to note that in the industry, the use of ash wood is not as widespread or traditional as oak. Oak highly favoured for its structural qualities and appealing flavours has an established historical use in maturation. However, as the industry continues to evolve and experiment it is possible that the use of alternative woods, including ash and others, may gain further exploration in the future.

Steps of experiment:

1. Obtain Wood Chips: Prepare Wood Chips: Ensure the chips are clean and free from any contaminants. Place Wood shavings in a dryer for 3 days evenly distributing moisture down to about 4% dry weight

2. Select Containers: Choose separate glass containers for each wood type, to ensure the flavours from different woods remain distinct.

3. Measure Wood Chips: A consistent amount of wood chips for each container. The amount depending on personal preference. A few grams per 100ml of base spirit is a reasonable ratio. In the container the wood communicates with the spirit, absorbing it and then releasing it. Be conservative and do not add too many shavings at once; less is more.

4. Add Base Spirit: In each container completely cover wood chips with New Make Spirit.

5. Tightly seal containers to prevent evaporation and contamination. One of the main disadvantages of using wood chips in containers is the lack of oxidation. This natural occurrence in aging spirits adds complexity and intensity to flavours and is largely responsible for the fruit, mint and spice

notes. The whisky can breathe inside the leak proof but porous cask, allowing oxygen to enter through its 'pipes'. Clearly the same cannot be said for any sealable glassware.

6. Allow Infusion: Place the containers in a cool, dark place and allow the wood chips to infuse the spirit. Shake containers gently every few days to enhance contact between the wood and spirit.

7. Taste Testing: After the desired infusion period, conduct taste tests to evaluate the flavours imparted by each wood type. Take notes on colour, aroma and taste characteristics.

Ash Wood results:

Aroma: Pure, light-yellow fruits, slightly sour, lemon, mango, powdered cream cookies, concentrated aromatic essential oils and fragrant lily. Just a little oily but smells nice and clean. There are small changes and layers without twists. High openness giving a high sense of pleasure.

Palate: Interesting, something different from the usual whisky. Sweet and juicy fruit jelly, some honey and cream embellishment. Displays a bigger body but is not heavy. However, it has an oily feel, slight herbal lemon grass with light spices.

Finish: The finish is medium; flavours focused on honey, herbal spice, nut and vanilla spice. Medium to slightly dry without noticeable astringency or bitterness.

Colour:

Figure 10 At the start of experiment, clear New Make Spirit and at the end a lovely yellow amber colour.

Carpathian Mountains oak results:

Aroma; A distinctly light and Penderyn-like nose with aromas of toffee and cake. Marzipan and almond flavour and a vanilla and creamy sugar undertone that totally reminds of Almond cakes.

Palate; All of these dessert-like flavours carry flavour. When it hits the lips, an extra bit of lemon-peal freshness but then the real treat comes at the end of the bite. A crazy liquorice meets cinnamon and almost cayenne spices and takes over all those appetizers. Generally sweet tastes.

Finish: These spicy notes also take over the finish complemented by a rich spicy touch. Not in a dominant or overwhelming sense. Simply bringing a fuller flavour profile to the table.

Colour:

Figure 11 At the start of experiment, clear New Make Spirit at the end a lovely deep copper colour.

Caucasian Mountains oak results;

Aroma: Wonderful sweet and fruity aroma, plum jam, banana bread, dark chocolate covered cherries, creamy coconut and refreshing mango cinnamon ice cream.

Palate: Meringue with mango coulis and fresh raspberries. The initial start replaced with matcha powder giving this dessert flavour a slightly spicy Asian touch.

Finish: Candied orange sticks and candied clementine with Moroccan spices.

Colour:

Figure 12 A clear New Make Spirit finishes as a pleasant burnished hue

Chapter 6: Conclusion

6.1 Summary of Findings

The use of different wood types in the whisky industry is a testament to the craftsmanship and innovation of the distilling community. From the vanilla sweetness of American oak to the intricate flavours of Ash tree casks, each wood type contributes to the symphony of tastes that make every whisky unique. As distillers continue to experiment and push boundaries, the influence of wood remains a cornerstone in the ever-evolving world of whisky production.

Today, whisky production has become a global industry with countries such as the United States, Canada, Japan, Wales, Israel and others producing high-quality whiskies. Craft distilleries have also emerged contributing to a diverse and dynamic whisky market.

Experimenting with different types of wood in whisky production can yield a wide range of flavours and characteristics, ultimately contributing to the diverse and evolving landscape of the whisky industry.

The choice of wood significantly influences the flavour profile of whisky. Different wood types, such as oak, cherry, chestnut, ash wood and others, impart unique characteristics, ranging from sweetness and spiciness to nuttiness and fruitiness. While oak remains the traditional and predominant wood for whisky maturation, distillers and cooperages are increasingly experimenting with unconventional woods. These experiments aim to push boundaries, create distinct flavour profiles and offer consumers novel and exciting whisky experiences.

Oak is popular for its versatility and ability to offer a wide variety of flavours. The toasting and charring processes used in oak casks play a crucial role in shaping the final taste and colour of the whisky. Processes like STR (Shaved, Toasted, and Re-charred) display how innovations in barrel construction techniques can influence maturation. These methods aim to rejuvenate barrels and extract unique flavours from the wood. Distilleries may release unique expressions or limited editions that highlight the impact of different wood types. These releases provide enthusiasts with an opportunity to explore and appreciate the nuances brought about by experimental wood choices.

Some wood types, such as Ash Tree have different porosity and tannin levels, potentially leading to accelerated maturation. This characteristic affects the aging process resulting in whiskies with distinct profiles in a shorter period. New distillers engaging in wood experiments meticulously document their processes, wood choices and the aging duration. This information serves as a valuable resource for learning and refining techniques in subsequent experiments. The use of different wood types in whisky production represents a dynamic and creative aspect of the industry. As distillers continue to innovate, whisky enthusiasts can anticipate a continued expansion of flavour possibilities and an evolving appreciation for the art and science of wood influence in whisky maturation.

6.2 Implications for the Whisky Industry

The investigation of several wood species for whisky ageing offers numerous useful ramifications for distillers, offering chances for uniqueness, distinction, and catering to changing consumer tastes. Distillers can innovate and produce distinctive whisky expressions by utilising the knowledge they have gathered through experimenting. In a crowded market, this innovation can help distilleries stand out and draw in customers looking for unique tasting sensations. Distillers employ a variety of wood varieties to produce speciality or limited-edition products. These expressions spark interest among aficionados and end up as collector's items.

Understanding the impact of different woods allows distillers to tailor flavour profiles of their whiskies. Specific wood types chosen to enhance certain characteristics, whether it is emphasizing sweetness, add spiciness or introduce unique fruity notes. Experimentation that accelerates maturation can be practical for distillers looking to produce high-quality whiskies in a shorter period. This is particularly useful for meeting demand or releasing products sooner. Knowledge of wood interaction enables distillers to optimize their barrel management processes and informed decisions made on barrel reuse, maturation times or implementing toasting and charring techniques. Distillers use experiments as a tool for consumer education. Sharing the details of wood choices, maturation processes and the resulting flavour profiles can engage consumers and deepen their understanding and appreciation of whisky.

Keeping an eye on market trends and consumer preferences is crucial. Experimenting with different wood allows distillers to respond to changing consumer tastes and preferences thus staying relevant in a dynamic market. Distillers can explore the use of alternative and sustainable wood sources for barrel construction so aligning with the industry's focus on environmentally friendly practices.

The affects of wood are further refined by collaboration with cooperages, researchers, and other industry specialists. It may result in the exchange of knowledge and the creation of fascinating new wood-related inventions. Distillers are able to preserve process consistency through meticulous recording of wood tests. Knowing the behaviour of various woods allows for more control over the finished result, guaranteeing a dependable and superior output.

In conclusion, experimenting with various wood kinds has more uses in the whisky industry than only developing new flavours. Utilising this information strategically will allow distillers to fulfil consumer needs, innovate, and add to the general growth and vibrancy of the whisky market.

With the evolution of the whisky industry, research will continue to explore how wood affects the maturation and flavouring of whisky in the coming years.

1. Regional variations in wood characteristics and their influence on flavour profiles. Considering factors such as climate, soil composition and tree growth conditions.
2. The role of microorganisms, including yeast and bacteria, in the interaction between wood and whisky during maturation. Understanding microbial dynamics may provide insights into the development of unique flavour compounds.
3. Genetic variations in oak and other wood species and their influence on the compounds extracted during maturation. This could lead to the development of wood types specifically bred or selected for whisky maturation.
4. The effects of wood treatment techniques, such as varying levels of toasting, charring or innovative use of ultrasound or pressure treatment. Determine how these processes influence the extraction of compounds and change the resulting flavour profile.
5. Methods for accelerating maturation while maintaining quality. This includes exploring the use of smaller cask sizes, increased wood surface area and other techniques to achieve desirable flavour development in a shorter time.
6. Sustainable practices for wood sourcing. This includes alternative wood types, barrel reuse and assessing the environmental footprint of different wood-related practices.
7. Conduct studies on consumer preferences related to wood influences in whisky. Use sensory analysis to identify key attributes that appeal to consumers and guide distillers in creating products that align with evolving market tastes.

8. In-depth chemical analyses of the compounds extracted from different wood types during maturation. This can provide a comprehensive and chemical understanding of the specific compounds contributing to flavour, aroma and colour in whisky.
9. The interaction of different wood types in various distillation processes (pot, column and hybrid stills). How wood influences integrate during fermentation and distillation.
10. Long-term effect of various woods over extended maturation periods to understand how certain profile characteristics develop and mature with time.
11. Collaboration between distillers, cooperages, researchers and other stakeholders to share insights and knowledge. A collaborative approach can accelerate research efforts and lead to innovations in wood-related practices.

Continued research in these areas deepen our understanding of the complex interactions between wood and whisky, allowing further innovation and refinement of high quality and diverse whiskies.

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Module Code: ACFA7004

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Research proposal Different type of wood in whisky industry by Aista Phillips Student Number: 2126964

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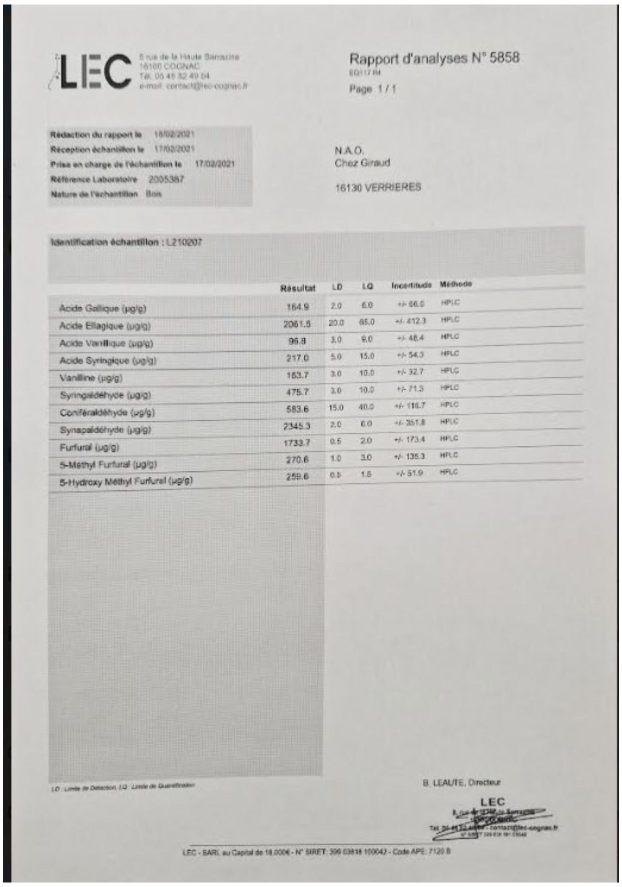
Appendices

Appendix A- 2 analyses of wood chips sampled from the inside of 2 different new oak barrels:



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Rapport d'analyses N° 5858
EQ117 R4
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Rédaction du rapport le 18/02/2021
Réception échantillon le 17/02/2021
Prise en charge de l'échantillon le 17/02/2021
Référence Laboratoire 2005387
Nature de l'échantillon Bois

N.A.O.
Chez Giraud

16130 VERRIERES

Identification échantillon : L210207

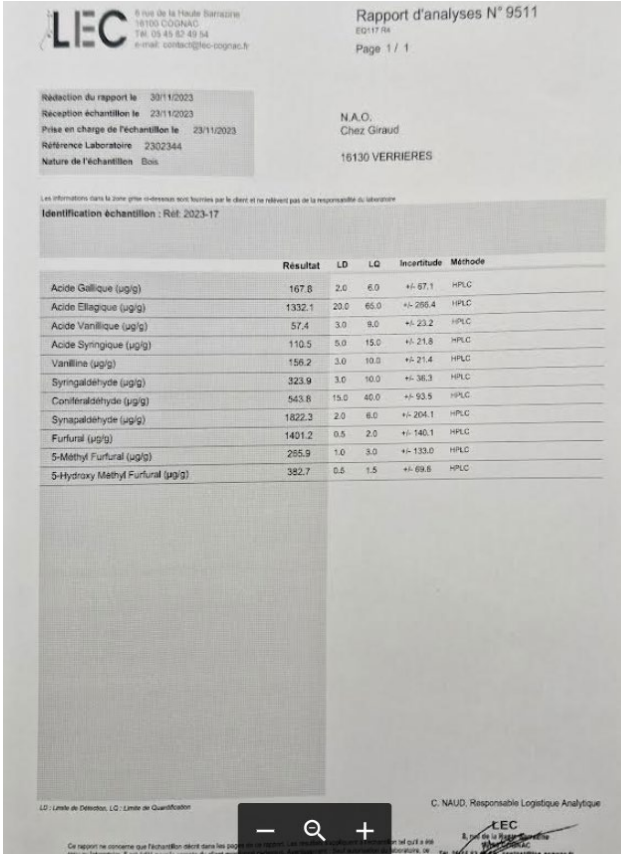
	Résultat	LD	LQ	Incertitude	Méthode
Acide Gallique (µg/g)	164.9	2.0	6.0	+/- 66.0	HPLC
Acide Ellagique (µg/g)	2061.5	20.0	65.0	+/- 412.3	HPLC
Acide Vanillique (µg/g)	96.8	3.0	9.0	+/- 48.4	HPLC
Acide Syringique (µg/g)	217.0	5.0	15.0	+/- 54.3	HPLC
Vanilline (µg/g)	163.7	3.0	10.0	+/- 32.7	HPLC
Syringaldéhyde (µg/g)	475.7	3.0	10.0	+/- 71.3	HPLC
Coniféraldéhyde (µg/g)	583.6	15.0	40.0	+/- 116.7	HPLC
Synapaldéhyde (µg/g)	2345.3	2.0	6.0	+/- 351.8	HPLC
Furfural (µg/g)	1733.7	0.5	2.0	+/- 173.4	HPLC
5-Methyl Furfural (µg/g)	270.6	1.0	3.0	+/- 135.3	HPLC
5-Hydroxy Méthyl Furfural (µg/g)	259.6	0.5	1.5	+/- 51.9	HPLC

LD : Limite de Détection, LQ : Limite de Quantification

B. LEAUTE, Directeur

LEC - SARL au Capital de 18.000€ - N° SIRET: 390 03818 100042 - Code APE: 7120 B

• French oak barrel – 24 months of maturating



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Rapport d'analyses N° 9511
EQ117 R4
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Rédaction du rapport le 30/11/2023
Réception échantillon le 23/11/2023
Prise en charge de l'échantillon le 23/11/2023
Référence Laboratoire 2302344
Nature de l'échantillon Bois

N.A.O.
Chez Giraud

16130 VERRIERES

Les informations dans la zone grise ci-dessous sont fournies par le client et ne relèvent pas de la responsabilité du laboratoire

Identification échantillon : Réf: 2023-17

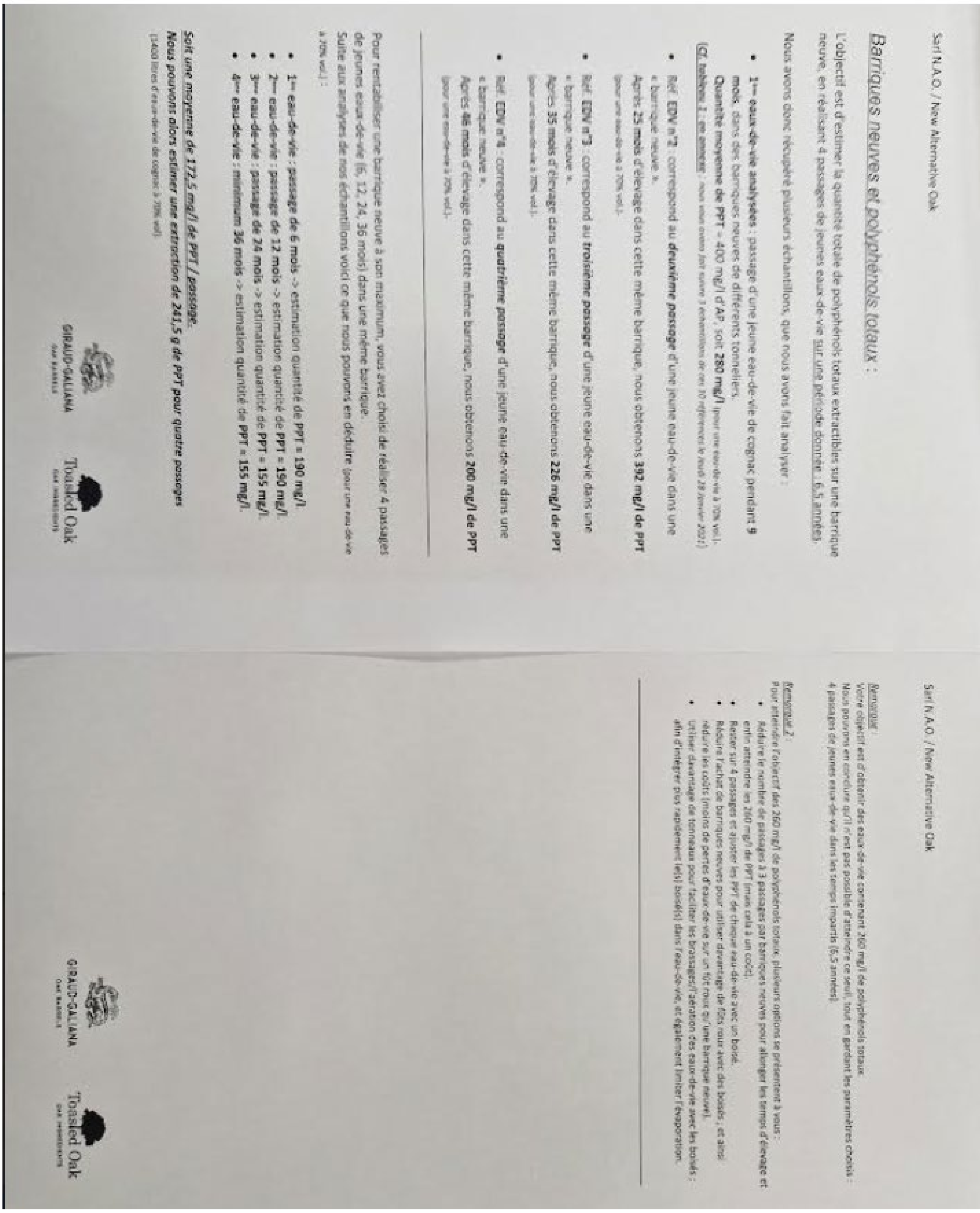
	Résultat	LD	LQ	Incertitude	Méthode
Acide Gallique (µg/g)	167.8	2.0	6.0	+/- 67.1	HPLC
Acide Ellagique (µg/g)	1332.1	20.0	65.0	+/- 266.4	HPLC
Acide Vanillique (µg/g)	57.4	3.0	9.0	+/- 23.2	HPLC
Acide Syringique (µg/g)	110.5	5.0	15.0	+/- 21.8	HPLC
Vanilline (µg/g)	156.2	3.0	10.0	+/- 21.4	HPLC
Syringaldéhyde (µg/g)	323.9	3.0	10.0	+/- 36.3	HPLC
Coniféraldéhyde (µg/g)	543.8	15.0	40.0	+/- 93.5	HPLC
Synapaldéhyde (µg/g)	1822.3	2.0	6.0	+/- 204.1	HPLC
Furfural (µg/g)	1401.2	0.5	2.0	+/- 140.1	HPLC
5-Méthyl Furfural (µg/g)	265.9	1.0	3.0	+/- 133.0	HPLC
5-Hydroxy Méthyl Furfural (µg/g)	382.7	0.5	1.5	+/- 69.6	HPLC

LD : Limite de Détection, LQ : Limite de Quantification

C. NAUD, Responsable Logistique Analytique

•Carpathian Oak – 24 months of maturating

Appendix B- Analysis « how to optimize the purchase of a new barrels », with several filling but respecting our goal, reaching a certain concentration of tannins (+/- the same concentration per filling) every time.



Sarl N.A.O. / New Alternative Oak

Barriques neuves et polyphénols totaux :

L'objectif est d'estimer la quantité totale de polyphénols totaux extractibles sur une barrique neuve, en réalisant 4 passages de jeunes eaux-de-vie sur une période donnée : 6,5 années.

Nous avons donc récupéré plusieurs échantillons, que nous avons fait analyser :

- **1ères eaux-de-vie analysées** : passage d'une jeune eau-de-vie de cognac pendant **9 mois**, dans des barriques neuves de différents tonneliers.
  Quantité moyenne de PPT = 400 mg/l d'AP, soit **280 mg/l** (pour une eau-de-vie à 70% vol.).
  (Cf. tableau 1 : en annexe : nous vous avons fait suivre 3 échantillons de ces 10 références le Jeudi 28 Janvier 2021)
- Réf. EDV n°2 : correspond au ***deuxième passage*** d'une jeune eau-de-vie dans une « barrique neuve ».
  Après **25 mois** d'élevage dans cette même barrique, nous obtenons **392 mg/l de PPT** (pour une eau-de-vie à 70% vol.).
- Réf. EDV n°3 : correspond au ***troisième passage*** d'une jeune eau-de-vie dans une « barrique neuve ».
  Après **35 mois** d'élevage dans cette même barrique, nous obtenons **226 mg/l de PPT** (pour une eau-de-vie à 70% vol.).
- Réf. EDV n°4 : correspond au ***quatrième passage*** d'une jeune eau-de-vie dans une « barrique neuve ».
  Après **46 mois** d'élevage dans cette même barrique, nous obtenons **200 mg/l de PPT** (pour une eau-de-vie à 70% vol.).

Pour rentabiliser une barrique neuve à son maximum, vous avez choisi de réaliser 4 passages de jeunes eaux-de-vie (6, 12, 24, 36 mois) dans une même barrique.
Suite aux analyses de nos échantillons voici ce que nous pouvons en déduire (pour une eau-de-vie à 70% vol.) :

- **1ère eau-de-vie : passage de 6 mois** -> estimation quantité de **PPT = 190 mg/l**.
- **2ème eau-de-vie : passage de 12 mois** -> estimation quantité de **PPT = 190 mg/l**.
- **3ème eau-de-vie : passage de 24 mois** -> estimation quantité de **PPT = 155 mg/l**.
- **4ème eau-de-vie : minimum 36 mois** -> estimation quantité de **PPT = 155 mg/l**.

Soit une moyenne de 172,5 mg/l de PPT / passage.
Nous pouvons alors estimer une extraction de 241,5 g de PPT pour quatre passages (1400 litres d'eaux-de-vie de cognac à 70% vol).

GIRAUD-GALIANA OAK BARRELS — Toasted Oak OAK INGREDIENTS

Sarl N.A.O. / New Alternative Oak

Remarque :
Votre objectif est d'obtenir des eaux-de-vie contenant 260 mg/l de polyphénols totaux.
Nous pouvons en conclure qu'il n'est pas possible d'atteindre ce seuil, tout en gardant les paramètres choisis : 4 passages de jeunes eaux-de-vie dans les temps impartis (6,5 années).

Remarque 2 :
Pour atteindre l'objectif des 260 mg/l de polyphénols totaux, plusieurs options se présentent à vous :

- Réduire le nombre de passages à 3 passages par barriques neuves pour allonger les temps d'élevage et enfin atteindre les 260 mg/l de PPT (mais cela à un coût).
- Rester sur 4 passages et ajuster les PPT de chaque eau-de-vie avec un boisé.
- Réduire l'achat de barriques neuves pour utiliser davantage de fûts roux avec des boisés ; et ainsi réduire les coûts (moins de pertes d'eaux-de-vie sur un fût roux qu'une barrique neuve).
- Utiliser davantage de tonneaux pour faciliter les brassages/l'aération des eaux-de-vie avec les boisés ; afin d'intégrer plus rapidement le(s) boisé(s) dans l'eau-de-vie, et également limiter l'évaporation.

GIRAUD-GALIANA OAK BARRELS — Toasted Oak OAK INGREDIENTS

Appendix C - Document is talking about « wood extraction » and the different ways you can use to reach your goal; concentration in tannins, esters, wood aromatics compounds (aldehydes, furanes…) by using new oak barrels or used/exhaustive oak barrel or alternative products (liquid oak/oak concentrate)

Noms / Parametres	F200358	F200359	F200360	F200361	F200362	F200363	F200364	F200365	F200366	F200367
	g/hl d'AP	g/hl d'AP	g/hl d'AP	g/hl d'AP	g/hl d'AP	g/hl d'AP	g/hl d'AP	g/hl d'AP	g/hl d'AP	g/hl d'AP
Ethanal	1.6	1.3	2.3	2.4	2.2	2	2.1	2.1	2.5	1.7
Isobutanal	0.8	0.7	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.9
Formiate d'ethyl	0.9	0.9	1.4	1.4	2.1	2.1	2	1.2	1.1	0.8
Acetate d'ethyl	35.1	31.4	37.3	35.6	36.4	37.6	37.1	34	36.5	36.4
Acetal	1.6	1.3	3.2	3.5	3.2	2.8	3.1	3.2	3.3	2.3
Methanol	35.4	31	35.5	36	35.4	35.9	35.9	32.9	34.8	34
Butyrate d'ethyl	0.2	0.2	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.2
Butanol 2	0	0	0	0	0	0	0	0	0	0
Propanol	28.6	25.7	29	28.4	27.8	28.5	28.4	26.8	28.1	29.1
Isobutanol	68.8	61.1	69.5	67.9	66.8	68.1	68.6	63.8	67.5	75
Acetate isoamyle	3	2.9	2.6	2.8	2.7	2.9	2.6	2.4	2.8	3.3
Alcool allylique	0	0	0	0	0	0	0	0	0	0
Butanol 1	0.3	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.2	0.3
Methyl2Butanol 1	46.7	42.3	46.7	47	45.7	45.7	46.4	43.6	45.7	49.9
Methyl3Butanol 1	188.3	169.2	188.2	188	185.1	187.1	189.9	179.3	188	201.9
Caproate d'ethyl	0.9	0.7	0.8	0.8	0.7	0.8	0.9	0.8	0.8	0.6
Acetoïne	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Acetol	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Triethoxy-1.1.3 propane	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Lactate d'ethyl	15.3	14.4	14.4	15.8	15.3	15.2	15.2	14.2	15.4	15.6
Hexanol	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.8	0.9	1.1
Cis 3hexenol-1	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Caprylate d'ethyl	38.4	40.5	22.7	14.9	28.6	34.7	30.2	14	24.1	8.6
Furfural	7.5	8.4	4.7	5.2	9.8	12.5	12.8	4.3	3.8	2.3
Butanediol-2,3 levo	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Butanediol-2,3 meso	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Caprate d'ethyl	14.6	13.1	14.6	15	14.4	14.6	14.8	13.8	14.3	14.1
Succinate d'ethyl	0.3	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.4	0.3
Laurate d'ethyl	8.4	7.2	7.7	7.6	8	7.8	8.1	7.4	8.2	7.7
Phenyl ethanol	1.7	1.5	1.5	1.5	1.5	1.7	1.5	1.4	1.5	1.5
isopentanols	235	211.5	234.9	235	230.8	232.8	236.3	222.9	233.7	251.8
aldehydes	**2.2**	**1.8**	**3.5**	**3.7**	**3.4**	**3.0**	**3.3**	**3.3**	**3.7**	**2.6**
Somme des alcools sup	**264**	**237**	**264**	**263**	**259**	**261**	**265**	**250**	**262**	**281**
Somme des esters	**61.4**	**60.8**	**45**	**37.5**	**51.0**	**57.1**	**53.1**	**35.2**	**46.6**	**30.4**