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WINE SCENTS: BRETTANOMYCES

THE ROLE OF YEAST IN ALTERING WINE'S AROMATIC PROFILE

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Part A: The Scents of Wine

Introduction

A winemaker in the chain of production has, as a principal objective, the aim of making a wine that must satisfy the expectations of an ever more demanding consumer, desiring a certain level of quality, cleanliness and health benefits of foods in general and wine in particular.

It follows that the aromatic profile of a wine and its olfactive and taste sensations must be pleasing in both a sensorial and hedonistic sense to the consumer. In crafting a wine, the enologist therefore must always keep these aspects in mind (Fugelsan, 1997). Achieving these results is possible through the consideration that the organoleptic characteristics of the finished wine do not depend only on the characteristics of the raw material, including varietal, maturity, health conditions, etc., but also from other factors that the winemaker must control and manage according to style of wine desired. The technological factors, which are the basis of the process of transforming grapes into wine, and above all, the microbiological factors, which depend on yeast and bacteria activity, can modify the sensorial profile of the wine either positively or negatively throughout each phase of production. Accurate and careful management of microbiological aspects during the production process is therefore indispensible to meeting the predetermined winemaking goals. In particular, controlling the microbiological status of the wine, the musts and the grapes during all the transformation phases is critical. This is because numerous species of yeast and bacteria find this matrix an ideal habitat in which to live and develop, and if they are not properly monitored and managed, they can cause irreversible alterations of wine quality (Fleet, 1993).

The Scents of Wine

Wine is a complex product, derived from numerous transformations of a microbiological nature (carried out mostly by yeasts and bacteria), a chemical one (oxidation, esterification, etc.) and an enzymatic one (enzymatic release of specific perfumes that are the precursors of aromas) (Boulton et al., 1996). The vine type, the soil, the microclimate, the training form and pruning of the vine, the vinification system and the length and preservation method (stainless steel or barriques) have a determining influence on all the peculiar and typical organoleptic characters of both red and white wines (Ribéreau-Gayon et al., 1998).

Clearly, the sensory and aromatic profile of a product is the expression of many factors that, collectively, contribute to the definition of an aromatic style that is characteristic and distinctive of each type of wine. The aromatic substances that typify wine can be classified according to different aspects:

- Chemical origin
- Type of aroma
- Chemical formula

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The aromatic substances can be divided into odorant substances (i.e., terpens) that pass directly from the grapes to the wine and non-odorant substances, which produce aromas only after chemical transformation, particularly in the pre-fermentation phase. The odorant substances are responsible, for example, for the floral sensations that are typical of moscato and are principally linalool, otrienol, citronellolo, a-terpinol and geraniol.
In addition, there are the substances derived from yeast activity and lastly, the aromatic substances that develop during the aging phase of the wine in the *barrique* or in the bottle (Ribéreau-Gayon et al., 1998; Di Stefano, 1987).
The odorant substances of wine can be schematically classified in the following way:

By Origin

- VARIETAL AROMAS: substances found in the grapes with characteristic aromas, such as Moscato, Malvasia, Traminer, Sauvignon, which pass as such into the wine, giving it a typical perfume. In fact, in Moscato, the typical aroma is due mainly to the presence of terpens. However, other chemical substances also belong to a wine's varietal aromas, and they are very different from terpens; for example, 2-methoxy-3-isobutyl-pirazine which is responsible for the characteristic vegetal note of potato, green grass and green pepper of Cabernet Franc and Sauvignon, or like Methyl Anthranilate responsible for the foxy odor of the vines derived for the American hybrids and the *Lambrusca* genus, and the furaneol that brings a strawberry scent to mind.

- PRE-FERMENTATION AROMAS: substances (aroma precursors) present in the grapes of certain vine types such as Pinot Noir, Riesling, Chardonnay and others, that do not have a particular aroma. They become odorant following particular chemical transformations (enzymatic hydrolysis) that occur when the grapes are crushed and after fermentation.

- FERMENTATION AROMAS: compounds that do not derive directly from the grapes, but originate from the yeast metabolism during alcohol fermentation (acids, alcohols, esters, acetates, etc.). They are essentially responsible for the "vinous" character of the wine.

- POST FERMENTATION AROMAS: they form after alcoholic fermentation, during wine maturation and aging, in relation to the type of storage (steel or wood vats). They evolve and transform, giving origin to other substances that are responsible for the wine's aromatic profile. These derive both from complex chemical phenomena and reactions (redox, hydrolysis, esterification, etc.) and from microbiological alterations (lactic bacteria, yeasts of the *Brettanomyces* genus, etc.) that take place during *barrique* aging and can also continue in bottle.

By Chemical Structure:

The following ten groups can generally be distinguished:

1. ESTERS: both for quality and quantity, they represent the major part of wine aroma substances (>100ppm).

2. ALCOHOLS: unlike esters, alcohols are not always considered a quality factor.

3. TERPENS: they represent the aromatic substances typical of aromatic grape varieties (Moscato, Gewürtztraminer) and determine the great difference between the aromatic grapes and the non aromatic ones, which contain only a trace of this substance.

4. FATTY ACIDS: they confer scents that are described like butter, cheese, etc.

5. LACTONES: they can have different origins: from the metabolism of the amino acids by yeast; from the action of Botrytis on the grapes and from the oak during barrique aging (for example the whisky-lactones that confer the particular odor of coconut).

6. CARBONYL COMPOUNDS: a great number of aldehydes and chetones have been found in wine, and they are responsible for very characteristic sensory notes.

7. ACETATES: these compounds are mainly obtained through the chemical reaction of the principal wine aldehydes (acetaldehyde and benzaldehyde) and the principal alcohols (ethanol, and 2 and 3-methylbutanol).

8. SULFURIZED VOLATILE COMPOUNDS: responsible for the characteristic sulfur notes derived from the condensation of the mercaptans with the fatty acids.

9. NITROGEN VOLATILE COMPOUNDS: amine, acetamide (mouse nest) pirazine, methyl anthralinate.

10. VOLATILE PHENOLS: 31 volatile phenols have been identified and many of them contribute significantly to defining the aromatic profile of wines. The most important are: the 4-ethylphenol (4-ETF), 4-ethylguaiacol (4-ETG), 4-vinylphenol (4-VNG), guaiacol, eugenol, and orto and para creosol. Among these, 4-ETG, 4-ETF, 4-VNG and 4-VNF help to determine the aromatic character of a wine because of their low perception threshold and their very distinctive aroma. In particular, 4-VNG seems to play a determining role in the aromatic expression and typicity of the Traminer wine at concentrations >100ppm compared to wines with less varietal characterization. These have only 20-70ppm. Further studies demonstrated that wines defined as "phenolated" had a high concentration of 4-ETF and 4-ETG, which are responsible for the appearance of the typical "BRETT" character (that will be discussed in detail in the following chapters).

By Aroma Type

The most well known aroma classification was published in 1984 in the American Journal of Enology and Viticulture, written by a series of authors and coordinated by Ann Noble, of the Department of Viticulture and Enology of the University of Davis, California (Noble et al., 1984).
The so-called "aroma wheel" is built along three concentric circles that define three levels of sensory perception. The central one is the most generic, while the external one is the most specific. The circular structure of the wheel does not make it possible to establish a beginning and an end of the aromas. In any case, the groups of aroma descriptors are not necessarily connected or resulting from one another, so each group can coexist with the others, or can be the only one present in a wine.

Thus this aroma wheel defines both the "good" scents and the "bad" scents that can at times manifest themselves following particular chemical phenomena (e.g., notes of resin or rotten apple caused by oxidation reactions of the wine due to its uncontrolled and excessive exposition to the air). They can also be the result of biological phenomena (e.g., notes of medicine, band aid and barnyard due to the uncontrolled activity of the *Brettanomyces* yeasts).
The list of aromas that make up the aroma wheel is reported below in detail.

1. Floral: (rose, violet, orange blossom, geranium)
2. Spicy: (cloves, black pepper, licorice, anise)
3. Fruity: (grapefruit, raspberry, strawberry, black currant, peach, etc.)
4. Herbaceous or Vegetative: (grape-stalk, cut grass, sweet pepper, eucalyptus, asparagus, green olives,etc.)
5. Dried fruit: (almonds, walnut, hazelnut)
6. Caramelized: (butter, chocolate, honey, molasses, etc.)
7. Woody: (vanilla, phenolic, resinous, burnt toast, etc.)
8. Earthy: (mold, earthy, mushroom, dusty, etc.)
9. Chemical (*petroleum*: kerosene, diesel fuel, plastic, tar; *sulfur*: mercaptan, garlic, onion, sulfur dioxide, cooked cabbage, etc.)
10. Pungent: they confer sensations of heat (ethanols) or cold (menthols) to the wine
11. Oxidized: (acetaldehyde, sherry)
12. Microbiological: (horsey, mouse nest, yogurt, sauerkraut, leesy, baker's yeast, etc.)

It is easy to understand the complexity of a wine's aromatic profile and the important role that various microorganisms play during all the phases of the winemaking process.

Part B: Alterations in a Wine's Aromatic Profile Caused by Brettanomyces Yeasts

The aromatic profile of wines is complex and can often be traced back to the activity of various microorganisms. They can strongly alter the typical traits of a wine.

The quality alteration of wine is due to micro-organism contamination, as Ribéreau-Gayon affirmed in his *Treatise of Enology* ("the microorganisms 'make' the wine and they are also the ones that ruin it"). These alterations can easily occur on their own, as wine is an excellent substratum for the development and multiplication of numerous species of yeasts and bacteria throughout the product's lifespan and even after bottling. Only targeted and timely enological operations can prevent, or limit, the development of undesirable microorganisms that can irremediably alter the product. Modern technology and a more thorough understanding of the chemical, physical and biological phenomena underlying the winemaking process have reduced the chance of anomalies ozccurring. However, alterations and modifications of the aromatic characteristics of wine, during the course of its evolution, occur very frequently and they can compromise product quality, sometimes irreversibly. "Organoleptic alterations" are considered, by definition, the anomalies in wine that can be perceived as a change in the color, appearance, smell and taste, and that can become real defects when they irremediably alter and compromise the commercial value of the product (Loureiro, 1999). In particular, the defects due to the presence of abnormal scents in wine are difficult to identify, especially at the onset of their occurrence, because they are part of a pre-existing complex aroma profile. Often these anomalies are the most difficult to prevent, considering the various biological (microbial activity) and physical-chemical (wine-air contact, etc.) phenomena that take place during the phases of wine making. These are often microbiological alterations, as wine provides a favorable environment for the development of various species of microorganisms, even after alcoholic and malolactic fermentation.

Their activity can give rise to aromatic molecules that, in some cases, give wine an appealing sensory complexity and nuances, while in other cases they can alter the product to the point that it is no longer marketable (Deak, 1996). In fact, the aroma wheel highlights the sector of the so-called "microbiological odors" which are separated into three parts, according to the factors, which cause them (yeasts, bacteria, other micro- organisms). This sector identifies a series of particular aromatic descriptors that are an index of a quality alteration in wine, when they are very evident, and when the molecules responsible for this are found in high concentrations. Often, these microbiological alterations become evident during particular phases of wine production, such as in the barrel aging phase. In brief, there are three critical moments in the vinification process when it is easier to have micro- biological spoilage, as can be seen from the in- depth analysis below.

1. Grapes-musts:

the first stage comprises grapes that can be contaminated by molds, yeasts, and lactic and acetic bacteria, according to the soil climate conditions, the grapes' sanitary status and ripening condition, in addition to the type of pre-fermentation treatment carried out on the grapes and musts (elimination of stalks, clarification of musts, sulfiting, etc.).

2. Fermentation phase:

the second stage is represented by alcoholic fermentation, and this is rarely carried out by the single species Saccharomyces Cerevisiae, as there is a varied population of yeasts and indigenous bacteria in the musts that can be responsible for collateral, undesirable fermentation activity, able to alter the final product.

3. Preservation and aging phase:

the third stage begins at the end of alcoholic and/ or malolactic fermentation; as the wine always has a residual quantity of sugars (200-300 mg/l / .02- .04 ounces/gallon) and has many compounds that can be used by different species of microorganisms, it is susceptible to microbiological alterations of various origins.

The Brettanomyces yeasts are one of the causes of the modification and alteration of wine quality characteristics. They are important because they are responsible for the formation of particular metabolites, such as the vynil and the ethyl phenols, that confer characteristic aroma descriptors to wine like "phenolic", "medicinal", "band aid" and in the worst cases "barnyard" and "horse sweat." Another metabolite formed is isovaleric acid, which is responsible for the rancid, and fried oil notes, or other molecules that cause "mouse nest" notes (Parish et al., 2003; Chatonnet et al., 1992).

The combination of these scents gives a wine very peculiar notes that are identified technically by the term "Brett character" (Lickner et al., 1994). The study of the sensory impact of the activity of these yeasts and the ethyl phenols on aromatic profile of wines is an object of ongoing discussion and controversy.

A special guest: Brettanomyces

Worldwide microbiological studies have found that yeasts, and in particular those belonging the Brettanomyces genus, in its spore-forming form Dekkera, are responsible for particular and specific aromatic and olfactive alterations of wines (Heresztyn, 1986; Schutz, 1993).

In fact, the Brettanoyces are responsible for the formation of the molecules (4-ethyl guaiacol, 4-ethyl phenol,

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acid isovaleric, etc.) which are able to determine the presence in wine of specific aromatic notes that, on the aroma wheel, are characterized by the phenolic and medicinal descriptors and generally labeled as "Brett" character. In particular, "Brett" character is associated with notes of soot, smoke, hydrocarbon, and burned plastic when the yeast is found in small quantities, and with notes of wet fur, wild game, a barnyard tang of henhouse, band aid, stables, medicine and horse sweat when a wine has been strongly contaminated by Brettanomyces. Even if the 4-ethyl guaiacol and the 4-ethyl phenol have been considered indications of Brettanomyces yeast activity since 1964, other aromatic compounds found in wines attacked by the Brettanomyces produce a very complex and characteristic aroma (Licher et al., 1994).
These molecules form after the transformation of various phenolic compounds found in wines. In particular they are produced by decarboxylation and reduction of the hydroxycynnamic acids (p- cumaric and p-ferulic acids) that derive both directly from the grapes and from the wood after maturation and aging in casks and barriques (Chatonnet et al., 1992).
More recent research has demonstrated that the aromatic profile conferred to wines by Brettanomyces is the result of a complex mixture of odorant substances that can be traced back, both to the volatile phenols, and to the volatile fatty acids, alcohols, aldehydes, chetones, etc.
The volatile fatty acids, like isovaleric acid (3-methyl butoanoic) isobutiric and 2-methyl butyric acid, are produced in elevated quantities by Brettanomyces and give wine a harsh, rancid, and pungent note. This complex mixture of odorant substances determines the appearance of notes, which enable the unequivocal distinction between those wines that are affected by Brettanomyces and those that are not(Licker et al, 1994). Brettanomyces have been involved in the sensory alterations of different alcoholic beverages (white and red wine, sparkling wines, sherry, beer, cider) in all the areas of the world where these are produced (Di Stefano, 1985).
At present, 5 species of Brettanomyces have been classified: B Anomalus, B Bruxellensis, B. Custersianus, B. Naardenensis and B. Nanus, but the most interesting are the B. Bruxellensis and B Intermedius (Chatonnet, 1995). The first systematic study of Brettanomyces morphology and physiology was already being carried out by M.T.J. Custers in 1904, when he was the director of the New Carlsberg Brewery (Copenhagen, Denmark). N. Hjelte Claussen was the first to use the term "Brettanomyces" from "British brewing industry fungus": these non-Saccaromyces yeasts gave the beer very peculiar sensory characteristics. Later, the presence of Brettanomyces in bottles of wine was highlighted for the first time (Gilliland, 1961).
Numerous studies demonstrate the diffusion of Brettanomyces in cellars and Peynaud wrote, in 1984, that "the enologist must be aware that all the cellar surfaces and the equipment can be contaminated with Brettanomyces cells." As regards the presence of Brettanomyces in the cellar, there are various sources of contamination, development and diffusion of these yeasts. The risks of contamination are constant, starting from the plant surface of the vineyards to the means of transport used during harvest (carts or containers) and they increase as the harvest proceeds. All the harvesting equipment, which is used daily, must be kept impeccably clean, to avoid increasing the risk of contamination. Even insects of the Drosophila type can be an important force for diffusing Brettanomyces. In any case, fermenting and maturing grapes and other products are the media that are favorable to the development of these yeasts, as well as the entire cellar environment and the equipment used for the various operations. Live cells of Brettanomyces have been found inside poorly-cleaned taps/spigots, in small drainage channels, in the bung hole of the barriques, in the cracks in the wood, in silicon bottle tops, etc.
It is easy to deduce that Brettanomyces can be found in all wine cellars, as they spread easily on hard- to-clean surfaces, or on those surfaces that are not cleaned thoroughly, such as pumps, transport pipes, grape-presses, valves, and every place where organic deposits can accumulate over time (Boulton et al., 1996; Fleet, 1993). It is thus fundamental to adopt strategies to limit and contain the population of Brettanomyces by properly sanitizing cellar equipment and appropriately adding sulfate to the musts. These are

indispensable conditions for controlling the development of these yeasts (Chatonne et al., 1993).
There are different characteristics that make yeasts of the Brettanomyces genus very particular and knowing them is indispensable for preventing contamination, controlling their development, and limiting their damage.

- Use of cellobiose as a nutrient source

When they are used, the new and toasted barriques are free of microbial contamination because of thermal treatment, but nevertheless they contain large quantities of polysaccharides, in particular, cellobiose. It is a dimer of cellulose that forms after the toasting treatment and the pyrolysis of the wood polymers.
These molecules are an important source of nourishment for Brettanomyces, which are among the few species of yeasts able to utilize cellobiose as a source of carbon. Therefore, in new barriques, the risks of microbial development are greater compared with wood containers that have already been used and well maintained (washed, treated with sulfur, etc).
Trials carried out contaminating barriques of different ages have demonstrated that in new ones, there is a greater increase both in the population of Brettanomyces cells, and in the ethyl-phenol concentration. Furthermore, in new barriques, the absorption of free and molecular sulfur oxide is much more rapid than in used ones, and it declines rapidly during the first months of wine aging. This does not guarantee an adequate control of Brettanomyces, as they are fairly resistant to this anti-microbial agent. Accordingly, it is important to correctly measure out the amount of sulfur dioxide to be used, based on a barrique's age, as it represents a factor that must be considered to limit the development of these yeasts.

- Population of Brettanomyces and the formation of ethyl phenol: uncorrelated factors

The velocity of growth and development of yeasts in wine is mostly strain dependent. At any rate, it can generally be said that Brettanomyces follow a bell-shaped development curve, reaching a maximum point and then declining. However, the height of yeast development does not correspond to the maximum formation of the ethyl phenol, which occurs only some months later.
It seems that Brettanomyces cells are able to use specific substrata that can favor their development, in the first phase. When they have been depleted, the yeasts considerably reduce their activity. In this way, the level of contamination tends to diminish even without operations aimed at containing the development (filtration, centrifugation, sulfur treatments, etc.) to the point of an actual death and autolysis. The concentration of ethyl phenol does not increase sharply during this phase, but tends to do so during the phase of reduced yeast activity, during the 10^{th} month after inoculation. This suggests that the ethyl phenols are produced in a limited concentration during yeast development and multiplication, and in greater quantities, above all, during the phases of cell death and autolysis.
In fact, studies carried out at Cornell University demonstrate that after death, Brettanomyces yeasts, like other yeasts, go through a process of autolysis and release of their cellular components in wine, as well as its enzymatic pool. The enzymes produced by the yeasts come in contact with the phenolic substratum (ferulic acid, and coumaric acid) found in wine, determining the formation of the ethylphenols, whose concentration tends to increase as it finds a less vital population.
This suggests that, when there is a massive contamination of Brettanomyces yeasts, they should be removed as soon as possible. In these cases, an adequate sulfur treatment can reduce the entity of the live cell population and, thereby limit, though not prevent, the risks of accentuated phenolated and animal notes in wine. This operation enables the reduction of the contaminating population, but should always be followed by the removal of the yeasts by filtration and/or centrifugation operations. On the other hand, pasteurization determines both the death of the cells and the denaturation of the enzymes produced by the yeast. This can be an efficient way to contain the formation of the ethyl phenols, even after their metabolic deactivation following sulfur treatment. This would also explain why there is often an

increase in Brettanomyces notes in the bottle as well, even though the wine does not contain microbiologically active cells.

- "Cluster" effect

When yeasts that belong to the Brettanomyces genus are in the presence of glucose and in conditions of oxygen availability, they accentuate alcoholic fermentation activity, producing considerable quantities of acetic acid. On the contrary, yeasts belonging to the Saccharomyces genus tend to accentuate phenomena of respiration and cell multiplication, in anaerobic conditions (Ciani et al., 1997). This fact is very important because often a wine that has begun developing some Brettanomyces yeasts manifests abnormal notes that often are not easily identifiable and cannot be traced back to a reduction condition. Consequently, wines with this kind of aroma profile often undergo aerating to attenuate the phenolic character. However, because of the cluster effect, this operation favors the fermentation activity of Brettanomyces and stimulates their multiplication and development (Malfeito-Ferreira et al., 2000).

- Collateral enzymatic activity

Finally, it should be mentioned that Brettanomyces activity is at the basis of wine's sensory modification both indirectly, through the formation of new malodorous ethyl phenol, and directly, through the enzymatic degradation of the aromatic molecules of wine that form during the phase of alcoholic fermentation. These yeasts are endowed with a great ester-spoiling activity, so the contaminated wines are rapidly robbed of the fruity scents that form mostly during alcoholic fermentation. These scents are associated with the presence of esters that are the substances responsible for the fruit notes in wines. They are naturally and slowly lost through chemical hydrolysis during wine preservation. Brettanomyces can accelerate the loss of this fruity character because of the production of esterasic enzymes that destroy this molecule (Speapem et al., 1982; Mansfield et al., 2002).

Brettanomyces and Wood

Taking a cue from the aroma wheel, the sector which describes the aromatic characteristics attributable to "wood odor" is the sector where the descriptors indicate microbiological alteration.
It is not easy to precisely define the contribution of the wood to wine. It is necessary to interpret these odors in technological terms (use of the barrique, and release of wood to wine) or in evolutionary terms, that is, the formation of the odors which comes about by way of complex phenomena that occur in the wine during the aging period in wood containers (oxidation and esterification).
In standard enological practice, the refinement and aging processes of wine involve its storage in wood containers (barriques of 225 and 350 Liters / 60 and 92 gallons, up to 500 Liters / 130 gallons, and casks of 13.000 Liters / 3746 gallons). These containers have a characteristic that distinguishes them from every other type of container because their role is "technologically active" and determines the evolution of the wine. In detail, wood favors the appearance of particolar aromas that derive from the presence of specific compounds defined as volatile phenols. These derive, in part, from the wood and are responsible for notes of smoke, toast, vanilla and spice. Other aromas are due to the activity and presence of Brettanomyces, which find an optimal environment for their activity and development in the wood. The most frequent contamination from Brettanomyces occurs in finished wines, during refinement, when the alcoholic and malolactic fermentations have ceased.

Even in cases of difficult alcoholic or malolactic fementation, conditions favorable to the development of Brettanomyces can be created. In fact, in these situations, the wines are often left for weeks, if not months, at high temperatures, with low levels of sulfur dioxide and in the presence of sugars.
At this moment, phenomena of antagonism and competition between microorganisms and Brettanomyces can utilize the residual sugars, which are always present in the wine even at the end of alcoholic fermentation (glucose, fructose, mannose, galactose, and trehalose), to multiply and colonize both in the product and in the tanks and equipment with which they come into contact.
It has been demonstrated that the fermentation of a quantity of sugars around 300 mg/l, normally present in a "dry" wine, is sufficient to induce the formation of ethyl-phenols up to the preferred threshold (around 426 µg/l), beyond which these molecules can give a wine notes and aromas that are easily perceivable and sometimes disagreeable (Chatonnet, 1995).
These yeasts use the wood as a haven and a substrata and, for this reason, they can be found more frequently in wines that have undergone periods of aging in wood containers. This presence stems from the great difficulty of sanitizing and cleaning the wooden cooperage, as the porous cellular structure which characterizes this material is the perfect haven for the microorganism. In fact, the internal surfaces of the barriques and the casks, having a certain irregular structure and porosity, are a favorite niche in which the yeasts can hide and continue to live, absorbing nourishment from the media and protecting themselves against cleaning operations (treatments with hot water or vapor) and from the application of anti- microbial agents such as sulfur dioxide. The picture of an uncontaminated wood structure and one contaminated by numerous cells of Brettanomyces can give an idea of the difficulty posed when trying to deep sanitize the barriques. Furthermore, the tartar precipitations, as well as the presence of other precipitates of various nature, can protect these microorganisms even more, as they make up a stratum that covers the internal surface of the wooden wine vessels. Removing this surface is essential for an efficient control of Brettanomyces, using an adequate washing and cleaning system (Chatonnet, 2000). At any rate, it is important to underline that refinement in wood is not always the cause of contamination and the consequent appearance of a phenolic character in wines.
Certainly, conservation in wood, used and badly conserved barriques, untimely cask topping or correction of sulfur dioxide content, and ineffective washing and sanitizing operations can be a combination of circumstances that favor the onset and development of contaminating microorganisms in general, and of Brettanomyces in particular. Accordingly, the contaminated barriques must be immediately identified, isolated and even destroyed if the contamination is too difficult to remove. Although it is not possible to arrive at a "zero Brettanomyces" level, keeping the population controlled at a tolerable level is sufficient to limit the problem. Furthermore, the tolerable population level, the concentration of ethyl phenols and the intensity of the Brett character are specific to and variable from wine to wine, according to the vine type, the cellar, the territory and the enological techniques. Therefore, monitoring the Brettanomyces population and regularly controlling the evolution of the ethyl phenol tenor during the refinement process are essential operations. If the enologist has an idea of the true extent of contamination pertaining in the cellar, he can take all the measures necessary to contain the problem.

- Instruments and methods for identifying and controlling Brettanomyces

An incipient development of Brettanomyces yeasts can be identified principally by perceiving and monitoring particular sensory changes that wine goes through.

Besides the sensory analysis, which is the principal tool for analyzing wine evolution during the maturation phase, the monitoring of this yeast can be carried out both with specific microbiological and technical analyses, as briefly reported below:

1) microbiologic control on Petri dishes: this method uses specific media that are selective for Brettanomyces (with the addition of a specific antibiotic, actidione and cicloeximide) and successively uses a micro- scope to count and verify the number of colonies that have developed. Although these methods are sufficiently specific to enable the isolation and fairly precise computation of the contamination level, they are time consuming (Perez et al., 2000; Rodrigues et al., 2001).

The development of colonies in the dishes requires, in the best of cases, a 5-8 days' wait, but at times even more (7-14 days), and subsequently it is always necessary to identify the Brettanomyces cells by observing the single colonies under the microscope. In fact, these yeasts are characterized by a very particular morphology, so they are identified by recognizing the oval, more or less elongated form of the cells, with a typical shape that ranges from a Gothic or pointed arch to a rhombus (ogive). This characteristic is very distinctive of this yeast (Barnett et al., 1996). However, the development times of Brettanomyces in Petri dishes are often not compatible with the timing of the winemaking process and the cellar. In these phases, the risks of an eventual contamination and appearance of undesirable phenolic notes must be managed in a rapid, efficient and preventative way.

2) microbiologic control using PCR: this method is based on a genetic test, technically called PCR (Polymerization Chain Reaction), which enables the identification of the Brettanomyces cells by means of identifying its DNA. It is more accurate than the Petri dish method (Ibeas, 1996). Although specialized laboratories can furnish a test result within 24 hours when using this method, most cellars cannot adopt it due to its high costs and the professional experience required for its use.

3. Gas chromatography analysis of the ethyl phenols: another method for monitoring the activity of the Brettanomyces yeasts consists of determining the evolution of the ethyl phenol concentration in the wines, through gas chromatography and mass spectrometry.

This method is based on the periodical control of the products resulting from Brettanomyces activity (4-ethyl guaiacol and 4-ethyl phenol). These data are cross-checked with the degree of contamination of the wines based on the determined population using Petri dish analyses. This enables the evaluation of the wine's evolution and the definition of targeted operations (Zoecklein, 1995; Pollnitz et al., 2000).

In addition, the increase in the concentration of volatile phenols is generally associated with a considerable increase in volatile acidity, which can be considered another parameter that indicates the presence and activity of Brettanomyces yeasts. At any rate, this control procedure is not very widespread in cellars, even if it is a very effective method that is time and cost-efficient.

Banfi has used this method of analysis for several years and the measurement of the ethyl phenols is carried out periodically in wines stored in steel tanks but, above all, in wines maturing in wooden cooperage (barrels and barriques) and in bottled wines.

Relative to the methods for controlling the development of the Brettanomyces yeasts in the cellar, there are different tools and tactics that enable the prevention of contamination and control of development, if adopted in time and managed correctly. Often, some operations that can be adopted to control the contaminating microorganisms do not meet certain enological specifications and can even jeopardize the quality of the final product. Diminishing the pH, increasing sulfur dioxide concentrations, avoiding or limiting refinement in wood containers, using sterile filtration or even pasteurization of the contaminated wines are all effective operations for controlling microorganisms in general and the Brettanomyces in particular, but at times they can have a less than positive enological impact.

The instruments for preventing and containing the activity of the *Brettanomyces* in particular are based on three fundamental aspects:

1. careful sanitizing and cleaning operations of the cellar and the equipment that is used daily (pumps, pipes, etc.)

2. periodic and effective cleansing and sanitization of the wooden cooperage

3. correct use of sulfur dioxide (potassium metabisulfite) according both to the type of container (wood or steel) and to the period of wine maturation (winter or summer) as well as to the age of the *barriques*.

Sulfur dioxide is recognized as the most powerful means of controlling the majority of the micro-organisms present in wine, including *Brettanomyces* in particular. Sulfur dioxide management involves maintaining adequate levels of free SO , and above all, active or molecular SO . This is the sulfurous fraction, which actually has anti-microbial properties – Chatonner *et* al., 1993. It has been proven that *Brettanomyces* are inibite by molecular SO concentrations of around 0.30- 0.40 mg/l and are destroyed by values higher than 60 mg/l, but in certain cases the development of *Brettanomyces* can occur even with molecular sulfur dioxide values of 0.8 mg/l. This confirms the existence of some strains of yeasts that are particularly resistant to this substance.

When contamination is discovered early, when there is slow fermentation or difficult malolactic fermentation, it is certainly preferable to sulfitize and filter before re-inoculating to prevent the alteration of the entire mass and the contamination of the whole cellar. In more critical situations, flash-pasteurization can be used, as it is a very efficient, though drastic, procedure (Bertrand, 1981). Particular attention must be reserved for the wood receptacles that, as explained above, are most at risk and the most difficult to sanitize as the *Brettanomyces* hide in them and develop more easily.

Thus wines matured in wood must be checked and analyzed more frequently and in a timelier manner than those stocked in steel tanks. In fact, barrels and *barriques* require particular care and maintenance and in cases of proven contamination and strong presence of *Brettanomyces*, specific treatments, such as a vigorous cleansing of the container with hot water at 80°-85°C/186°-185°F at high pressure or the use of steam, are necessary. The use of ozone and microwaves are other innovative techniques, though their use is not very wide-spread (Froudiere *et* al., 1990). After washing the *barriques*, it is a good rule first to dry them to eliminate the residual water, and then to treat them by burning sulfur wicks. This operation makes it possible to saturate the *barriques* with gaseous sulfur dioxide, which penetrates the wood's pores, causing even deep down microorganisms to die. Finally, it is particularly important to monitor the development of *Brettanomyces* even in the bottles: in fact, because of their morphology and characteristics, these yeasts can pass through even sterile filters (0.45mm) as they are generally smaller than the *Saccharomyces* (from 2 to 4 μm in diameter versus the 5-20mm of the *Saccharomyces*). They are elongated and when they are quiescent, they can shrivel and become small enough to pass through the filtering screen. Thus the phenolic character, which generally becomes most evident during the maturation of wine in wood containers, can also occur in bottles when the sulfur dioxide treatment and the filtration have not secured the total elimination of vital cells. The latter, in the presence of a substratum and of high temperatures (18°-20°C), can multiply further and determine a deterioration in the quality of the wine through the onset or accentuation of animal and phenolic notes characteristic of this type of contamination (Gaia, 1987).

Ethyl Phenols and brett character

This character, technically known as "the phenolic character of red wines" is directly tied to the presence of volatile phenols in wine in a quantity superior to the perception threshold (426 μg/l), and in particular to the presence of 4-vynil phenol and 4-vynil guaiacol in white wines and of 4-ethyl phenol and 4-ethyl guaiacol in reds.
White wines can often have high concentrations of vynil phenols (4-vynil phenol and 4-vynil guaiacol) while the red wines can only have traces. However, red wines can have high concentrations of ethyl phenols (4-ethyl phenol and 4-ethyl guaiacol).
In Table 1, the concentrations of these compounds in white and red wines are reported, with the relative thresholds of perception and preference and the sensory characteristics typical of each molecule. In particular, 4-vynil phenol has a significant negative effect on the aroma of white wines, masking their fruit notes. On the other hand, 4-vynil guaiacol, in concentrations lower than 570 μg/l causes floral and spicy notes, contributing to an increase in the aromatic intensity that plays an important role in the varietal expression of certain vine types, such as *Gewürztraminer* (Versini, 1985).
The ethyl phenols can also derive from other causes:

- Microbiologic activity of the Saccharomyces yeasts.
- Secondary enzymatic activity present in enzymatic preparations that are not pure.
- Release from the wood of the *barriques* because of lignin degradation.
- Microbial activity of the lactic bacteria.

We will focus our attention only on the causes of the ethyl phenol formation, as these substances have a greater enological impact, excluding the activity of the *Brettanomyces*, which is the main cause of this problem:

- Yeasts of the genus *Saccharomyces cerevisiae*, responsible for alcoholic fermentation, can produce ethyl phenols, but not in significant quantities. Their enzymatic mechanisms, responsible for the transformation of the phenol acids into the corresponding volatile phenols, are inhibited by the polyphenols present in the medium (tannins, anthocyanins, flavonoids). On the other hand, *Brettanomyces* yeasts do not have this type of inhibition and retain their capacity to produce volatile phenols, in great quantities, even during all the phases of red wine making (Chatonnet *et* al., 1997).
- The use of extractive pectolitic enzymes during red and white vinification can favor the formation of these compounds and the appearance of anomalous aromas. In fact, towards the middle of the ‘70s, some German researchers observed that a relationship could exist between the premature aging of some white wines and the use of extractive pectolitic preparations. The loss of freshness that they observed has subsequently been attributed to cinnamil ester enzymatic activity found in numerous fungi, including the *Aspergillus Niger*, widely used in the production of enzymes (Bertrand, 1981).
- Lactic bacteria, including the *Oenococcus Oeni*,

can contribute to the formation of vynil and ethyl phenols through the metabolism of the hydrocinnamil tartaric acids, but in insignificant concentrations compared to the activity of the *Brettanomyces*. (Cavin *et* al., 1993).
Furthermore, bacteria, together with *Brettanomyces*, are responsible for the formation of particular molecules (acetyl tetrahydropyridine) that confer the notes of popcorn, acetamide and mouse nest to the wine. These compounds can derive, in part, from the wood of the *barriques*. In particular, 4-ethyl guaiacol originates following the preparation that the wood undergoes in the production of *barriques*, and in

particular, after the toasting operation. However, the determination of 4-ethyl phenol and 4-ethyl guaiacol concentrations higher than the perception and preference thresholds is generally a sign of severe contamination and of the uncontrolled development of Brettanomyces/Dekkera yeasts, as these are the only ones able to form quantities of the compounds great enough to decrease, and at times compromise, wine quality (Deak et al., 1996). Finally, it is important to specify that the perception and preference thresholds of the animal and phenolic characters are strongly influenced by different factors, including grape variety and the wine's individual structure. Recent research (Laureano et al., 2001; Chatonnet, 1995) has deepened the understanding of the "Brett" character expression in different varieties of grapes, The results highlight how the musts and/or wines of different grapes, in relation to their specific composition in terms of quantity and quality of the substrata used by the yeasts, are more or less likely to have intense phenolic and animal notes. Within the range of the same type of wine, the intensity of Brettanomyces character also varies according to the chemical composition of the wine itself. The concentration of ethanol, fixed acidity, the polyphenolic content, and the type and length of the maturation phase (wood or steel) can significantly interfere with the intensity and the sensory profile that aromas characterized as medicinal, band aid, wild animal, barnyard, and char, etc. give to a wine. They are integrated in a more or less positive way with the peculiar character of the final product – Rodrigues, 2001. These last two aspects make the Brettanomyces topic even more complex and explain the numerous reasons why wines, with the same concentration of ethyl phenols, can have very different aromatic notes and profiles. They are different enough to obtain a more or less positive judgment and evaluation from tasters and consumers.

In fact, these problems have been approached by technicians, tasters and consumers in different ways. Some refuse a wine that has any phenol and animal traces; others tolerate a light note of Brett so long as it is integrated well in the wine's aromatic profile; while still others seek out a certain Brett character in wines and judge the phenol and animal traces to be elements of aromatic complexity and maturity typical of some wines (Parish, 2003). Thus, it is not simple to furnish an answer about the role that the ethyl phenols play, and thus the Brett character, in defining wine quality. For this reason, these problems have been the object of a study at the Castello Banfi estate, considerino the great interest of the enological sector in appropriately "managing" Brettanomyces throughout the winemaking process.

Tab. 1 - Reference values for the volatile phenols in the wine (values expressed in μ/L)

Compound	Perception threshold in water	Perception threshold in wine	Preference threshold in red wine	Contents of white wines			Contents in red wines			Descriptors
				mean	min	max	mean	min	max	
Vynil-4-phenol	85	180	180	301	73	1150	35	0	111	Medicinal, Phenolic
Vynil-4-guaiacol	32	130	570	212	15	496	12	0	57	Spicy, cloves
Total vynil Phenols			**725**	**513**	**88**	**1646**	**47**	**0**	**168**	
Ethyl-4-phenol	130	440	520	3	0	28	440	1	6047	Horse sweat Barnyard, band aid
Etil-4-guaiacol	25	47	140	0.8	0	7	82	0	1561	Smoky, Spicy
Total ethyl phenols			**426**	**3.8**	**0**	**35**	**522**	**1**	**7608**	

Tab. 2 - Incidence of volatile phenols in the red wines (%).

Country	>426mg/l*	>620mg/l **
France/Bordeaux	36	28
Italy/Piedmont	49	19
Australia	59	46
Portugal	42	27

Why study *Brettanomyces*

Brettanomyces yeasts are considered responsible for the organoleptic alterations of wines, even if there is debate about the real role that they have in determining their quality.
Many studies (Chatonnet et al.; 1992, Di Stefano, 1985; Pollnitz et al., 2000) have dealt with the evaluation of ethyl phenol concentrations in red wines. Here, the concentrations of the ethyl phenols are reported (4-ETF and 4-ETG).
While an increasing number of wines have ethyl phenol concentrations below the preferred threshold, there are many wines, both red and white, that have ethyl phenol concentrations significantly above the threshold, and thus are not well accepted in the market. The consequence, in economic terms, is that *Brettanomyces* yeasts have been found in all the vine and wine-growing areas of the world, often causing wine loss worth millions of dollars. Table 2 demonstrates the percentage of international wines with ethyl phenol concentrations above the preference threshold. This is a threshold that represents a limit beyond which the phenolic character can be significantly perceived and can thus influence the commercial value of the product. In conclusion, it can be deduced that it is very difficult to keep wines completely free of *Brettanomyces* and this is especially true for quality wines that have undergone a period of maturation in wood. Thus, control operations and reducing of the number of contaminating yeasts must guarantee levels of ethyl phenols that do not compromise the commercial value of the final product.
The relationship of "quantity of ethyl phenols to the degree of consumer preference" is an object of ongoing debate and discussion in the field of enology, since experts, enologists and technicians have different opinions about the aromatic contribution that the volatile phenols have on the sensory profile of the wines.
For several years, Banfi has studied the interaction between the yeasts of the *Brettanomyces* genus and the wine matrix to:

- identify the factors and causes of the onset of this microbial activity;
- evaluate the developmental kinetics and the dynamics of these yeasts;
- define and implement the most efficient control methods and strategies, best suited to prevent and contain the activity;
- evaluate the sensory impact of the ethyl phenols on the organoleptic characteristics of the final product.

The impact and the contribution of the scents determined by the activity of the *Brettanomyces* in the wines represent a critical aspect in the enological process for two main reasons. Firstly, because of the complexity of these phenomena, and secondly because consumers differ in the ability to perceive and recognize, as well as appreciate, the final so- called *Brett* aromas within a wine's aromatic profile. This ability is the subject of current debate.
For the above-mentioned reasons, Banfi's attention has been particularly focused on the study of the *Brett* character in wines on the market. This study is carried out by analyses and tasting sessions, the results of which are reported in the following chapters. The study regarded:

1. evaluation of the presence of the *Brettanomyces* and ethyl phenol concentration in the 1997 vintage Brunello di Montalcino wines;
2. evaluation of the presence of the *Brettanomyces* and ethyl phenol concentration in wines originating from the most renowned vini-viticultural areas of the world (Australia, Chile, France, Spain, Italy);
3. evaluation of an expert tasting panel's ability to identify and recognize the *Brettanomyces* aromas in order to assess the panel's overall sensitivity to this phenomenon;
4. evaluation of the contribution of these aromas to the overall preference judgment of the wines;

5. evaluation of the correlation among analytical data, microbiological conditions and preference judgment stated by the tasting panel.

In the following chapter, some tools for controlling and monitoring Brettanomyces yeasts that have been adopted by Banfi will be described. The analytical and sensory results of two distinct tasting sessions (Brunello di Montalcino and international red wines) are reported. These sessions were aimed at evaluating the diffusion of Brettanomyces activity and the impact of the aroma it produces on wine quality. The study also considers the tasting panel's judgment on the preference and appeal of the wines.

Control and Prevention of Brettanomyces Yeasts and the Volatile Phenols in the Banfi Winery

For Banfi, the Brettanomyces problem has been one of the most important topics to be studied and thoroughly analyzed, both at an experimental and a research level. This is due both to the complexity of the factors that are at the basis of the formation of the ethyl phenols and to the particular sensory impact that the activity of these yeasts has on the aromatic profile of wines. For these reasons, for the past few years Banfi has paid particular attention to preventing this problem by adopting systems for monitoring, identifying and controlling the development of Brettanomyces, both during the fermentation phase and, above all, during maturation in wood. At the Banfi winery, Brettanomyces have been studied mostly from the standpoint of the sensory impact that ethyl phenols have on wines. In fact, the sensory analyses of the wines represents the best tool for evaluating an eventual development of Brettanomyces, the presence of ethyl phenols and the quality of their contribution to the overall sensory profile of wines.
This study took its cue from two important considerations:

1. the concentration of ethyl phenols and the organoleptic profile of the wines do not always correspond, as the phenomena of "cellular multiplication of the Brettanomyces, formation of the ethyl phenols, perception of the phenolic character, and composition of the wine matrix" interact in a very complex way;
2. the contribution of the Brett character to the wines is a very complex element that can be judged and perceived positively or negatively.

Since "zero Brettanomyces" is practically impossible to attain in the cellar (even supposing it is actually qualitatively beneficial to attain), and that, in other words, the technician has to learn to live with these yeasts, it is important to find the answers to the following questions:

- what is the degree of Brettanomyces diffusion in the wines?
- what is the concentration of the ethyl phenols in the red wines and what is the variability?
- what is the ability of tasting panels and consumers to identify the specific notes caused by the Brettanomyces activity?
- what is the relationship between the concentration of ethyl phenols in the wines and the degree of consumer preference?
- what are the other analytical parameters (alcohol, extract, Index of Total Polyphenols, etc.) that can mask or amplify the expression of the animal and phenolic notes.

Methods and instruments: Controlling Brettanomyces in the Banfi winery

- Monitoring the Brettanomyces population by analyzing specific media

Quantitative evaluation of a wine's level of contamination is most commonly obtained by determining the development of Brettanomyces yeasts on filtering material, using specific culture media for these yeasts. These media, as already mentioned, are treated with an antibiotic (actidione) that almost completely inhibits the development of yeasts of other genera, while the antibiotic-resistant Brettanomyces manages to develop and form colonies of varying sizes and color.
Unfortunately, this identification method of the Brettanomyces is relatively time-consuming since it requires an 8-to-12 day stay in a controlled environment for the appearance and complete formation of the colonies. This can be compared to the 2-3 days required for the yeasts belonging to the Saccharomyces genus.

Further tests, necessary to correctly identify which Brettanomyces are present, are the ones which use the presence of a clarification halo around a colony that has developed in culture media with a calcium carbonated addition. After observing the characteristics of the colonies, it is indispensable to observe under the microscope the individual microbial cells that make up the colonies in order to identify and quantify the degree of contamination of the sample under study. These cells have a specific and characteristic morphology since, besides being oval and rather elongated, there are others with a pointed arch form (ogive) that is typical of the Brettanomyces genus.
To evaluate the efficacy of washings and sulfur treatments, microbiological checks are carried out periodically both on wines matured in barriques of different ages, and directly on wood samples taken from the internal surface of the wooden cooperage.

- Monitoring of the ethyl phenol concentrations by gas chromatography analysis

Gas chromatography analysis is an indispensabile tool for monitoring the evolution of ethyl phenols during the winemaking process and the maturation of the wine, both when it is stored in steel and matured and aged in wood containers.
The concentrations of compounds which indicate a Brettanomyces contamination (4-ethyl phenol and 4-ethyl guaiacol) are monitored at the Banfi winery, and even though it is a complex analysis, it is possible to check a significant number of samples. The information thus obtained, cross-checked with the results from the Petri dish and sensory evaluations, enables a reliable quantification of the possible contamination of the wines. These data, evaluated in the light of the volatile acidity and sulfur dioxide values of the wine, make it possible to define the true extent of the microbial contamination and to identify the correct treatments to perform.

- Barrique management

Wood cooperage plays a technological and active role in the evolution of the wines, both red and white. Thus, its management is a critical aspect, considering the fact that wood is the seat of accumulation and development of microorganisms that can negatively modify the organoleptic cha acteristics of the wines.
Cleaning operations are an important aspect of barrique management, and they must be standardized

and modulated according to the age of the container, the level of residue and crust present, and the level of cleanliness of the wine container. These operations must be followed by an effective system that guarantees a complete drying of the barrique's internal surface and penetrates the entire depth of the staves. Next, the barrique undergoes a sulfur treatment, by burning some sulfur wicks inside until the barrique is saturated with sulfur dioxide gas. This gas penetrates inside the microscopic pores of the wood, when it is sufficiently dry, and favors its in-depth sanitation. This significantly reduces the degree of microbial contamination.
Finally, the maintenance of adequate levels of sulfur dioxide in the wines ensures an efficient control of the Brettanomyces population and reduces the risk of the appearance of animal and phenolic notes that can decrease the wine's commercial value. Generally, these operations are carried out manually and not always in an impeccable and efficient way. For these reasons, and because the Banfi winery has more than 6000 barriques, it was deemed useful to introduce (in the winemaking process using barriques) an automatic management system that could guarantee the abovementioned operations (emptying, cleaning, drying, etc.) in an effective, standard and efficient way.
The barrique treatment system was developed to attain the following objectives:

- to facilitate the execution of the emptying-fine lee removal-refilling operations of the barriques themselves
- to optimize and standardize the operation of washing-drying-sulfitizing
- to increase the frequency of the barrique treatment operations

The system consists of two conveyor belts where the barriques are placed with the help of a forklift, and it has either a wood or steel pallet. The two conveyor belts are connected by a shuttle that transports the pallets from the first to the second belt and after filling, they are removed and put back in the "barriquerie" .
Several simple operations take place on the levels of the two conveyor belts, and they are described below:

1. emptying: the barriques are emptied automatically and this can be performed only with the protection of inert gasses, to avoid wine-air contact;
2. rotation and lees removal: the barriques are rotated; the wine and the lees remaining in the container are removed and gathered in a tank, for subsequent evaluation and possible re-utilization. This aspect is very important, especially for white wines, where an attempt is made to manage the finer and cleaner lees to exploit the lees' organoleptic contribution to the wine in the course of the maturation phase.
3. washing: this is the most important part of the entire process. It includes a system with rotating heads that ensure the complete and uniform cleansing of the internal surface of the barrique. It can be carried out using high-pressure water and water temperature can be regulated up to 90°C according to, for example, the quantity of tartrates present, the nature of the incrustations and the age of the barriques;
4. drying: it consists of a system of air blown at high-pressure that can be heated to remove residual water in the wood's deeper layers. This maximizes the efficiency of the subsequent sulfur treatment operations on the barrique;
5. rotation and sulfur treatment: the sulfur pith is burned manually, allowing the saturation of the entire barrique with sulfur dioxide. In this way, the sulfur dioxide gas penetrates into the microscopic pores of the wood, performs its anti-microbial function against the contaminating population, even deep down;
6. refilling: the barriques are refilled automatically and this can take place contemporaneously with the emptying operation;

The system is very versatile as it allows the handling of two wines at the same time, emptying one from the barriques and refilling them with another one immediately.
The automatic barrique management system has a work hour capacity of 16-18 units and enables a reduced movement of the containers that undergo, in a single operation, all the critical treatments that influence both the quality of the barrique's contribution to the wine and its longevity.

Evaluation of the impact of Brettanomyces on Brunello di Montalcino wine, vintage 1997

The aim of the tasting session was to evaluate the impact of the Brettanomyces character on a DOCG wine, Brunello di Montalcino, produced in its designated growing area. Brunello di Montalcino, according to winemaking regulations, is produced exclusively from Sangiovese grapes and must mature in wood for a minimum of 2 years. The final product can be sold on the market only 5 years after vintage. Thus, Brunello di Montalcino is produced according to a vinification technique that easily exposes it to Brettanomyces contamination. In fact, there are several critical points that can favor the onset of this problem:

1. medium-long alcoholic fermentation and maceration, lasting variably from 10-12 days to 20-25 days, in the more traditional vinification;
2. vinification temperatures during the fermentation and maceration phase that tend to be high, from 22-25°C to 28-35°C / 72-77°F to 82-95°F;
3. on average, a long maturation in wooden cooperage (barrels or barriques) – according to regulations, at least 2 years;
4. on average, low concentrations of sulfur dioxide during all the phases of maturation and aging; the Sangiovese wine is renowned for having tannins that tend to be harsh and astringent at the end of the fermentation-maceration. Steady levels of sulfur dioxide certainly enable a more effective control of Brettanomyces development, but at the same time this implies a significant slowing down of the wine's evolution. This phenomenon is evident above all when dealing with the polyphenolic component, as it limits the polymerization reaction and the condensation of the tannins-anthocyanins. These processes are the basis both of the reduction of the astringent and tannin sensation typical of young wines, and of the process of color stabilization.

Such vinification conditions of Brunello favor the multiplication and diffusion of the Brettanomyces yeasts. If they are not effectively controlled with systems that are alternative to and/or synergetic with sulfiting (i.e. frequent and efficient washing and sulfur treatments of the barrels and barriques, low conservation temperature and maturation in wood, etc.) they can lead to the formation of ethyl phenols in concentrations that could result in the appearance of negative animal and phenol notes. The analytical and sensory study of the Brunello di Montalcino wines aimed at evaluating the entity of the Brett character in a typical Tuscan wine, known the world over. Wines originating from 15 different estates in the Montalcino district were examined, for a total of 20 wines.
To reach this end, several different aspects of the wines were analyzed:

- analyses of the classical chemical parameters (alcoholic content, residual sugars, pH, total acidity, volatile acidity, coloring intensity, coloring tonality, etc.);

- determination of the ethyl phenol concentration (4-ethylphenol and 4-ethylguaiacol) by gas chromatography;
- determination/establishment of the presence of Brettanomyces by using Petri dishes and microscopic techniques;
- sensory evaluation and recognition of the descriptors typical of the Brettanomyces character (animal, plastic, bandage, medicinal) by using the appropriate tasting notes;
- elaboration of the analytical and sensory data.

The data obtained from the abovementioned analyses, namely the concentration of 4-ethylphenol (4-ETF) and 4-ethylguaiacol (4-ETG), the presence of vital cells of Brettanomyces, and values of turbidity were all very heterogeneous. Twelve wines, out of a total of 20, were found to have vital cells of Brettanomyces in the bottle, expressed as Units Forming Colonies (U.F.C.). Their number varied from a minimum of 150 to 1056 U.F.C per bottle (750 ml).

Indeed, various studies have demonstrated that most filters generally used for bottling are less effective in treating Brettanomyces yeasts, compared to other yeasts, as these are very small. In particular, when dealing with Brunello, the filtering systems are often mild to avoid decreasing the quality profile of the wine.

Besides this, the wine matrix always contains a minimal source of nutrition for the eventual Brettanomyces present in the bottles. Therefore, these yeasts can multiply further, and thus lead to, after only a few months, the appearance of phenolic and animal notes in wines that had ethyl phenol concentration below the perception threshold at bottling, (i.e., they had no evident phenol notes).

In Figure 16 the concentrations of ethyl phenols are reported for all the wines analyzed, as a sum of 4-ethylphenol and 4-ethylguaiacol, compared to the preference threshold of volatile phenols equal to 426 μ/L. This figure shows that only one wine, out of the 20 analyzed, had ethyl phenol concentrations below the preference threshold. All the others were characterized by extremely variable concentrations that even reached figures 4 times higher than this threshold (2755 μ/L in the G wine, whose concentration is plotted in red because it goes off the graph).

Most of the wines have ethyl phenol concentrations that range from 600 to 800 μ/L.

Even the N.T.U. values were extremely variable, from 0.4 to 37, and the highest were found in the wines where the Brettanomyces development in bottle was the most pronounced.

The two parameters tend to be correlated and in the wines where no microbiologically active Brettanomyces were found, the variability range of the turbidity values (measured as N.T.U.) ranged from

0.4 to 6. However, in the wines where Brettanomyces contamination was found, the variability range for turbidity went from 3.2 to 37.

This observation leads to the hypothesis that a microbiologically active population of Brettanomyces can interfere with wine turbidity and limpidity and thus, eventually, with its commercial value.

The data obtained from the Brunello demonstrate the intensity of the "plastic" and "animal" descriptors found in the wines analyzed. It is interesting to note that, even though the wines had very different concentrations of total ethyl phenols, the plastic and animal descriptors were perceived with almost the same intensity in most of the samples, except for sample G. This wine represents a very different situation from all the other wines analyzed. Furthermore, the two detected sensory characters had parallel variations and very similar trends.

Sample G requires further explanation. It had very high concentrations of ethyl phenols (2755 μ/L), which were way beyond the preference limits. In addition, it had the lowest values of vital Brettanomyces in the bottle (15 cells/bottle) and a low turbidity value (0.8 N.T.U.).

This analytical profile indicates a less than optimal evolution of the wine, which has suffered, in the vinification phase and above all in the phase of maturation in wood, from an uncontrolled contamination by Brettanomyces. This resulted in the formation of the great concentration of ethyl phenols. In fact, the production of these compounds probably did not occur in the bottle, but during the evolution and maturation phase of the wine. At the moment of bottling, the contaminating population of Brettanomyces was partially removed by the fairly narrow filtrations. On one hand, this guaranteed attainment of optimal N.T.U. and turbidity values, but on the other, it drastically reduced the contaminating microbial content. However, this did not interfere with the sensory profile, which had already been compromised during the aging phase of the wine.
This case is representative of the lack of adequate, consistent, and periodical monitoring of the Brettanomyces population in the aging and maturation phase of the wine in wood without timely prevention treatments aimed at reducing and containing re-infestation. It is interesting to stress that the G sample also stands out for the preference score (63.8) that is the lowest, confirming that the Brettanomyces character, which is very evident, was perceived and judged to be negative by all the tasters.
Excluding sample G, one notes that the preference test scores and the concentration of the total ethyl phenols follow a bell-shaped curve, suggesting the following observations;

- the wines that received the highest scores are also the ones with the ethyl phenol concentrations ranging from 600 to 800 µ/L;
- between 600 and 800 µ/L of ethyl phenols were found also in wines with scores below 80, demonstrating how other factors play a role in the general evaluation of the product;
- concentrations below 600 µ/L and above 800 µ/L resulted in the lowest scores on the preference test. It seems evident that wines with particularly pronounced animal and plastic sensations were penalized.

It is important to stress that this evaluation was more clear-cut in the case of technicians and expert tasters, who easily identified and penalized this character. On the contrary, other tasters, who were less familiar with the Brett character, were less sensitive to it and showed a relative appreciation of the aromatic sensations typical of some wines that were evidently "bretty".

Evaluation of the Brettanomyces impact on some international wines

Pursuing the same goals and with the same panel of expert tasters, international red wines of different geographical origin (Italy, France, Spain, Chile, Australia) and principally from the 1999 vintage were tasted. The great difference of the ethyl phenol values among the wines analyzed can be noted, and they range from concentrations that are significantly below the preference threshold (140 µ/L) to values that are 4 times greater than this threshold (1593 µ/L).
In fact, the variability of the ethyl phenol concentration was more pronounced in the international wines than in the Brunello di Montalcino ones. However, Figure 21 demonstrates the intensity of plastic and animal notes found in the wines. In most of the wines tasted, there is an evident predominance of the animal note compared to the plastic note, unlike the Brunello wines, where the two notes were distinguished and recognized in a less evident way.
In fact, what emerged from the tasting sessions was that, for international wines, tasters identified the Brettanomyces character with animal notes rather than plastic ones. On the contrary, for Brunello di Montalcino wines, the "Brett" character was identified with both notes and with an intensity similar to

most other wines. The relationship between the scores of the preference test with the concentration of ethyl phenols can be represented, even for the international wines, by a bell curve with a flattened course compared to what was seen for the Brunello wines. This indicates that the two provided less correlated parameters. Finally, when comparing the values of ethyl phenols found in Brunello with those found in the international wines, several different sensory characteristics of the wines under analysis emerged. However, the differences between the two groups do not stand out if the respective total concentrations of ethyl phenols are compared. These values, which span between 344 and 1094 µ/L in the Brunello wines (excluding sample G) and between 140 and 1593 µ/L in the international wines, are quite similar. Instead, the most interesting differences were found when comparing the 4-ethyl guaiacol concentrations, which are responsible for the toast and smoke notes, to the 4-ethyl phenol concentrations, which are responsible for the animal, band-aid, and plastic notes. In fact, it can be seen that the Brunello wines feel the effects of the 4-ethyl guaiacol contribution to a greater degree than the international wines. However, for the latter, the most important contribution of the total ethyl phenol values is given by the 4-ethyl phenol.

The two groups of wines analyzed demonstrate significant differences. For Brunello, the 4-ethyl guaiacol: 4 ethyl phenol ratio varies from a minimum of 1:2 to a maximum of 1:6 (excluding sample G). For the international wines, the above-mentioned ratio varies from 1:2 to 1:12, and 10 samples out of 15 have a 4-ETG:4-ETF ratio greater than 1:6, which represents the limit beyond which the concentration of 4-ETF causes animal, barnyard and band aid aromas, off-aromas that are particularly evident and perceptible. This explains why the animal notes found in the international wines were more evident compared to those in the Brunello wines, where it was more difficult to distinguish between the two sensorial impacts. In fact, in the Brunellos, the sensory impact of the 4-ethyl phenols of medicinal, barnyard, and band aid, was probably mitigated by the greater concentration of 4-ethyl guaiacol that increased wine complexity, giving smoky and spicy notes that are typical of this molecule. This aspect shows the different profile that the Brettanomyces yeasts can confer to a wine related to the multiple factors, such as the wine type and the prevailing Brettanomyces species found in the wine (B. bruxellensys and/or anomalus).

In fact, 4-ethyl phenol and 4-ethyl guaiacol can be found in the wines in varying ratios, ranging from 1:2 to 1:8, and this ratio is the basis of the different expression of the Brettanomyces character. Thus, this character can determine very different sensory profiles as a consequence of many factors that can be traced back to the territory (climate conditions), the variety and the vine cropping techniques, the vinification system, the degree of contamination, the most widespread contaminating species, the quantity of other odorant molecules (valerianic acid, responsible for rancid off-aromas, etc.) the maturation and aging techniques, the characteristics of the wine matrix, the filtering- bottling techniques, etc. In light of the above, and considering that the panel of tasters was composed of the same members for both groups of wines, it follows that the Brettanomyces character of the Montalcino territory wines seems to be easily distinguishable from the other wines examined, and it is characterized by very specific and peculiar scents and aromas.

Conclusions

The yeasts of the Brettanomyces genus are mainly responsible for the formation of the volatile phenols in wines, and in particular, of the 4-ethyl phenol and 4-ethyl guaiacol. Beyond a certain threshold, defined as the preference threshold, these compounds can alter wine quality, resulting in a negative impact on the aroma and taste sensations. The concentration is variable among the wines. The values of ethyl phenols and the sensory notes that can make a wine pleasing or unpleasant are very variable, as can be

seen from the test results of the studies carried out in the Banfi winery. The alterations caused by excessive quantities of volatile phenols are relatively subtle as the chemical composition of each type of wine can reflect or mask the profile.
Contrary to the microbiological alterations caused by other microorganisms, the defects that arise because of the presence of these substances are difficult to resolve. The main consequence is a general flattening and uniformity of the organoleptic characteristics of the wines affected by this problem. All this brings about the loss of the organoleptic peculiarities of the wines, as an expression of grape variety, of the territory, and of the uniqueness that characterizes each single product.
Observing the standard norms of hygiene in the cellar, a periodic control of wine maturation and aging, and a correct use of current technologies makes it possible to avoid the damaging effects of Brettanomyces yeasts in red wines. The results of this study show that the contribution of the Brettanomyces yeast activity and the sensory effects of the 4-ethyl phenol and 4-ethyl guaiacol on the wines should be evaluated from 3 important standpoints:

The complex relationship between wine and Brettanomyces- ethyl phenols

- Because several factors affect the expression of the Brettanomyces character in the sensory profile of a wine: the Brettanomyces species is predominant, the ratio between the content of 4-ethyl phenol and 4-ethyl guaiacol, the composition of the wine matrix, the presence of other microorganisms (lactic bacteria)

The Technician

- Because the technician can obtain a product with good quality characteristics by the application of monitoring and control protocols to contain Brettanomyces activity, in order to reduce risks and critical points such as: destruction and/or modification of the sensory profile, alteration of the wine's analytical profile (i.e. the noteworthy increase of volatile acidity), the difficulty of eradicating the problem once it is present in the cellar, the need to turn to operations that are not always compatible with wine quality (pasteurization, filtering, sulfitation) besides also being cost inefficient.

The Consumer

- Because of the following factors, it is very difficult to obtain a uniform preference and quality judgment from an expert tasting panel: the limited knowledge of this problem, the particular complexity of the Brett case, the scarce familiarity with aromas that are typical and consequent to Brettanomyces activity, the reduced capacity to perceive and recognize the Brett character in wines.

While waiting for new research and sensory evaluations on this topic to emerge on the international enological horizon, technicians and consumers will hopefully acquire more sensitivity and not over-emphasize the Brettanomyces problem, especially considering the normal presence of the "Brett" character in some historical denominations in the national and international enological panorama. Finally, in light of our experience, it is important to stress that the contribution of the Brettanomyces yeasts, if managed well, can add complexity. However, this can lead to undesirable characters if the technician is faced with an uncontrolled evolution and aging of the wine.

WOOD AND WINE: A CENTURIES-OLD RELATIONSHIP

R. Buratti, T. Bucci, L. Matricardi

Wood has been used to build containers for wine making and transportation since ancient times. An Egyptian tomb depicting the art of producing wooden vessels can be dated back to 2700 B.C., while we can assume that the Egyptian practice of storing wine in wooden and clay containers dates back to 1800 B.C. Herodotus (484 B.C.) tells us that the first wooden barrels were built using Assyro-Babylonian palm trunks. The vessels used for wine storage and transportation varied in shape and size (dinos, olpe, dinochoe, craters, vase, kyathoi, simpulum, kantaros, mastos, horn) and was made from many different materials (clay, leather, silver, wood, bucchero, etc.).
However, throughout ancient times, wood played a secondary role in storing and preserving wine because it was often difficult to make containers of every shape and size and working the wood required an expert's knowledge, as opposed to the easy and common handling of clay. Furthermore, wooden vessels were more easily contaminated and thus more perishable compared to other materials, which are more resistant from every viewpoint (Beyer *et* al., 1991). The first wooden containers were obtained by digging out a piece of trunk. Later on, containers were made of vertical staves arranged in a frustum of cone wedged at the bottom. The frustum of cone shape was, however, inconvenient for transportation: the later rounded shape was much more efficient for transporting and holding the wine. In fact, that is how barrels are made nowadays. Starting from 90 B.C., there are numerous references in art showing rural life and craftwork referring to the cooper and to the transportation and conservation of wine in wooden cooperage. In fact, in Roman times the use of wood for processing, storing and shipping wine greatly increased, mostly because of the important properties possessed by some woods that improved the wines' organoleptic characteristics after a certain period of conservation and maturation.

The use of medium and large sized wooden containers became widespread and, for the first time, they were also used for fermenting the musts, apart from the successive phase of wine conservation and aging. After the fall of the Roman Empire and the subsequent barbarian and Saracen invasions, vine cultivation suffered a significant reduction. It survived only in the Benedictine monasteries and therefore even the art of the "cooper" gradually disappeared. Slowly, however, even the new rulers began to appreciate wine, to the point where some of them, from Theodoric to Charlemagne, proclaimed laws that protected viticulture. Over time, vine cultivation and wine production increased and wine trade started up again in central and northern Europe. As wine was transported in wooden barrels, the art of the copper flourished once again. They started forming corporations with precise statutes regarding the quality of the materials to be used for building the wooden vessels, the tools to use, etc.

This was even truer in France, where the master coopers founded numerous corporations initially called *Barilliers*. By 1790, the guild of the Tonneliers already counted 202 producers of wooden containers. Wood becomes increasingly important not only for building barrels and vats, but also for all the other receptacles and accessories used for grape harvesting and shipping, from wine production to storage, aging, trading and shipping (Brunet, 1948). Numerous and different wood species have been used for producing the containers employed in the wine sector mainly because they were cheap and easy to find.
Some of the most used species have been acacia, eucalyptus, ash, palm tree, black locust, the common alder, larch, poplar, chestnut, beech and pine (Camus, 1936).
As the world of wine and the art of making *barriques* evolved, oak and chestnut took over and established themselves as the main wood species used in the wine sector (Bourgeois, 1992).

These choices were not made for arbitrary or casual reasons. It was simply an obvious choice: these two types of wood, and oak in particular, are the only ones capable of positively impacting the aromatic and taste characteristics of wines and distilled liquors. Subsequently it was observed that chestnut wood had properties, which were not always compatible with wine's organoleptic traits.

Its high polyphenolic content made this wood very astringent and bitter. For this reason, the containers made from chestnut wood were often coated on the inside with paraffin to keep these substances from being transferred to the wine. Furthermore, since chestnut wood had a particularly coarse grain, it had a marked porosity, which often created leak- age problems.

Therefore, since oak had the best work characteristics and had a positive organoleptic impact on the wine, it soon became the main, if not the only, species used in the wine-producing sector.

The oak is a tree that has always played a unique role for man, particularly in Western Europe. It has always been a symbol of longevity and strength; it has also been worshiped in some religious ceremonies. Last but not least, it has been a source of nourishment for animals and of building material for man. The wood obtained from this tree has been widely used in the past for building ships, and in many forms for urban architecture and art.

Today, oak is in particular demand because it has especially positive and respected chemical and physical characteristics. The building of wooden vessels for wine, among all the crafts of woodwork, is one of the most ancient. In fact, when oak and wine come in contact, the bonding between them is almost perfect: oak, more than any other type of wood, has everything wine needs to best express its characteristics. Oak plays a major and unique role in the evolution of wine.

Wood's availability greatly influenced the spread of using wooden containers and the proliferation of barrel makers. The areas where wood was most available until the '60s were the vast oak forests of Slavonia. Interesting statistical data clearly show how the greatest importer of Slavonian wood was not Italy, but France. It imported enormous quantities of staves to make large and medium sized barrels.

In fact, because these forests were characterized by a high tree density and particularly poor soils, they produced trunks with few knots and a fine grain from which particularly long and good-quality staves were made. Trunks with these characteristics were used throughout all of Europe, particularly in Italy and France, to make 6-8 cm / 2-3 inch wide staves. They were very durable and good for building barrels with a great capacity. In Italy, the barrel factories flourished in the vine- growing areas that had easily available wood supplies, such as Veneto and Piemonte. Here, only Slavonian oak took hold, since the main trade and shipping centers for the staves were the ports of Trieste and Fiume, from which enormous quantities of wood were shipped to all the European countries.

Therefore, in northern Italy and in the main vine- growing areas, oak barrels of different sizes (from 500 to 13.000 liters / 130 to 3.400 gallons) were used for maturing and aging particularly esteemed wines, such as Barolo and Barbaresco in Piemonte and the Brunello di Montalcino in Tuscany. Particularly in Tuscany, the use of barrels was extended to the areas of Montalcino and Montepulciano, as well as to the famous Chianti area. Here even today, red wines are left to age for a considerable period inside barrels of different sizes made of Slavonian oak.

A survey conducted in 1974 in Tuscany revealed that, out of 1.007 producers with a total capacity of 1.190.000 hl / 314 million gallons, 70% of the wines were aged in oak-made barrels or vats, while only 20% were aged in concrete containers and just 10% in steel vessels. Later on, the wood coming from French forests became increasingly widespread. These forests were characterized by a limited density and by generally poor and dry soils as well as the presence of particularly interesting oak species.

On one hand, these forests yielded particularly high-quality wood, because it was compact and had a very fine grain; however, they supplied trunks with very close knots. This greatly limited their use because the staves obtained from them were generally short and only good for small-sized containers. Therefore, the French *Tonnelleries* started reducing imports of staves from Slavonian forests and, perfecting the old "cleft splitting" technique, increasingly used their own oak forests to make short staves. These were used for the production of small containers, generally between 228 and 251 liters /60 and 66 gallons, known today as *barriques*.

After a few experiments carried out during the '80s, the use of *barriques* started spreading also to Italy, and within a decade, for various reasons, it became well established in all the main vine-growing and wine-producing areas of the world.

The reasons for which wine-producers chose to use this new container are various:

- The indisputable quality both of the French wood and particularly of some forests (Allier, Tronçais, Nevers, etc.) which supplied particularly fine grained wood with an excellent aromatic profile;
- The higher contact surface available with the *barrique* as opposed to the barrel causes a faster organoleptic and sensory evolution of the wine both because of the higher concentration of molecules released by the wood, and the higher wine-oxygen contact;
- The easier sanitation of the *barriques* as opposed to the barrels which, once contaminated by unwanted microorganisms, are more difficult to manage;
- The easier transportation and mobility of the *barriques* compared to containers of larger size greatly changed the structure of the cellar operations;
- Last, but not least, the reduced availability of oak wood from Slavonia due to socio-economic reasons, which have greatly compromised the use of the forests to make wooden containers.

Thus, during the '70s and '80s the percentage of the wooden containers used in Italy fell almost to 20% as a result of the rapid spread of steel- coated and stainless steel containers. There was also a simultaneous dismantling of the concrete containers and, most important, of the old and contaminated barrels. From the '90s on, there has been an enormous increase in the use of the barriques that are increasingly placed beside barrels of medium capacity (18-30-50 hl / 500-800-1300 gallons) for the aging not only of great red wines (*Barolo, Barbaresco, Brunello di Montalcino, Chianti, etc.*), but also and increasingly for white wines.

Wood: an element which "ennobles" wine

Wood's role in wine making is very complex and the interactions that are established between the two matrixes are of a variable nature and depend mostly on the following factors (Beyer *et* al., 1971; Lehtonen *et* al., 1983a, 1983b):

- wine characteristics;
- *barrique* characteristics;
- transformation phase of the product (alcohol fermentation, malolactic fermentation, ripening/ maturation, etc.);
- environmental conditions during storage (humidity, temperature, etc.);
- frequency of certain technical interventions
(topping up, decanting, sulfitizing, etc.);
- frequency and techniques of sanitation interventions of the *barriques* (hot or cold water, ozone and sulfur treatments, etc.).

In this chapter some of the main effects that wood has on wines will be briefly discussed.

These effects make the barrique an almost irreplaceable tool both in producing both red and white wine (Singleton et al., 1971, Singleton, 1974). Generally, white wines of a certain type and style, following widely established winemaking processes, come in contact with the wood already during the alcohol fermentation phase. Usually small and medium sized wooden containers are used (225 liters / 60 gallons, 350 liters / 90 gallons, up to 500 liters / 130 gallons) and during this phase wine-wood interactions are established which are very important for the aromatic profile of the finished wine. (Bricout, 1971; Dyer, 1985; Reazin, 1981; Rous et al., 1983).
Afterwards, the wine can remain in the same wooden containers where alcohol fermentation took place and start a new maturation phase which can last a variable length of time and during which the wine is enriched with new aromas and scents derived from the interactions with the wood (Feuillat, 1987).

To simplify, we can say that in white wines one generally looks for two traits:

- The best integration between the wood's scents and the wine's aromatic profile thanks to the yeasts' activity.

Alcoholic fermentation in the barrique softens the impact of the wood's scent; thus the wood aroma of a barrique-fermented wine is milder, but more complex, delicate and blended better into the wine's aromatic profile than that of a wine put in a barrique after alcoholic fermentation.
The wood, in fact, adds some very particular aromatic notes such as a vanilla scent, produced by the vanilline aldehyde molecule; the scent of coconut, caused by the so-called whisky-lactone; the scent of ground cloves, produced by the eugenol; and the scent of toasted almond, caused by the furfuraldehyde. These are only the most important aromatic molecules. When found in small quantities, these molecules positively impact the aromatic profile of the finished wine; however, if they are too evident, the wine appears to be rough and with little character (Somers, 1990; Chatonnet et al., 1992). During alcoholic fermentation, this very particular aspect of the wood-yeast interaction is capable of transforming scent molecules released by the wood into less scented forms. An example of this is the transformation of the vanilline aldehyde in vanilline alcohol or the transformation of furfuraldehyde in furfural alcohol. These molecules have a much lighter aromatic impact; therefore, this phenomenon causes the barrique's aromatic impact to be milder, permitting a better integration of the wood's scent with the varietal's aromatic profile.

- Enhancing the interaction between wine and yeast bio- mass

A peculiar aspect of white wine's barrique maturation phase, after alcoholic fermentation, is caused by the yeasts' action on the finished wine's structure and quality. In fact, the yeasts have a membrane made of polymers of a polysaccharide nature primarily made up of glucans and mannoproteins. These are released into the wine, partly during fermentation but mostly during the maturation phase, as a result of the processes of autolysis, which the yeast goes through once alcoholic fermentation, is completed (Charpentier et al., 1993). The periodical resuspension of the yeasts deposited on the bottom of the barrique during auolysis helps enrich the wine with polysaccharide molecules. These have various roles and contribute to the volume, thickness and softness of the finished wine (Llauberes, 1987). Regarding red wines, their contact with the wood generally occurs during the aging and maturation phase, even though alcoholic fermentation is increasingly being carried out in oak barrels and tubs, rather than steel vats.
As happens for white wines, the main impact that wooden containers have on red wines is aromatic, but, considering the more complex composition of the red wines and mainly their longer wine- wood contact, many other interactions take place between the wood's molecules and the wine's molecules. This has an

effect on all the organoleptic properties of a great red wine (Dubois, 1989; Singleton, 1962, 1974).Color intensity and stability, the aroma, the scent, the softness and thus the tannin structure and the longevity of a great red wine are all characteristics that the barrique can influence either positively or negatively (Chatonnet, 1990).
During a red wine's aging in a wooden container (barrique or barrel) one can observe different important phenomena that can be summed up in the following six points:

1. spontaneous clarification phenomena caused by the flocculation of numerous suspended colloidal substances which make the wines, at the end of alcoholic and malolactic fermentation, still very muddy;
2. diffusion and dissolution phenomena of the wood's aromatic and polyphenolic molecules in the wine;
3. de-carbonation phenomena;
4. tartrate stabilization phenomena of the wine due to tartrate precipitation;
5. phenomena of slow and constant dissolution of the oxygen in the wine;
6. phenomena of color modification, evolving towards more orange and brown shades.

Leaving aside some of the abovementioned aspects, not because they are of less importance, but because they require a separate discussion, let us thoroughly analyze the oxygen aspect, as the wooden container helps its slow and constant dissolution in the wine throughout the maturation and aging phase, significantly affecting the wine's evolution.
For the white wines, the contact with oxygen is particularly limited during the entire barrique maturation phase to avoid oxidative phenomena that would negatively impact both the wine's sensory and organoleptic profile. On the contrary, for red wines the limited and gradual dissolving of oxygen is particularly useful as it causes a slow but essential evolution of the polyphenolic and chromatic structure (Sims et al., 1994; Singleton, 1995). Contrary to what is normally reported, most of the oxygen that comes in contact with the wine during the maturation phase does not enter through the staves, but as a result of the various operations which the wines undergo during the long aging period in wood (topping, decanting, sulfiting, etc.) (Pontallier et al., 1982; Puech, 1981; Puech et al., 1982).
With adequate thermal conditions and mild sulfuric levels, the oxygen is associated with the interaction of metallic cations (iron, copper, etc.) present in the wine and with the wood's hydrolysable polyphenols (ellagitannis and the wine's polyhydric phenols (catechine, epicatechine and proanthocyanidins) This starts some complex chemical reactions that determine the colored monomer molecule reduction (the anthocyanins) and the formation of polymeric chemical structures through condensation and polymerization reactions (Boidron et al., 1990; Naudin, 1989; Puech, 1984 and 1987).
These combined reactions between the molecules of wine and wood, catalyzed by oxygen, are crucial for the evolution of a great red wine because they are the basis for two fundamental sensory elements:

- stabilization of color: the polymeric forms are more stable than the monomer ones and are responsible for the color of great old wines.
- softening of tannins: the polymeric structures have less of an organoleptic impact and thus, with age, a wine's astringent and tannic traits are reduced, while the sensations of softness and roundness develop.

From what has been briefly said, one can deduce the importance of oxygen in the evolution of a red wine and, therefore, the importance of using a wooden container that, contrary to a steel container, spontaneously favors a very slow and constant evolution of the product. It is not otherwise possible to achieve this result in the time and with the balance that a barrique or a barrel guarantees.
The technician, therefore, must be able to properly manage all the parameters that can influence the abovementioned phenomena (type of wood, type of toasting, sulfur levels, frequency of topping and decanting, etc.) to make the wooden container (barrique or barrel) a receptacle that "ennobles" the wine that matures within it.

BANFI

Dedicated to a finer wine world

The peculiarity of the wood used for the construction of the wooden cooperage

The use of wood for making wine and distilled spirits is by now a common practice in the alcoholic beverage industry. Different kinds, sizes and shapes of wooden vessels are used for making both red and white wine. The study of polyphenolic and aromatic substances found in the wood and their extraction by the wine during fermentation and *barrique* maturation is of particular interest because of the great sensory impact that these molecules have on a wine's organoleptic characteristics (Nebeta *et* al., 1987; Nikitin, 1966; Nishimura *et* al., 1983). These compounds, either originating naturally from the wood or newly formed after the various operations which the wood undergoes (seasoning and toasting), can reach levels higher than the perception thresholds in the wine, therefore giving pleasant vanilla, spicy, toasted, etc. scents. The wood species, its geographic origin, and the seasoning and toasting techniques of the *barriques* are actually very important aspects in the production of "quality" *barriques*. Their style has enormous effects on the wine style produced (Chatonnet, 1991).
In fact, with a careful combination of the above- mentioned factors, it is possible to produce *barriques* with a peculiar polyphenolic and aromatic composition. It is therefore important to talk about a "quality style" of the *barriques* that must match, as closely as possible, the "wine style" to maximize the positive impact that the wood has on the wine.
Barriques style can be defined by making targeted combinations of 4 essential factors:

1. Wood species

2. Geographic origin

3. Seasoning

4. Toasting

Through this approach, the technician can follow the appropriate *barrique* production process to attain the production of *barriques* that respond perfectly to the desired wine style.
Rather than being considered a simple container, the *barrique* must be viewed as a technological tool that has to meet certain quality standards in relation to the wine characteristics and the desired wine style. Therefore, now more than in the past, wine maturation in wooden containers (barrels or *barriques*) represents a very important phase in winemaking operations both for its impact on the quality and composition of the finished wine, and for its significant effect on wine-production costs (Feuillat, 1991).
Consequently, it is necessary, (as for every other product used in the winemaking process), to know and to manage the "wood" product according to the desired winemaking goals. This should be done while getting the most out of the advantages and limiting any possible defects and/or problems than can arise due to raw material of doubted quality. The abovementioned subjects have been the object of studies and research at the Banfi Estate. Before analyzing them in-depth, it is best to discuss certain concepts that will help to make this phenomenal wood species more familiar and to better understand the irreplaceable role that it plays in producing high quality wines.

The oak genus

Oak is one of the highest ranking forest species for its longevity, size and its multiple uses, not only in the wine sector.
Oak belongs to the *Quercus* genus and has more than 250 species, the majority of which are located in the temperate zones of the northern hemisphere. They can generally be divided into two distinct categories: white oak and red oak. The latter is very porous and cannot be used for making barrels or *barriques* (Camus, 1936).
The *Quercus* genus is divided in to two sub-genera:

- The *Cyclobalanopsis* sub-genus, found in the tropical and sub-tropical regions;
- The *Euquercus* sub-genus that is widely found in the northern hemisphere and includes the economically important species for barrel and barrique production. The *Euquercus* sub-genus is divided in to six categories, of which the *Lepidobalanus* is the most important as it includes the species which are particularly interesting for making containers for alcoholic beverage maturation (wine and spirits).

In Europe, the most commonly present species, which are also used in the wine-producing sector, are the *Quercus Petrea* Liebl. (Q. *Sessilis or Sessiflora* Sm.) commonly known as "sessile oak" and the *Quercus Peduncolata* Ehrh. (Q. robur Lin.) commonly known as "pedunculate oak."
The area of diffusion of the Q. *Peduncolata* goes from the northern part of the Iberian peninsula to the Urals and Caucasian mountains. Its presence is limited in the regions and areas that have a dry summer season, or in the colder northern areas, but it is very common in the Western part of the French Central mountain range.
The area of the Q. *Sessilis* is, on the other hand, less vast and goes from the extreme northern part of the Iberian peninsula to the southern part of Scandinavia, then east to Poland and western Russia. In France it is particularly abundant in the central and northern forests.
Other than these two species, in recent years the so-called American "white oak" is becoming of particular interest. It is mostly commonly found in North America and its use in the wine sector is becoming increasingly important. Commercially, American oak is often mistakenly identified in the Q. *alba species* which, however, represents only one of many different species, such as Q. *macrocarpa*, Q. *montana*, Q. *virginiana*, Q. *lylata*, Q. *stellata*, that are found in the forests where the wood is obtained for building barriques.
The area where American white oak is found goes from southern Ontario, Minnesota and Nebraska to Florida and Texas. For the production of *barriques* the most important areas are Missouri, Ohio, Wisconsin, and Illinois.
Much of the oak used for making wooden containers for wine and spirits maturation comes from the forests of western and central Europe (mostly in France, Slovenia and Austria); however, in the last few years interest has grown in the forests of eastern countries such as Hungary, Poland, Romania, and Russia. In the central European regions, and mostly in France, the species of sessile and pedunculate oak make up a great part of the forests that are of enological interest.
These two species have a very different diffusion according to their specific soil-climate requirements but a preponderance of either makes wood more attractive for the maturation of wines and spirits.
The pedunculate oak is common in the warmer, more humid areas, which have cool and typically fertile soils. For these reasons, this species has a particularly rapid growth that negatively impacts wood quality, especially in terms of the grain. In fact, the wood obtained from this species is, in fact, commercially defined as "coarse grained" and has a chemical composition, which is not particularly good for wine maturation. On the contrary, the sessile oak adapts better to more difficult soil-climate conditions and is common in the poorer and drier soils. Growth and development are slower; therefore, the wood obtained from

these forests is commercially defined as "fine grained" as it is more compact than the pedunculate oak. This compact quality has positive effects on the wood's physical and chemical properties. It is more aromatic and less rich in polyphenols, putting demand particularly in the winemaking sector of barrel and barrique production. Therefore a forest's qualities and the value of the wood obtained from it are related to the forest's botanical composition. Accordingly, the forests mostly made up of Quercus peduncolata, such as the typical ones of the Limousine department, provide a weakly aromatic wood, particularly rich in polyphenols, that is used more for the maturation of spirits than of wine (Miller et al., 1992; Mosedale, 1996; Masuda et al., 1971).

Contrarily, the forests that mostly have plants belonging to the Quercus sessilis species are particularly renowned, and their woods are used in the wine-making sector. These woods are put on the market under the names of the Departments and the forests of provenance. The most valuable, sought after and used wood in the winemaking sector comes from the Nevers, Chers, Bourgogne, Fontainebleau, Jupille, Bertrange forests, as well as Allier, with its spectacular Tronçais forest (Keller, 1987).

As we will explain in the following chapter, geographic origin is the basis of the first quality classification of the wood used for barriques. This is because there is a strict correlation between the higher or lower presence of one oak species, sessile or pedunculated, rather than the other, and therefore with the enological properties of the wood.

In general, the chemical-physical traits that a wood species must have to be used in the enological sector are the following:

- It must release a moderate amount of polyphenolic compounds (lignin, ellagitannins, coumarins, phenolic acids, etc.);
- It must release aromatic substances that improve wine complexity (whisky-lactone, eugenol, vanillin, etc.);
- It must not give the wine or the spirit astringent, bitter or herbaceous notes;
- It must ensure a perfect hold and avoid leaks;
- It must be sufficiently pliable and easy to work with

Besides these, other wood characteristics important for wine maturation include: "grain", "porosity" and "texture"; terms that are often found when talking about wine and barriques, but whose meaning and enological implications are not often discussed.

Some of the wood's structural characteristics: grain, texture and porosity

Wood's structure is very heterogeneous since it is composed of a succession of spring wood (initial wood) and summer wood (final wood). Spring wood is often more porous, lighter and softer, as it has big veins (trachea and tracheids responsible for carrying the crude lymph) and little fiber. On the other hand, summer wood is generally less porous, harder and more compact as it is composed of fewer, smaller veins and mostly of fiber.

Together, the summer and spring wood make up the so-called annual growth rings: each ring represents a year in the tree's life (Esau, 1965; Jacquiot et al., 1973).

For "grain" we mean the "width of the annual ring" and therefore the spring and summer wood together.

In an APECF (Association pour la Promotion des Emplois du Chêne Français) publication of 1989, regarding the length of the rings, this classification was made:

- "fine" grain: the annual ring has a width < 3 mm / .1 inch;
- "medium" grain: the annual ring has a width of 3-4.5 mm / .1-.2 inch;
- "thick" grain: the annual ring has a width > 4.5 mm / .2 inch.

This aspect is of extreme importance as it is both at the basis of the structure and composition characteristics of the wood, and significantly affects the wine's or spirit's evolution. The alternation of these two distinct zones, and thus the type of grain, is related mostly to the oak species (the *Quercus Peduncolata* generally yields wood with a medium-coarse grain, while the wood of the *Quercus Sessilis* has a very fine grain), but other factors acting on the trees' growing speed can cause the grain to be fine, medium or coarse (Vivas, 1995; Fengel *et* al., 1984).

The geographic origin, and therefore the soil-climate conditions, greatly influence ring thickness, so forests which grow on fertile and warm soils will have a particularly coarse grain, regardless of the botanical species.

"Texture" is another important quality factor of wood, strictly related to the grain. It is, in other words, the ratio between the thickness of the summer wood and the ring's total thickness. This parameter expresses the effect of the more compact and fiber-rich area of the wood (summer wood) on the total thickness of the annual ring.

Trees grow faster mostly in the summer and less in the spring; thus, high texture values correspond to a greater amount of summer wood and therefore to a higher percentage of compact, less porous wood on the total thickness of the annual ring (Seikel, 1971). This aspect is of great importance as it has direct repercussions on a third parameter, porosity, which plays a crucial role in determining wood's enological properties. Wood is composed of a number of "empty spaces", created by apertures that mainly have a transportation function, and of "full spaces", created by the cell walls and fibers, that mainly have a supporting function.

In fine-grained woods, there is a high incidence of less compact spring wood on the annual ring's total wood, (as in the oak coming from the Allier forests), and there is a lower density compared to the coarse-grained wood. The latter is generally less porous because it is richer in the more compact summer wood, typical of the wood of Limousin origin.

One can deduce that generally the coarse-grained wood is denser and is thus less permeable to gasses because it has a higher percentage of summer wood on the total annual ring's thickness (typical of Limousin). As already noted, in fact, when the oak accelerates its growth, it does so at the expense of the summer wood, so the area containing mostly fibers and small veins grows.

In 97% of the cases this means that the wood increases its density and longevity (resistance), and its color becomes darker because it is richer in polyphenols and poorer in aromatic molecules. On the contrary, in conditions of slow growth, even the summer wood is reduced. Fibers are present in limited quantities and the summer wood with its big veins is prevalent. Therefore the wood appears lighter in color, less dense and less rich in polyphenols while having more aromatic molecules.

The main impact on winemaking of the above- mentioned wood properties are the following: the increase in grain, associated with the increase in growth speed, generally results in a diminished production of aromatic compounds and a higher production and buildup of polyphenols.

Thus, it is clearly important to choose the wood according both to its geographic origin and to the type of grain. The grain should generally be fine or medium-fine, according to which the impact of the *barriques* on the wine will be more or less positive. The reasons will be discussed more thoroughly in the following chapters.

In light of what has been said, generally the wood's geographic origin, the first and most important classification criteria for wood used to make *barriques*, should sufficiently guarantee the properties and characteristics of the *barriques* that will be produced from it. However, often lots of staves sold under the same name (Allier, Never, Trônçais) have very different characteristics both in terms of grain and chemical composition (Yoshinaga, 1997). One can easily verify this by confronting the characteristics of stave lots declared to have the same geographic origin and coming from different *barrique* factories (*tonnellerie* or *cooperage*).

A careful control and selection of the stave lots, during the seasoning phase, regardless of the geographic origin of the wood, is therefore a useful approach to obtain *barriques* of "reproducible" quality.

In this way, it is possible to define the enological outcome of the barriques based on a set of analytic and sensory evaluations that a technician should carry out in order to obtain the best combination of the barrique "style" with the desired wine style.

Oak: an ideal material

Better than any other wood species, oak wood has the characteristics, properties and chemical composition that make it irreplaceable in the winemaking sector (Masson, 1996).
Generally we can sum up oak's peculiarities in the following points:

- Optimal mechanical properties: oak wood is very resistant to compression and flexion, generally giving the containers good resistance; furthermore it is pliable, which facilitates the stave bending operation in the barrique and barrel production process, avoiding major cracking and breaking of the staves;
- Optimal seal of the wine: oak wood has a structure which gives the container (barrique or barrel) an almost perfect seal to avoid wine leakage through the staves;
- Optimal porosity: to ensure a slow but constant oxidative evolution of the wine;
- Optimal chemical composition: limited polyphenolic concentration and good concentration of volatile substances that have a particular aromatic impact.

The reasons for such physical and chemical peculiarities are found in the inner structure and cellular organization of the oak wood. This will be briefly discussed, simply to understand where the "noble" character of this prestigious wood species lies.
Firstly, we must say that the part of the oak used for making staves is the heartwood: the part of the wood that by now has no more active function in the plant's physiology. The heartwood is formed through transformation of the sapwood, which is the part of the active wood made up by veins (trachea and tracheids) responsible for transporting the crude lymph, to duramon. These veins, after the first year of activity, loose their function as transportation elements and are transformed to duramon and become structure and support organs.
They undergo a radical transformation by forming particular outgrowths, called tyloses, whose function is to fill the empty apertures of the vessels, which no longer serve any purpose, increasing their stiffness and mechanical resistance. At the same time there is the gathering, mostly at the level of the tyloses, of a great quantity of polyphenols. Due to their good anti-microbial properties, these substances make the heartwood very resistant to microbial attacks and therefore very hard and durable over time.
For these reasons, the tyloses are very important organs and their quantity in the wood's structure depends both on the wood species and on the soil-climate conditions in which the plant develops (Miller et al., 1992).
Oak has an average number of tyloses compared to other wood species, such as the chestnut that has a much higher quantity. This fact has repercussions on the accumulation and concentration of water soluble polyphenols (ellagitannins and gallotannins) in the wood. This affects the chemical properties and thus the enological use. In fact, while oak has a relatively mild concentration of water soluble polyphenols, compatible with wine and spirit maturation, on the other hand chestnut, particularly rich in polyphenols, furnishes a bitter and astringent wood, to the point that its use has been greatly reduced in the enological sector. But it is the radials that, together with an abundant quantity of tyloses, make oak more particularly suited than other woods for the construction of barriques and barrels.
The radials, as opposed to the trachea and the tracheids that carry the lymph from the base of the tree

towards the top, are veins that connect the internal part with the external part of the tree from which the staves will be made. This way they are parallel to the staves' thickness, when these are made with the cleft splitting system and therefore perpendicular to the direction of the wine's passage from the barrique outwards. As a general guideline, we can say that three types of radials exist, defined as uniseriati, multiseriati and pluriseriati.

The Quercus Sessilis wood has abundant levels of radials that are particularly large, long and blocked at the edges, and these guarantee an optimal seal of the wine. This way the radials form an actual barrier to the passage of liquids, reducing wine leakage through the staves, without however limiting the gas exchange with the outside of the barrel. These properties are guaranteed when the staves are obtained with the cleft splitting technique which avoids breaking these rays (Giordano, 1985; Hankerson, 1947).

American oak, and specifically the Quercus alba species, has a great quantity of pluriseriati radials. This means that different layers of smaller and more compact cells cross the trunk radially, making the wood more compact and with a better seal in comparison to the French oak, but less pliable and more difficult to work with. For these reasons, the staves can be obtained also by sawing the trunk. This breaks the rays and, because they are more compact and numerous, they ensure good sealing properties.

On the contrary, chestnut generally has uniseriato radials. In other words, it has a single line of cells that run through the trunk from the inside towards the outside, not guaranteeing a seal against leakage.

Notes on the techniques for preparing staves

For the construction of the barriques, trees that have reached an age between 200 and 250 years are used and have a variable diameter from 40 to 60 cm / 16 to 24 inches (Ralph, 1993).

The trunk, once it is cut and graded on the basis of knots, defects, microbial attacks and grain, can be used for making staves.

The techniques for the production of the staves are basically three:

- splitting;
- quartering;
- cutting.

The "splitting" technique is carried out by splitting the trunk sideways into 4-6 "segments"; the staves are obtained from each of them. Though this is certainly the most arduous technique, it has the great advantage of respecting and preserving the integrity of the wood's fiber and radials, as the splitting is done parallel to them. These staves, therefore, have a good mechanical resistance and limited permeation resulting in a good seal, since the radials go across the wood lengthwise, not in depth and therefore are perpendicular to the wine's passage.

With this technique, almost 0.2 cubic meters / 7 cubic feet of staves are produced from 1 cubic meter / 35 cubic feet of wood, with which it is possible to produce almost 2 barriques; this technique is generally used for the French oak because it is not very dense or very compact.

The "cutting" technique is carried out by sawing the staves with large band saws, so the trunk is not cut into "segments", but, after the bark and the sapwood have been removed, it is simply sawed. All barrels that have a capacity greater than 6-8 hl / 150-200 gallons are built with sawed staves, also because it is nearly impossible to obtain staves of this size by splitting. Unfortunately, compared to the previous ones, these staves are less durable and have greater seal problems due to the breaking of several conducting veins, and particularly of the radials. However, since they are generally bigger and destined for the production of larger barrels, all the defects are compensated by their greater thickness. Using this technique one can obtain 0.5 cubic meters / 18 cubic feet of staves from 1 cubic meter / 35 cubic feet of

wood, with a yield that is one and a half times higher than the previous technique.
The "quartering" technique can be defined as a hybrid of the two previous ones, as the trunk is first split, obtaining 4 or 6 "segments," and then from each one the staves are obtained by cutting first on one end and then on the other of the quarter. This technique is mostly used for the American oak for the above-mentioned reasons (Hankerson, 1947). This way only a few fibers are cut, giving intermediate results between the two previous systems. These results are better when the wood's veining is followed during cutting operations; moreover the radials are sideways to the staves' depth, resulting in a good seal and limited wine leakage.
These last two techniques are usually used for making the staves from American oak which is more compact, denser and more resistant than the French one.

Outlines of the oak wood's chemical composition

Regarding chemical composition, it is sufficient to say that the oak wood has a great variety of organic compounds that are divided into:

- Volatile compounds;
- Non-volatile compounds.

On average, the composition of oak:

- 40% cellulose;
- 25% lignin;
- 20% hemicellulose;
- 10% ellagitannins;
- 5% of other substances: sugars, sterols, volatile and mineral substances.

Some of these substances are soluble and are rapidly transferred to the wine during the first 10-12 months of maturation and aging, while other molecules are extracted more slowly as a result of chemical interactions between the wine and the wood (Hillis *et* al., 1962; Joseph *et* al., 1972a, 1972b; Otsuka *et* al., 1980; Sefton, 1991). Regarding the composition of the wine-matrix, the alcohol percentage, acidity and the polyphenolic content have an influence on the extraction processes that occur inside *barriques*. Ethanlolysis and acidolysis reactions of the wood's polymers regulate the quantity and quality of the substances released in the wine during maturation and aging (Browing, 1963; Giordano, 1971; Sarkanen *et* al., 1971).
The factors that regulate the wine-wood ratio are many and traceable both to the wine-matrix composition and to the type of production process the *barrique* has gone through, such as toasting and seasoning. These subjects will be explained in the following paragraphs. Without going into a detailed discussion about the differences between the various groups of polymers that are part of the wood, we shall make only a few remarks concerning the aromatic substances, both naturally present in the live wood and newly formed. On the contrary, a more in depth discussion will be undertaken about wood's polyphenols and the ellagitannins, which play a crucial role in the wine's quality evolution and which have basically been the object of study and research at Banfi.

The volatile compounds of oak wood

Oak's aromatic substances make it a particularly special and highly esteemed wood species from an enological standpoint. The notes that wood imparts to wine can be traced back to numerous sensations and scents (Chatonnet, 1988; Maga, 1989; Marche *et* al., 1975).

At panel tastings, the most commonly found sensory descriptors are vanilla, coconut, cloves, toasted almonds, anise, hazelnut, dried fruit, etc. that can also border on more unpleasant off-aromas such as paint, sawdust and herbaceous (Motounet et al., 1989; Waterhouse et al., 1994).

The aromatic substances found in wood are part of a group of very complex substances, due both to their nature and origin. They can be divided into:

- volatile compounds typical of fresh wood and of the wood species
- newly formed volatile compounds, following the production process of the wood, such as seasoning and toasting

Oak wood, when it is made into staves and during the first months of seasoning, has some particularly pronounced aromas that are reminiscent of rose and fruits, and often there is the aroma of peach and apricot. These scents soften during the course of wood seasoning and other notes are added to them by the slow and gradual transformation of more complex molecules, such a lignin, hemicellulose and cellulose, into simpler molecules with a more pronounced sensory impact (Marsa, 1987,1987b; Viriot 1994).

Even wood color is a quality and differentiation character. In fact, as soon as the staves are cut, they are yellowish-ochre, often with rose shadings that are accentuated above all around the radials.

The main aromatic compounds that have a significant impact on the aroma of fresh wood are:

- b methyl-g-lactone: it is the main aromatic molecule found in fresh wood, typical, above all, of American oak; it has a pronounced aroma of coconut that can turn into paint at particularly high concentrations;
- eugenol: the aroma is reminiscent of clove and its aromatic impact tends to soften during the stave production process;
- vanillin: responsible for the vanilla notes, it is found in fresh wood, but it mainly forms during toasting, due to lignin degradation.

Oak's aromatic profile after the seasoning phase, and especially after toasting, is much more complex (Guymon et al., 1972; Sefton et al., 1990a 1990b). In fact, as will be demonstrated in the following sections, wood seasoning, and especially toasting, radically transform the polymers that make up the aromatic profile, modifying, accentuating, and making the olfactive potential of the wood more complex through the formation of numerous aromatic compounds (Boidron, 1994). For these reasons, the Banfi Estate designed different experiments aimed at evaluating how the seasoning and toasting regimes can influence barrique composition, and consequently, the organoleptic characteristics of the finished wine. Particular attention was paid to the impact the regimes had on the polyphenolic content of the wood, which is constituted mainly by the so-called ellagitannins. But let us try to understand why these substances are so important for the evolution of both red and white wines.

The polyphenols of wine: the ellagitannins

Wood, like grapes, contains polyphenolic substances of various nature, but they are different both in terms of quality and quantity from wine's polyphenols.

In fact, grapes contain mostly flavonoid polymers that are called condensed tannins as they originate mainly from the condensation of monomer forms such as catechine and epicatechine. Wood, however, has a limited concentration of this kind of molecule, and is therefore particularly rich in polyphenolic substances traceable to the so- called hydrolysable tannins, whose concentration is around 10% of the wood's dry weight (Chen 1970; Markman, 1974; Mayer et al., 1969 and 1971; Peuch et al., 1990; Rabier, 1991).

These molecules are characterized by the hydrolysis properties in water-alcohol solution. Two groups of tannins can be identified, based on the molecules that they release:

- The ellagitannins: following hydrolysis, they release ellagic acid;
- The gallotannins: following hydrolysis, they release gallic acid.

These two groups of hydrolysable tannins mainly derive from the polymerization of two monomers, which are vescalagina and castalagina, and are found in wood chiefly in the form of dimers and trimers, such as the Ruberine A, B, C, D, E and the Grandinine (Herve du Penhoat et al., 1991a, 1991b; Moutounet et al., 1989).
The highest concentration of these substances is found in fresh wood and it decreases during seasoning, and mainly after toasting, as they undergo oxidation and thermal degradation. Beyond the chemical characteristics, which will not be treated in depth, it is important to briefly mention the role that these substances have in wine evolution, and how it can be managed according to the desired winemaking goals. The ellagitannins are synthesized and accumulated at the level of the heart-wood, chiefly after the sapwood is transformed to duramen. This represents the phase of death and transformation of the veins with the formation of an important number of tyloses inside the cellular apertures of the trachea and tracheid.
The ellagitannins, which accumulate at the level of the duramen, based on their localization, can be divided into two groups (Bariska et al., 1986; Klumpers et al., 1994; Moutounet et al., 1994; Peuch, 1987):

- free tannins found as isolated granules or grouped at the level of the tyloses and the parenchymal cells;
- tannins bound to the cell walls at the level of the polysaccharide structures, that constitute “tannin incrustations”.

The concentration of the hydrolysable polyphenols is a factor of strong variability of wood quality, and thus of barriques, as their accumulation depends on many aspects. Some of these aspects are the age of the heart-wood (the innermost heart-wood, thus the oldest, has a lower concentration of polyphenols), wood grain (woods with coarse grain have lower aromatic and higher polyphenolic contents) Masson, 1994; Masson, 1995; Scalbert, 1990. The different placement and concentration of these polyphenols have repercussions on three important aspects:

- on their removal during the seasoning stage and on their breakdown during the toasting stage;
- on the concentration gradient of the ellagitannins in the thickness of the barrique staves;
- on the kinetics and velocity of wine extraction during the period of wine-barrel contact

The layer involved in the extraction phenomena during the 3 years of barrique utilization is about 10mm / .4 inch and most of the ellagitannins are extracted very rapidly starting from the first months of contact with the wine (Morgan et al., 1969; Peng et al., 1991; Pocock et al., 1984; Scalbert et al., 1990).

Ellagitannins and the properties of wine

Ellagitannins play an important role in the evolution of both red and white wines. Our attention has been turned towards the role that the ellagic tannins play in the oxidation and polymerization reactions of the polyphenolic substances of red wines, and in particular, the anthocyanic fraction. In fact, the ellagitannins are more reactive to oxygen than the wine polyphenols thanks to the greater number of functional hydroxylics. They rapidly consume the dissolved oxygen in the medium and thus act as

antioxidants for the other polyphenolic compounds, particularly the anthocyanins.
Thus it can be presumed that the ellagitannins accelerate the condensation reactions of the procyanidines with the anthocyanins and acetaldehyde molecules, contemporaneously having a protective function in terms of the oxidative degradation of the anthocyanic monomers. In addition, test results show that wine color remains more intense when there are ellagitannins, compared to oxygenated wines without this molecule, where there is a more rapid degradation of the coloring substance.
Furthermore, oxidation occurring in the presence of ellagitannins ensures a faster evolution of the polyphenolic structures of the wine toward forms that are more condensed, more stable, and less aggressive on the palate (Glories 1987; Kramling *et al.*, 1969). Furthermore, the polysaccharides that form the wood polymers (cellulose and hemicellulose) are also disolved into the wine. In fact, the abovementioned polymers undergo a first degradation, de-polymerization and transformation into monomer forms during the seasoning phase, and are then further degraded by the heat during the toasting operation. Successively, when the wood enters into contact with the wine, the actions of wine acidity (acidolysis) and of ethanol (ethanolysis) accentuate the release of these molecules in the wine (Shiraishi *et* al., 1975; Skaar, 1969). This contributes to the sensation of richness and roundness of the wine and decreases the astringency and harshness of the tannins (Chatonnet, 1990).
Barrique maturation of wines significantly modifies their organoleptic characteristics. Thus it is very important to stress the taste characteristics of the main polyphenolic compounds:
Tests and panel tastings made it possible to evaluate the organoleptic impact of the wood's polyphenols, using wood extracts in water-alcohol solutions ("imitation-wine" solution). The polyphenolic compounds of wood can be divided into three groups:

- the astringent molecules: the ellagitannins;
- the acid molecules: gallic acid, coumarin aglicon;
- the bitter-green molecules: coumarin eterosidic.

As can be seen, the mixture and combination of these molecules can make a wood more or less bitter and/or astringent, significantly affecting the wine aroma. During the first months of *barrique* aging, the wine is enriched with specific polyphenolic compounds from the wood, such as the coumarines, that impart a character that is often perceived as astringent or bitter (Monties, 1992).
However, the complexity of the wine matrix masks the real quality characteristics of the wood and thus of the *barriques*, so it is preferable to perform the tasting of the wood extracts in water-alcohol solutions.
In particular, as regards the role oak wood ellagitannins play in determining the taste characteristics of wines, the conclusions reached by various studies are different.
Quinn and Singleton (1985) suggested that this molecule contributes to determining the astringent and bitter character of wines aged in wood. Later, Somers (1990) rejected this hypothesis, considering that the concentrations of ellagitannins in wines are too weak and low to have a significant organoleptic impact.
Actually, the fraction of ellagitannins is only a part of the phenolic compounds that are made soluble in the course of the wine-wood contact. Recently, Pocock *et* al., (1994) pointed out that the perception threshold of the wood extracts depended on many factors (seasoning and toasting regime, etc.) so only the tasting of the wood extracts enables an objective evaluation of the wood's quality. Indeed, besides the ellagitannins, other substances have been considered responsible for the bitter notes of wines and spirits. Among them, the coumarines play a major role when occurring as glucuosides, that is, when tied to sugars. In fact, the aglycon forms do not have this organoleptic characteristic and their concentration is strongly influenced by how the wood has been processed. For example, the seasoning regime has an important effect on diminishing the values of the glycosilate forms, favoring the formation of the aglycon forms, which are sweeter and less bitter.
It is important to clarify that even the polysaccharides have a sensory effect. In fact, as the concentration

increases, the astringent impact of the wood decreases (Jindra *et* al., 1987).
The study of wood composition has enabled a division into different groups of soluble and extractable compounds:

- a soluble fraction, including the polyphenolic compounds, like the oligomeric ellagitannins, the phenol acids, and the phenol and coumarin aldehydes;
- an extractable fraction, composed of non-water soluble polymers (lignin) and non alcohol soluble polymers (polysaccarides).

In light of these considerations, it can be observed that:

- The polyphenolic substances are mainly formed in the course of the transformation of sapwood to duramen and these substances are found in different concentrations within the same tree;
- the localization and extraction conditions of the ellagitannins heavily influence the chemical evolution and composition of wines;
- the taste properties of wood's principal components are fundamental for a good enological result in terms of certain technical choices (type of wood, length of seasoning, type and length of toasting).

Following these observations, it becomes clear that it is important to have a good knowledge of wood composition from a polyphenolic standpoint, and chiefly the evaluation of the probable impact that it can have on the wine.
The ellagitannin profile is characteristic of the various species of oak and is significantly correlated to the geographic origin of the wood. Thus, it is an important factor of intraspecific classification and a parameter of compositional differentiation of the *barriques*.
Because of these reasons, and due to the complex role these substances play in the evolution of both red and white wines, the Banfi Estate, in collaboration with its own suppliers of barriques, carried out analytical evaluations. In particular, the ellagitannins of numerous lots of staves were evaluated, at three distinct stages of the barrique construction process:

- selection of the lot on the basis of declared geographic origin;
- management of the seasoning technique;
- management of the toasting technique.

The analytical data is reported and some sensory evaluations which enabled, for the types of wine available at Banfi, the management of the *barrique* variable in a less "variable" way. This management technique is more targeted and fits in with the Estate's desired winemaking goals.

BANFI

Dedicated to a finer wine world

THE IMPORTANCE OF WOOD'S GEOGR APHIC ORIGIN IN THE PRODUCTION OF FINE WINE

The geographic origin of wood destined for the production of barrels and barriques for wine maturation has always been a very debated aspect of the winemaking process.
The sources of wood supplies have historically been defined in relation to the available resources and to the ease and rapidity of transport, besides the quality of the raw material and its cost. Among the main and historical sources of wood supplies for stave construction, the following should be mentioned:

- Wood from Trieste and Bosnia: it was used particularly until the end of the 19th century. It was fine-grained and without knots, but generally had a high tannin content, and therefore often used for the maturation of spirits and wines with little structure;
- Wood from Danzig, Stettin, Lubech: considered of high quality, as it has a very fine grain, excellent texture, and is rich in aromatic substances. It was reserved for the great red wines because of the relatively high cost.
- Wood from Odessa: it has a medium-fine grain and is less sought after and appreciated.
- Wood from Slavonia: of excellent quality because of the grain and the scarcity of knots, used mainly for the construction of medium to big barrels.
- American wood: its use spread mainly to Spain, but it has attracted little interest because it has an aggressive aroma and is particularly difficult to work, as it is hard.

These woods were used and sought after mostly during the 18th century as they represented the only forests able to furnish good quality wood. Moreover, as the French forests had been totally abandoned, the wood produced there did not have the right characteristics to allow its use in the enological sector (wood with many knots, often with defects caused by insects and microorganisms, etc.) (Vivas 1993 and 1995, Chatonnet, 1991). Thus, purchasing supplies of wood was difficult; the price was particularly high; and the quality was not always impeccable.
In the 19th century, with the creation of the "National Office for the Forests" (ONF), an intense program aimed at enhancing the value of the French forests began. A first step was the introduction of a Forestry Code to restore forests planted with wood species of particular value, like the Quercus Sessilis and the Quercus Robur. These species were widespread throughout France and their enological value was, by then, undisputed.
An in-depth study of French forests was undertaken, and the "forestry stations" were identified and defined according to three fundamental characteristics:

- botanical species present (Quercus Sessilis and the Quercus Peduncolata);
- soil and climate conditions of the area;
- specific forest management techniques and forestry operations aimed at obtaining wood for the enological sector.

In this way, at the end of the 19th century, the enological sector began to use the woods from French forests, as the higher quality species of oak were particularly suited for it, guaranteeing the production of raw material with particular chemical and physical characteristics.

Accordingly, the use of barriques established itself in the enological sector, and it was mainly identified with the name of the forest or Department of origin, such as Allier, Tronçais, Jupille, Bourgogne, Never, St. Palais, Laurede, Bertranges, Citeaux, Darney, Fontainebleau, Bitche, etc. (Keller, 1987; Puech et al., 1988 and 1989).

These forests are characterized by particular climate conditions and by the predominance of the Quercus Sessilis, which is undoubtedly the botanical species of the greatest enological value.

Thus, the name of the geographic origin has become the first criteria for the commercial evaluation of barriques, as it guarantees certain specific wood qualities and thus the enological value of the barriques themselves. Notwithstanding this, it is important to remember that wood is a material of biological origin and, as such, is characterized by a strong variability, both in terms of physical and chemical characteristics (Francis et al., 1992; Marco et al., 1994).

Indeed, the chemical and physical properties of wood and its enological value are the result of complex interactions among the following main components:

- the soil conditions and, in particular, its depth and water-retention capacity;
- the climate conditions, and, in particular, the rainfall of the area;
- the botanical species present;
- the conditions of inter- and intra specific competition that establish themselves in the forest and condition its biodiversity;
- management systems and techniques of the forest (reproduction by seeds or by cuttings).

These five points illustrate the complexity related to the aspect of the geographical origin of the oak wood used for the construction of the barrique staves. It also illustrates the complexity of wood variability, which is a phenomena that must be "measured" and dealt with.

There are many elements of variability of the raw material. If these are added to the elements of variability induced by the operations that the wood undergoes after having been chosen from the forest (techniques and systems of stave production, techniques, systems and length of seasoning phase; techniques, systems and length of toasting phase) it is easy to understand how much work remains to be done before the technician can manage, and not be a victim of, the wood variable.

Evaluation of the geographic origin of the wood for barriques at the Banfi Estate

In light of the above, it becomes necessary to give a dimension to the "variability" factor that characterizes wood, in relation to its geographical origin, to be able to maximize and optimize the technological value of the barriques.

The Castello Banfi Estate has more than 6.000 barriques, and about 20% of them are renewed annually.

Therefore, it is understandable that managing to control the actual enological value of the wood, and thus of the barriques, starting from the first phases of their production process, is important for the Estate. This begins with the choice of the wood and the lots of staves for the construction of barriques destined for the maturation and aging of high quality wines.

To this end, a sampling study was carried out at the Banfi Estate on the staves of defined geographic origin, and on the different wood species provided by the various French and Italian suppliers. This was done to evaluate the degree of chemical and sensory diversity of the various lots in the initial seasoning phase.

The analyses and controls carried out enabled the evaluation of the composition of the lots of staves of different geographic origin. Successively, these analyses also enabled both the definition of the production methods of the woods, differing in terms of seasoning regime (technique and length) and of toasting regime (traditional or temperature- controlled), and a more targeted destination of the woods

according to the desired wine style.
The goals of the work were the following:

- to evaluate the chemical and sensory characteristics of the wood of defined geographic origin;
- to evaluate the degree of diversity and variability of the lots of staves from a given geographic origin;
- to define the usable lots in relation to the chemical characteristics of the wood and the desired winemaking goals.

As regards the oak wood analyzed, the most noteworthy differences were found relative to the concentration of total polyphenols. In the woods originating from the Limousin and Massif Central areas, the total polyphenols were found in concentrations twice as high as those found in oak coming from other departments and forests. The lowest concentration was found in samples of wood coming from the Fontainebleau forest, while, as numerous studies have already pointed out, chestnut wood had the highest concentration of total polyphenols.
The polyphenolic composition of the various matrices, expressed as asorbancy values at different wavelengths of the hyroalcoholic extracts of the various wood samples, is reported in Figure 2.
As can be observed, oakwood originating form the areas of Allier and Fontainebleau had the lowest concentrations of both polyphenols (absorbence at 280nm) and phenolic acids (absorbence at 320nm), indicating a minor concentration of the more astringent and bitter phenolic forms.
Instead, the oakwood coming from the Nevers and Blois areas was slightly richer in polyphenols and simple phenolic molecules, distinguishing itself chemically from the oak of other different geographical origins, and from the other wood species analyzed. With the wood sample analyses, it was possible to classify and analytically distinguish the lots of oak wood offered by the suppliers and this was a starting point for defining and chosing the lots destined for producing the barriques, both for white wines (Chardonnay and Sauvignon) and the reds (Brunello in particular).
A particularly marked difference among the oak samples was highlighted by determining the concentration of the ellagitannins in the hydroalcoholic extract .
On the basis of the concentration of the ellagitannins, the wood species analyzed were divided into three groups:

a. the oak originating from Limousin (where Quercus Peduncolata is predominant); here the chestnut was richest in ellagitannins, having concentrations greater than 10 mg/g;
b. the oak originating from the forests of Nevers, Bourgogne and the Massif Central had concentrations, which were about 1/3 lower;
c. the oak originating from the forests of Allier and Fontainebleau had the lowest concentrations of ellagitannins, which did not exceed 5 mg/ g of wood. Between groups b and c, the difference of ellagitannin concentration was, on average, 40%!

Next, two different extraction techniques were compared. This was done to evaluate, using the same wood-solution contact time, both the quantity of total ellagitannins present in the various wood samples and the extractability of this substance.
An identical quantity of wood underwent extraction in a 12% water-alcohol solution, acidified up to pH 3.5, and with an extraction in acetone at 40%. In this way, with the 12% water-alcohol solution, it was possible to evaluate the partial diffusion of the ellagic tannins in a solution that could simulate the kinetics of extraction in wine, compared to the almost total extraction of the wood's polyphenols in a solution with greater solvent power, such as acetone at 40%.

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The aim of this study was to obtain the following information:

- the concentration of total ellagitannins in oak samples coming from different geographical areas, compared to the partial extraction obtained with a wine-like solution;
- the ease of extraction and diffusion of the ellagitannins in the medium, in relation to the structure of each wood sample;
- the quantity of ellagitannins present in of each type of wood, in relation to the geographic origin, the grain, and the rate with which this "supply" of tannins passes into the wine during the barrique's life-span.

The percentage increase of the ellagitannins found in the extracts obtained with the acetone-based solution were evaluated and compared to the extracts obtained with the water-alcohol solution. These data were studied in relation to the geographical origin of the wood and the kind of wood species, creating a particularly interesting comparison.
The lots of oak were analyzed by Banfi and the data from the analyses of the extracts led to the following considerations:

- oak originating from the forests of Allier and Fontainebleau had increases in ellagitannin concentrations of around 20%;
- oak originating from the forests of Massif Central, of Nevers and Burgundy had increases of ellagitannin concentrations above 33%;
- oak originating from the forests of Limousin as well as the chestnut had ellagitannin concentrations, which were about twice the amount that was extracted in a water-alcohol solution.

The factors at the basis of the different composition of the various samples of French oak can be attributed to the following influences: genetic, botanical, soil, environment and climate.
In fact, as mentioned before, the forests of the Allier and Fontainebleau areas are characterized by the predominance of the Quercus Sessilis species. This tree grows slowly and furnishes wood poor in polyphenolic substances. In addition, the soil- climate conditions of this forest induce the trees to grow slowly, and consequently, the staves made from this wood are particularly fine grained, with a good density and texture, and rich in radials. This particular wood structure causes a low accumulation of ellagic tannins that, given the particularly fine grain, are extracted very slowly and gradually during the wine-wood contact period. Although commonly considered valuable, the forests of Nevers and Bourgogne, and chiefly those of the Massif Central are characterized by a greater presence of Quercus penducolata, which is a less valuable botanical species of oak than the Quercus sessilis.
In addition, the soil-climate conditions favor a faster growth of the trees and thus the wood obtained from this forest can have a grain that is slightly less fine compared to the wood from the forests of Allier, Tronçais and Fontainebleau. Consequently, this wood has a greater concentration of ellagitannins and needs adequate seasoning and toasting treatments to achieve its full winemaking potential.
Thus, it is easy to understand the importance of the geographical origin of oak. This can be defined and evaluated considering two quality aspects of the wood;

- the total quantity of ellagic tannins;
- the extractability of the ellagic tannins.

These considerations have repercussions on four aspects of fundamental importance for enology;

1. the quantity of ellagic tannins accumulated in the wood during the initial seasoning phase;
2. the evolution of the tannins following the seasoning and toasting phase;
3. the "extractability" of the tannins during the maturation phase of the wines;
4. the "enological longevity" of the barriques, that is, their ability to slowly release the phenolic

compounds, which are still "deposited" in the wood's polymers.
Accordingly, for the polyphenols of the woods, it is important to introduce the concept of extract- ability, as it is defined for the polyphenols of the grapes.
In fact, the quantity of polyphenols found in the wood after toasting, their location in the wood structure, and the wine extraction and diffusion kinetics are all aspects that strongly impact the quality of white and red wines because of the multiple roles that the ellagic tannins play in their aromatic and organoleptic evolution. The lots of wood furnished by different suppliers and sold as Allier and Fointainebleau were studied more in depth to evaluate and measure the degree of variation in ellagitannin concentrations. Numerous samples of wood from Allier, from 4 distinct lots, and from Fontainebleau, from 3 lots demonstrated a significant variation in ellagic tannin concentrations expressed in mg/g of wood. However, while the lots from Allier had a wider range of variability (from 3 to 9 mg/g), the wood from the forests of Fointainebleau had ellagic tannins with a more modest variability (from 2.5 to 5.5 mg/g).
Finally, to better appreciate of the degree of variability of the wood samples originating from Fontainebleau and Allier which were analyzed in relation to the concentration of the ellagitannins, there was a comparison of the data obtained from the multiple samplings of the woods that had undergone two years of seasoning and could, according to the suppliers, be used for producing barriques.
Each sample consisted of the extraction and analysis of 3-5 samples of wood per lot.
It was observed that the samples of wood said to originate from the forests of Allier had a variablilty greater than 110%, while the samples originating from Fontainebleau had a variability of "only"
70%. At this point, in light of these observations, a question comes to mind: does the technician have to tolerate this variability or does he have some means of managing it since it can have a great impact on the finished wine. To simply accept this variability signifies never really being aware of the actual enological value of one type of wood versus another, above all if the technician must work with barriques that are from Allier only by name!
Thus one is forced to turn to many suppliers to mediate both the successes, and the failures! Certainly, using the "grain" parameter is already a way to reduce the variability of wood composition, supposing that fine-grained woods derive from forests where there is a predominance of Quercus Sessilus, while coarse-grained woods are typical of forests where the Quercus Peduncolata is particularly widespread.
This correspondence, however, does not always hold true!
Therefore, accepting that a wood's geographical origin gives one an idea of its quality, obtained by pairing "territory x species," can provide an adequate guarantee to the technicians only if it is backed by a system of "traceability" and "tracking" along all the barrique production cycle.

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THE EFFECTS OF STAVE SEASONING ON WINE QUALITY

Seasoning the staves:
an important phase of wood maturation

The seasoning phase is considered the first operation which the staves undergo before they are processed for producing wooden wine vessels. Indeed, it is important to remember that the manufacturing process of barrels and barriques actually begins in the forest, with the selection of which trees and trunks to use for the construction of the staves.

Therefore, even before felling the trees of the species that are of interest, those that meet certain criteria are identified (aged between 200 to 250 years, trunk diameter 40-60 cm. / 16-24 inches, etc.) and later, the best portion of the trunk (the straightest, with the least knots and without defects caused by parasites, etc.) is selected for construction of the staves (Chatonnet, 1995).

When the trunks are cut, in pieces of variable lengths according to the type of container to be constructed (for the barrique, pieces of about 1 meter /39 inches are required), the wood is grouped into classes according to its grain. This operation is extremely subtle since the criteria is exclusively visual, thus making the operator's experience critical. After the staves have been made, which can be carried out in different ways (splitting, sawing in quarters, etc.) they are aged 1 to 4 years.

This phase is critical for the final quality of the wood, and consequently, for the enological value of the barriques and barrels, because it allows for important transformations of the wood matrix. When the wood is cut and worked, it has 70% humidity. However, to be utilized for the construction of barrels, a stave must have a humidity, which is in equilibrium with the surrounding atmosphere, to avoid barrel deformations and consequent leaks. Therefore, before being used for barrel construction, the staves must be aged for a period before working on them, to reach a humidity level between 12 and 18%, which is determined by the length of the process and the climate in which the staves have been aged.

Wood seasoning, for humidity reduction, can be carried out in two ways:

1. Naturally: the staves are stacked in the open air;
2. Artificially: in high-temperature ovens/kilns (80-90°C)

These two seasoning methods require different lengths of time and produce woods that are very different in quality. According to the climate and the thickness of the stave, natural seasoning can last from 2 to 4 years, while artificial seasoning can range from 4 to 6 months (Martin, 1986).

Artificial drying enables the attainment of the desired degree of humidity in less time, but furnishes staves that are of low quality from several stand- points, which will be mentioned briefly.

Rapid water loss, for example, can have negative consequences on the quality characteristics of the wood matrix, as it produces a rapid tightening of the tissues and fibers and the formation of cracks/ fissures and lacerations of various sizes, whose depth depends on the speed of dehydration. These lacerations have a strong negative effect on the wine-wood relationship and, mainly, on the kinetics of diffusion and extraction of the molecules from the wood. On the whole, the only advantage of this kind of treatment is that it enables attainment of the desired humidity in a shorter amount of time, with a great cost savings. However, it is important to point out that the enological value of the materials, and thus of the barriques, does not depend only on the degree of stave humidity when processed, but also on many other factors that will be briefly discussed. Artificial seasoning (or better yet, dessication!) in kilns only causes the dehydration of the wood to the humidity level desired, without causing any other changes in the structure or the molecules of the wood. On the other hand, besides water loss, natural seasoning favors

other very important phenomena and modifications of wood structure and composition, which enhance the value of the botanical species.
For this reason, one speaks of the natural process of seasoning and natural maturation of the wood, and not simply of dessication. Traditionally, natural seasoning is carried out by stacking the piles of staves in open air, placing them in a way that favors a uniform quality evolution. The piles are also arranged on various levels and with enough distance between them to allow air and water circulation.
In any case, the process must be slow and gradual, above all in the first months, so generally, the wood is periodically sprinkled in the summer months, using sprinkling systems.

When dealing with the length of seasoning, coopers unanimously agree that it takes at least a year of seasoning for each centimeter of stave thickness. Thus the staves for barriques that are generally 26-27mm / 1 to 1.1 inches thick need 2-3 years of seasoning before the wood can obtain the best quality characteristics compatible for enological use (Sefton et al., 1993).
For a better understanding of the impact that natural seasoning has on wood quality and the important role it plays in determining barrique quality, the following points sum up the main transformations that the staves undergo, as they lose water/humidity:

- Leaching phenomena and removal of molecules of tannic nature carried out by rainwater;
- chemical breakdown and oxidation phenomena of herbal and green molecules;
- development of fungal microorganisms on the staves' surface which modify the structural and composition characteristics of the wood.

Therefore, as one can see, natural seasoning causes an actual maturation of the wood, literally changing its chemical and physical characteristics: wood seasoning accomplishes more than merely drying the wood.
In fact, studies carried out on wood in the drying phase have shown that the slow and constant passage of water through staves, left out in the open, is essential for the elimination of the tannin molecules that cause the freshly-cut wood to be astringent and bitter (Chatonnet, 1998).
As a result of the surface water's evaporation, the water's capillary column that is found at the surface level of the wood never reaches an equilibrium; therefore humidity is constantly drawn from the deeper layers to the surface. If evaporation is too sudden and if the external layer dries completely, as can happen during artificial drying, the water column breaks and the discharge of humidity and expelling of phenolic molecules stops (Vivas, 1993). In fact, the water flow from the inside of the staves towards the surface plays an important role in transferring the tannins and bitter substances. Once these are outside, they can be washed away completely by rainwater or by occasional sprinkled water.
The rainwater's leaching effect, along with the cold and winter frosts, alternated with periods of hot weather, are the main causes of the removal of the phenolic molecules present in the wood. This favors the wood's quality transformation towards sweeter and much less astringent and herbal notes. Last, but not least, rainwater helps the development of a micro-flora on the staves' surface, which breaks down the wood's polymers, resulting in a reduction of the polyhydric phenol molecules and the formation of aromatic molecules.
The fungal species present on the staves' surface have been isolated and shown to be mainly the following: Aureobasidius Pullulans, Trichoderma Harzanium and Trichoderma Konigii. They seem to be able to penetrate the wood's structure for at least a couple of millimeters and produce exo-cellular enzymes (hemicellulase and cellulase) which are able to break down the polysaccharide polymers (cellulose and hemicellulose) and favor both the extraction and elimination of the phenolic substances, and the formation of particularly aromatic phenolic aldehydes, from the break down of lignin, cellulose and hemicellulose (Vivas et al., 1993; Vivas et al., 1996).

This evolution of the wood has significant effects on the barriques' qualitative traits, as has been amply demonstrated by the sensory differences between the naturally prepared and artificially prepared woods.
In conclusion, during the wood's drying and seasoning there is a loss of astringency and bitterness, due to the elimination of the extractable polyhydric phenols, particularly of ellagitannins and also to the breakdown of certain molecules, such as glycosidase coumarins, responsible for the fresh or poorly aged wood's typical bitter notes.
At the same time, there is the breakdown of the wood's polymers (cellulose, hemicellulose and lignin) and the formation of aromatic molecules, making the wood soft and sweet both on the surface and several millimeters below, at the end of the seasoning period.

Monitoring of the barrique wood's seasoning phase at the Banfi Estate

The seasoning phase of the staves used for barrique construction is critical for defining the enological qualities of these containers. The variables, which can influence this phase and affect the final product are many:

- the actual arrangement of the staves;
- their thickness;
- the climate conditions of the seasoning area
(low and high temperatures, rainfall, etc.);
- the number and type of sprinklers used during summer;
- the movement of the staves during the seasoning period in order to make the evolution of the different stockpiles even.

Therefore, as these aspects impact barrique quality in a critical way, their management should not be left to the sole discretion of the supplier, but rather a simple quality control system of the staves must be followed. This would allow for processing only that wood that has the analytic and organoleptic characteristics compatible with the required enological objectives.
For these reasons, since 2001, Castello Banfi has started managing this critical phase of barrique production in two distinct ways:

1. at the supplier level: analytically and organoleptically evaluating and selecting samples reflecting the lots of staves theoretically ready to be transformed;
2. at the company level: by carrying out the seasoning phase of a good number of staves directly on the property and evaluating both the traditional and modern seasoning systems relative to the geographic origin of the wood.

Controlling stave seasoning at the supplier level

A complex aspect of barrique production is evaluating the actual degree of seasoning reached by the wood destined to build these containers. This evaluation does not always follow enological criteria!
The problems associated with this phase are many:

- WHEN is the lot of wood, with a specific geographic origin and grain, qualitatively ready to be transformed into barriques?
- WHO should monitor the wood's actual maturation and decide to prolong or shorten the seasoning

phase?

- WHICH PARAMETERS, analytic and sensory, can be easily monitored, in order to effectively evaluate the wood's degree of seasoning and therefore its enological destination?

As a matter of fact, until recently it was barrique producers who decided the degree of seasoning of the wood lots, and chose which to use for barrique production. However, though guided by their valuable experience, they are generally not equipped with monitoring instruments that enable the technician to guarantee the "real" composition and organoleptic quality of the chosen lots.
In fact, monitoring many wood samples from different suppliers having the same geographic origin and grain and having been declared seasoned for a period of 2 years, has revealed a significant difference in their composition.
This observation has confirmed the great variability in wood quality at the end of the seasoning period. This is a burden, which the technician, perhaps unwittingly, has to bear, since he is to evaluate its full consequences on the wine's quality only after a certain period of being in contact with the barrique.
An important aspect of evaluating the wood's quality relative to seasoning has been implementing, together with barrique producers, a system for evaluating and choosing the seasoned wood based mainly on analytic criteria and evaluations, related to enological goals. To this end, a system for monitoring the quality of the stave lots during the "final" seasoning phase has been set up, of which the most important points are listed below (Protocol 1):

- Monitoring of the stave lots during seasoning based on their geographic origin.
- Monitoring, choice and selection of the lots based on the grain.
- Sampling of the selected lots at various points in the stacks.
- Obtaining hydro-alcoholic extracts of the wood.
- Chemical analysis of the hydro-alcoholic extracts and evaluation of some organoleptic characteristics, such as tannin content, bitterness, sweetness, etc.
- Correlation between chemical analysis and sensory evaluations and choice of the effectively "ripe" and seasoned lots to be transformed (low tannin content, pleasing aromatic characteristics, lack of herbal and green scents, etc).
- Making of the barriques and monitoring of the toasting phase.
- Use of the barriques according to their defined enological target.

Obviously the lots of wood which are not ready to be processed, because they do not have optimal analytical and quality requirements, are re-evaluated in a later phase and used after a longer period of seasoning.
This type of approach to the management of such a complex phase of barrique production has reduced the differences in quality of the wood matrix and has significantly limited the variability of the wine- vessels' composition.

Monitoring stave seasoning at Castello Banfi

Stave seasoning at Castello Banfi has been organized in order to directly evaluate and manage the evolution of wood quality and is carried out on a number of staves that on average represents 30% of the company's annual barrique needs.
The seasoning area at the Banfi estate today has more than 100 m^3 of seasoning wood, with the staves arranged to allow wood quality to evolve evenly and steadily.
In particular, two stave seasoning techniques have been compared:

- Traditional arrangement of the staves (as a cube);
- Arrangement of the staves with the octagonal system.

The first system (Traditional), generally used by most of barrique producers, consists of arranging the staves cross-wise to form a cube with an average size of 1 m^3 .
In this way actual stockpiles are built that are several levels high and moved periodically to permit an even seasoning of all the stave lots.
There are several advantages to this technique; but primarily, it requires less space, enabling the stocking of greater volumes of wood in a limited space for extended periods of time.
The second method (Octagonal) consists of arranging the staves in an octagon, putting the staves one on top of the other and building structures as high as 1.5 m and 0.5 m large, as shown in the picture.
This method has the disadvantage of requiring much more space for the storage of the same amount of wood, as opposed to the traditional method; furthermore the staves are not moved during seasoning. However, from an organoleptic and analytical standpoint, experience shows that it yields an optimal seasoning of the staves.
The traditional method, though being the most frequently used, requires that the staves be arranged in a way to create a web, with the staves placed orthogonally and close to each other. As the picture shows, this type of arrangement can reduce above all the staves' contact with rainwater, creating a central area less exposed to the elements and which therefore seasons more slowly. Moreover, the staves overlap at various points, creating a large area, which ages more gradually.
In fact, during wood sampling, the stocks were dismantled and the traditionally seasoned wood always showed higher humidity levels than the wood aged with the octagonal method. With the latter system, the staves, which are placed farther apart to permit a good circulation of air and water, overlap only on the ends, thus significantly reducing the overlapping area compared to the traditional method. Furthermore, this method makes it possible to have, in the central part of the structure, an open area 1 m large, which guarantees even exposure of the staves to the weather, both on the inside and on the outside. This results in a more even seasoning of the staves.
During the entire seasoning period, stave samples were taken from different stocks and from different areas in each stack to organoleptically and analytically evaluate the wood's evolution in relation to the seasoning method (traditional opposed to octagonal) and the geographic origin (Allier compared to Fontainebleau). The analytical data and the organoleptic evaluations, shown in the following figures, refer to the first lot of seasoned staves starting from May 2001 and analyzed at the beginning of the seasoning phase (T0) and from then on, every 10 months (T1, T2, T3). The polyhydric phenol composition of the extracts of Allier and Fontainebleau wood in hydroalcoholic solution is shown in figures 1a and 1b. One can observe that the wood coming from Allier has a strong reduction of the total polyhydric phenol concentration (absorbency at 280 nm) already after 10 months of seasoning, both with the traditional method and with the octagonal one.
It was later observed, however, that with the traditional method, the decrease of the wood's polyhydric phenol concentration was small, opposed to a constant and significant reduction of this parameter using the octagonal seasoning method, and confirmed when sampled after almost 30 months of seasoning. This trend was noted also in the wood coming from Fontainebleau, sampled in the same period of time and analyzed with the same procedure. Concerning phenolic acids (absorbency at 320 nm), variations were less evident probably because the evolution of the wood's polyhydric phenols consists in the breakdown of the more complex forms into simple phenolic acids, which formed during the entire seasoning period (Chatonnet, 1991). Finally, it was interesting to evaluate the trend of the total polyhydric phenol concentration during the three years of seasoning related to the oxidation phenomena that transform these molecules in polymeric polyhydric phenols, responsible for the wood's

yellow-brown color, and are quantified by determining the absorbency at 420 nm of the hydro-alcoholic extract. Figure 2 reports the percentage decrease, compared to the figures found in fresh wood, of the total polyhydric phenols and of the yellow-brown forms found in the wood samples coming from Fontainebleau during the three years of seasoning.
It should be noted that with the octagonal system, after 30 months of seasoning, there was a greater than 50% decrease in total polyphenols, with a parallel decrease of over 45% of the oxidation products, responsible for the yellow-brown color of the wood. However, with the arrangement of the staves in the traditional manner, there was less of a breakdown of the total polyphenols, compared to the octagonal system. It also limits the removal and extraction of the oxidated forms through leaching by rainfall or by water spraying. These are removed in quantities around 20% compared to the 46-54% found with the octagonal system.
Arranging the staves in a compact manner and with fewer spaces between them, as happens with traditional seasoning, causes less wood-air contact and thus the maturation is slower and less even. On the contrary, with the octagonal system, since the stacks are less thick and the staves are placed less compactly, the removal of polyphenols and the relative oxidized forms is more accentuated and more rapid in the same amount of seasoning time. Therefore, it appears evident that the seasoning system, and particularly, the arrangement of the staves, impacts the final composition of the wood and the barriques in an important way.

Even the trend in the ellagitannin concentrations, which represent the majority of the inherent polyphenolic properties of the wood, was similar to the trends in the parameters analyzed previously.
It has been observed that with the traditional system, the decrease in ellagitannin content from 20 to 30 months, is limited to 7-9%. This indicates that, using this system, after about 2 years, the wood loses most of its polyphenolic properties. Therefore, with a longer seasoning period, the traditional system does not support a decrease in ellagitannin content that would justify a seasoning period of almost 3 years. On the contrary, the octagonal seasoning system increases wood contact with meteorological factors solely through a different arrangement of the staves. It allows a significant reduction of the phenolic molecules by prolonging the seasoning period up to 30 months, with a reduction of ellagic tannin of over 20%.
These molecules are still found in extractible forms in the stave's thickness and particularly, at a certain depth, whereas at a superficial level, both techniques guarantee the almost complete removal of the polyphenols. This means that the molecules that are removed later on are ellagic tannins remaining in the deeper layers of the staves. If these are not removed during seasoning, they can eventually come in contact with the wine, conferring green and astringent notes, typical of this molecule.
Instead, as the traditional technique limits the exposure of the wood to external factors, the efficiency of the seasoning process is reduced and limited. This is evident during the first 20-24 months, but becomes significantly less so in subsequent months. However, the wood can still contain molecules, mostly deep down, which could negatively impact wine quality. Technical procedures and the length of seasoning should be able to reduce the number of these molecules in a constant and even way.
Besides analytical monitoring, the study carried out at Castello Banfi considered the sensory evaluation of the wood at the end of the seasoning period through panel tasting of the water-alcohol extracts of the analyzed woods.
From an organoleptic standpoint, the samples with the least intensity of “bitter” and “tannin” descriptors were the samples of wood from Allier aged with the octagonal system, while there were no differences found in the “vanilla” aroma. These differences were more marked when dealing with wood from Fontainebleau . Finally, putting the total polyphenol values (absorbency at 280 nm) in relation with the sensory evaluations of the water-alcohol extracts, a tight correlation between the two parameters was found.

The water-alcohol extracts of the samples of aged wood were less bitter and "tannic" to the palate than the wood samples that had not undergone seasoning. In particular, the bitter sensation was more correlated to the decrease in total polyphenols, in respect to the tannic sensation. The samples that had the least tannin and bitter sensations were those that had undergone seasoning with the octagonal system.
The concentration of ellagitannins found in the water-alcohol extracts of the wood samples without seasoning ("control sample") was compared to that from the traditionally and octagonally aged samples. The comparison shows that these molecules significantly influence the astringent and bitter character of the woods.

In particular, the correlation between the two parameters under consideration was very significant when dealing with the samples aged with the octagonal system, as these were clearly distinct from all the other samples analyzed. It is interesting to note the trend of the tannin curve compared to the bitter character in the samples that were analyzed and tasted. There is a limited reduction of this character in the traditionally aged samples, compared to the control sample, while the most rapid reduction is found in the samples aged with the octagonal system. These observations highlight how a technician can equip himself with a simple control system for wood quality and thus be able to choose a lot of staves based not only on the geographical origin of the staves themselves, but also by working together with the producer to:

- analytically verify the tannin structure of the wood at the beginning of the seasoning phase;
- perform periodical analytical and sensory control operations on the staves during seasoning;
- choose (the technician, not the producer of the barriques!) which lots of staves are ready to be made into barriques in relation to other analyses and tasting of the water-alcohol extracts of the wood;
- evaluate and verify the "toasting quality".

This control system and collaboration between the cellar and the barrique producer limits the customary variability in wood, so it is no longer necessary to suffer its negative effects on wine quality!

THE ROLE OF BARRIQUE TOASTING IN THE PRODUCTION OF FINE WINE

Toasting the barriques:
the fire that "ennobles" the wood

The typical notes that characterize a wine that has spent part of its life in a barrique or barrel can be traced back to very particular aromas that are generally described with the terms toasted, almond, vanilla, smoky, cloves, etc. It is a well-known fact that these notes derive from the barriques, but they are also found in imperceptible quantities in the wood, at the end of the seasoning process. Thus it is natural to ask where they come from, and chiefly in what conditions they form in the wood. In fact, toasting is considered a crucial phase in the preparation of wine vessels as it significantly influences their chemical-physical characteristics and, consequently, the organoleptic imprint that they are able to give the wines after a certain period of maturation and aging. Thermal treatment of the wood is carried out after the seasoning phase and can be divided into two operations:

1. the bending of the staves;
2. the actual toasting.

After the staves have been assembled and the realization of the "mise en rose" or raising of the barrel, there is the bending phase. The "rose" or partially constructed barrel is placed over source of heat, which is a brazier, for 15-20 minutes. In addition, during the bending, the wood is repeatedly dampened, as the combination of heat and moisture causes the wood to become softer and easier to work, due to the physical transformation caused by the heat on the structural polymers at temperatures of 110-120°C / 230-250°F.

Wood has a structural composition that makes it very rigid and hard to bend, as it is not very pliable at normal environmental temperatures. When it is bent in such conditions, the staves often break at the point of maximum stress. In essence, wood is composed of certain thermoplastic polymers (lignin and hemicellulose) that lose their rigidity when they are exposed to heat. This allows the staves to be bent and worked while limiting the risks of breaking (Boeglin et al., 1993).

After the bending operation, the barriques undergo the actual toasting.

This thermal treatment consists of heating the barriques using a natural source of heat up to temperatures that can vary between 130 to 230°C / 265 to 445°F for a length of time between 30-60 minutes, according to the degree of toasting desired.

The toasting operation profoundly changes the chemical composition of the wood, allowing structural modifications of the polymers (cellulose, hemicellulose and lignin) and the formation of particular new aromatic compounds (vanilla, furfural...etc.) and causes the heat breakdown of the phenolic compounds (ellagitannins) - (Bourgois et al., 1988).

From the technological and applicative standpoint, in the enological sector, toasting plays a primary role in barrique production, as it significantly modifies the chemical composition of the wood, and thus the sensory and oraganoleptic characteristics of the finished wines (Chatonnet et al., 1989; Aratajona et al., 1991; Aiken, 1984).

The two main parameters used for defining the toasting level of barriques are:

- treatment temperature of the wood;
- length of thermal treatment.

On the basis of these parameters, there are 4 different levels of toasting identified:

Level of toasting	Temperature °C °F	Length (minutes)
Light toasting Medium	30/86	120-130
toasting Medium-strong	35/95	160-170
toasting Strong toasting	40/104	180-190
	45/113	200-230

It is important to note that these are only indicative/representative values, because they can vary greatly from one barrique producer to another, as this operation can be carried out following different procedures.

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Therefore, a particularly critical aspect of the entire barrique production process lies in the fact that barriques sold with the same level of toasting (light, medium, heavy) can have extremely different compositional characteristics.

Following this treatment, and according to the production procedures, the aromatic and quality profile of the barrique can be very different and thus impact the quality of the finished wine either positively or negatively. Toasting determines a thermal breakdown of the wood compounds by complex reactions (pyrolysis, carbonization, etc.) whose intensity depends mainly on the thermal level, which was reached, and the length of the treatment. The thermal treatment permits the development of volatile compounds of various natures. Regarding this, more than 200 have been identified, and the most important are reported in Figure 2 (Dumon, 1982; Gimenez Martinez, 1996).

Most studies have considered the effects of heat on wood, the thermal breakdown of the polymers, such as the cellulose, the hemicellulose and the lignin, the formation of particular aromatic molecules, the breakdown of the polyphenolic substances and the study of the parameters that control and influence the thermal properties of the wood matrix (Giordano, 1971; Fengel et al., 1984; Drewe et al., 1985). Toasting the barriques causes the wood properties to change (Nomendedeu, 1988 and Nomendedeu et al.,1988; Paciorek, 1976; Pearl, 1991) because of the succession of the four principal and fundamental transformations listed below:

- Pyrolysis of the hemicellulose: it is the most easily thermo-degradable component of wood, starting at temperatures of 80-120°C / 176- 250°F; the products of the breakdown impart peculiar aromatic characteristics to the barriques, such as notes of toasted almond, attributable to the newly formed furfuryl aldehydes;
- pyrolysis of the lignin: it begins after the break- down of the hemicellulose, at temperatures of about 120-140°C / 176-285°F, and causes the formation of a great quantity of new volatile phenols with a strong aromatic impact, like the vanilla aldehyde, which is responsible for the characteristic notes of vanilla;
- pyrolysis of the cellulose: this is noticeably modified at temperatures ranging from 230-250° C/ 445-485°F, as it is very thermically stable;
- thermal breakdown of the polyphenols of the wood (ellagitannins and gallotannins) and formation of simple tannins (ellagic tannin and gallic acid) that are almost completely eliminated at the level of the first 4-6mm / .15-.23 inch of depth of the stave (Krohl et al., 1978).

Actually, the toasting operation, as it is presently carried out, is conducted in a very empirical way and varies from firm to firm, as the procedures they follow are dictated more by tradition and experience than by a control over the parameters of the process. For example, to control the heating velocity of the wood and the temperature, in most cases, the master cooper “manually” evaluates the thermal state of the barriques, deciding, very empirically, the grade of toasting it has reached (Dumon, 1982). At the same time, however, many aspects influence the impact of toasting on wood quality. If they aren’t monitored and managed well, they can lead to very uneven heat treatment.

In light of this, listed below are some operations that have a direct impact on the intensity of the thermal treatment and thus on the quality result of the barrique toasting operation:

1. Stave bending: it can be carried out directly with fire or by immerging the barrique in hot water (70-80°C / 158-176°F);

2. Barrique placement in relationship to the heat source: regarding this subject, the firms use very different systems, positioning the barriques directly on the ground or 2-4 cm / .8-1.5 inches above it. This seemingly insignificant aspect has an important effect on the toasting operation, as it modifies both the intensity of the heat source and the flow of wood heating. In fact, by increasing the circulation, an air flow crosses the barrique, modifying the wood-heat relationship significantly, allowing irradiation and frequently the carbonization of the barrique’s surface (Bourgois et al., 1988; Giordano, 1971); 3. Water sprinkling during

toasting: it modifies the thermal gradient of the wood and the penetration of the heat in terms of depth, slowing the heating speed and allowing hydro-thermal reactions of the wood components and of the polyphenols in particular (Drewe et al., 1974). Different firms perform this operation in different ways, in terms of water quantity and treatment frequency;

4. Intensity and temperature of the heat source: the toasting of the barriques can occur by direct contact with the fire on the wood surface (irradiation) or by heat transmission through heated air inside the barrique itself (convention and convection). These two systems of transmitting heat occur simultaneously and it is possible, using various techniques, to emphasize one or the other, radically modifying the results of the thermal treatment;

5. Partial covering of the barrique during the thermal treatment: this permits air movement/flow inside the barrique and the "saturation" of the container with hot air, favoring an homogeneous heating all along the height of the barrique. Wood toasting occurs more by way of convention and conduction than by irradiation, as the source of heat is very mild and the wood-fire contact is very limited;

6. Repeated rotation of the barrique during toasting: this is performed at 7-10 minute intervals to enable uniform toasting of the ends of the barriques and is indispensable when the heat source is too strong. There is a simultaneous significant fluctuation of the wood temperature of about 20-30°C / 68-86°F that increases the difference in the performance of this operation;

7. Speed of wood heating: it has been calculated that thermal treatment should cause the wood to heat with a gradient of 4-5°C/7-9°F a minute, to prevent rapid dehydration of the stave surfaces that could cause the formation of cracks and blisters. These would be easily subject to later phenomena of carbonization and combustion;

8. Maximum temperature reached by the wood: this can vary widely according to the technique adopted and significantly impacts wood quality, whose components are variably sensitive to heat. Among the various toasting techniques adopted by the barrique manufacturing firms, there is a noteworthy difference in toasting temperature. This can vary from 150-280°C / 300-536°F in medium toasting, and even go up to temperatures over 300°C / 536°F in some cases, with evident phenomena of combustion and carbonization of the barrique surface. The control of the thermal system is thus indispensable for understanding the impact that the various toasting systems have on the enological quality of the barrique (Woo et al., 1987; Shafizadeh et al., 1977). Many studies have pointed out the importance of thermal systems, the length of treatment and the characteristics of the wood matrix used. Additional importance is given to environmental factors such as humidity, air availability during treatment, reactions of pyrolysis of the wood's polymers and the consequent formation of volatile and non volatile compounds (Chatonnet et al., 1989).

In practice, it is interesting to observe that when the barrique's internal surface is heated too quickly, 8-10°C / 14-18°F per minute (on average it should be 4-5°C / 7-9°F per minute), and the heat source is not adequately controlled, incomplete reactions of pyrolysis, combustion and carbonization occur.
In this way, areas characterized by a layer of carbonized wood act as a real and typical "thermal shield" as they have a limited thermal conductivity, which slows and hinders the penetration of heat into the deeper layers of the wood (Chatonnet, 1989, 1993).
Thus, heat will penetrate the depths of the barrique with a particularly carbonized internal surface less than those with less toasted internal surfaces. Therefore, there is a great diversity of treatments in the course of the operation and these differences are attributed to various factors, like the variations in heat source, and air flow across the barrique, which can cause important thermal variations.

The final effect of the heat treatment also depends on the kind of wood used and thus on the specific physical-chemical characteristics of the wood species. This makes the standardization of this procedure and the reproducibility of execution even more difficult (Chatonnet et al., 1989; Puech et al., 1993 and 1988).

Thus each barrel manufacturing firm adopts toasting techniques that are simply a combination of the above-mentioned operations, dictated by the experience acquired over the years and by a very empirical control system. As there is no rigorous control system of the technological factors applied in the thermal treatment of wood (temperature, length, humidity, oxygen, etc.), it is almost impossible to achieve reproducibility and uniformity of the toasting operations both among the various firms and even within the same firm!

Therefore, it is understandable that the diversity of the toasting techniques adopted by the barrique manufacturing firms leads to the production of wooden wine vessels with varying characteristics that are introduced into the wine production process.

Management of the toasting operation at Castello Banfi

Forty percent of Banfi's wine production undergoes barrique or barrel maturation for a length of time varying between 6-8 months for white wines and 24-28 months for red wines.

This means that, during the maturation period, the barriques impart a strong and marked style to the wines, strongly defining their final sensory and aromatic characteristics.

Panel tasting sessions of the red and white wines found notes of toast, vanilla, etc., which are very different and not always pleasant. The impact of the barrique on white wines is greater. In fact, the notes imparted by the barrique can at times border on coal, smoke, ashes or towards greener, more herbaceous notes, such as fresh wood, up to sensations of sawdust and paint.

Therefore, it is easy to understand the importance of adopting a control system that would limit the variability of barrique quality, not only in the phase of selecting the lots of wood according to geographical origin and in the seasoning phase, as reported in the preceding chapters, but particularly in the toasting phase (Cantagrel, 1993).

These considerations have been confirmed by a series of tests carried out on numerous barriques originating from different suppliers, produced with wood of the same geographical origin (Allier), which had undergone the same level of toasting (medium). The barriques were opened to evaluate the various characteristics:

– External

- quality and homogeneity of the grain;
- direction of the radials;
- presence of knots, etc.

– Internal

- comparison of the degree of toasting among the various suppliers;
- presence of carbon aromas, of burnt plastic, or of vanilla, of dried fruit and toasted almonds;
- degree of homogeneity of the thermal treatment at every level of each barrique;
- presence of carbonized areas;
- presence of blisters due to the explosion of vapor pockets that form when the wood is heated too rapidly;
- degree of penetration of the heat in the stave depth;
- quality of the heads of the barriques, etc.

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A comparison between the barriques coming from different suppliers allowed for an improved assessment of the problem of the quality variability of these containers. This is a particularly important problem. For this reason, an evaluation scheme was introduced at the Castello Banfi estate to assess barrique quality following a specific protocol (Protocol 1). This protocol enables the verification of the correspondence of what is declared by suppliers, and actual barrique quality.

Control of the barriques in the acceptance phase
(Protocol 2)

- the barriques are opened when they are received in the cellar and the grain and anomalies are evaluated;
- barrique quality is compared in relation to the declared level of toasting;
- toasting degree and intensity is evaluated;
- toasting quality is evaluated (carbon scents, blisters);
- possible points of carbonization and toasting homogeneity are evaluated;
- beginning procedures of non-compliance.

Barrique evaluation was then performed comparing not only the various suppliers, but also many barriques of the same supplier to quantify the reproducibility of the thermal treatment and the quality uniformity of the barrique lots.
In light of these observations and of the peculiarities and/or problems shown by each type of barrique, two lines of action were chosen:

1. to consciously manage and exploit the compositional variabilities and peculiarities of certain types of containers according to the desired winemaking goals;
2. to define other typological problems of barriques; verify the factors to optimize and apply a control protocol to the toasting procedure that is rigorous and corresponds to the winemaking goals of the estate.

Relative to the second point, in collaboration with some firms, a monitoring system was applied to the toasting procedure, to evaluate and optimize the technological factors (temperature, humidity, etc.). If these are not controlled with enough rigor, they can cause uneven levels of barrique quality that the technician, in most cases, must simply put up with!
The main aspect that was monitored was wood temperature during the toasting operation. This was determined using an infrared pyrometer to evaluate the following aspects:

- speed of wood heating (°C/min)
- maximum temperature reached
- average lenght of toasting
- degree of the barrique's thermal uniformity
- intensity of the heat source (brazier) and the toasting by direct fire-wood contact (toasting by irradiation) or by heating the air inside the barrique (toasting by convection and conduction).

Traditionally, the barriques are toasted using a very intense heat source. This causes a very energetic thermal treatment of the wood, which is not always optimal.
The temperature recorded is highlighted every 5' both in the bottom part of the barrique and at the top (at about 25 cm / 10 inches from the extremities).
At the end of the bending phase, the barrique is at a temperature of about 90-95°C / 194-203°F. During toasting, a very irregular heating was registered between the bottom and upper parts of the container,

with a maximum temperature difference of 45°C / 113°F after only 20 minutes of toasting .
A reference temperature of 180°C / 356°F was taken, as it is the thermal level at which the chemical transformations affecting the wood's polymers begin to occur. It is interesting to note that, while the top part of the barrique reached this temperature after only 18', the bottom part took 28' to reach the same temperature. The heating velocity was 7°C / 12.6°F per minute in the top part and 4°C / 7.2°F per minute in the bottom part and the entire internal surface of the barrique reached a level of uniformity only after 35 minutes and repeated rotation.
Finally, after 45 minutes of toasting, the top part of the barrique reached temperature levels of up to 250°C / 482°F, with evident phenomena of wood carbonization and combustion.
Therefore, it is easy to understand that this kind of system does not allow for uniform heating and treatment, because the heat source causes a rapid heating of the top part of the barrique due to the direct contact of the flame with the wood (direct irradiation). On the contrary, the heating of the bottom part occurs mainly due to the super-heating of the air (convection) and, obviously, is less due to direct contact with the flame.

Generally, an operation performed by the master cooper to limit the diversity of the toasting operation consists of rotating the barrique repeatedly during the thermal treatment. In this way, it is possible to limit the formation of areas that are only toasted by direct contact with the flame, and there is also a noteworthy cooling of the barrique itself, as the thermal regime becomes more variable. This toasting system was probably the cause for the great diversity of treatment that was found in the barriques that were inspected, even considering the precision of this operation, is determined very empirically.
To limit these drawbacks, a toasting system was defined. Its aim was to guarantee a greater uniformity of treatment by following the scheme reported in Photo 7.
The toasting operation was performed paying special attention to two aspects:

1. utilizing a heat source with a low flame, but a lot of live coals, which give a direct emission of heat without direct flame;

2. containing the heat within the barriques by using a perforated cover, which avoids excessive dispersion of the heat and saturating the entire internal surface with overheated air, allowing for a uniform and gradual heating of the internal surface of the barrique.

It was found that this system enabled the uniform attainment of 180°C / 356°F on the entire internal surface of the barrique after about 16-18 minutes, with an average heating speed of about
4°C / 7.2°F.
The toasting of the barriques was more uniform, without the formation of carbonized points and without the combustion reaction even when the maximum temperature of 220°C / 428°F was reached.
For winemaking goals, a particularly important aspect was the degree of toasting both on the surface and in depth, at 8-10 mm / .31-.4 inch from the surface. This layer comes into contact with the wine in the course of the barrique's life-span, which varies on average from 3-5 years.
In fact, it is important to address the enological life span of the barrique as it relates to the quality and quantity of the substances it is able to release during its repeated use. The evaluation of this quality aspect of the barrique has been carried out by taking samples of staves, cut in the middle part, and comparing the degree of change in color that could be ascribed to the toasting operation through the thickness of the staves themselves .
It was interesting to note that the traditional toasting system caused a higher degree of browning and charring of the stave surface compared to a toasting where the wood-flame contact is highly limited, with the same maximum temperatures. This higher degree of surface toasting did not go hand in hand with a noteworthy toasting in-depth, which was found in the barriques which underwent

temperature- controlled toasting.
In fact, the latter toasting technique heated the surface more gradually and principally by hot air (convection) rather than by direct flame (irradiation), avoiding surface carbonization and favoring the heating of the wood even in depth. At the end of the toasting process, the external temperature of the barrique was 90-100°C / 194-212°F with the traditional system and 120-130°C / 248-266°F with the temperature-controlled one. This confirms that there is greater penetration of heat through the wood's structure with the latter system.
Finally, from an analytical standpoint, with the temperature-controlled toasting system, there was less variability of the ellagic polyphenol concentrations.
In fact, compared to a mean value for the concentration of ellagic tannins which was almost the same (1.45 mg/g for the temperature-controlled technique vs. 1.69 mg/g for the traditional technique), there was an enormous variability among the various samples taken (29% variability vs. 152% respectively).
These observations lead to the conclusion that all the toasting techniques can be effective; they have affirmed themselves over the years and their effectiveness has been validated by scores of years of experience that the various producers, and, above all, the master coopers, have acquired. However, one step forward must be taken. It is important to understand the consequences and the transformations that the various techniques have on barrique quality. This will enable a greater awareness of the advantages, limitations and strengths of every type, allowing for a more targeted and adequate definition of the destination and use of barriques. Therefore, the effects these techniques have on the final composition of the wood should be carefully evaluated when choosing which toasting procedure to adopt. Measuring the uniform quality of the barriques means being able to take advantage of this variable. Moreover, it is possible to introduce measures that allow for the production of barriques that correspond more closely to the goals of the winemaker.

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THE WINE CELLAR OF THE FUTURE

T. Bucci

Local Challenge

Outside the heat was oppressive, but in the meeting hall there was an ancient coolness, ancient as the historic city hall with its great room facing the Piazza del Popolo.
The newly minted mayor listened to us with interest, but also with some poorly concealed perplexity. We spoke to him about projects that must have seemed to him to be excessive.
Those, in fact, were the years of hit and run business management. Italy, especially in the south (the former Cassa del Mezzogiorno area), was full of unlikely businessmen whom, thanks to various types of public assistance, built production facilities that would then never be put into production. This time, however, was different, there wasn't even a shadow of assistance, other than that it was difficult to imagine somebody planting a vineyard would run away before it began to produce. There was truly the fear that a community with a great past history could be distraught over the arrival of the new big business "Villa Banfi," as it was known then.
To counter the heavy population drain (from over 12.000 to just 5.000 inhabitants) due to the abandonment of the fields, for the most part belonging to large agricultural estates, one time managed under the "mezzadria" share-cropping system, together with the loss of competition among the historic artisan activities, any project to build a production facility would be auspicious.
The local administration supposed, among a million suspicions, that Banfi could put into effect resources and ideas that would put Montalcino into decline along with its principal "Brunello" wine, already prestigious but substantially unknown to most. But the greatest resistance came from within the world of agriculture itself. The great farming estates and the direct growers, some of whom were formerly share croppers, were as a rule in perennial conflict with each other, but, worried about the presence of this new arrival, they put together a common front to block in any way possible our progress.
This is the climate in which we laid out the first plans for our winery, which had the following guidelines:

- Maximum rationale and logic for the working spaces
- Temperature control in every phase of operation
- Impeccable working conditions in terms of hygiene and security
- Complete integration of the winery in the succession from vineyard to winery to finished wine to market
- Perfect balance between tradition and innovation
- Expandability of work spaces in function of foreseen and inevitable growth
- Access to the winery as a primary means of communication for the wines and the territory

This last point raised every possible type of ridicule. Those were the years in which large wineries were, in general, seen, as places that were best kept hidden.
Dignity was given to the grape and to the wine, but almost never to the winery; there were rare exceptions and almost unknown to the vast majority of wine drinkers.
The combination of the political and local conditions, and the input of the Mariani family, represented an ambitious and complex challenge, because more than anything else the desire was to affirm that quality is not tied to dimension, as in the overused concept that "small is beautiful," but that quality is only a voluntary accomplishment tenaciously pursued. At that point it might seem that the market for quality Wine was not yet ready to absorb great quantities, but things, as we witnessed, were about to change completely.

The first layout of the project took a 180-degree turn in respect to the winery that was completed. Entering the winery, from the same side as one enters today, we found the bottling line at the far eastern end of the vinification area, completely opposite where it is today (see design on page 389). This turnaround from the original plans was the result of a dynamic confrontation with the local administration that brought about an initial halving of the buildable area. This step was designed to guarantee that the growth of the winery would be commensurate with the development of the investment and to the relative production and employment. As demonstrated by the phases of growth, the ability to expand the winery in successive phases toward the west proved itself in optimal time, both from a technical and logistical point of view.

Commercial and Economic Challenge

We started planting the vineyards in 1978, more or less at the rate of 70 hectares / 175 acres per year, together with the 110 hectares / 270 acres of existing vineyards acquired in 1984, to reach the current area of 850 hectares / 2.100 acres under vine. The winery, therefore, had to vinify, and vinified the first grapes in 1982. It also had to generate as soon as possible the entries to help the estate survive on its own resources. It should not be overlooked that a vineyard takes 5 years to give full production and in this zone, meaning the regulations for Brunello, the wine rests another 5 years in the cellars. Therefore, while awaiting the wines produced from our own vineyards and in order not to have to seek funding for our day to day operations as well as the already significant initial investments, it was indispensible to seek other means to render this initial phase less burdensome.
This opportunity came with the possibility of bottling in Montalcino all the wines that Banfi USA was acquiring at the time in Italy and sold mainly on the North American market. This possibility restricted us, obviously, to wines produced elsewhere, which were sent for bottling in Montalcino, together with the Montalcino wines.
It was thanks to two table wines, Bell'Agio and the Entrée family of wines, together with Italian wines of more or less importance, that we were able to survive the long years awaiting the release of significant quantities of our own wines from our own grapes without additional help. In truth, the initial programs, while aggressive, were much less optimistic than what turned out to be the future reality. At the time it was thought that the greatest consumption would be covered by beverage-type wines for the younger generations. Let's not forget that in those years the vast majority of wine was consumed as bulk wine and greatly outnumbered the amount of bottled wines.
In any case, the base idea was half whites, half reds, half traditional, half international, as we said at the time. The traditional varietals were represented by Sangiovese, of which the clones are locally called Brunello, a discussion well covered in this publication, while among the whites we put much emphasis on the re-launch of a very ancient and, in its time, prestigious Moscadello. It was at a point of almost being forgotten. Among the so-called international varietals, the standouts were Chardonnay and Cabernet Sauvignon.
This situation imposed upon us a long harvest period. Chardonnay-Moscadello-Sangiovese-Cabernet Sauvignon would have been the rationale imposed by our human resources and equipment, both on the agricultural side and in the winery. In fact, an operation of this dimension (more than 700 of the 850 hectares / 1.730 of the 2.100 acres of vineyards planted were in production) would have been unmanageable with a harvest period of two weeks instead of two months. The fact that since the beginning we focused on a bottling line made up of a nucleus of work areas which, with the slight integration of seasonal workers, allowed us to survive this imposing harvest period without excessive problems.

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Set-up of the Winery

The winery with its fishbone expandability permitted many advantages from the start:

1. Receiving area for the grapes with a trailer scale and refractometer
2. Vinification with 2 crushing/de-stemming lines, 10 horizontal hydraulic presses with fully automated loading and discharge, and 6 vertical temperatures controlled auto-draining fermentation tanks
3. Filtration of musts with 9 temperature controlled clarification tanks, 2 refrigeration tanks, 2 plate filters for lees, 1 centrifuge for must and 1 for wine, one vibrating screen filter, one fixed screen filter with centrifuge discharge, and one must pasteurizing machine
4. 3 refrigerated areas for the conservation of Moscadello must 5. Ready fermentation with 12 fermentation tanks, 24 autoclaves for effervescent wines, blending tanks, hermetic wine centrifuge, carbon filters, and plate heat exchanger
6. Barrel cellars with large casks and barriques
7. Bottling line and warehouse
8. Technical services with 2 electric boxes, one emergency generator, central station for drinkable and fire extinguishing water, temperature control center, cryo-container for liquid nitrogen, compressed air tank, refrigeration center, and filtering area for used water
9. Offices, lab and work shop
10. Facilities for workers

Architecture

The initial surface area was composed of about 14.300 square meters / 17.200 square yards, including 4.000 square meters / 4.785 square yards underground.
Dimensions of this type could not be integrally realized with traditional construction; for the bottling line alone, to avoid structural obstacles a room of 60 x 60 meters / 66 x 66 yards with 48 meter / 53 yard beams and only two internal pillars. In other work areas we wanted free hanging lights from 24 to 34 meters / 26 to 37 yards. For these motives about two thirds of the area was put together with pre-fabricated structures.
The architect Marcello Matteini was most capable in dealing with movement and harmonizing such heavy volume, with such economic elements as pre-fabrication. He also gave greater possibilities to indulgence in the cask and barrique cellars. Further, he knew how to dress it all brilliantly with green outer treatments, but also make it pleasurable to withhold from above, considering that the winery is at the base of a valley, overlooked by about 100 meters / 328 feet mile of the Maremma Provincial Highway.
All of this was at least twenty years ahead of the curve in fashion for wineries designed by the big names in architecture.
Internally, the surfaces were routinely paved with Klinker tiles fused with an epoxy resin at a 1% pitch.
According to the individual situation, drainage was realized through tubing or dry wells, therefore with a pitch in two or four directions.
Very often the surfaces beneath the tanks not subject to heavy traffic were sealed with a subtle epoxy resin film or with auto-leveling polyurethane resin.
The Klinker tiles offer optimal characteristics:

- Robustness and resistance to abuse including heavy traffic, including fully loaded fork lifts
- Resistance to aggressive chemicals (acids, alkali, detergents and solvents)
- Ease of washing and sanitizing

- Resistance to staining from oils and/or coloring substances, which could be easily washed off
- Good friction co-efficient even in the presence of water (therefore intrinsically non-skid surfaces)

Cold Technology

Temperature control in every working phase was, as has been stated, one of the cornerstones of the winery, though at the time in Italy it was a rare phenomenon, even controversial and rarely used. It was decided to control the temperature for reds as well as whites, controlling also the phases of vinification and storage of the wine in tanks or wine being aged in casks and barriques, and even for bottled wine waiting for labeling or shipment. The use of cold comes in many different forms:

- With direct expansion or with secondary fluid, with the product moving through tubular ex- changers or plates
- With a still product, in refrigerated tanks and isolated or in refrigerated rooms

After the initial resistance, the chain of cold, over the course of the years, has been uniformly accepted, and its application has become even more diffused:

- Temperature-controlled fermentation
- Refrigeration of white musts post-pressing
- Refrigeration of crushed grape
- Refrigeration in the winery of whole grapes with carbonic snow or with an initial period in refrigerated rooms
- Refrigeration directly in the vineyard upon harvest, with carbonic snow or in refrigerated containers
- Night harvest

Evolution

In this chapter graphs are used to show the passage from the first designs made in 1979/1980 to the first pieces of the winery constructed in 1982/1983, the year of the first harvest.
The evolution is well documented in these tables, with numbers testifying to the concrete efforts made by Banfi over the years in the pursuit of excellence in winemaking. Examination of these charts shows certain figures that demonstrate these efforts better than anything else:

1. Vinification capacity for red wines goes from a 7.3% share of the total capacity in 1984 to a 16.7% share in 2003;
2. The average capacity of stainless steel tanks goes from 515 to 283 HL / 11.300 to 6.230 gallons;
3. The use of casks or barriques as a percentage of total production grows from 15.5% to 21.5% after a low of 13% in 1986;
4. The use of barriques as a percentage of total wood aging jumps from 16.2% to 63.7%.

All of this goes to prove the following:

1. The growing importance of red wines;
2. The passage from mass production to diversified micro-vinification with dedicated treatment of individual crus;
3. The growing importance of aged red wines;

4. The passage from oak casks, seen principally as containers, to barriques, viewed foremost as a means of conserving and exalting the inherent qualities of the grape.

Not Just for Aging

In these years the work with oak was so great that it gradually took a 360° turnabout. In addition to the use of oak in aging wines, for the first time we dusted off – not without some skepticism – the old conical wood tanks for fermentation of red grapes. After some trials, using a single wood 50 HL / 1.300 gallon tank (2001/2002/2003), results were interesting enough from a quality point of view, but very discouraging in terms of functionality. We decided, together with our regular suppliers, to try out two modified wood fermenters. A wood fermenter was used bearing a traditional base and an opening that measured about half of the diameter of the base itself. On this opening, we used a flange to attach a base of stainless steel, equipped with a discharge slide and rotating paddle for extraction of wet pomace. A second fermenter was made using a full base of stainless steel similar in function to the previous one.
In this case the traditional upright fermenter using wood for both vertical staves and a base was revolutionized, coupling the wood staves with a stainless steel base (we patented this system in various forms). The qualitative results were even more positive and thus, as throughout our history, we were able to obtain appreciably better results with the same grapes. But managing fermentation remained a complex matter, with the only improvement being the ease of unloading the wet pomace.
Pumping over was difficult, but the greatest challenge was in controlling the temperature profile. The operations of pumping over and/or punching down the cap presented several hygiene problems relating to soiling the ceiling of the tank. This inconvenience is closely tied to the dimensions of these vats and makes the cleaning operations particularly difficult and hardly efficient.
We further modified these tanks throughout the year, when they took on the function of aging, and therefore needed to rest in an environment with controlled humidity and temperature, the classic 18°C / 64°F and 70%-80% relative humidity. These conditions, in our case, and more, are present in our vinification area. Besides the convenience, using the wood fermenters also for aging had another motive as well; it is commonly recommended to not keep them empty, so as to avoid the formation of mold and the growth of any yeast, bacteria, etc. Reflecting on all of this and having dismissed doubts about the coupling of stainless steel and wood, we thought to take a decisive leap forward.
To the body of the fermentation tank, made up of a wall of wooden staves in a conical trunk, we added a stainless steel base and cap completely equipped. We also sought to resolve the problem of the need to periodically renew the staves, which, most experts agree, should be changed every 4 to 5 years. The stainless steel portion of the tank, of course, is nearly eternal, only likely to be replaced if it became technologically obsolete. We devised a robust flanged ring of stainless steel to bond the stainless steel head and base to the wood body; to replace the wood staves, all that is required is to unfasten the bolds holding the large flange in place.

What evolved is a composite fermenter that has a lower part that is essentially a large stainless steel bowl that mainly contains the following:

- The automatic pumping over system
- A refrigeration line
- A heating line
- A guillotine type door for the removal of wet pomace
- A rotating palate extractor- All accessories including a large faucet, sounding lines, and tasting spigot

- The control and command panel

Above that sits the hollow trunk of oak, free of any accessories.
On top of the trunk, attached with this same flanged ring, the closed cap is furnished with the following:

- Refrigeration line
- Top sprinkler for the must cap
- Bottom sprinkler for the must cap
- Expansion tank
- A laminated stainless steel skirt to block liquid and/or pomace from being trapped in the circular crown between the oak staves and the steel cap

The stainless steel cap allows the staves to be used completely during fermentation. Traditional wood fermenters are widely known to hold crushed grapes up to only about eighty percent of their capacity, which is why they are hardly used in fermentation any more. With the composite tank, the free space runs into the area of the stainless steel cap; the refrigeration line is not used during initial fermentation but comes in quite handy during the aging period. The trials undertaken in the 2005 vintage confirmed our expectations in terms of quality, and exceeded them in terms of any reservations we had about functionality. In fact, our tests yielded positive results not only for the traditional fermentation of red wines, but also for whites, though not discounting certain functional differences compared to the best fermentation tanks made completely of stainless steel.