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Understanding the Effect of Barrel-to-Barrel Variation on Color and Phenolic Composition of a Red Wine

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Aging in oak barrels is a traditional and widespread practice in winemaking worldwide. Alternative containers, such as stainless steel tanks, concrete vessels, or polyethylene tanks, surpass barrels in some respects, like price, hygiene and material homogeneity. Nevertheless, barrels are still firmly established in quality wine production due to their positive influence on the organoleptic quality and complexity of wine.[1,2.]

Various phenomena related to physical and chemical characteristics of the oak are directly responsible for these effects. First, there is water and ethanol non-negligible evaporation due to the porosity of the wood,[3] as well as some wine absorption by the wood (especially in new barrels).

Second, there is the transfer of extractable compounds, such as ellagitannins and volatile substances, like guaiacol, eugenol, ethyl- and vinyl-phenols, as well as oak lactones (ß-methyl-y-octalactone) and furfural (-derivates).[4] The total amount, though, is limited and quickly reduced by the extraction process into wine.[5] The extracted substances influence sensations, such as astringency and mouthfeel, and increase aroma intensity and complexity.

Third, moderate oxygen permeation and diffusion, through the wood, promote different reactions of oxidation, polymerization, co-pigmentation and condensation, involving anthocyanins and proanthocyanins, which stabilize the color and reduce astringency. Storage in barrels accelerates the natural sedimentation of unstable colloidal matter, thus contributing to wine stability and limpidity.[2]

Barrels are made from a natural product, wood. The most commonly used species are: *Quercus petraea* (sessiliflora oak), *Quercus robur* (pedunculated oak) and their hybrids, and *Quercus alba* (white American oak). Locally, alternative botanical species, other than oak, may also be used.[6]

Wood composition and the production process underlie a variation.[7] The main influencing factors are the oak species and origin of wood,[8] the seasoning and its location,[9] and the toasting process in the cooperage.[5]

Barrels influence wine phenolic composition and color development during aging. For this reason, phenolic compounds are likely to be affected by barrel-to-barrel variation. This variation is widely known to winemakers, resulting in tastings and analytical control of individual barrels. Despite these facts, there is little to be found regarding barrel-to-barrel variation in the literature.

Variation of barrel influence can be problematic for analyses of barrel lots as it bears the potential of misinterpretation of results. This study aimed to shed light on the variable influence of barrels on wine color, pigments and phenolic composition of wood-aged wine. This trial stands out due to its practical background with a wine produced at winery scale. The large number of 49 barrel samples from four cooperages resulted in robust results (**FIGURE 1**).

Effect of Cooperage on Barrel-to-Barrel Variation

The Principal Component Analysis (**FIGURE 2**) revealed overlapping areas for all cooperages. It's therefore consistent that no significant differences were found between the cooperages A, C and D for almost all analyzed parameters. However, cooperage B revealed for some analytical parameters significant differences between just one or two of the other cooperages but also, in a few cases, to all other cooperages.[1] Why cooperage B showed slightly different characteristics might originate in a smaller oxygen uptake through the wood and rifts between the staves.[9] Hence, this might be related to the cooperage's production techniques and oak wood selection. To conclude, the wine aged for 12 months in different barrels varied in its phenolic and chromatic characteristics, but the cooperage of an individual barrel could not explain these variations.

Furthermore, it was checked if the cooperage had an influence on the barrel-to-barrel variation by comparing the average coefficient of variation to the barrel-to-barrel variation of each cooperage.

The standard deviation ranged from 0.5 percent for general physical-chemical parameters, over 1.2 percent for most phenolic parameters, to 3.1 percent for pigments and 7.9 percent for anthocyanin-related parameters.[1] Due to the small standard deviations, it can be concluded that the cooperages do not differentiate from each other with practical relevance in their internal variation for most parameters analyzed in this trial, with the exception of pigments and especially anthocyanin-related parameters.

Effect of Barrel on Barrel-to-Barrel Variation

Chemical characteristics analyzed in this experiment showed individual barrel-to-barrel variation with a range from 0.01 percent to 37.2 percent. General


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FIGURE 1: Schematic Representation of the Aging Assay[1]

1.

Harvest
of Touriga Franca (*Vitis vinifera* L.), PDO Douro, Portugal, 2017 vintage

2.

Conventional red winemaking
at industrial scale
(28 °C alcoholic fermentation; spontaneous malolactic fermentation)

Initial wine characteristics:

- alcoholic strength: 13.3% vol.
- total dry matter: 27.3 g/L
- total acidity: 5.5 g/L (tartaric acid)
- volatile acidity: 0.57 g/L (acetic acid)
- pH: 3.78

3.

Barrel filling
49 new barrels, 4 cooperages *(Quercus petraea)*, medium toasting

4.

12 months of aging
T.: 15 - 18°C
Humidity 75 - 85%

SO_2 corrections were carried out periodically in order to keep a free SO_2 level of 40 mg/L, combined with topping up the barrels with wine of the same batch stored in a stainless steel tank.

5.

Sampling
51 samples

6.

Chemical analysis

- General physical and chemical analysis (FTIR)
- Chromatic characteristics (CIELab parameters: H*, L *, C*, a* and b*)
- Anthocyanin-related parameters
- Total phenols
- Flavonoids and non-flavonoids phenols
- Tanning power
- Copigmentation
- Flavanol monomers, oligomeric proanthocyanidins and polymeric proanthocyanidins

7.

Statistical analysis

Principal components analysis (PCA) Variance analysis (ANOVA)	Investigates the relationships between barrels and assesses cooperage and individual barrel effect.
Coefficient of variation (CV)	Shows the degree of variability in relation to the population average. Identifies the variation from barrel to barrel and in between the cooperages.
Required barrel samples	Can be seen as a translation of the observed variation of a parameter into a number of samples of a barrel lot needed to retain results of a certain reliability.

vs.

If the notion of “sustainability” has crossed your mind lately, consider this fact: The typical mature French oak tree will yield about 7 traditional barrels. The very same tree will yield about 500 barrels worth of StaVin barrel alternatives. Our various time-perfected infusion systems are just as meticulously resourceful as how Sioux hunters once harvested their buffalo, with absolutely nothing at all going to waste. And that includes a whopping savings of 94% in operating costs.

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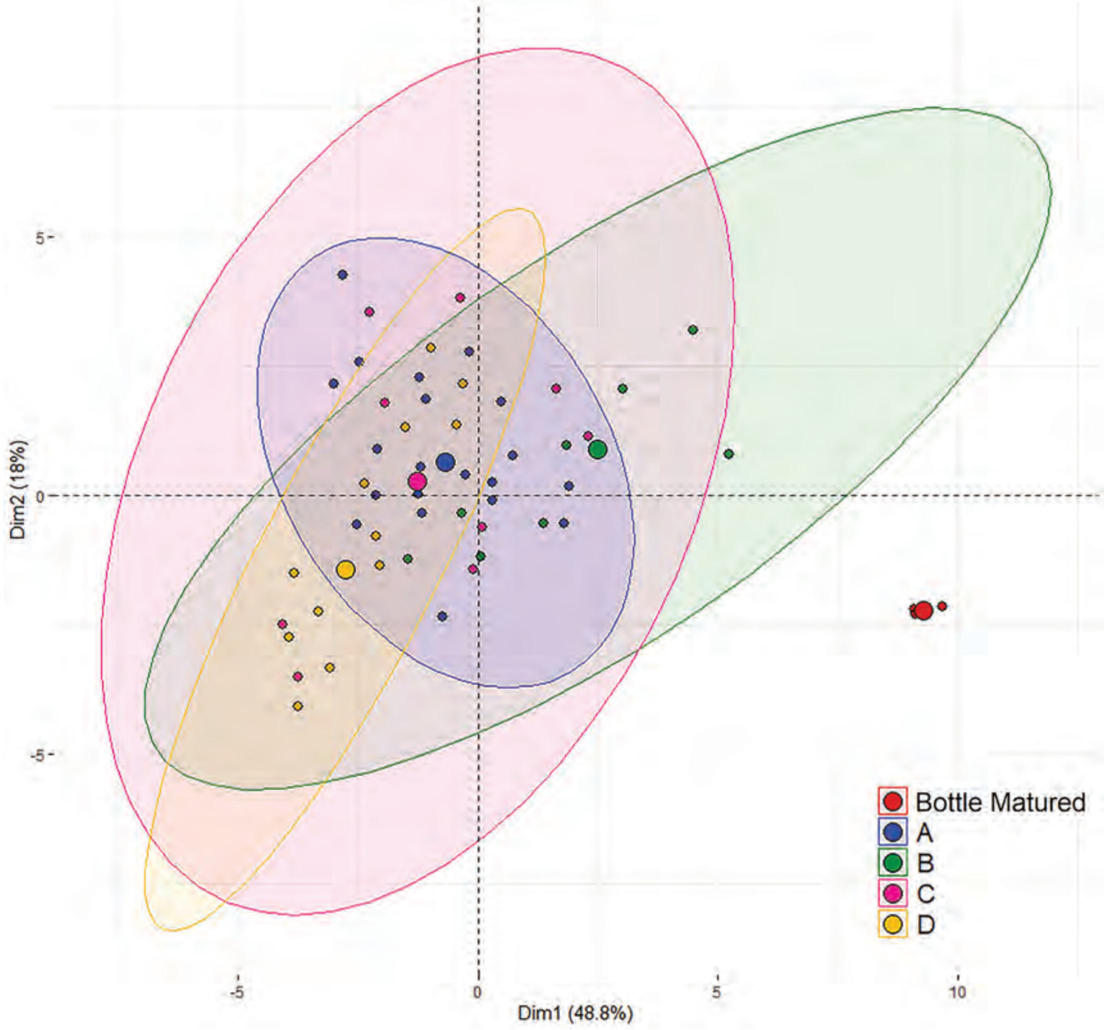

FIGURE 2: Principal Component Analysis performed on wines aged in oak barrels from the cooperages A, B, C and D and bottle-matured wine in a total of 50 wines. The wines are represented in the plane of the two first components which express, respectively, 49 percent and 18 percent of the total variation.

physical-chemical parameters showed the lowest barrel-to-barrel variation in the trial (always less than 2 percent).

Exceptions were volatile acidity and residual sugar; however, this variation is likely to originate in different microbiological activity and is not necessarily linked to influence of the barrel. It can be concluded that the effect of barrel aging on general characteristics, like density, alcoholic strength or total dry matter, is either small or similar, with less than the individual barrels.[2]

The same is true for chromatic characteristics to a certain degree. On the other hand, the change from blue to yellow notes was prone to a higher variation, which is likely related to the variation found for anthocyanins. The observed variation for total pigments and polymerization index led to the conclusion that polymerization reactions are probably influenced by the barrel, most likely by a variance in the permeation of oxygen.

In summary, these findings indicate that the effect of barrel-to-barrel variation on chemical parameters of a red wine depends on each specific parameter and is not uniform. Especially anthocyanin content shows high variation between barrels in general and is, to a lesser degree, impacted by a cooperage.[1]

Barrel Sample Requirements

Upon analyzing a barrel lot filled with the same initial wine, one can ask, "How many barrels need to be analyzed to get reliable results representative for all the wine in the different barrels if hypothetically racked and joined together in a big tank?"

The characteristics of this hypothetically racked wine from all the barrels is referred to as the "true barrel lot mean."

Reliable results are a point of discussion as not every situation requires the same exactness of results. More analyses usually translate to increased accuracy but require more resources too. Therefore, in practical circumstances, a compromise is often necessary. To be able to make this decision, it is beneficial to know the link between the analytical parameter in focus, the necessary number of barrel samples and the resulting accuracy of results. The analytical parameter to be analyzed plays a critical role as variation from barrel-to-barrel changes with different parameters, and the greater the variation, the more samples of a batch are needed to determine, in their average, the true barrel lot mean.

To investigate this link, a backwards calculation based on the high number of samples of this trial was conducted. The calculation requires a predefined desired precision for the results, which has been set at 2 percent, 5 percent, 10 percent, 15 percent and 20 percent.[1] For better understanding, a precision of 10 percent, for example, means all results will be inside a range of 5 percent above and 5 percent below the true barrel lot mean.

The results revealed that all phenolic and chromatic characteristics, except for the tannin fractions analysis and anthocyanin-related parameters, which can be analyzed with only two barrel samples per barrel lot at 20 percent accuracy. When increasing the exactness, more analytical parameters require larger sample numbers per barrel lot. At a 10-percent range around the true barrel lot mean, several analytical parameters require more than two barrels per lot, for example, total pigments and polymerization index. At a 5-percent range around the true barrel lot mean, only clarity, tonality and color due to copigmentation, as well as most physical-chemical parameters, can be analyzed with up to two barrels per lot.

General physical-chemical parameters required the smallest samples due to low barrel-to-barrel variation. To achieve reliable results (5 percent around the true barrel lot mean) for the analysis of general wine characteristics and wine color, in most cases between one to three barrels per barrel lot are sufficient. Analytical parameters influenced by wine maturation, such as formation of polymeric pigments, polymerization of phenolics and especially anthocyanin-related parameters, require more samples per barrel lot; otherwise, a reduction in the accuracy of the results needs to be accepted.

Limits of the Study

This experiment included only new barrels with the same toasting while for barrel lots of different age and toasting levels, a qualified statement cannot be made. The calculated number of barrel samples needed to analyze volatile acidity and residual sugar in a barrel lot should be taken with care because these parameters are influenced not only by the barrel but by many other factors. Therefore, in practical circumstances, analyses of these two parameters might need different barrel sample amounts.

Chemical Parameters Differ in Their Variation

It could be shown that the influence of the individual barrel on barrel-to-barrel variation in wine phenolics and pigments was greater than the influence of the manufacturing cooperage. Chemical parameters analyzed in this study were prone to barrel-to-barrel variation at individual levels, overall ranging from almost 0 up to 37 percent. Especially parameters related to anthocyanins were found to have a high barrel-to-barrel variation.

Barrel-to-barrel variation of a chemical parameter influences the required sample size needed per analyzed batch. Detailed recommendations on the required sample size for certain chemical parameters at different levels of accuracy were calculated and can be used as an aid to generate measurements involving barrel lots. **WBM**

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