Iowa State University
Extension and Outreach

Midwest Grape and Wine Industry Institute

Oak Aging of Red Wine

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Maturation and aging can be considered as a group of reactions and series of changes that occur in wine during storage and lead to wine improvement. Boulton et al (1996) suggested that wine aging should not be viewed as single procedure and single event but rather a family of changes. They further suggested a distinction between the term maturation and aging. Term maturation used for the changes during bulk storage and aging used for the changes during bottle storage. The key difference is that during bulk storage a wine is likely to be exposed to air where as in bottled it is stored in essentially anaerobic conditions. For the purpose of this presentation when we say oak aging of red wine we also mean oak maturation of red wine.

The process of maturation/aging involves time, type of storage container and the conditions of storage in the cellar such as temperature and humidity. Cellar temperature is an important factor that will influence aging reactions. Generally a reaction that occurs at a given temperature and length of time, will occur in a shorter time if the temperature is increased. Many types of material are used for storage containers, such as stainless steel, concrete, plastic and wood. The size and the material used for the container will have a profound effect on wine development during maturation. This presentation will focus on wood containers/barrels and its impact on wine aging.

Should I use wooden cooperage/barrels in my winery?

The answer to this question depends on three key points. They are wine types and style, the economic aspect and the aesthetic appeal. For many fresh and fruity styles of wines made for early release and are meant to be consumed young, oak aging is seldom used. In some styles of wine it may not be necessary. Examples include: light and fruit forward whites, aromatic whites, picnic style roses and blush, red nouveaus and some fruity red marketed at lower price points. In the production of premium red wines such as those with good body, complex flavor, supple texture and long finish, oak aging is often employed.

In oak aging many extracted aromatic compounds are well integrated with the wine’s intrinsic aromas and they greatly contribute to wine’s richness and flavor complexity. The important point is that the wine must have a certain aromatic fineness and sufficiently complex structure to blend well with oak derived flavors. Ordinary wines can not be turned into quality wines by oak aging. (Riberau-Gayon et al, 2000) It is for this reason some red wines are more suited to oak aging than others.

Use of barrels adds to the cost of wine. The expense includes not only the cost of the barrel, but other factors such as, barrel storage, maintenance, barrel exhaustion and loss of wine due to evaporation, leakage, and sometimes spoilage. If a winery can make a profit with higher production cost then it makes economic sense to use the barrel for aging red wines.

Many wineries in the Midwest sell most of their wine at a winery. The visitors are often given a tour of the facility and told a story. Oak barrels neatly stacked add to the aesthetic appeal of the cellar and have a public relations value. This experience can translate into wine sales. This would justify by having barrels even if it is for a show.

Since we are discussing oak aging of red wine it is important to consider first oak as a cooperage and then its effect on red wine aging.

Why is White oak preferred?

Oak is a preferred wood for cooperage due to many qualities. It is a strong wood, that is resilient and therefore bendable. It grows as a large tree and yields straight grained stave bolts, it makes a liquid tight container with minimal shrinkage (wet to dry) and imparts no objectionable flavors. The two structural features that make oak desirable for barrel making are the medulary rays and tyloses.

Medulary rays - The medulary rays consist of elongated cells that extend radially from the pith to bark along the trunk axis. The rays form diffusion channels for horizontal transfer of water and nutrients. (Appendix 1) In conifers the rays are small, one cell wide and are called uniseriate. In white oak the rays are two or more cells wide and are called multiseriate. These large rays make wood strong and resilient. In various oak species these rays constitute about 19-32% of wood volume. In American white oak (Quercus alba) the rays account for 28% of wood volume. In other hard woods they represent about 15% and in conifers even less about 8% of the wood volume. (Singleton,1974) When barrel staves are made, the stave bolt (trunk) is cut into four quarters (quarter sawn). The staves are cut from the face of each quarter sawn bolt. This way of cutting positions rays parallel to the width of the stave. In this arrangement, the rays oppose diffusion of liquid through the sides of the barrel. It is estimated that a molecule of water will have to pass through five or more large rays in order to escape through the side of the barrel. Thus rays provide a formidable barrier to the diffusion of liquid and make oak wood relatively impermeable.

Tyloses-Oak is a ring porous wood. Each annual ring consists of spring growth and a summer growth. The pores (xylem vessels) formed during spring are larger than those produced in summer. These pores permit the flow of water and nutrient up the tree during the growing season. In white oak these pores become plugged with cellular inner growth called tyloses as the sapwood differentiates into heartwood. The tyloses development is so extensive in white oak that it effectively renders wood impervious to the movement of liquid. It should be noted that in absences of tyloses the pores would remain open. If such a wood used to make a stave the liquid (wine) would seep through the end of the stave. In the US wine industry many other woods have been tried as cooperage. These include red oak, chestnut oak, sweet gum, sugar maple, sweet birch, cherry, sycamore, redwood, spruce and many others. But none of them are as suitable as the white oak.

How important is the source of oak?

The source of oak is important to winemakers because of the genetic diversities of oak species that grow in different regions. The different species can produce different flavors in oak aged wines. The two most common sources of oak wood are North America and France/Europe. In America, the most predominant species of oak is Quercus alba but several other species are also found and may also be used for making barrels. These other species include: Q. prinus, Q. bicolor, Q muehlenbergii,Q stellata, Q. macrocarpa,Q, lyrata and Q. durandii. Among the species mentioned above Q. alba is considered most significant. It is estimated to account for 45% of the standing white oak east of the Rocky Mountains. It grows in the widest area from Southern Canada to nearly Gulf of Mexico and from the Atlantic to Iowa, and south up to Texas (Singleton 1974).

The French Oak /European Oak is represented by mainly two species, Quercus robur and Q. Sessilis. Both of these species are preferred for the cooperage and they are very similar. The oak wood in France is generally identified by the region or the forest even though the species may be the same. The main French oak producing areas are: Lomousin, Allier, Troncais, Bourgogne, Nevers and Vosges. The French oak Q.robur has a wide geographic distribution and is found in many other European countries.

The main difference between American and European oak lies in the relative amounts of odorous components and other oak extractives. Quantitatively these differences are large. New European oak barrel can be expected to contribute more (160%) solids and more than double the phenols as compared to American oak barrels of same size. (Singleton 1974) In addition to the genetic diversity other factors also influence the amount of oak constituents. These include, age of the tree, rate of growth and the part of the tree from which the staves are made. A typical barrel consists of about 30 randomly selected staves most likely representing different trees growing in different locations, of different age, and of different growth rate. Such a large number of staves in a barrel help in minimizing the differences in barrel.

What size is ideal for aging?

Extraction of oak constituents and oxygen permeability are the two important aspects of oak aging. Both these factors are closely related to the surface to volume ratio per liter of wine stored. The smaller the barrel, the larger the surface to volume ratio and the larger the barrel the smaller the ratio. The table below shows the relationship of surface area to volume expressed in square centimeters per liter capacity of the barrel.

Volume in liters	Barrel surface area in cm2/liter
20	195
200	90
2000	42
10,000	24
100,000	11

Source Schahinger and Rankine (1992)

Note that a 10 times increase in barrel volume reduces the surface to volume ratio by nearly half.

Now suppose you have a big red wine that requires 3 years of barrel aging in a new 200 liters (53 gal) barrel. You can cut down the aging time in half to 1-1/2 years by using 10, 20 liter capacity barrels. This means caring for 10 barrels instead of one. Conversely, you may decide to use a 10 times larger, a 2000 liter barrel, in this case you will need twice the amount of time (6 years) to get similar aging effects. This long storage can be expensive. The traditional 200 liter barrel is a compromise between needing too many barrels on one hand and requiring unacceptably long aging time on the other. Many winemakers generally use a 200 liter barrel, but barrels of larger sizes are also used in the wine industry. Other sizes of barrels used in the world are listed below (Schahinger and Rankine1992).

Barrel (United states)	190 liters
Barrique (Bordelaise)	225 liters
Barrique (Bourgogne)	228 liters
Hogshead	300 liters
Botte (Italy)	400 liters
Butt (Sherry)	490 liters
Puncheon	475 liters
Fuder (Germany)	1000 litters

Depending on wine type, style and economic considerations, winemakers need to choose an appropriate size barrel. It is important to note that due to the availability of barrel alternatives such as chips, and staves it is now possible to use large containers for wine aging in a reasonable amount of time.

How much wood is extracted from a barrel?

Calculations based on the surface area per liter of wine show that in a 200 liter barrel wine penetration for 1mm depth would extract 7.6 grams of wood per liter of wine. This means that in a new barrel one can find wine penetration to about 0.5 mm depth in a two months period, resulting in 3.8 grams of extracted wood per liter of wine. Based on the tasting results, this is about 3 to 10 times the amount necessary to produce a tastable difference in wine. (Singleton 1974) For the economic use of a barrel it is better to store the wine in a new barrel for a relatively short period of time and refill it or if it becomes heavily oaked blend it with unoaked wine.

Oak barrel effects on wine development during maturation/aging

There are two important ways in which barrel maturation affects wine quality.

1. Many volatile and nonvolatile compounds are extracted from oak wood and these constituents influence flavor and quality of wine. It is important to note that in barrel making the oak wood is seasoned and toasted to various levels. These treatments modify the oak constituents which contribute to oak derived flavors in barrel aging wines.
2. Controlled oxidation of wine during storage enhances and stabilizes red wine color and produces wine with decreased astringency and suppleness.

Effect of oak extractives on wine flavor

Main Oak wood constituents

Oak wood is composed of four principal constituents (Crum1993).

Cellulose: A major constituent making up about half the dry weight of the wood. It is a long structural polymer made of 2500 to 3500 glucose units. It contributes to the strength of the wood and undergoes little chemical alteration during processing of the wood.

Hemicellulose: Made up of mostly 5 carbon sugars such as xylose and some arabinose with small amount of 6 carbon sugars (mannose and galactose), and makes up to 20-25% volume. The hemicellulose polymer is smaller than cellulose, consisting of 75 to 100 units. Heat treatment causes decomposition of hemicellulose yielding furfural, maltol, cyclotene and ethoxylactone.

Lignins: Lignin makes up 25-35% of the dry weight of wood and can be degraded by heat, hydrolysis and the microbial action. During seasoning and toasting lignins undergo substantial chemical changes. Many compounds resulting from thermal degradation of lignin play have important influence on wine’s flavor. They include vanillin, guaiacol, 4-ethyl guaiacol, ferulic acid, eugenol, 4-methyl guaiacol, 4-ethyl phenol and p-coumaric acid.

Tannins: Oak tannins (5-10% of wood) are gallic acid esters of glucose and ellagic acid. Ellagitannins are the major phenolic compounds of oak. They are astringent and precipitate with proteins.

Flavoring compounds of Oak

Many oak derived compounds contribute to the flavor of wines aged in a barrel. Some of these compounds are present in harvested timber and others are formed during the seasoning and toasting of barrels. The oak flavoring compounds can be placed in to several categories described below (Sefton 1991b).

Volatile Phenols

These compounds are derived from the degradation of lignin. Vanillin is a major component of oak extract and is responsible for the vanilla character in oak aged wines. It is influenced by seasoning and toasting of the wood. A significant increase in vanillin level occurs in toasting the barrels. Eugenol has a spicy clove like aroma and is present in highest level in green wood. The amount of eugenol decreases during seasoning. Guaiacol and 4-methyl guaiacol have smoky aroma. They are found in trace amount in untoasted wood but are present at much higher levels in toasted wood. They are generated from lignin decomposition at higher temperatures. The level of toasting is important factor in giving smoky character to the wine. Other volatile phenols of some importance include 4-ethyl guaiacol, which has smoky, spicy and some what medicinal aroma and 4- ethyl phenol which has medicinal and horsey aroma. These compounds are present in trace amounts in oak extract but aged wine can have much higher levels. The formation of these compounds seems to have microbial origin. 4-ethyl phenol level is well correlated with Brattanomyces activity in barrel aged wines.

Carbohydrate degradation products

These compounds are formed from thermal degradation of hemicellulose. Toasting yields furfural, hydroxyl methyl, furfural, maltol and cyclotene. With the exception of furfural these compound have sweet-associated burnt sugar or caramelized aromas. The sweet and toasty aroma of oak chips has been attributed to maltol and cyclotene. Ethoxylactone is another carbohydrate derived product which has sweet and fruity aroma. (Sefton et al., 1990a)

The Oak Lactones

The oak lactones, also called the whisky lactones include two isomeric gamma-lactones. The cis-isomer has much lower aroma threshold and 4 to 5 times more intense aroma than the trans-isomer. Chatonnet et al (1990) showed that in lower concentrations these oak lactones give woody aroma which improves the quality of red wine. But at higher concentrations they can give resinous and coconut-like aroma which may be less desirable. Oak lactones occur in all oak wood used for cooperage but compared to other species, cis-lactones is present in much higher levels in American white oak. The level of both lactones increases during seasoning and toasting.

Hydrolysable tannins

Oak tannins are also referred to as ellagitannins or gallotannins. They are different from the condensed tannins found in grapes. They are also called hydrolysable tannins because they are unstable at wine pH and breakdown yielding gallic and mostly ellagic acid.

Ellagitannins are astringent and precipitate proteins. At 500 mg of dry wood per liter of wine, American oak would be expected to contribute about 30 mg of extracted solids and about 8mg of (GAE) phenol. Similarly European oak should yield about 50 mg of extracted solids and 26mg of (GAE) total phenol/L. (Boulton et al 1996) The sensory impact of oak tannins is widely assumed to have an impact on astringency and mouth feel of a wine. However, more sensory research data is needed to validate their sensory impact.

Terpenes

Monoterpenes, sesquiterpenes and many norisoprenoied have been found in oak extracts of both American and French oak. Norisoprenoids are important to the flavor of tobacco, tea and some fruits. More research work is needed to understand their role in flavoring oak aged wines.

Many oak constituents are extracted in wine during maturation. Some of these occur below sensory threshold and may have indirect effects. Not all of them are known and with future research more new compounds and their sensory impact will be discovered. The common descriptors of oak aged wines include oaky, vanilla, smoky, toasty, spicy, and coconut.

How does air/oxygen gets into the barrel?

When a wine is stored in a barrel, some of it is lost due to evaporation. Generally the loss is about 2 to 5% in volume per year. Water and ethanol are smaller molecules that diffuse into wood as liquid and escape as vapor. The loss is influenced by the cellar temperature and humidity. Cellar humidity should be maintained about 65%. In a drier cellar more water is lost resulting in higher alcohol content in the wine. In humid cellars more alcohol is lost which decreases the ethanol content in the remaining wine. In both cases those substances not lost by evaporation will concentrate. Loss of wine in a barrel causes empty space above the wine surface. If the barrel is liquid tight it will generate a vacuum. But if no vacuum is formed, it means the air got into the barrel through some leak. The empty space containing air/oxygen is likely to promote oxidation and acetic spoilage. To prevent this problem winemakers often top the barrels with wine. During topping operation some oxygen gets dissolved in wine. Oxygen pick up can also occur during wine processing operations such as pumping, filtering, and racking. At cooler cellar temperature about 6 ml/ or 8 mg of oxygen/L can be dissolved in a wine to reach a saturation point. During the course of wine processing generally, one can expect up to 6mg/l of oxygen pickup unless the wine is protected from air. It is important to note that dry wood is permeable to oxygen, but if the barrel staves are wet and barrel has no leaks the oxygen will not be able to get in.

Effects of controlled oxidation on wine quality

Traditionally high quality red wines are aged in barrels. During the course of barrel aging a red wine is periodically exposed to air/oxygen. The oxygen reacts with wine's phenolic compounds, such as pigments and tannins and brings about many positive changes. The main positive effects of aging (controlled oxidation) include enhancement and stabilization of red color, softening of tannins, development of complex aromas and improvement in wine's body and mouthfeel.

The key is limited or controlled oxidation. Excess oxygen will adversely affect wine quality. Therefore, a winemaker needs to closely monitor the maturation process, which implies allowing just the right amount of oxygen in wine based on wine's phenolic composition. A wine with higher concentrations of phenolic compounds will need longer aging time to soften the tannins.

During red wine aging phenolic compounds undergo many transformations that depend on temperature, SO2 content of the wine, degree of oxidation, aging time and the ratio of anthocyanins to tannins. The phenolics of grape and wines and their transformation during maturation have been described by Riberau-Gayon and Glories (1986). The two main phenolics in wine are anthocyanins and tannins.

Anthocyanins are the pigments responsible for the red wine color. The free (monomeric) anthocyanins occur in colorless and various colored forms. These are sensitive to pH and bisulfate. At a lower pH higher proportion of free anthocyanins occur in red form. During maturation/aging the monomeric anthocyanins combines with tannins to form tannin –anthocyanin combination product (TA) also referred as polymeric pigment. In combined form the polymeric pigment is less susceptible to discoloration through increased pH and bisulfate addition. The polymeric pigment is more stable and this contributes to color stability. In combined form, the proportion of pigments in colored form increases following aeration which accounts for intense color. The tannin anthocyanins combination reaction depends on temperature, oxygen, types of tannin and the tannin/anthocyanins ratio.

The changes in tannins are more complex and many oxidative as well as non oxidative reactions are involved. With oxidation procyanidin condenses and in association with other molecules gives tannin, which is pale yellow with molecular weight (mwt.) of 500 and maximum astringency. Procyanidin may also undergo non-oxidative polymerization forming yellow-red colored, condensed tannins with mwt. Of 2000 to 3000 and diminished astringency. Further polymerization leads to the formation of yellow-brown colored, highly condensed tannins (mwt 3000-5000). When polymerized tannins become too large they precipitate. Tannins can also condense with polysaccharides and proteins. Tannin -polysaccharide combination improves wine's flavor by softening tannins and giving more body to the wine.

Processing options for extracting more phenolic compounds during wine making.

In order to benefit from oak aging a wine must be rich in desirable phenolic substances. This means one needs to consider both the quantity and the quality of pigments and the tannin in grapes at maturity and their extraction during the processing. Assuming that the grapes at maturity have desirable phenolic composition, a winemaker can employ several techniques to promote phenolic extraction. Some of the techniques are:

1. Cold maceration prior to fermentation. (results can vary based on variety and the temperature)

2. During fermentation:
    - Adjusting maceration time and temperature
    - Draining some juice to increase juice to skin ratio.
    - Using Color extracting enzyme and tannins
    - Pump-over, punch-downs and cap management techniques

3. Extended maceration

Following extraction proper barrel maturation with controlled oxidation is essential to make wine with good color, balance, softness and distinctive fruit aromas and rich mouth feel.

Barrel alternatives

Oak barrels are important to red wine production, particularly high quality wines marketed at higher price points. With the availability of barrel alternatives many winemaker are now able to offer quality wines with oak derived aromas at affordable prices. The main barrel alternative used in wine industry include: oak chips, barrel/tank inserts, oak blocks, oak chains and oak extracts.

Oak chips are used like tea bags. Generally chips are packed in a cheese cloth or nylon bags and submerged into wine. When sufficient flavor is extracted the bags are removed. The barrel inserts consists of a series of oak staves vertically placed inside the barrel or tank. The number of inserts depending on the amount of surface per unit volume to be replenished (100%). Oak chains are pieces of wood linked together that can be inserted into a barrel through a bunghole. The limitation of this alternative is that there is no way to insert more than about 33% of the barrel's surface area through the bunghole and still be able to process wine through the barrel (Roger 1999). Oak blocks and oak boards are larger pieces of oak and are relatively easy to handle.

Barrel alternatives are used more widely in winemaking then commonly acknowledged.

For some time the regulations regarding the use were not clear and in Europe its use was banned until recent time. However, now the use of barrel alternatives is allowed, the quality of barrel alternative products has improved and winemakers have gained considerable experience in using these alternatives.

Oak barrels provide oak flavors and also permit controlled oxidation necessary to improve wine color and softening of tannins. When barrel alternatives (barrel inserts) are used in conjunction with depleted barrel or wooden cask, the technique closely simulates new barrels. Depleted barrels provide oxidation and the barrel alternatives provide the rich oak flavor.

When barrel alternatives are used in steel tanks, unlike barrels, the oxygen accesses is limited. To overcome this challenge winemakers are using micro oxygenation.

Barrel alternatives offer an opportunity to add a significant amount of oak character at a fraction of the cost of new barrels and allow for some high-speed winemaking. It is however important do conduct a lab trial with control to evaluate the kind of alternative, and the amount to be used in winemaking. Generally barrel alternatives should be used in early stages of winemaking to get the most benefit. Later additions should be done in small increments to avoid over oaking the wine.

Oak aging of wine is a key to making high quality red wines. But this depends on the phenolic composition of grapes. In order to make superior red wines from Midwest grape varieties we need to know their phenolic composition in terms of pigments and the quality and quantity of tannins. Some of the varieties seem to have the potential to make full bodied wines and the future does look bright.

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