

# DESIGN MY BARREL

*Reference Handbook*



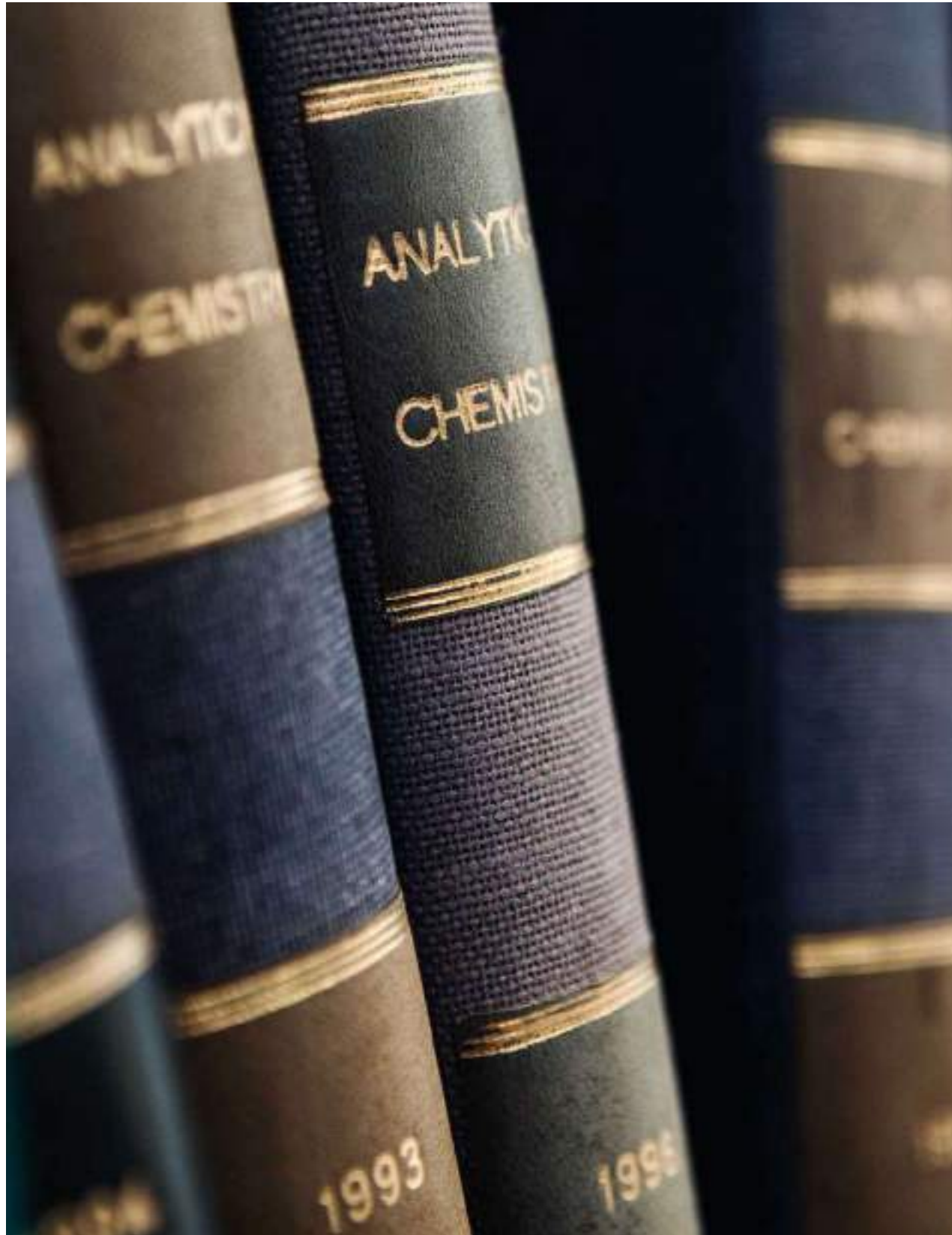
DEMPOTOS

# EDITORIAL

With DesignMyBarrel by Demptos, the traditional barrel becomes a powerful ageing tool. The distiller now has the power to select a customized profile of their barrels. Using the combined experience and expertise of the teams at Demptos, the Speyside Cooperage and the Demptos Research Center, this Reference Handbook is a concise distillation of the core knowledge and key issues at the heart of quality cooperage. This guide is here to help you design and configure the perfect barrels for your spirits. It contains everything you need to know about the key factors affecting spirit ageing. The user can take this knowledge and adapt their barrel resources to suit their objectives, from structure and colour to bouquet and flavour development. When you understand the material, the interactions between the wood and the liquid and the alchemy of spirit ageing, you can define the outcome. Together, we can stay on the same page and speak the same language, adapting and modulating our expertise into something truly personalised: a barrel in your image.

**Welcome to the barrel designers' family !**

**François Witasse**  
Chief Executive Officer



# PREFACE

The relationship that sets between whisky and wood over the years in the warehouse is fascinating: as much for the spirit-maker to see his precious liquid develop and evolve, as for the spirit-lover to discover the sensory diversity that emanates from his glass, and as for the scientist who observes, analyses, and interprets the complexity of the interactions over time.

Therefore, without removing from the maturation process its share of magic and mystery, this handbook aims to provide a better understanding of the subtle marriage between wood and spirit. Through this scientific guide, the Demptos Research Center wishes to share with you its expertise on the intrinsic properties of oak wood, in order to understand how these physicochemical parameters condition the spirit's organoleptic quality, and this throughout the maturation process.

My experience in applied research in the wine and spirit field reinforces my belief that creating a unique and authentic product requires a certain degree of knowledge of what is happening at molecular level. This integrates various fundamental notions, such as how volatile compounds make up aromas, how polymers evolve in colour and taste perception, and how their mixture affects the human sensation. This scientific vision is essential to master the evolution of spirits in casks, and thus adapt the maturation conditions to create the most favorable environment for the optimal expression of their aging bouquet ... especially since the possible combinations of maturation for spirits are, most of the time, limited only by the producer's imagination!

I will therefore let you browse through these different chapters that I enjoyed writing, with the aim of making the scientific approach of barrel maturation both accessible and useful for distillers. Hoping, ultimately, that it will arouse your curiosity and meet your needs, questions, and expectations.

Dr Magali Picard  
R&D Manager  
Demptos Research Center



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CHAPTER 1

# THE OAK WOOD STRUCTURE

Historically, barrels were made of the most abundant wood in the area where they were produced and their manufacture was very much conditioned by the development and needs of the shipping industry. For this reason, many woods from different species of trees have been used in cooperage, but nowadays barrels are almost exclusively made of oak wood.

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# Why oak wood for spirit casks?

The wood used in the manufacture of barrels should have a straight grain in its pieces, be free of defects that may cause leaks, and it must not contribute unpleasant flavours. In addition, it should be thermoplastic, allowing wood bending using heat, which is an essential operation in the manufacture of the barrel. The typical anatomy of oak offers greater resistance, flexibility, easy-handling to bending, high stability, and low permeability in relation to those provided by other woods. It also contributes to a wide variety of desirable flavours, and its porosity allows the oak extractives to be more accessible.

## IN QUERCUS WE TRUST!

Oak belongs to the *Quercus* genus, which contains over 500 species, mainly growing in the northern hemisphere. The *Quercus* genus is subdivided into two subgenera, *Cyclobalanopsis* and *Euquercus*: the first includes tropical species and some from Asia and Malaysia not used in the manufacture of barrels, while those within the subgenera *Euquercus* are used in cooperage. Nowadays, three species of oak practically monopolize the market: they belong to the genus *Lepidobalanus*: *Quercus petraea* (*Quercus sessile* or *sessile oak*), *Quercus robur* (*Quercus pedunculata* or *pedunculate oak*) and *Quercus alba*. In recent years, forests in Hungary, Romania, Russia, or Iberian Peninsula, have started to be exploited, which has led to even more types of oak on the market. Even so, most oak barrels are currently French or American in origin. Consequently, it can be asserted that the term "American oak" refers exclusively to *Quercus alba*, while the term "French oak" includes two species, *Quercus robur* and *Quercus petraea*.

## FRENCH (EUROPEAN) OAKS

Forests cover 27% of the total area of France, and approximately 9% of these are oak forests. The main oak producing areas in France are Limousin, which is the principal producer of *Quercus robur*, and Nevers, Allier, Tronçais, Centre, Vosges, Bertrange, and Jupilles, which produce *Quercus petraea*.

## AMERICAN OAK

In the United States, the main oak production areas are the forests of Virginia, Missouri, Minnesota, Pennsylvania, North Carolina, California, and Oregon. Although *Quercus alba* is the main oak species produced for cooperage, *Quercus macrocarpa* and *Quercus muehlenbergii* are also used, albeit to a lesser extent.

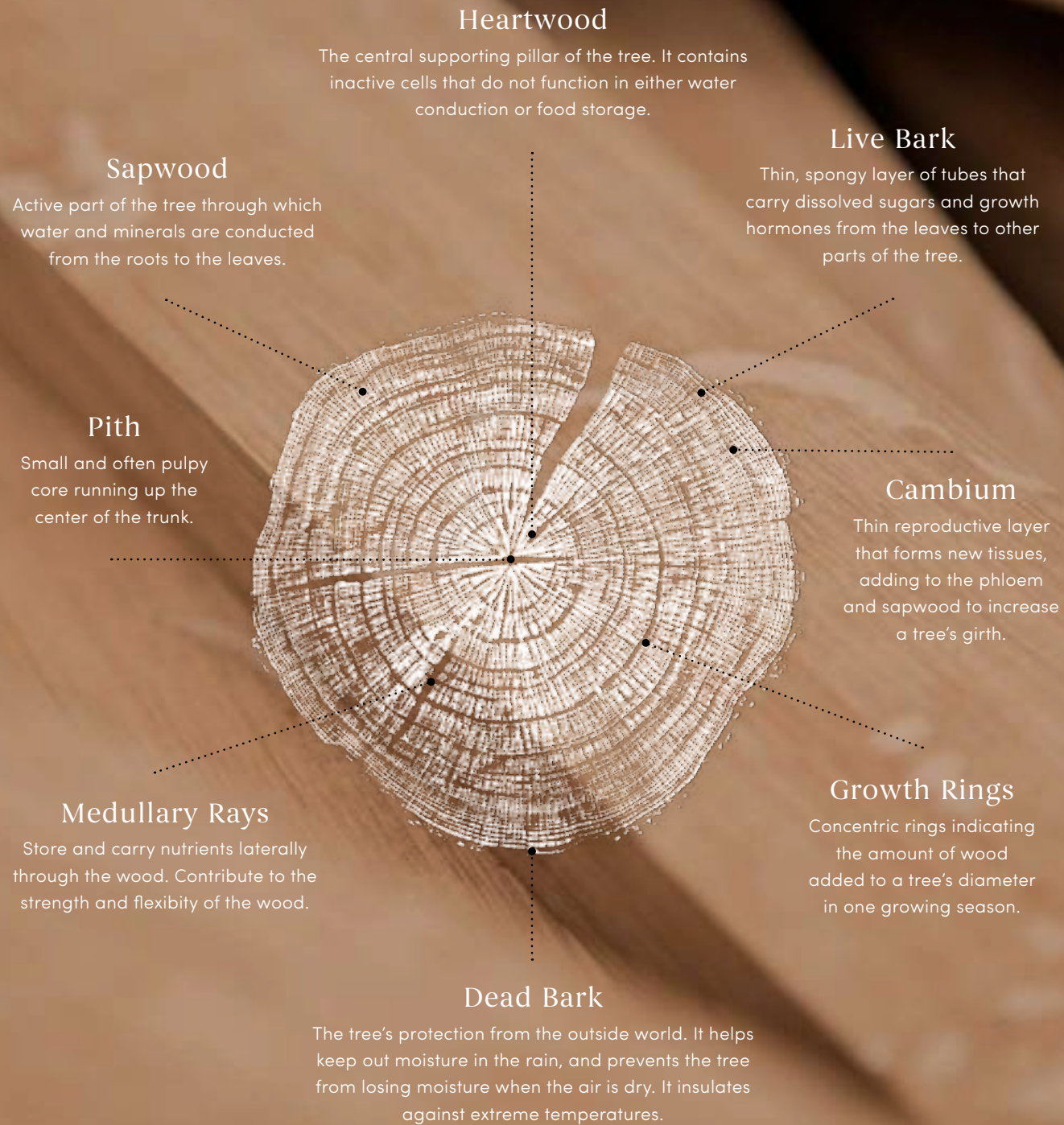


France



United States of America





# The oak trunk composition

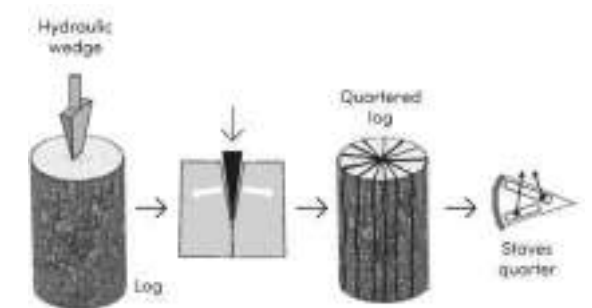
## HEARTWOOD AND SAPWOOD

During the growth of the tree, the older living and active sapwood cells die and become heartwood. Heartwood (or duramen) is the central core of the trunk. It can be distinguished from the sapwood by its darker color. Compared to sapwood, heartwood is more durable and less subject to attack by certain insects. It is less permeable to liquid and contains more valuable extractable materials, such as tannins. In contrast, sapwood has a relatively high moisture content, shrinks and moves considerably when dried, and is more susceptible to decay and staining by fungi. It is also free from odour and taste.

## STRUCTURE DIFFERENCES BETWEEN AMERICAN AND FRENCH OAKS

American oaks have higher density and resistance and lower porosity and permeability than European species. American woods have also larger tyloses, which allows this wood to be cut by sawing without compromising the water tightness. In contrast, European oaks have vessels more permeable to liquids, increasing the risk of leakage in the barrels. Thus, two different techniques are used for obtaining staves in cooperage: hand splitting for French oaks, and sawing for American oaks. When by splitting it is impossible to obtain more than 25% of staves from a log, the sawing can give more than 50%. For this reason, American oak barrels are much less expensive to produce.

## Wood cutting techniques for obtaining staves



### HANDSPLITTING

Medullary rays of staves are parallel to the contact surface with the spirit:  
**low risk of leaking**



### SAWING

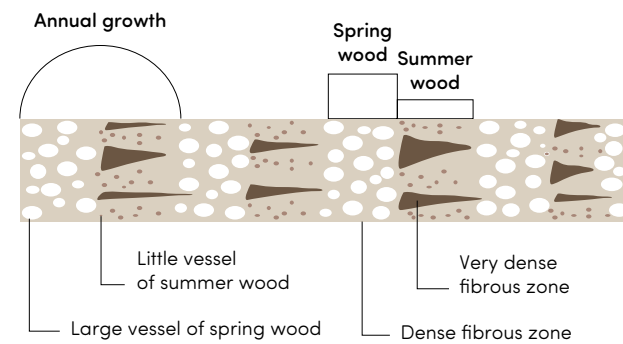
Medullary rays of staves are oblique to the contact surface with the spirit: **high risk of leaking except with large tyloses**

# The concept of oak grain

One of the most important characteristics of the wood used in cooperage is its grain, which depends to a great extent on the botanical and geographical origin of the trees. In cooperage, grain refers to the size and regularity of the tree's annual growth circles. The heartwood is composed of the succession of spring wood (large vessels and porous) and summer wood (few and small vessels, denser) layers which make up the annual growth rings.

The size of the grain affects the oxygen transfer. In short, more oxygen enters when the grain is smaller. The size and regularity of the grain depend on the species of oak, but also on the edaphoclimatic conditions of the terrain in which it is planted. It can also vary significantly among trees within the same forest. It is generally accepted that *Quercus petraea* has a fine grain, *Quercus robur* a medium to coarse grain and finally American Oak (*Quercus alba*) has a fine to medium grain although it tends to be more variable.

Oak woods are classified according to the grain size as fine, medium or coarse. The size of the grain is linked to the proportion of summer wood, depending on the tree's growth rate.



Slow growth > Thin summer wood layer > Fine grain  
 Fast growth > Large summer wood layer > Coarse grain

	Grain size	Structure	Porosity
<b>FINE GRAIN</b>	1-2 mm	Major part of spring wood, large vessels	Highest permeability to oxygen
	> French oak QUERCUS PETRAEA		
	> American oak QUERCUS ALBA		
<b>MEDIUM GRAIN</b>	2-4 mm	Balance between summer and spring wood layers	Intermediate permeability to oxygen
	> French oak QUERCUS ROBUR		
	> American oak QUERCUS ALBA		
<b>COARSE GRAIN</b>	4-5 mm	Major part of summer wood layer, little vessels	Lowest permeability to oxygen
	> American oak QUERCUS ALBA		





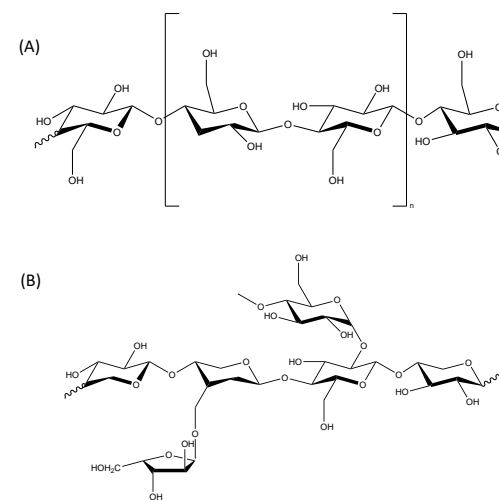
# Oak wood molecular profiling

Oak wood contains many chemical constituents that contribute to the complexity of spirit odour and flavour. A sound understanding of the oak derived compounds and their effect on the spirit sensory properties is essential to get a successful maturation in wood casks. Two major chemical categories of compounds are identified: the polymers (polysaccharides, lignin, and hydrolysable tannins) which are high-weight and non-volatile molecules and the aroma compounds, low-weight and volatile molecules.

## POLYSACCHARIDES

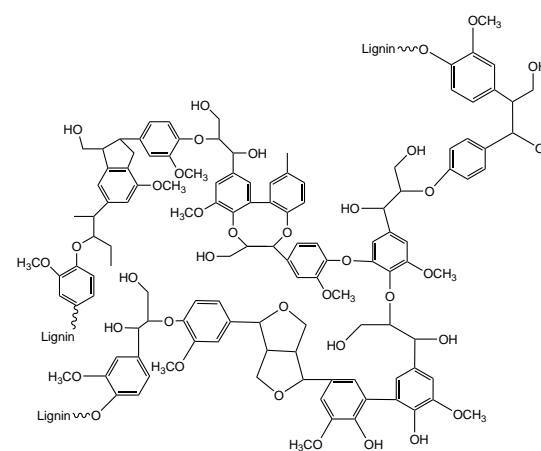
Cellulose is the most abundant component of wood. It is made up of glucose units forming a long structural polymer. 40 to 50% of cellulose are in crystalline form and contribute to the wood strength. Hemicellulose, is made up of sugars, mostly pentoses and hexoses. It acts as a binding agent, holds cellulose and lignin together.

General chemical structures of (A) cellulose and (B) hemicellulose



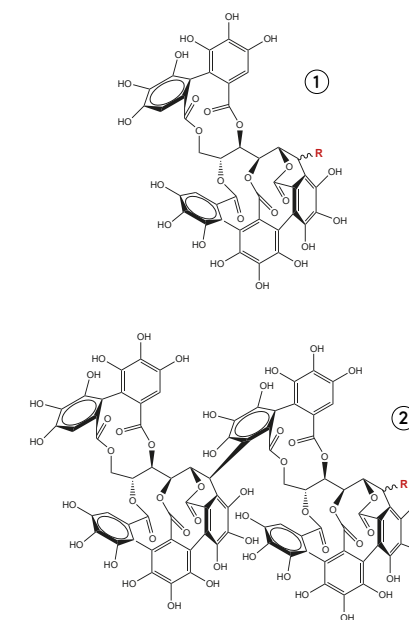
## LIGNIN

Lignin is the third major component of wood. It has a complex tridimensional structure, composed of syringil and gaiacyl units. It improves the wood impermeability and allows the stave bending.



## HYDROLYSABLE TANNINS

They are mainly gallotannins and ellagitannins, which release phenolic acids after acid hydrolysis (gallic acid and ellagic acid, respectively). The most abundant ellagitannins in oak wood are castalagin and vescalagin, which represent between 40% and 60% of the total. Ellagitannins are known to be powerful oxidable and antiradical compounds and contribute to oxydo-reduction reactions.



①	R	②	R
Castalagin	$\alpha$ - OH	Roburin A	$\alpha$ - OH
Vescalagin	$\beta$ - OH	Roburin D	$\beta$ - OH
Grandinin	$\beta$ - Lyxose	Roburin B	$\beta$ - Lyxose
Roburin E	$\beta$ - Xylose	Roburin C	$\beta$ - Xylose

## ALL OF THE WOOD POLYMERS HAVE A SENSORY IMPACT ON SPIRIT

**A direct impact on the flavour :** Since they are partially soluble in ethanol, all polymers increase the warm impression of alcohol, softness and thickness. Ellagitannins also contribute to the astringency perception.

**A direct impact on the colour :** Ellagitannins and lignans derived from lignin contribute to the coloured nuances of whisky.

**An indirect impact on the aroma :** By thermal pyrolysis during the barrel-making process, both polysaccharides and lignins are degraded into a large range of aroma compounds.

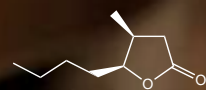
### Four main chemical compounds

are initially present in oak wood and are found in several mg/L in matured whisky. Vanillin, eugenol and isoeugenol are also formed during the toasting process, by thermal degradation of lignin. Other key aroma compounds from wood are terpenes and norisoprenoids, which actively participate in freshness nuances, tobacco, spicy and floral notes.

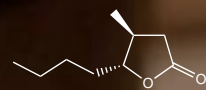
## Coconut

AROMAS

**Whisky lactones** / First identified in whisky and then in oak wood, they are present in the form of two isomers (*cis* and *trans*) and responsible for the coconut aromas. The *cis* isomer has a much lower perception threshold than the *trans* one, making its contribution to coconut perception in whisky much more intense.



Cis-whisky lactone

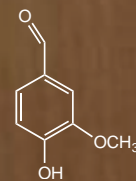


Trans-whisky lactone

## Vanilla

FLAVOUR

**Vanillin** / This phenolic aldehyde contributes to the vanilla flavour of whisky.

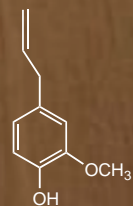


Vanillin

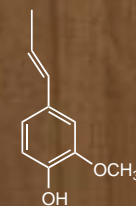
## Clove

NUANCES

**Eugenol and isoeugenol** / They are responsible for clove typical nuances. They have low perceptive threshold (7 µg/L in 40% of ethanol solution) and thus a strong aroma impact.



Eugenol



Isoeugenol

A sound understanding of the oak derived compounds and their effect on the spirit sensory properties is essential to get a successful maturation in wood casks.

### VARIATION WITHIN SPECIES

By now, it is clear that the species of oak and its forest of origin are the main factors to take into account when choosing a barrel. Some specificities and differences are observed in the molecular composition of the three most common species used in cooperage.

**Quercus robur** provides the highest levels ellagitannins and the lowest concentrations of whisky lactones, eugenol, and vanillin.

**Quercus alba** provides the lowest levels of ellagitannins and the highest levels of vanillin and whisky lactones. Moreover, American oak has levels of more than 90% for the most aromatic *cis* isomer of whisky lactones, which increases the impact of coconut notes.

**Quercus petraea** provides intermediate levels ellagitannins, whisky lactones, and vanillin. In contrast, it provides the highest levels of eugenol.

Differences in chemical composition are also related to the grain size: the higher the grain size, the lower the release of aroma compounds and the higher the release of ellagitannins. Overall, these specific structural and chemical features of oak species lead to a different but complementary impact on whisky maturation.

AMERICAN OAK Quercus Alba	FRENCH OAK Quercus Petraea	FRENCH OAK Quercus Robur
Highest aroma impact	High content of aroma compounds	Low content of aroma compounds
Low level of ellagitannins	Intermediate level of ellagitannins	Highest level of ellagitannins
Fine to medium grains: <b>medium oxygen permeability</b>	Fine grains: <b>highest oxygen permeability</b>	Coarse grains: <b>lowest oxygen permeability</b>
Strong <b>aroma</b> impact	<b>Complexity</b> and <b>balance</b>	Strong <b>structure</b> impact



# THE

1 / OAK IS THE MOST WIDELY USED VARIETY OF WOOD used in barrel-making as its typical anatomy offers resistance and easy-handling. Its chemical composition also favorably modifies the sensory characteristics of the whiskies.

2 / THREE MAIN OAK SPECIES are used in cooperage: *Quercus alba* (American oak), *Quercus robur* and *Quercus petraea* (European or French oaks).

# OAK

3 / DUE TO ITS POSITIVE PHYSICAL AND CHEMICAL STRUCTURE, heartwood (or duramen) is considered as the best part of the trunk for cooperage applications.

4 / THE NOTION OF GRAIN is crucial and refers to the size and regularity of the tree's annual growth circles. According to the grain size, oak can be classified as fine, medium or coarse grain. The grain size directly affects the oak wood permeability to the oxygen as well as its chemical composition.

# WOOD

5 / THE FLAVOUR OF THE MATURED WHISKIES is influenced by the presence of many volatile and non-volatile oak wood extractives. The main components of green oak wood are vanillin, whisky lactones, eugenol and isoeugenol for aromas; polysaccharides, lignin and ellagitannins for structure, gustatory and colour properties.

6 / OAK SPECIES PRESENT SEVERAL DIFFERENCES in both their structure and sensory potential. *Quercus alba* is marked by a distinct coconut aromas, a low ellagitannins content and a medium permeability to oxygen. In contrast, *Quercus robur* with its coarse grains is less porous and aromatic, and contains high level of ellagitannins. Due to its fine grains, *Quercus petraea* presents the highest porosity, and has a good sensory balance of aroma and ellagitannins compounds.

# STRUCTURE

01  
Timber Selection

02  
Splitting or sawing

03  
Seasoning

04  
Raising

05  
Heat Treatment

05  
Head assembly  
& Integrity

06  
Cask using

CHAPTER 2

# THE BARREL MAKING PROCESS

## IMPACT ON THE WOOD CHEMISTRY AND SENSORY PROPERTIES

Green wood cannot be used for cooperage since it contains between 40 and 60% humidity and its extractable compounds are not compatible with the objective of improving the quality of spirits. The wood process during barrel-making includes a series of stages that influence the structure and the final chemical composition of the wood. In this workshop session, a specific attention will be paid on the 3 main steps affecting the composition of the oak wood: the seasoning, the heat treatment and the re-use of casks.



# Expression of the oak potential by natural seasoning

The drying process has a great impact on the quality of the whisky, because it determines to a large extent what the wood releases during ageing. Wood seasoning in cooperage usually happens under natural conditions: after cutting, the staves are stacked on pallets and dried in the open air during a variable time period between 18 and 36 months. During natural seasoning the staves are washed by rainwater and dried by the sun until they have

the right level of moisture needed to mould them and give the barrel its characteristic shape. Thus, seasoning allows reduction of the high percentage of humidity in wood until it is in balance with the ambient humidity: the humidity in the wood decreases from 70-80% to ideally 15-18% at the end of drying. During this process, oak wood goes through dehydration and rehydration phases. This constant humidity thus reduces the risk of fissures appearing in the stave.

## The natural seasoning conditions improve the oak wood properties used in cooperage

### IMPACT OF CLIMATIC FACTORS

The geographical site where the wood is seasoned does not significantly influence the drying speed. However, the volume of precipitations and its annual distribution condition the feasibility of air-drying. In case of rainfall, only the wood surface is rehydrated. The ideal conditions are met for oceanic climates and continental climates with oceanic margins.

### ENZYMATIC ACTIVITY

During seasoning, the surface of staves is covered by a fungal flora. Only 3 fungi species are resistant to wood matrix toxicity. They also resistant to high temperatures (> 40°C) and quite low hygrometry (35 to 65%). These micro-organisms penetrate through micro-cracks in the wood depth and release different enzymes that directly affect the wood composition, by degrading some substances and transforming others.

### IMPACT ON ELLAGITANNINS COMPOSITION

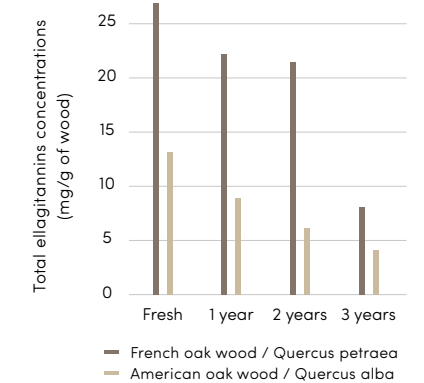
The loss of hydrosoluble polyphenolic substances, such as ellagitannins, is due to various physical and chemical mechanisms, including: **Stave leaching**, they are carried away by rainwater / **Hydrolytic oxidative degradation**, leading to a polymerization of ellagitannins / **Fungal enzymatic activity**, which degrades the ellagitannins structure. This contributes to a decrease in astringency and bitterness.

### IMPACT ON AROMA COMPOSITION

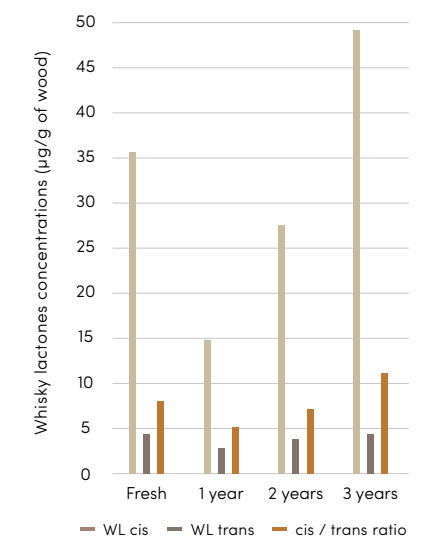
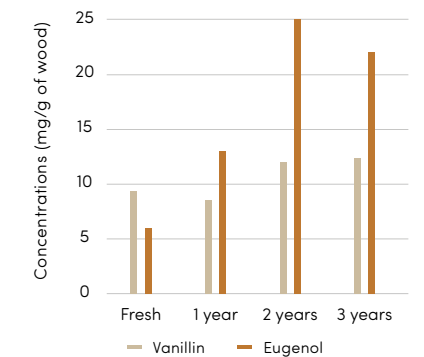
Natural seasoning also has a significant effect on the aromatic profile of wood. Phenolic aldehydes (such as vanillin) and eugenol usually increase their concentrations in wood during natural seasoning. They are released from lignin degradation by either an enzymatic or a chemical process. Whisky lactones levels increase thanks to the enzymatic activity of micro-organisms. The trans-whisky lactone content is quite stable whereas cis-lactone increases, leading to a higher organoleptic impact. Natural seasoning also leads to a significant reduction of off-flavours, by decreasing the content of some aldehydes responsible for sawdust and herbaceous notes of the green wood.

Overall, natural seasoning, through various chemical and biochemical processes, contributes to improve the oak wood quality. It can be accelerated by artificial drying which simply consists of dehydrating the wood in drying chambers. However, the natural air-dried oak has a greater maturation potential than kiln dried oak, since it has a higher impact on the wood composition (higher levels of aroma congeners lower ellagitannins content).

Evolution of ellagitannins content during natural seasoning



Evolution of main wood aroma compounds during natural seasoning



The combination of various chemical reactions during toasting produces a large range of complex aromas. This increases the aromatic potential of wood.

**HEAVY TOASTING**

Empyreumatic and roasted aromas. Low level of ellagitannins.

**LIGHT TOASTING**

Freshness and spicy aromas. High level of ellagitannins.



**MEDIUM TOASTING**

Complex, sweet, spicy and toasted aromas. Balance of soft ellagitannins.

# The heat treatment as flavour influencer

**TOASTING**

This operation consists of two stages. During the first stage, called bending or cintrage, the heat of the open fire increases the flexibility of the staves which allows the winch to bend the staves until they form the characteristic shape of the barrel. The second stage, properly named toasting or bousinage, changes the wood chemical composition and physical structure.

Despite the diversity of toasting protocols, the toasting level is usually classified as: light, medium and heavy. Toasting temperatures in Demptos cooperage generally vary between 110 and 230°C. Medium +, a specific level of medium toasting also exists. The intensity of heating naturally affects the compounds produced from the degradation of wood macromolecules.

During the toasting process, a variety of pyrolysis reactions take place, producing the degradation of wood polymers. The thermodegradation of lignin mainly leads to the formation of phenolic aldehydes and volatile phenols. The thermodegradation of lipids and glycosidic esters also conducts to an increase of whisky lactones. The degradation of polysaccharides leads up to furanic aldehydes, and allows the Maillard reaction, which produced a large panel of aromatic heterocyclic molecules with roasted notes.

Higher level of volatile phenols are obtained at heavy toasting, due to the degradation of syringaldehyde and vanillin. Whisky lactones are found to decrease as barrel toasting temperatures increase. The heat treatment also exerts a significant influence on total ellagitannin concentration: the higher the toasting level, the lower the total ellagitannin concentration. This drastically reduces the astringency sensations.

Chemical process	Polymers / precursors	Aroma products
<b>THERMODEGRADATION &amp; PYROLYSIS</b>	Cellulose & Hemicellulose	Furanic aldehydes
	Lignin	Phenolic aldehydes Volatile phenols Phenolic ketones
	Glycosilated precursors	Whisky lactones Tabanone
<b>MAILLARD REACTION</b>	Sugars & Amino acids	Furanic aldehydes N-heterocycles

## Rejuvenation of casks does not perfectly recreate the initial sensory properties of wood

### CHARRING

Charring occurs at higher temperatures (> 280°C) and refers to the development of a charcoal layer. The charring process has three main effects:

**Filtration:** the creation of the well-known active carbon layer that adsorbs undesirable aromatic substances, such as sulfur compounds.

**Penetration** of the whisky deep inside the wood through the cracks caused by the flame, leading to more reaction with the uncharred oak.

**Extraction:** the release of several aromatic molecules during maturation is affected by a higher production of volatile phenols and a decrease of whisky lactones and ellagitannins extractive content.

### A GRADIENT IN THE WOOD DEPTH

According to the toasting level, changes in the wood ultrastructure occur at the inner surface of the staves but also in deeper layers:

**A smooth and vitreous aspect** on the surface at medium toasting, leading to weaker permeability of the first surface layers.

**The formation of cracks** at heavy toasting and charring, leading to an increased penetration by the distillate.

The intensity of toasting also impacts the aroma composition of wood in the deeper layers: differences in composition take place throughout the thickness of the stave, depending upon the thermal stability of various extractive precursors. For example, at medium toasting, lignin break-down products are at their maximum at the surface of the stave, while whisky lactones are found at higher concentration in the middle of the stave. With heavy toasting, wood composition can be influenced up to a depth of 6 mm.



The association of a toasting and a charring improves the wood sensory potential overtime

**Short**  
MATURATION

**Toast&Char® #1**  
Sweet and spicy bouquet  
(tobacco, cinnamom, vanilla, cloves, caramel)

**Toast&Char® #2**  
Roasted bouquet  
(Pecan nuts, roasted peanut, liquorice, smoke)

**FRENCH OAK**

**Toast&Char® #1**  
Complex bouquet combining spices with toffee, moka and chocolate notes

**Toast&Char® #2**  
Deep and intense roasted bouquet

**Long**  
MATURATION

**AMERICAN OAK**

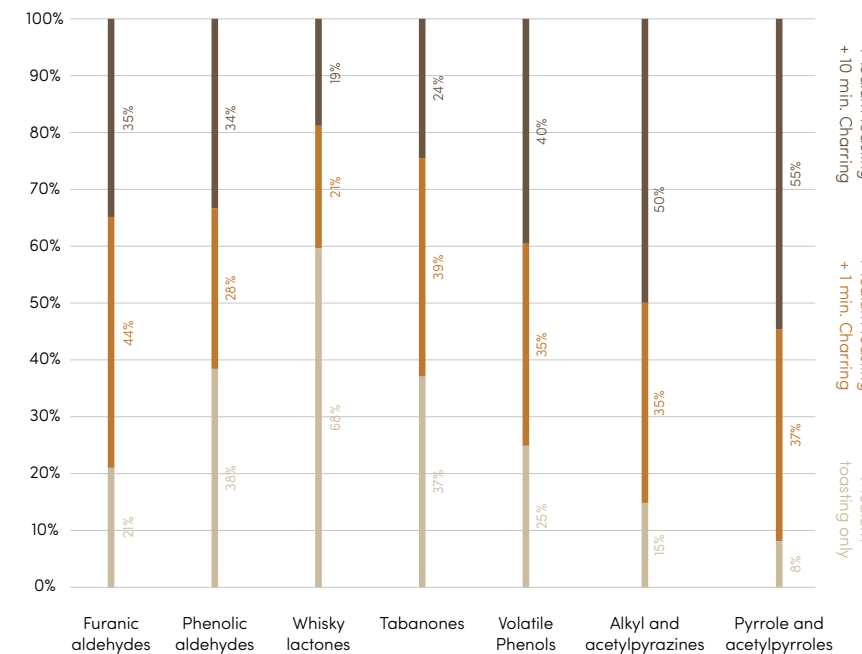
**Toast&Char® #1**  
Sweetness and roundness bouquet characterized by a large diversity of spices and aromatics

**Toast&Char® #2**  
Bouquet dominated by the coconut and vanilla sweetness balanced by subtle roasted notes

**THE TOAST&CHAR® PROCESS:  
REVEALING THE AROMA COMPLEXITY OF OAK WOOD**

Charring and toasting are not mutually exclusive since combining these two kinds of heat treatment offers a dual advantage on both surface and deeper in the wood. Recent experiments performed in the Demptos Research Center revealed that the application of a medium toasting following by a charring increases the aromatic complexity of the oak wood. Roasted and smoke notes are particularly enhanced, and well-associated with the coconut and spicy sensory profiling. This is mainly due to the production of volatile phenols, pyrazines and pyrroles derivatives during the charring, which perfectly balances the level of whisky lactones and tabanones brought by the medium toasting.

In Demptos cooperage, we developed two Toast&Char® styles. Indeed, we observed that charring time also presents a significant impact on the sensory and chemical profiling of the oak wood, and thus on the typical whisky aromatic bouquet over the cask maturation. Whatever the oak species considered (French or American oak), applying a short charring (1 min) to a medium toasted oak wood gives a singular spicy and sweet bouquet, while a long charring (10 min) gives higher perception of chocolate, liquorice, and roasted hazelnuts aromas.



In a deeper wood layers (until 10-mm depth), chemical differences are observed depending both on the oak species and the charring time used. This offers a large range of possibilities for diversifying the typical whisky ageing, specifically for a long maturation upon wood (more than 5 years).

**RE-USING CASKS  
FOR WHISKY MATURATION**

Casks are re-used for maturation until the ability to mature the spirits is considered lost by the distiller. However, the levels of many cask extractives decline with re-use and thus strongly influences the quality and speed of whisky maturation.

Decline in cask viability led to the adoption of various methods of rejuvenation, such as scrapping and re-charring. This allows the release of aroma compounds from the deeper layers of the staves. However, neither whisky lactones nor ellagitannins are regenerated. In contrast, whiskies stored in new casks are richer since they contain congeners (aroma compounds and ellagitannins) originating both from the inner (charred) layer and the new wood directly under the char layer. With heavy toasting, wood composition can be influenced up to a depth of 6 mm.



# THE

1 / THE PROCESS DURING BARREL MAKING in cooperage includes a series of stages that influence the quality of oak wood, especially seasoning and toasting.

2 / IN ADDITION TO DECREASE THE MOISTURE CONTENT of oak wood, natural seasoning also results in the wood maturation. By means of changes in its chemical composition, it decreases bitterness and astringency, and increases aromatic properties.

# BARREL

3 / NATURAL SEASONING IS PREFERRED TO ARTIFICIAL DRYING since the enzymatic activity observed during natural seasoning contributes in a large part to the sensory potential of oak wood.

4 / TOASTING CHANGES BOTH THE QUALITY AND THE QUANTITY of extractable compounds in oak wood used for whisky maturation. Toasting increases the aromatic potential of the wood, since new aroma compounds with various nuances are formed.

# MAKING

5 / THE HIGHER THE TOASTING LEVEL THE HIGHER THE SMOKED AROMAS and the lower astringency. Medium toasting is a good compromise to increase the whisky complexity and preserve the sensory balance.

6 / COMBINATION OF TOASTING AND CHARRING PROCESSES can lead to higher aroma complexity in the wood's depth, since aroma compounds are easily accessible by the distillate through the cracks during maturation.

# PROCESS

7 / EVEN REJUNEVATED "used" wood is less efficient than new wood in integrating the whisky's components and that make it more complex.



DEMPOTOS

Making barrels since 1825.

30 years of Research to pair tradition and innovation.

Your best partner for ageing.

## CHAPTER 3

# THE SPIRIT AGEING BOUQUET

## A MULTISENSORY EVOLUTION

The appreciation of whisky character is a synergistic and holistic perceptual process, combining extrinsic (branding, labelling, marketing, packaging) to intrinsic (aroma, taste, mouthfeel, appearance) attributes. Whisky tasting is thus a multimodal experience where gustatory, olfactory, visual, environmental, and mood cues can all play a role in determining our perception of what we drink.

More than a sum of individual component perceptions, whisky should be considered as a whole. Especially as its sensory balance including taste, colour and aroma, is of key importance for determining its complexity. Maturation accounts among the most important factors influencing the quality of whiskies and thus the consumer appeal. The colour changes from clear to golden brown, the taste becomes smooth and mellow, and the flavour and aroma become

complex and pleasing. The evolution of sensory profile of the maturing spirits is due to changes in the composition and concentration of volatile and non-volatile components released during maturation upon wood. These changes integrate several kinds of chemical reactions either in the wood or the distillate, but also involve physico-chemical interactions between them.

# WHISKY GLASS

## Ear

Ambiance: Noise, Lighting,  
Motion, Smells

## Hand

Weight, Texture, Temperature

## Eye

Colours, Legs, Presentation

## Nose

Aroma

## Mouth

Taste, Mouthfeel, Astringency, Viscosity,  
Sweetness, Burn, Temperature

## Brain

Experience, Mood, Expectation,  
Health, Genetics, Focus

TASTE

# Aromatic aspects

## A THREE-STEP MATURATION

*The composition of a matured whisky is the result of complex interplays between the various contributions from each step involved in the production process including cereals malting, distillation, and barrel aging. The impact of oak wood on the distillate is decomposed on several kinds of maturation phenomena.*

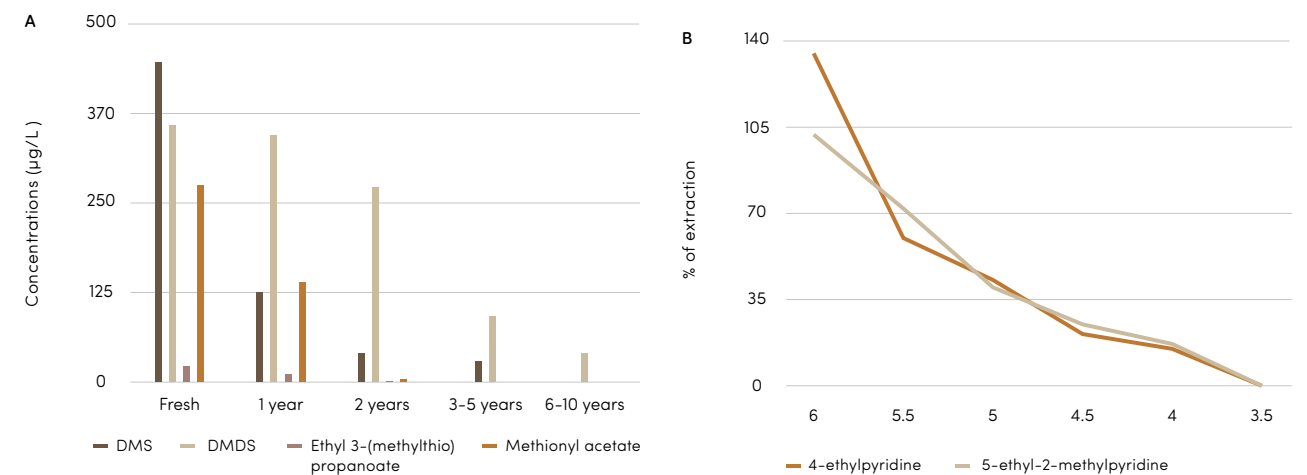
### SUBSTRUCTIVE MATURATION

It corresponds to the loss or suppression of aroma compounds. Sulfur compounds, which give unpleasant aromas of cabbage, are removed from the distillate since they are oxydised into sulfoxides by ellagitannins and the charring process. Moreover, the pH decrease during maturation leads to the protonation of pyridines responsible to fishy and solvent notes. Acidity thereby lowers their volatility and their aroma impact in a matured whisky.

**“A combination of individual aromas to form a blended complex.”**

*Dr. Jim Swan*

Decrease of (A) sulfur compounds and (B) pyridines over maturation



**Additive maturation** corresponds to the extraction of aroma compounds from oak wood to distillate.

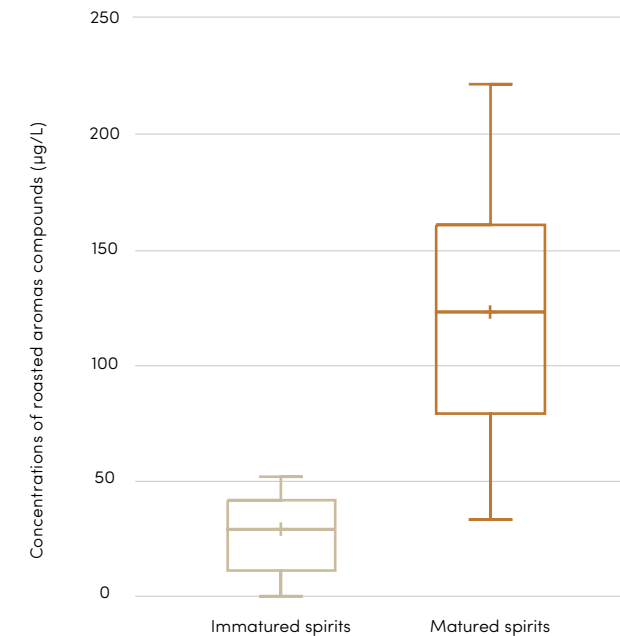
**Spicy and smoke** / This is mainly due to the degradation of lignin during the toasting step of the barrel-making process and in the ethanol phase of the distillate. This leads to the formation of several furanic and phenolic aldehydes as well as volatile phenols, responsible to a large palette of spicy and smoke notes.

**Coconut** / The amount of total whisky lactones is highly influenced by storage time in wood with an increase over the maturation period. Highest extraction efficiency for whisky lactones is achieved for alcohol content in distillate up to 40% and higher ratio for the cis-whisky lactone in spirits matured in American oak casks was found.

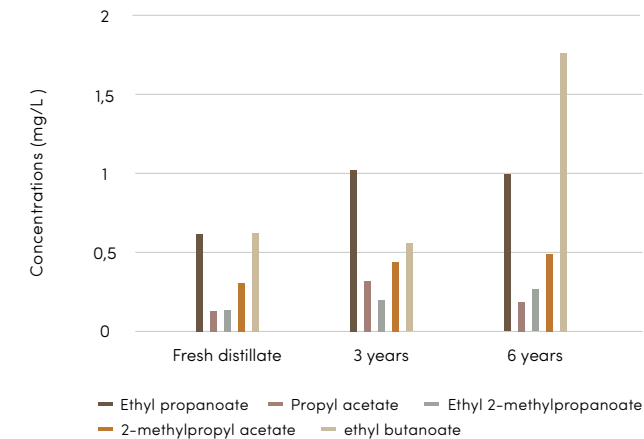
**Floral** / Oakwood with pink tones are rich in carotenoids and present a high aromatic potential. Indeed, the degradation of carotenoids during the natural seasoning and toasting step allows the formation of norisoprenoids. These new aromatic compounds, offering pleasant spicy, and floral notes are easily transferred to whisky during maturation.

**Roasted** / The content of pyrroles and pyrazines, formed during malting and distillation increases during the maturation. By transferring them to the spirit, wood acts as an enhancer of the roasted derived nuances.

Increase of roasted aromas compounds in spirit over wood maturation



Evolution of some fruity esters over whisky maturation upon wood



### INTERACTIVE MATURATION

Corresponds to reactions occurred between wood and distillate components. Such reactions are typified by esterification, due to the reaction between free acids and ethanol, acetic acid of wood and higher alcohols of distillate. Aromatic acids extracted from the cask wood such as syringic and vanillic acids are also known to form ethyl esters during maturation with woody notes. The increase in quantity and multiplicity of esters enhances the fruity, floral and creamy characters of the whisky.

Although oak is traditionally associated with woody, spicy, or toasted aromas, its aromatic contribution extends far beyond these familiar registers. During maturation, the wood releases also a variety of volatile terpenoids and norisoprenoid compounds capable of imparting floral and mint nuances to the spirit.

These molecules are not only extracted from the oak but also participate in a series of transformation and condensation reactions that occur during maturation in oak cask. Their behaviour is dynamic: some are gradually liberated from the wood structure, while others are formed through oxidation or rearrangement processes within the spirit matrix. Moreover, these compounds can interact with the floral notes already present in the new-make spirit, resulting in a reinforced and more complex floral signature over time.

The level of toasting further modulates this perception. A medium toast tends to enhance the floral dimension, likely through the thermal release of molecular precursors stored in the wood, whereas higher toasting levels favour the formation of spicier and caramelised compounds.

What makes this aromatic expression remarkable is that it coexists with the oak's more classic influences. The floral and mint freshness is not masked by woody or spicy notes; instead, it coexists with the toasted and spicy tones, contributing to a sense of balance and aromatic brightness.

### THE AROMA COMPLEXITY

Since the whisky aroma is typically a mixture of many components, the quantities and the relations of these components can vary within certain limits without inducing any considerable change to the whole aroma. Thus, the amount of a volatile component is not sufficient to tell how much a particular compound contributes to the overall aroma perception. For example, although alcohols are the main aroma components of whisky, their contribution is rather low, accounting to 10% of the overall odour intensity. On the contrary, esters and aldehydes are found in lower concentrations but contribute up to 80% of the overall aromas. This does not mean that these components alone can create the harmonious, mellow aroma of whisky, but their contribution to aroma intensity is considerable. This complexity thereby increases over ageing upon wood, since a higher content of aldehydes and esters compounds are found in matured whiskies.



# Tasting and colour aspects

## WOOD POLYMERS EVOLUTION OVER MATURATION

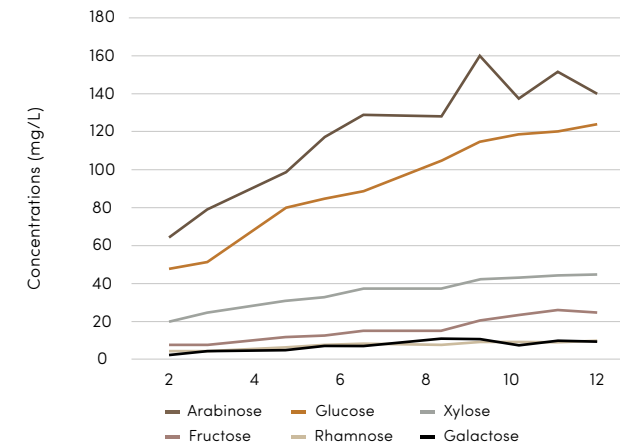
### POLYSACCHARIDES

The concentration of the individual sugars increases at different rates during maturation, resulting in progressive changes in sugar composition. The acidic hydrolysis of wood polysaccharides depends on pH, acid content and maturation time. This directly impacts on taste attributes of matured whiskies, such as softness, viscosity and alcohol warmth.

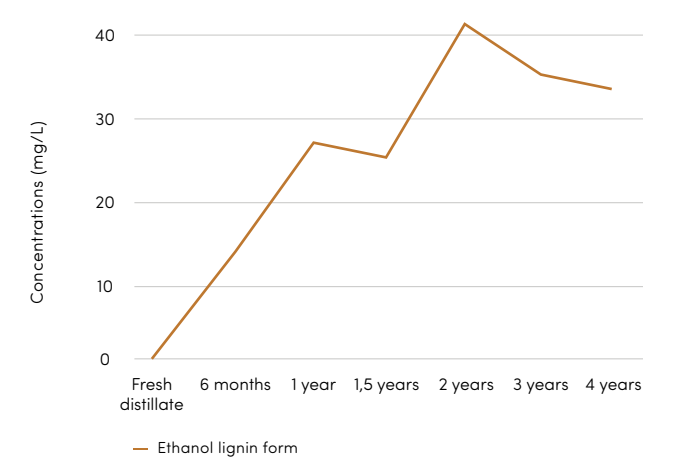
### LIGNIN

During maturation, about 5% of the lignin reacts with the distillate ethanol to produce an alcohol-soluble form of lignin. The ethanol lignin form increases in the first two years of maturation. Lignin is also chemically altered, and some differences in their structures in both aged spirits and oak wood were observed. The syringyl and guaiacyl forms ratio is higher in spirits than in wines, due to the availability within wood depth and the ethanol diffusion through the stave over maturation.

Monosaccharides profile of whisky during cask maturation



Evolution of ethanol-lignin complex during maturation



## ELLAGITANNINS

They may take part in the following reactions over whisky maturation in oak casks:

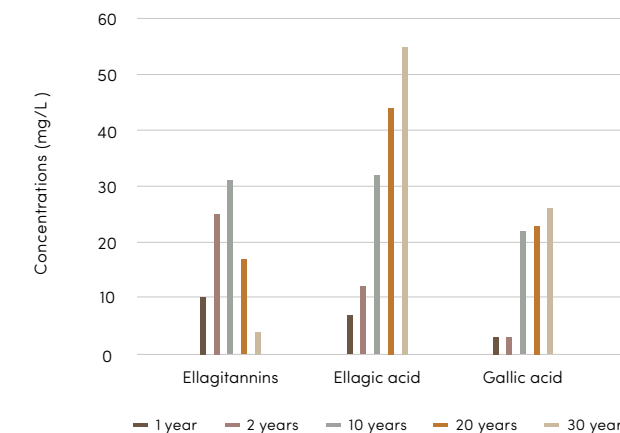
**Solubilization** by the spirit and diffusion through the wood.

**Hydrolysis** of soluble and/or insoluble ellagitannins, with formation of ellagic acid.

**Oxydative degradation.**

Their presence at medium levels improve the whisky sensory profiling, particularly its colour and structure. Re-using casks decreases the content of ellagitannins and ellagic acid in aged whiskies.

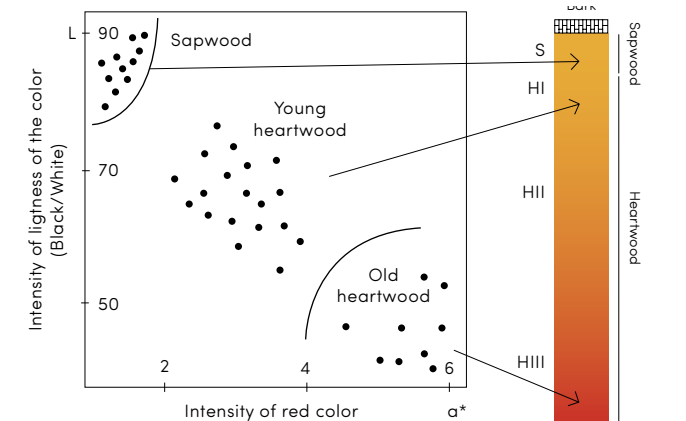
Concentrations profile of ellagitannins and phenolic acids in whisky over maturation



## ORIGIN AND CHARACTERIZATION OF OAK COLOUR

Oak presents a natural colour, clear and light in sapwood, dense and dark in heartwood. During the heartwood ageing, the colour becomes darker, redder and yellower: woods from young trees have lighter colour than those from older trees. This is correlated to the ellagitannins content decrease, due to hydrolysis reactions, polymerisation, and insolubilisation. The main part of the inner heartwood soluble colour is explained by oxidation involving polymerisation of the ellagitannins and a large association with polysaccharides. These polymeric forms are responsible to the yellow-brown natural wooden colour.

Impact of the sapwood and heartwood on the oak wood colour and lightness



Although a large part of the soluble heartwood colour is due to the polymeric form of ellagitannins, further sources of colour exist that are redder nuances. They are derived from these specific lignans.

### FIRST INVESTIGATIONS ON MATURED SPIRIT COLOUR

During maturation upon wood, especially in new oak casks, the main visible modification of fresh distillates is their increase of colour. Colour clues have been shown to drastically affect people's perception: pale whisky appears to be unaged, and one typically expects more aggressive flavours, while darker colours give the appearance of greater age, and one expects a rounder, smoother flavour profile.

### INFLUENCE OF MATURATION TIME

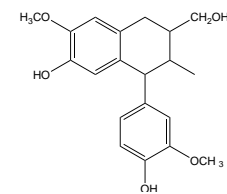
As described previously, colour of matured spirits is mainly due to the extraction of the polymerized polyphenols from wood. The composition of freshly distilled spirits becomes thus more complex and darker during cask maturation, particularly in new oak casks.

### INFLUENCE OF ETHANOL LEVEL AND PH

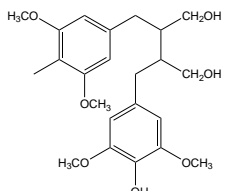
A darker, reddened, and browned colour is obtained when ethanol content increases. This is due to the better solubilisation of coloured chromophores in the high ethanol content solution, such as lignans and polymerized ellagitannins. During the initial part of maturation with a high pH, the extraction of compounds is improved. Moreover, a high ethanol content results in an increase in the pH of spirits. This enhances the fibre swelling of wood and solvent extractability, and positively affects the rate of extraction during the first period of maturation.

### INFLUENCE OF BARREL TOASTING AND SPIRIT DIFFUSION THROUGH THE WOOD

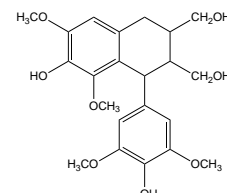
Toasting level increases both the yellow-brown and red nuances. The toasting of casks results in a dramatic change in wood composition, depending on the intensity of toasting. The toasting of new oak casks or the charring of old ones reduces the content of dry extract and the concentration of polyphenols in the first layers. Deeper within the stave (from 4 to 12 mm), untoasted parts predominate and are a major factor of the phenolic composition and colour in spirit during a long-term maturation. However, the rate of colour accumulation is not linear, occurring quickly during the first 10 years and diminishing after.



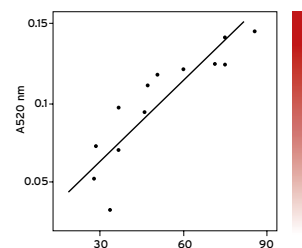
Isolariciresinol



Secoisolariciresinol



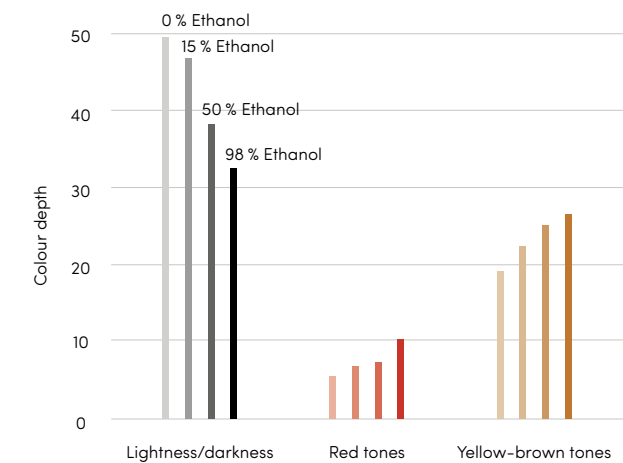
Lyoniresinol 1 & 2



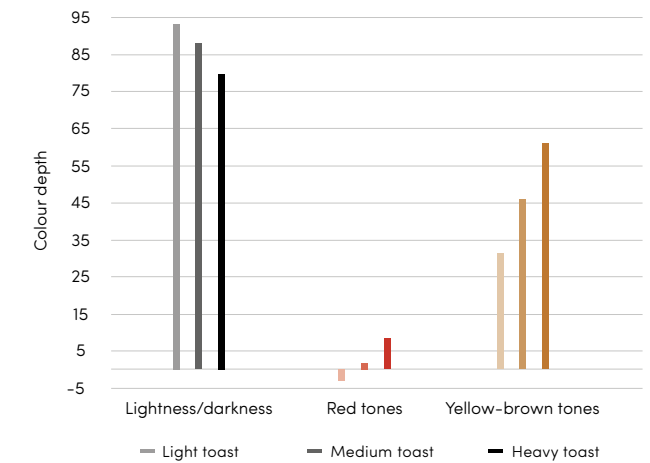
Lignans\* (mg/g of DW)  
\*Lyoniresinol 1, 2 ; isolariciresinol ; secoisolariciresinol

Main lignans compounds of the oak wood responsible to its red nuances

Impact of the ethanol content on the lightness and colour nuances of spirit



Impact of the toasting level on the wood colour and lightness



Colour provided from toasting is easily extracted during the first years of maturation.

# Matrix effects

## IMPACT OF ETHANOL CONTENT ON AROMA RELEASE

Ethanol is the key component of whisky. The ethanol molecule contains both hydrophilic groups and hydrophobic "tails". The behaviour of ethanol in the water solution is largely established by the phenomenon of apolar or hydrophobic hydration, leading to the formation of micelles. This phenomena plays an important role of the flavour perception of whisky since some aroma compounds are trapped into ethanol micelles.

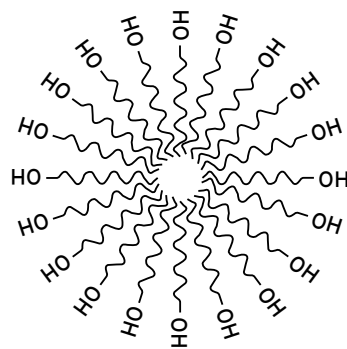
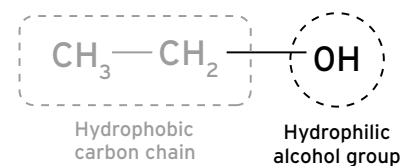
The dilution of whisky has a direct impact on the solubility of aroma compounds. In general, the solubilities of non-polar (hydrophobic) compounds decrease when water is adding, while polar (hydrophilic compounds) are minimally affected. This is particularly true for ester compounds: the act of dilution therefore promotes their release in the head space of the glass. The dilution of cask strength (reduction process) also promotes the release of some wood compounds, such as guaiacol responsible for smoke aromas.

However, when whisky is consumed, it is never in a static state, but is consistently moved and subsequently stirred. Thus, some differences are observed from static and dynamic systems. When glass is stirring, the evaporation of a compounds occurs in two steps: the molecules of the compound move to the surface (air/liquid interface) and then escape into the gas phase. In this context, the presence of ethanol in the solution helps to maintain the initial headspace solutes concentration, thus increases their delivery into the headspace.

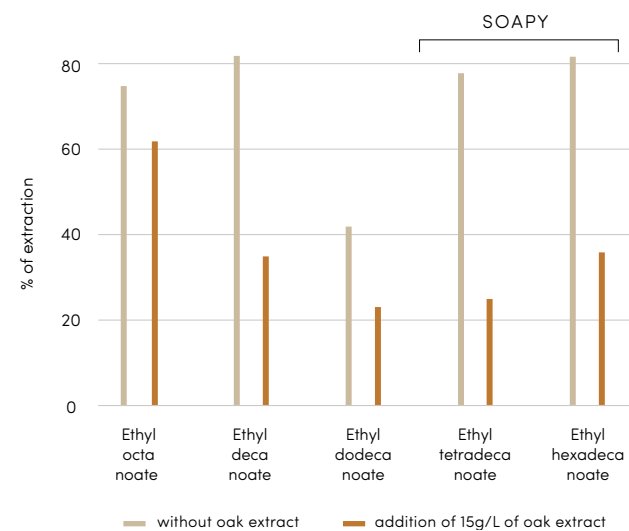
## IMPACT OF WOOD EXTRACT ON AROMA RELEASE

Dissolution of wood extract during maturation alters positively the release of aroma compounds in the distillate. More particularly, the presence of oak reduces the extractability of ethyl esters with chain lengths of 10-20 carbons, decreasing the immatured soapy character in matured whisky. The presence of wood polymers increases the stability on the release of these aroma compounds, and it is more particularly true when new casks are used for the maturation process.

The chemical structure of ethanol and its conformation in micelles with the presence of water



Impact of wood extract on ethyl ester concentrations



The dilution of the whisky during tasting has a direct effect on the flavour balance of the matured spirit.

The use of new casks is in favour to reduce the soapy character in the matured whisky.

The perception of flavour is not a static event but a dynamic process.



# The use of new oak in blending

In the world of spirits, blending represents more than the final stage of production: it is a creative process designed to build balance, texture, and aromatic coherence. Through the combination of spirits matured under different conditions, the blender can shape texture, structure, and aromatic balance with remarkable precision. Each component brings its own contribution: one delivers freshness and fragrance,

another provides weight or persistence, a third might add tautness or roundness. The mastery lies in understanding how these dimensions interact, how they reinforce or temper one another, and how the final blend expresses harmony rather than dominance. In this context, the blending stage offered an opportunity to observe, step by step, how new oak could modulate the sensory identity of a whisky.

## A PROGRESSIVE CONSTRUCTION OF COMPLEXITY

Traditionally, blending relies on spirits aged in refill casks, especially ex-Bourbon or Sherry barrels. Yet, the inclusion of new French oak offers a complementary perspective. Beyond its role in extraction, new oak introduces a different type of energy to the liquid, from structure to length.

A study conducted with the Demptos Research Center was designed to explore a simple but essential question: How does the proportion of whisky matured in new French oak casks influence the sensory identity of a blend?

To answer it, several experimental blends were created by combining spirits aged under two different conditions: one matured in refill ex-Bourbon barrels, the other in new French oak.

From there, five blends were prepared, gradually increasing the proportion of whisky from new French oak: 0%, 10%, 20%, 30%, and 50%. Each blend was then assessed at 50% ABV, focusing on descriptors such as complexity, floral intensity, spiciness, alcohol perception, roundness, and tannic structure.

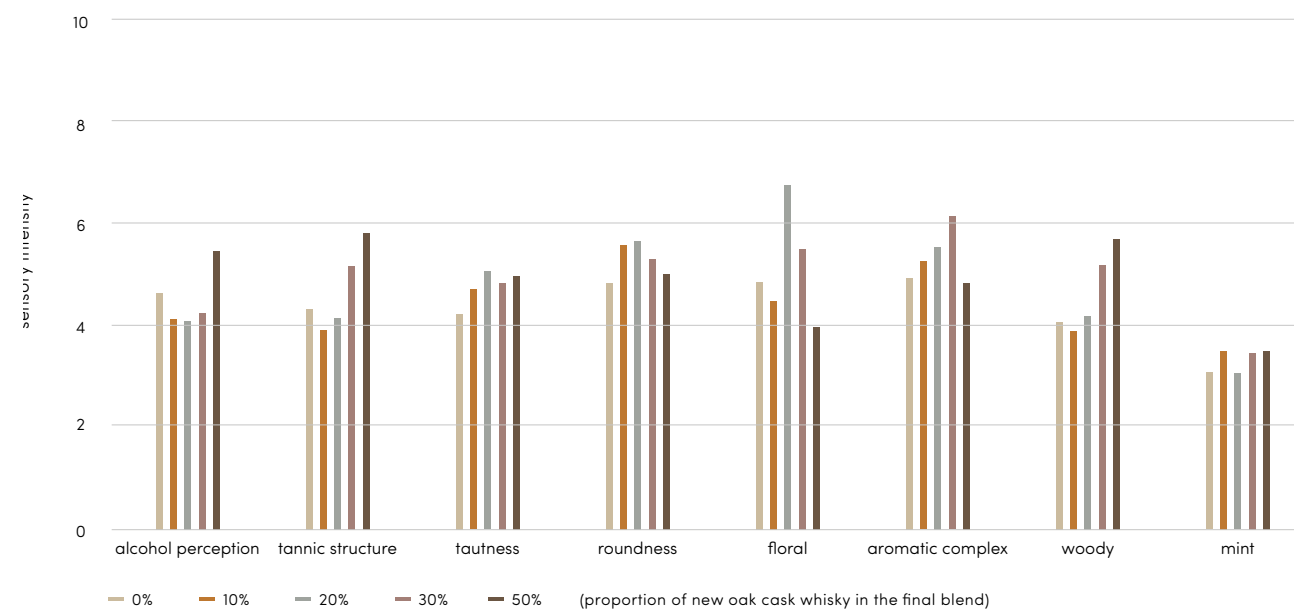
The results revealed a progressive evolution of both aromatic expression and texture :

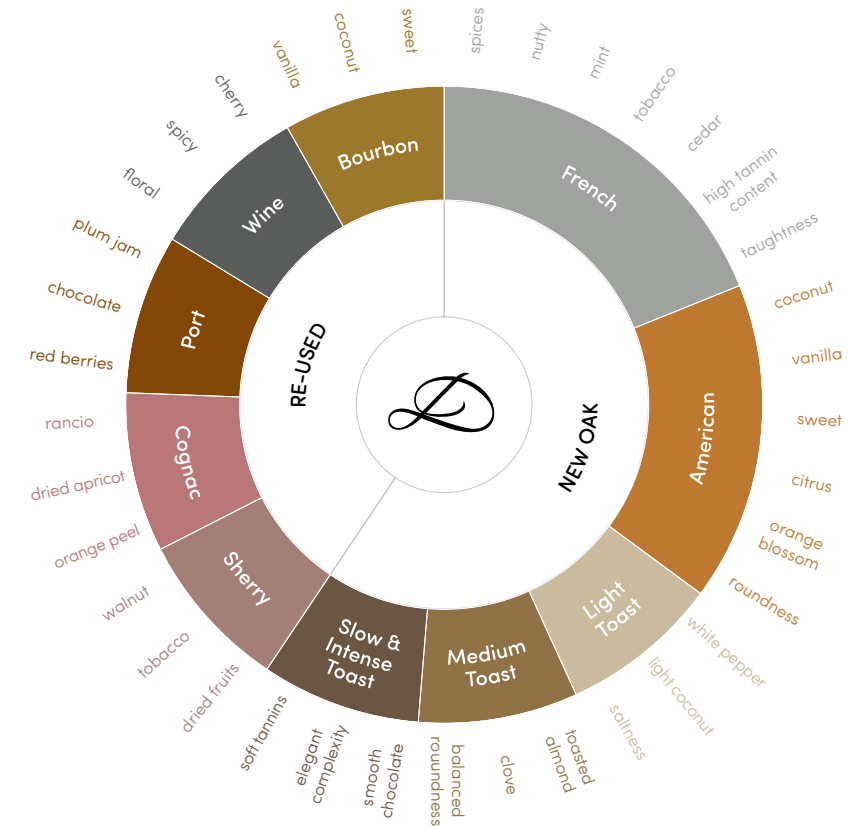
**At 10 to 20%**, the effect of new oak was subtle but measurable: the mouthfeel gained amplitude, the alcohol seemed better integrated, and the floral dimension started to emerge with clarity.

**At 30%**, the blend reached an equilibrium point – a form of aromatic coherence, where fruit, spice, and structure aligned to produce a sensation of harmony and length.

**At 50%**, the character shifted again: wood and spice became more dominant, tannins more pronounced, and the floral register more discreet. The whisky gained strength, but lost a part of its softness and complexity. This stepwise approach showed how the proportion of new oak in blend can act as a precision tool : each adjustment, even minor, brought a tangible change in aromatic contour and tactile sensation.

Figure 1. Impact of the proportion of whisky matured in new French oak cask in the blend





### THE AROMATIC PALETTE OF OAK

The diversity of oak types, toasting levels, and previous uses offers the distiller an extensive palette of maturation tools. Each cask type contributes its own register: new oak brings structure, freshness, and aromatic precision; re-used casks offer roundness, depth, and the memory of past contents; while variations in origin and toasting adjust the balance between sweetness, spice, and texture.

The complementarity between casks results from the interaction of contrasting influences. The structural intensity of new oak balanced by the integration of seasoned barrels, the tautness of French oak balancing the generosity of American oak gradually unified over time into a coherent aromatic expression.

Through careful selection and blending, the cooper and the distiller together shape an architecture of flavours where each element finds its place in the broader expression of the spirit ageing bouquet.



# THE

1 / SUBTRACTION, INTERACTION, AND ADDITION are the three chemical steps occurring during the maturation upon wood. They drastically improve the quality and complexity of the aging bouquet of the whisky.

2 / IN ADDITION TO DIVERSIFYING THE AROMATIC PALETTE of the whisky, wood also acts as an enhancer of the floral and nutty nuances specific to the distillate.

# SPIRIT

3 / THE EVOLUTION OF THE DISTILLATE TASTE from harsh to mellow is possible due to the solubilization of mono and polysaccharides from the wood, as well as the extraction and chemical transformations of wood ellagitannins.

4 / POLYMERIC ELLAGITANNINS AND LIGNANS EXTRACTED from the wood are responsible to the deep red and yellow-brown tones of the matured whisky.

# AGEING

5 / THE TOASTING LEVEL OF CASK also impacts the whisky colour, more particularly during the first years, and if the maturation is conducted in new casks.

6 / THE COMPLEXITY OF THE WHISKY MATRIX involves several synergic effects that deeply modify the aroma balance. Ethanol content impacts in different ways the release of aroma compounds while oak polymer compounds reduce the presence of long-chain ethyl esters responsible to the immature character of the distillate.

# BOUQUET

7 / INTRODUCING JUST 20–30% OF WHISKY FROM NEW OAK CASKS brings a clear lift in floral expression, balance, and lasting depth on the palate.



Nestled in the beautiful heart of Speyside,  
the percussion and precision of our Cooper's traditional  
skills has been serving the industry since 1947.

CHAPTER 4

# THE SPIRIT STABILITY OVER AGEING

Oxidative reactions have been extensively studied in the process of wine fermentation and maturation. In wine maturation, slow oxidation is preferred and the varying rates at which oxidation will occur in a wooden cask are deemed beneficial leading to a more complex mixture of oxidative products than would a constant rate throughout. It is shown that controlled oxidation leads to less astringency, and increases colour and stability.



# Spirit oxygenation during maturation

*During maturation upon wood, two phenomena occur simultaneously: spirit penetrates into the wood, a porous solid, allowing both water and ethanol to evaporate; oxygen from the air outside diffuses through the wood into the spirit.*

## THE OXYGEN TRANSFER RATE

The OTR is not the same for all barrels. The rate of oxygenation is impacted in several ways: more oxygen enters when the wood is dry, thin, and when the grain is smaller. Some properties of the casks also impact the oxygen transfer:

**The cask size:** the significance of cask size is the ratio of surface area to volume. In short, the smaller the cask, the greater oxygenation. The higher area/volume ratio of a small barrel means that extraction of wood components will proceed at a greater rate (larger spirit/wood contact), the rate of oxidation will be larger, and losses by volatilization will be greater.

**The re-use of cask:** the more the cask is used, the smaller oxygenation. After 10 years of using casks, the transfer of oxygen represents a decrease from 10 to 50% of the values recorded on new casks. This slows down the maturation process and limits the chemical reactions responsible to whisky complexity.

## THE SENSORY IMPACT

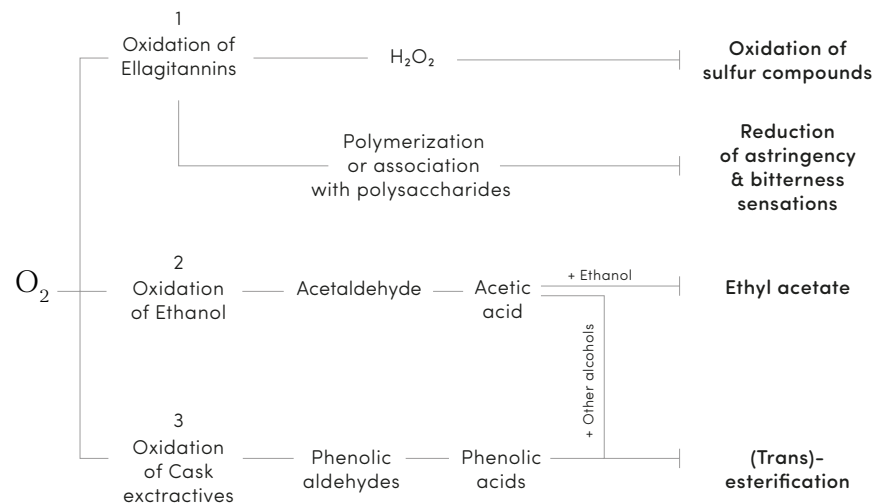
Oxygen is involved in different chemical reactions which improve the whisky quality:

**Oxidation of ellagitannins** promotes the polymerization of ellagitanins as well as their association with polysaccharides. Both these phenomena lead to a decrease of astringency and bitterness sensations and an increase of sweetness perception. Moreover, oxidation of ellagitannins is in favour of sulfur oxidation;

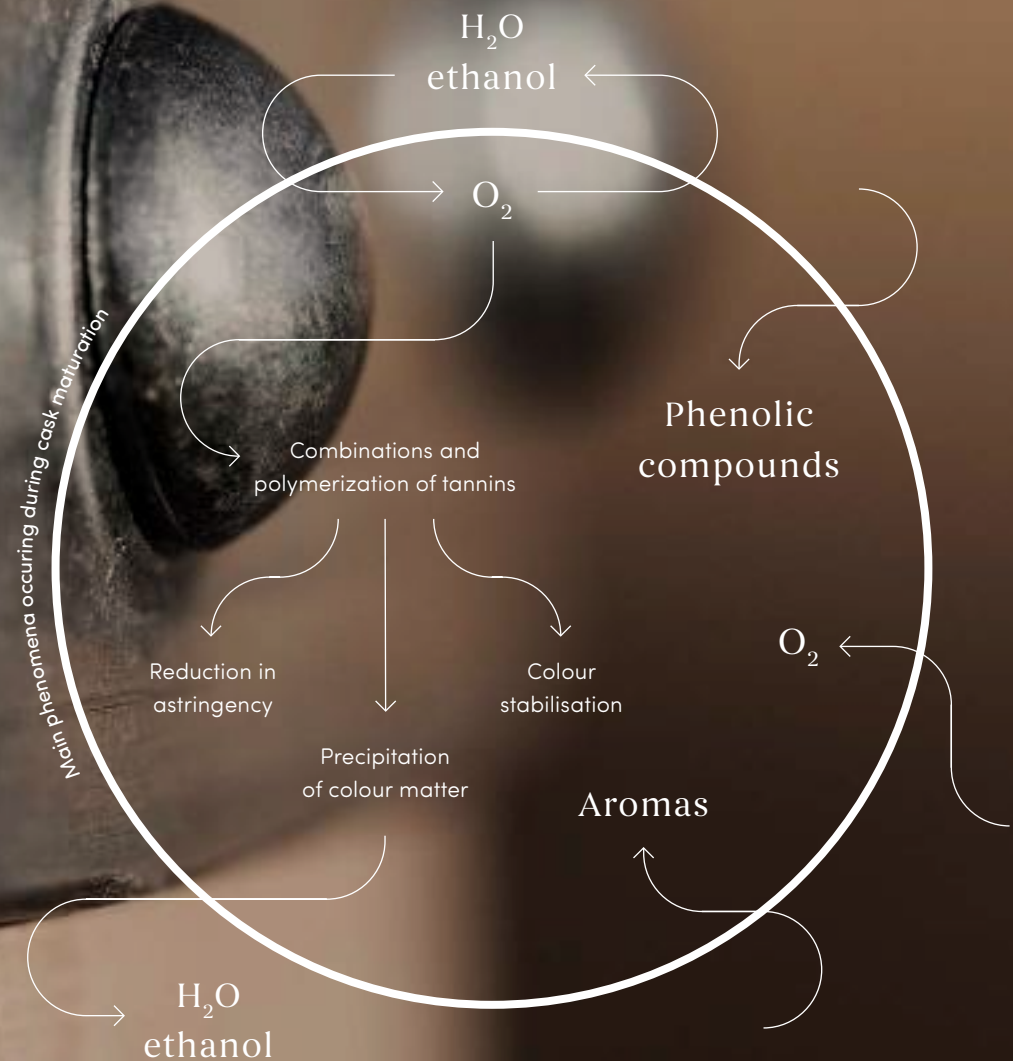
**Oxidation of ethanol** allows formation of acetic acid which is implied in esterification reactions;

**Oxidation of cask extractives** such as phenolic aldehydes into phenolic acids also leads to the generation of esters.

The various impacts of oxygen on the whisky composition and flavour

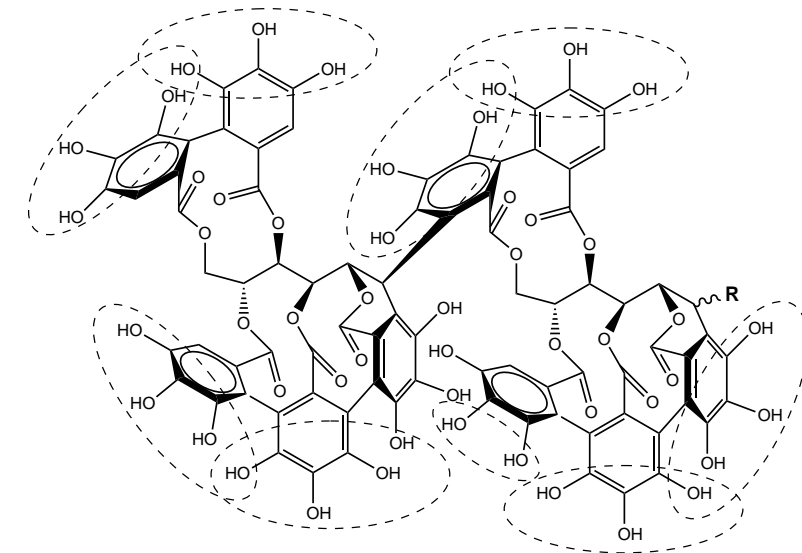


Slow and continuous oxidation of whisky during maturation in oak casks contributes to the quality of the final product.





# The key role of oak ellagitannins



## OXYGEN MANAGEMENT

Ellagitannins from oak wood present specific effects: they make the medium more oxidizable and favour the oxidative reactions. They also capture free radicals, avoiding too brutal radical oxidation. Finally, they have a very fast rate of oxygen consumption, capturing free oxygen to invest it in many reactions. The greater capacity of ellagitannins to consume oxygen is due to the presence of several ortho-hydroxy functions on the periphery of their chemical structure.

## ANTIOXIDANT ACTIVITY

Botanical species of oak wood have a great influence on the antioxidant capacity of wood used in cooperage. This is linked to the total phenol content (phenolic acids and ellagitannins), and more precisely to gallic acid and castalagin. *Quercus robur* has the highest antioxidant capacity, and *Quercus alba* the lowest.

Non-toasted oak wood samples showed more antioxidant power than those toasted. This fact is attributable to the effect of toasting on the polyphenolic content of oak wood.

During maturation, the abundance of ellagic acid, gallic acid (from ellagitannins) and lyoniresinol (lignan) increases. These compounds are capable of reacting with reactive oxygen species or other reactive free radicals. Through this oxygen scavenging activity, the three wood compounds prevent the formation of reactive oxygen species, and provide a smoother aftertaste by reducing the alcoholic burning sensation in matured whisky.

# The warehouse environmental conditions

## THE ANGEL'S SHARE

The loss of a small percentage of spirit is observed during its maturation and varies with the environmental conditions in a warehouse, more particularly with:

**The temperature:** raising temperature increases the evaporation losses of both ethanol and water.

**The humidity:** at high humidity, more ethanol than water is lost and strength decreases, at low humidity more water than ethanol is lost and strength increases.

Evaporative losses during maturation show marked regional variations:

**The relatively hot and dry** climate encourages preferential loss of water vapor relative to ethanol, and consequently strength increases during maturation.

**The maritime climate** (cool, and humid environment) promotes the loss of ethanol over water and strength decreases during maturation.

## TOP AND BOTTOM TIERS

Marked differences are observed between top and bottom tiers in a warehouse. The casks on top tier are marked by a daily decrease in humidity as the temperature increases, leading to a higher water loss. This increases the proof of the distillate and impacts the physical and chemical reactions of maturation. Optimal extraction of whisky lactones is obtained at 40% of ethanol, while lignin and ellagitannins are more extracted at 55% of ethanol. These variations are due to the both influence of the hydrolytic reactions, (such as the breakdown of polymer compounds), and the solubility of degraded compounds which is improved with increasing alcohol concentration.

Temperature and humidity affect the structure and the balance of the whisky.





# THE SPIRIT

1 / TINY AMOUNTS OF OXYGEN PLAY A VITAL ROLE in cask maturation, with an impact upon flavour, aroma and phenolic composition of aged spirits.

2 / THE OXYGEN TRANSFER RATE (OTR) in cask depends on the wood thickness and dryness, as well as the grain size. The greater surface area per volume in small casks promotes oxygen diffusion and contact with whisky, while re-using casks decreases it.

# STABILITY

3 / ELLAGITANNINS ACT AS CATALYSTS for many oxidative reactions during maturation, which favour the whisky's quality and complexity.

4 / THE ANTIOXIDANT ACTIVITY of ellagitannins varies between oak species. Its decrease during the toasting process is linked to the degradation of the wood polyphenolic compounds.

# OVER

5 / THE TWO PARAMETERS OF THE WAREHOUSE implied in the angel's share phenomenon are the temperature and the humidity. The whisky strength decreases at high humidity, and vice-versa.

6 / FOR EQUIVALENT CASKS MATURING THE SAME SPIRIT, the alcoholic strength can increase from the bottom to the top tier.

# AGEING

7 / EVAPORATION MAY THEN RESULT IN FURTHER EFFECTS on distillate composition. The highest rate of extraction occurs at the concentration where the two processes (water solubility and alcoholic extraction) are optimally balanced.



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