THE IMPACT OF DIFFERENT PACKAGING AND STORAGE TIME ON PHYSICOCHEMICAL PROPERTIES AND COLOR OF RED WINES

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INTRODUCTION

Packaging of wine is an important factor for wine quality evolution. Usually wine is packed in glass containers but in recent years PET containers (polyethylene terephthalate) have become an option for packaging. They can be produced as single-layer or multi-layer containers (Ghidossi et al., 2012). Other packagings of wine include bag-in-box or multilayer packaging. Bag-in-box packaging consists of a bag (single or multilayer) and an outer box or a container (Robertson, 1993). A multilayer packaging consists of several layers, usually plastic, aluminum foil and paper. One of the main characteristics of packaging that affects the quality of wine is the transfer of gases through the packaging material (Ghidossi et al., 2012). Gases can permeate through the packaging material or the closure and affect the wine characteristics (Lopes et al., 2009; Dimkou et al., 2011; Hofer et al., 2012; Toussaint et al., 2014).

Storage time also affects wine evolution and quality. For example, the storage time affects the evolution of phenolic compounds (Monagas et al., 2005), oxygen amount dissolved in wine, SO₂ amount (Dimkou et al., 2011; Ghidossi et al., 2012; Gambuti et al., 2013; Toussaint et al., 2014), sensory characteristics and color (Skouroumounis et al., 2005; Caillé et al., 2010). One of the main parameters that connects the influence of packaging type and storage time on wine evolution is the oxygen content in wine. Namely, oxygen can be present in wine as dissolved oxygen or in the headspace of the packaging container but it can also permeate into the package through the packaging material or the closure. Once inside the package (in the wine), oxygen can cause an oxidation reaction that affects SO₂ decrease in wine (Dimkou et al., 2011; Ghidossi et al., 2012), phenolic compound evolution (Gambuti et al., 2013), and color change or other sensory property changes (Skouroumounis et al., 2005; Lopes et al. 2009; Caillé et al., 2010; Dimkou et al., 2011; Ghidossi et al., 2012). All of these changes are time dependent. Therefore, packaging and storage time are important factors controlling the O₂ amount after bottling, and consequently the wine quality evolution. Furthermore, the influence of oxygen on the quality of wine can depend on the storage temperature. Wine is usually stored in wine cellars at 10 to 14 °C. But in stores, the storage temperature can be higher. The conditions of temperature can also influence the amount of oxygen in the wine and by that the changes in wine during storage. The influence of oxygen on the wine quality and the influence of packaging and storage time are still not completely understood.

The aim of this work was to study the influence of packaging (glass bottles, PET bottles and multilayer containers), and storage (0, 3, 6, 9 and 12 months, room temperature 25 °C) on wine characteristics (wine specific weight, distillate specific weight, alcohol percentage, total dry extract, total acids, volatile acids, free and total SO₂ and color. The study was conducted on four red wines (Cabernet Sauvignon, Frankovka, Merlot, and Pinot noir). Oxygen was measured during the whole storage period.

MATERIAL AND METHODS

Samples

Grapes from Vitis vinifera L. (Cabernet sauvignon, Frankovka, Merlot and Pinot noir) were cultivated in a vineyard in Baranja County, Croatia. After producing the wine from a 2018 vintage in a winery, wines were packed in glass bottles (Versus, PP neck - Vetropack, Croatia), polyethylene terephthalate bottles (PCO 28, transparent - Keples, Croatia) and multilayer packaging (multilayer paperboard with metallocone PE resin and aluminium foil (> 99 % aluminium) - SIG Combibloc, Switzerland). The volume was 0.5 L for all packages. Wine was stored at a controlled room temperature 25 °C, and analyzed at the time of packaging and after 3, 6, 9 and 12 months of storage. At each time period, new packages were opened for the analysis.

Physico-chemical properties

All analyses of the physico-chemical properties of wine were performed according to standard procedures of the International Organization of Vine and Wine (OIV, 2019). Alcohol in wine was determined by using OIV-MA-AS312-01B. Total acidity (as tartaric acid) was determined by the neutralization method with 0.1 M NaOH and a bromothymol blue as an indicator. Volatile acids were determined by using OIV-MA-AS313-02. Specific weights were determined by using OIV-MA-AS2-01A. Free and total sulfur dioxide in wine were determined by using the iodometric method by Ripper. Total dry extract was determined by using OIV-MA-AS3-03B. These methods were already described earlier (Kojić and Jakobek, 2019).

Dissolved oxygen measurement

Determination of dissolved oxygen was carried out using an oximeter (AL200XY, Aqualytic, Germany). The wine was poured into a laboratory glass, placed on a magnetic stirrer and mixed. The oximeter electrode was calibrated according to the oxygen content of the air. Electrode was then, immersed into the wine and the dissolved oxygen amount (mg/L) was measured.
Color measurement

Measurements were carried out on a UV-VIS spectrophotometer (Perkin Elmer, Lambda 2, Germany) in a 1 cm thick quartz cuvette versus distilled water as a blank. Using absorbance values at 420, 520 and 620 nm, five chromatic parameters were calculated according to the Glories method (Glories, 1984). These parameters were color intensity (CI), hue (H), percentage of yellow (Yellow %), percentage of red (Red %), and percentage of blue (Blue %). These five chromatic parameters were calculated according to CI = (Abs420 + Abs620) / 2, H = Abs420/Abs520, Yellow% = (Abs420/Ci) x 100%, Red% = (Abs520/Ci) x 100%, and Blue% = (Abs620/Ci) x 100%.

Statistical analyses

All results for the physico-chemical parameters and color were analyzed with multiple regression with main effects and two variable interactions using MINITAB software (MINITAB LLC., State College, PA, USA). The three variables from which regression terms were constructed are type of packaging, time of storage, and type of wine. Contrasts in the variables were defined for the regression to facilitate comparisons, and were typically arranged to be orthogonal contrasts to facilitate the identification of the subset of strongly significant terms (p < 0.01). Some three variable interactions were introduced when called for by residual analysis, so that no residuals had standardized values larger than 3. The purpose was to find statistically significant differences between wine characteristics and to create a model with fitted values and standard errors (SE) for each wine characteristic measurement.

RESULTS AND DISCUSSION

The changes in the chemical composition of wine depend on the storage time but also on the packaging material. Because of such changes in the first several months, wines are often packed and stored for a time period of approximately one year (Hopfer et al., 2012). Various wine characteristics may quantify these changes across time, including numerous physicochemical parameters like alcohol percentage, specific weight of wine and distillate, amounts of acids or SO₂, and color of wine. In this study four different wines were packed in three different packaging materials during one year and physicochemical parameters were analysed every three months to see the changes in those changes during time and the possible influence of packaging material on those changes. The results for the physicochemical properties of analyzed wines (Cabernet sauvignon, Frankovka, Merlot, Pinot noir) during storage time of 3, 6, 9 and 12 months were shown in Table 1 and figures 1 to 4. The values for specific wine weight (0.99310 – 0.99500), specific distillate weight (0.98000 – 0.98375), alcohol percentage (12.59 – 15.66), total dry extract (28.7 – 36.7 g/L), total acids (4.94 – 6.75 g/L), volatile acids (0.43 – 0.76 g/L), free SO₂ (7.9 – 41 mg/L) and total SO₂ (13.0 – 102 mg/L) were in accordance with data from literature (Dimkou et al., 2011; Ghidossi et al., 2012; Hopfer et al., 2012) and with our earlier study (Kojić and Jakobek, 2019).

| Time (months) | Glass | PET | Multilayer | Glass | PET | Multilayer | Glass | PET | Multilayer |
|---------------|-------|-----|------------|-------|-----|------------|-------|-----|------------|
| 0             | 0.99410 | 0.99410 | 0.99435 | 0.99435 | 0.99440 | 0.99460 | 0.99460 | 0.99375 | 0.99375 |
| 3             | 0.99415 | 0.99410 | 0.99430 | 0.99410 | 0.99430 | 0.99480 | 0.99440 | 0.99445 | 0.99355 |
| 6             | 0.99430 | 0.99425 | 0.99425 | 0.99405 | 0.99500 | 0.99470 | 0.99395 | 0.99310 | 0.99390 |
| 9             | 0.99425 | 0.99420 | 0.99465 | 0.99420 | 0.99445 | 0.99430 | 0.99370 | 0.99335 | 0.99405 |
| 12            | 0.99410 | 0.99405 | 0.99490 | 0.99455 | 0.99450 | 0.99470 | 0.99355 | 0.99355 | 0.99435 |

| Time (months) | Glass | PET | Multilayer | Glass | PET | Multilayer | Glass | PET | Multilayer |
|---------------|-------|-----|------------|-------|-----|------------|-------|-----|------------|
| 0             | 0.98060 | 0.98060 | 0.98060 | 0.98300 | 0.98300 | 0.98140 | 0.98140 | 0.98165 | 0.98165 |
| 3             | 0.98055 | 0.98050 | 0.98040 | 0.98295 | 0.98275 | 0.98295 | 0.98120 | 0.98115 | 0.98155 |
| 6             | 0.98065 | 0.98020 | 0.98095 | 0.98280 | 0.98260 | 0.98375 | 0.98095 | 0.98065 | 0.98185 |
| 9             | 0.98060 | 0.98080 | 0.98010 | 0.98280 | 0.98240 | 0.98295 | 0.98060 | 0.98045 | 0.98140 |
| 12            | 0.98085 | 0.98000 | 0.98105 | 0.98345 | 0.98240 | 0.98300 | 0.98090 | 0.98030 | 0.98185 |

| Time (months) | Glass | PET | Multilayer | Glass | PET | Multilayer | Glass | PET | Multilayer |
|---------------|-------|-----|------------|-------|-----|------------|-------|-----|------------|
| 0             | 15.11 | 15.11 | 15.11 | 12.97 | 12.97 | 12.97 | 14.40 | 14.40 | 14.15 |
| 3             | 15.15 | 15.20 | 15.30 | 13.00 | 13.08 | 13.00 | 14.59 | 14.61 | 14.22 |
| 6             | 15.05 | 15.48 | 14.80 | 13.13 | 13.30 | 12.32 | 14.79 | 15.07 | 14.39 |
| 9             | 15.11 | 15.60 | 14.64 | 13.15 | 13.52 | 13.03 | 15.10 | 15.21 | 14.11 |
| 12            | 14.87 | 15.65 | 14.70 | 12.59 | 13.45 | 12.98 | 14.81 | 15.38 | 13.76 |

| Total dry extract (g/L) | 0 | 3.4 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0                       | 34.9 | 34.9 | 34.9 | 29.3 | 29.3 | 29.3 | 34.1 | 34.1 | 31.2 |
| 3                       | 35.1 | 35.1 | 35.1 | 28.9 | 29.3 | 29.3 | 35.1 | 34.2 | 31.0 |
| 6                       | 35.2 | 36.3 | 35.5 | 29.5 | 29.5 | 29.0 | 35.5 | 34.3 | 30.2 |
| 9                       | 35.2 | 36.7 | 35.5 | 29.3 | 29.7 | 29.7 | 35.4 | 34.2 | 31.1 |
| 12                      | 34.2 | 36.3 | 35.7 | 28.7 | 30.1 | 29.7 | 35.6 | 34.2 | 31.1 |

Some physicochemical parameters of wine, like specific weight of wine, specific weight of distillate, alcohol percentage and dry extract were fairly stable during the period of storage of one year in different packaging (Table 1). Nevertheless, with statistical regression analysis, some statistically significant differences in these characteristics with time became visible (Table S1). Namely, specific weight of wine showed statistically significant difference over time in wines packed in multilayer and PET packaging. Specific weight of distillate and alcohol percentage were significantly different in wines packed in PET and multilayer packaging. Percentage of dry extract was significantly different in multilayer packaging after 6 months of storage. According to these results, glass bottles can be suggested as a good packaging for wine comparing to multilayer and PET containers, since no significant differences were shown in specific weight of wine, specific weight of distillate, alcohol percentage and dry extract in wines packed in glass bottles. However, it should be mentioned that all of wine parameters showed small differences. So, even though the statistical analysis pointed to some differences in physico-chemical parameters in wines packed in different packaging, those differences are not big. After creating regression models with the selected significant terms, the fitted values of the measured characteristics and their standard errors were also determined and shown (Table 2). The amount of total and volatile acids in wines packed in different packaging during one year was similar (Figures 1 and 2). Again, with statistical regression analysis, some differences can be quantified (Table S1). Statistically significant differences were found for the change of volatile acid amount in time for wines packed in multilayer packaging (Table S1). Accordingly, it can be suggested that glass and PET packaging preserved total and volatile acids better than multilayer container. Fitted values of these parameters with their standard errors were shown in table 2.
Some differences can be seen in the free and total SO$_2$ amount in dependence with time (Figures 3 and 4). Namely, the free and total SO$_2$ were decreasing with time which is in accordance with earlier studies (Dimkou et al., 2011; Ghidossi et al., 2012). The central role played by SO$_2$ is the consumption of oxygen. The decrease of SO$_2$ concentration suggests that O$_2$ is consumed and by that decreases the amount of SO$_2$. Moreover, some differences in the free and total SO$_2$ amount can also be seen in wines packed in different packaging. In the case of free SO$_2$ (Figure 3), after three months of storage, wines packed in glass bottles contained the highest free SO$_2$ amount, except Pinot noir. After 12 months of storage, higher free SO$_2$ was found in wines packed in glass bottles (Cabernet sauvignon and Frankovka wine) or in PET bottles (Merlot, Pinot noir). In addition, free SO$_2$ was the lowest in wines packed in multilayer containers. In the case of total SO$_2$...
(Figure 4), after three months of storage wines packed in glass bottles had the highest SO₂ amount, and exception was again Pinot noir. After 12 months of storage, wines packed in glass and PET bottles had higher total SO₂ amount (Merlot and Pinot noir) than wines packed in multilayer container, or the amount was similar (Cabernet sauvignon and Frankovka wine). According to these results, it can be suggested that glass and PET packaging protected the wine a little bit better than the multilayer container, due to the higher amount of SO₂. Statistical regression conducted for free and total SO₂ (Table S1) confirmed the suggested differences. Namely, the differences in the change of free SO₂ and total SO₂ amount over time were shown to be statistically significant. Moreover, statistically significant differences were found in the changes of free and total SO₂ amount in wines packed in different containers. Higher amount of free SO₂ in the wine packed in glass after 3 months of storage was statistically significant. Statistically significant differences were shown for the total SO₂ amount in wines in glass and PET containers while lower total SO₂ amount in wines in multilayer packaging were significant. The statistical analysis confirmed the observed differences in wines packed in different packaging materials. Fitted values of free and total SO₂ with their standard errors are shown in table 2.

![Figure 3 Free SO₂ amount during storage of 12 months at 25 °C](image)

![Figure 4 Total SO₂ amount during storage of 12 months at 25 °C](image)
| Time (months) | Cabernet sauvignon | Petroit | Francovka | Merlot | Pinot noir |
|--------------|---------------------|---------|-----------|--------|-----------|
|              | Specific weight of wine | | | | |
| 0 | 0.994228 | 0.994228 | 0.994228 | 0.994228 | 0.994228 |
| 1 | 0.994228 | 0.994228 | 0.994228 | 0.994228 | 0.994228 |
| 3 | 0.994228 | 0.994228 | 0.994228 | 0.994228 | 0.994228 |
| 5 | 0.994228 | 0.994228 | 0.994228 | 0.994228 | 0.994228 |
| 10 | 0.994228 | 0.994228 | 0.994228 | 0.994228 | 0.994228 |
| 12 | 0.994228 | 0.994228 | 0.994228 | 0.994228 | 0.994228 |
|              | Specific weight of distillate | | | | |
| 0 | 0.980577 | 0.980577 | 0.982020 | 0.982020 | 0.982020 |
| 1 | 0.980577 | 0.980577 | 0.982020 | 0.982020 | 0.982020 |
| 3 | 0.980577 | 0.980577 | 0.982020 | 0.982020 | 0.982020 |
| 5 | 0.980577 | 0.980577 | 0.982020 | 0.982020 | 0.982020 |
| 10 | 0.980577 | 0.980577 | 0.982020 | 0.982020 | 0.982020 |
| 12 | 0.980577 | 0.980577 | 0.982020 | 0.982020 | 0.982020 |
|              | Total dry extract (g/L) | | | | |
| 0 | 35.427 | 35.427 | 29.427 | 29.427 | 29.427 |
| 1 | 35.427 | 35.427 | 29.427 | 29.427 | 29.427 |
| 3 | 35.427 | 35.427 | 29.427 | 29.427 | 29.427 |
| 5 | 35.427 | 35.427 | 29.427 | 29.427 | 29.427 |
| 10 | 35.427 | 35.427 | 29.427 | 29.427 | 29.427 |
| 12 | 35.427 | 35.427 | 29.427 | 29.427 | 29.427 |
|              | Total acid (g/L) | | | | |
| 0 | 5.7937 | 5.7937 | 6.4121 | 6.4121 | 5.7574 |
| 1 | 5.7937 | 5.7937 | 6.4121 | 6.4121 | 5.7574 |
| 3 | 5.7937 | 5.7937 | 6.4121 | 6.4121 | 5.7574 |
| 5 | 5.7937 | 5.7937 | 6.4121 | 6.4121 | 5.7574 |
| 10 | 5.7937 | 5.7937 | 6.4121 | 6.4121 | 5.7574 |
| 12 | 5.7937 | 5.7937 | 6.4121 | 6.4121 | 5.7574 |
|              | Volatile acid (g/L) | | | | |
| 0 | 0.6714 | 0.6714 | 0.4360 | 0.4360 | 0.5244 |
| 1 | 0.6714 | 0.6714 | 0.4360 | 0.4360 | 0.5244 |
| 3 | 0.6714 | 0.6714 | 0.4360 | 0.4360 | 0.5244 |
| 5 | 0.6714 | 0.6714 | 0.4360 | 0.4360 | 0.5244 |
| 10 | 0.6714 | 0.6714 | 0.4360 | 0.4360 | 0.5244 |
| 12 | 0.6714 | 0.6714 | 0.4360 | 0.4360 | 0.5244 |
|              | Free SO₂ (mg/L) | | | | |
| 0 | 33.18 | 33.18 | 40.64 | 40.64 | 40.64 |
| 1 | 33.18 | 33.18 | 40.64 | 40.64 | 40.64 |
| 3 | 33.18 | 33.18 | 40.64 | 40.64 | 40.64 |
| 5 | 33.18 | 33.18 | 40.64 | 40.64 | 40.64 |
| 10 | 33.18 | 33.18 | 40.64 | 40.64 | 40.64 |
| 12 | 33.18 | 33.18 | 40.64 | 40.64 | 40.64 |
|              | Total SO₂ (mg/L) | | | | |
| 0 | 78.30 | 78.30 | 58.50 | 58.50 | 58.50 |
| 1 | 78.30 | 78.30 | 58.50 | 58.50 | 58.50 |
| 3 | 78.30 | 78.30 | 58.50 | 58.50 | 58.50 |
| 5 | 78.30 | 78.30 | 58.50 | 58.50 | 58.50 |
| 10 | 78.30 | 78.30 | 58.50 | 58.50 | 58.50 |
| 12 | 78.30 | 78.30 | 58.50 | 58.50 | 58.50 |
|              | Oxygen (mg/L) | | | | |
| 0 | 9.016 | 9.016 | 8.501 | 8.501 | 8.501 |
| 1 | 9.016 | 9.016 | 8.501 | 8.501 | 8.501 |
| 3 | 9.016 | 9.016 | 8.501 | 8.501 | 8.501 |
| 5 | 9.016 | 9.016 | 8.501 | 8.501 | 8.501 |
| 10 | 9.016 | 9.016 | 8.501 | 8.501 | 8.501 |
| 12 | 9.016 | 9.016 | 8.501 | 8.501 | 8.501 |
The oxygen amount in wine was shown in figure 5. The amount of dissolved oxygen in wines (0.85 – 9.49 mg/L) was similar to amounts reported in the literature (Dimkou et al., 2011; Ghidossi et al., 2012). During storage, the oxygen amount was decreasing in all studied wines and packaging. This is in accordance with earlier studies (Vidal and Moutounet, 2006; Dimkou et al., 2011). This also agrees with the SO2 decrease shown in figure 3 and 4. Furthermore, oxygen decrease was mostly pronounced after 3 months of the storage, and after that period the changes in oxygen amounts were slower. This is in accordance with some other studies where it was stated that the decrease in oxygen amount was faster during the first months of storage (Dimkou et al., 2011; Vidal and Moutounet, 2011; Toussaint et al., 2014). This suggests that at the beginning of the storage period, most of the oxygen was consumed and the changes in wine were occurring. After that period, the oxygen consumption becomes lower. Further changes can depend mostly on the packaging material. If the oxygen permeates through the package, the oxygen amount will slowly increase and further changes in the wine will occur. In our study, further increase of oxygen amount was somewhat higher for wines packed in glass (Cabernet sauvignon and Pinot noir, which might be due to closure, and not the glass material), or it was similar for all packaging materials. After multiple regression (Table S1) the statistically significant difference in oxygen amount during the storage period of one year was shown. The analysis also confirmed the differences in the oxygen amount in wines packed in glass containers. Fitted values of oxygen amounts together with standard errors was shown in table 2.

Table 3 showed the color of wine, its intensity, hue, percentage of yellow, red and blue color. The color intensity and hue were increasing during storage in all packaging, the same as the yellow color percentage. But the percentage of red and blue color were decreasing. Statistical analysis with multiple regression (Table S1) confirms that those characteristics change with time. Namely, the increase in color intensity was statistically significant (only in Merlot packed in multilayer container, a decrease was shown). The increase of hue and yellow percentage with time in all packaging was also statistically significant (the biggest increase in these color parameters was shown for Merlot wine in multilayer containers). The decrease in red and blue percentage were also statistically significant. Fitted values of color parameters together with standard errors was showed in table 4.

Earlier studies also showed that the yellow color increases with storage (Lopes et al., 2009; Hopfer et al., 2012). The increase in hue and decrease in red color shown in our study was also shown in an earlier study (Lopes et al., 2009). Measuring A at 420 nm (yellow color) is a helpful tool for the determination of wine development and the degree of oxidation (Lopes et al., 2009). Namely, the increase in yellow color has been attributed to the formation of brown pigments from the polymerization of flavanols and dimeric cyanidins (Francia-Arrieta et al., 1998; Drinkine et al., 2007). Similar reactions might have occurred in wines in this study.

In general, oxygen is an important factor for the wine quality. It can be dissolved in the wine before bottling or it can come from the headspace of the container. During storage, the oxygen amount decreases, because oxygen is consumed through oxidation reactions by various compounds (Dimkou et al., 2011; Ghidossi et al., 2012). Oxidation processes can be seen through changes in wine, such as changes in the wine color or SO2 decrease. Namely, the products of oxidation reactions can cause SO2 decrease (Dimkou et al., 2011; Ghidossi et al., 2012). The oxygen and free and total SO2 decrease was shown in our study in all wines and packaging types, which suggests the oxidation processes occurred in wine during the storage period. Changes in wine color were also observed in our study (color intensity, hue and yellow color increase, red and blue color decrease) which also suggests that the oxidation reaction occurred in the wine during the storage.

There were some differences in physico-chemical parameters of wine packed in different packaging materials. Namely, statistically significant changes in specific weight of wine and distillate, percentage of alcohol and total dry extract were occurring in wines, the SO2 – Aricha weight of wine and distillate, percentage of alcohol and total dry extract were occurring. After that period, the oxygen consumption becomes lower. Further changes can depend mostly on the packaging material. If the oxygen permeates through the package, the oxygen amount will slowly increase and further changes in the wine will occur. In our study, further increase of oxygen amount was somewhat higher for wines packed in glass (Cabernet sauvignon and Pinot noir, which might be due to closure, and not the glass material), or it was similar for all packaging materials. After multiple regression (Table S1) the statistically significant difference in oxygen amount during the storage period of one year was shown. The analysis also confirmed the differences in the oxygen amount in wines packed in glass containers. Fitted values of oxygen amounts together with standard errors was shown in table 2.

![Figure 5 Oxygen concentration during storage of 12 months at 25 °C](image-url)
| Time (months) | Cabernet sauvignon Glass | Cabernet sauvignon PET | Cabernet sauvignon Multiayer | Francovka Glass | Francovka PET | Francovka Multiayer | Merlot Glass | Merlot PET | Merlot Multiayer | Pinot noir Glass | Pinot noir PET | Pinot noir Multiayer | Color intensity (CI) | Hue (H) | Yellow % | Red % | Blue % |
|--------------|---------------------------|------------------------|-----------------------------|----------------|---------------|------------------|-------------|-------------|------------------|----------------|---------------|------------------|---------------------|---------|---------|--------|--------|
| 0            | 7.612                     | 7.612                   | 7.612                       | 6.109          | 6.109          | 6.109             | 7.612       | 7.612       | 7.612             | 6.109          | 6.109         | 6.109             | 7.612               | 7.612   |
| 3            | 9.035                     | 9.035                   | 9.035                       | 7.533          | 7.533          | 7.533             | 9.035       | 9.035       | 9.035             | 7.533          | 7.533         | 7.533             | 9.035               | 9.035  |
| 6            | 9.035                     | 9.035                   | 9.035                       | 7.533          | 7.533          | 7.533             | 9.035       | 9.035       | 9.035             | 7.533          | 7.533         | 7.533             | 9.035               | 9.035  |
| 9            | 9.035                     | 9.035                   | 9.035                       | 7.533          | 7.533          | 7.533             | 9.035       | 9.035       | 9.035             | 7.533          | 7.533         | 7.533             | 9.035               | 9.035  |
| 12           | 9.035                     | 9.035                   | 9.035                       | 7.533          | 7.533          | 7.533             | 9.035       | 9.035       | 9.035             | 7.533          | 7.533         | 7.533             | 9.035               | 9.035  |

Table 3. Color of wine during storage of 12 months at 25 °C.
The results showed that the physicochemical properties of wine are influenced by the storage time and packaging material. Namely, some small changes with time in specific weight of wine and distillate, alcohol percentage and dry extract were shown. On the other hand, the concentration of sulfur dioxide and oxygen decreased significantly over storage time. The color also showed statistically significant change with storage time (the color intensity, hue and yellow percentage showed an increased with storage period, blue and red color, on the other hand, decreased). This suggests the oxidation processes occurred in wine during the storage period. Changes in wine parameters with packaging type were also shown. The specific weight of wine and distillate, alcohol percentage, and total dry extract showed small changes in wines packed in PET and multilayer containers but not in glass bottles. The SO2 amount decrease was lower in wines packed in PET and Glass multilayer packaging.

Acknowledgements: Authors are very grateful to Kolar family cellars and winery Pinkert for giving wine samples for examination. We would also like to thank to prof. Andrew R. Baron (Yale University, USA) for his help in statistical analysis of the data.

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Table S1 The results of the multiple regression with the selected strongly significant \((p < 0.001)\) main effects and interactions for all physico-chemical parameters and color in wine

| Term | Coefficient | Standard error of coefficient | P-Value |
|------|-------------|-------------------------------|---------|
| **PHYSICO-CHEMICAL PROPERTIES OF WINE** | | | |
| Constant | 0.994228 | 0.000035 | 0.000 |
| Merlot vs Pinot noir | 0.000925 | 0.000092 | 0.000 |
| multilayer vs time | 0.000049 | 0.000008 | 0.000 |
| PET vs time | -0.000029 | 0.000007 | 0.000 |
| Merlot vs time | -0.000042 | 0.000011 | 0.000 |
| Merlot : multilayer : time at least 6 months | -0.001384 | 0.000148 | 0.000 |
| **Specific weight of wine** | | | |
| Constant | 0.981557 | 0.000024 | 0.000 |
| multilayer vs PET | 0.000526 | 0.000060 | 0.000 |
| Cabernet vs others | -0.001307 | 0.000056 | 0.000 |
| Frankovka vs Merlot and Pinot noir | 0.001554 | 0.000059 | 0.000 |
| multilayer vs PET : time 0 months vs others | -0.000658 | 0.000148 | 0.000 |
| multilayer vs PET : time 3 months vs larger | -0.000810 | 0.0000153 | 0.000 |
| Merlot vs Pinot noir : time 0 months vs others | -0.000087 | 0.000010 | 0.000 |
| Merlot : multilayer : time 12 months | 0.000778 | 0.000204 | 0.000 |
| **Specific weight of distillate** | | | |
| Constant | 14.2344 | 0.0217 | 0.000 |
| multilayer vs PET | -0.4587 | 0.0534 | 0.000 |
| Cabernet vs others | 1.1759 | 0.0498 | 0.000 |
| Frankovka vs Merlot and Pinot noir | -1.3782 | 0.0530 | 0.000 |
| multilayer vs PET : time 0 months vs others | 0.573 | 0.132 | 0.000 |
| multilayer vs PET : time 3 months vs larger | 0.745 | 0.137 | 0.000 |
| Merlot vs Pinot noir : time 0 months vs others | 0.07942 | 0.00870 | 0.000 |
| Merlot : multilayer : time 12 months | -0.746 | 0.182 | 0.000 |
| **Total dry extract (g/L)** | | | |
| Constant | 32.6671 | 0.0681 | 0.000 |
| Merlot vs Pinot noir | 3.335 | 0.198 | 0.000 |
| Cabernet vs others | 3.679 | 0.154 | 0.000 |
| Frankovka vs Merlot and Pinot noir | -3.481 | 0.165 | 0.000 |
| Merlot : multilayer : time at least 6 months | -4.508 | 0.331 | 0.000 |
| **Total acid (g/L)** | | | |
| Constant | 5.7937 | 0.0212 | 0.000 |
| Frankovka vs Merlot and Pinot noir | 0.9277 | 0.0519 | 0.000 |
| Merlot vs Pinot noir | 0.582 | 0.0599 | 0.000 |
| **Volatile acid (g/L)** | | | |
| Constant | 0.53906 | 0.00799 | 0.000 |
| Cabernet vs others | 0.1765 | 0.01550 | 0.000 |
| Frankovka vs Merlot and Pinot noir | -0.0884 | 0.02340 | 0.000 |
| Frankovka vs time | 0.01101 | 0.00297 | 0.000 |
| Multilayer : time | 0.0063 | 0.00168 | 0.000 |
| **Free SO2 (mg/L)** | | | |
| Constant | 16.872 | 0.372 | 0.000 |
| Merlot vs Pinot noir | -5.71 | 1.04 | 0.000 |
| time 0 months vs others | 20.379 | 0.925 | 0.000 |
| Frankovka vs Merlot and Pinot noir : time 0 months vs larger | 14.01 | 2.27 | 0.000 |
| **Total SO2 (mg/L)** | | | |
| Constant | 14.67 | 2.91 | 0.000 |
| **Oxygen (mg/L)** | | | |
| Constant | 3.3203 | 0.0679 | 0.000 |
| time 0 months vs others | 6.690 | 0.196 | 0.000 |
| glass vs others | 0.516 | 0.144 | 0.001 |
| Merlot vs Pinot noir | -0.843 | 0.192 | 0.000 |
| Merlot : time 0 months vs others | -2.162 | 0.392 | 0.000 |
### COLOR OF WINE

|                          | Color intensity (CI) |
|--------------------------|----------------------|
| Constant                 | 7.624                |
| Cabernet vs others       | 1.502                |
| Merlot vs Pinot noir     | 3.082                |
| Time 0 months vs others  | -1.424               |
| Merlot vs Pinot noir : multilayer | -3.558 |
| Multilayer : time        | -0.1629              |

**Hue (H)**

|                          | Hue (H) |
|--------------------------|---------|
| Constant                 | 1.1018  |
| Time 0 months vs others  | -0.1326 |
| Merlot vs Pinot noir     | -0.3610 |
| Cabernet vs others       | -0.1130 |
| Frankovka vs Merlot and Pinot noir | -0.1286 |
| Merlot : multilayer : time 12 months | 0.4681 |

**Yellow (%)**

|                          | Yellow (%) |
|--------------------------|------------|
| Constant                 | 40.657     |
| Merlot vs Pinot noir     | 4.260      |
| Cabernet vs others       | 2.352      |
| Frankovka vs Merlot and Pinot noir | 4.152 |
| Time 0 months vs others  | 2.338      |
| Merlot vs Pinot noir : time 0 months vs larger | 4.62 |
| Merlot : multilayer : time 12 months | -6.71 |

**Red (%)**

|                          | Red (%)   |
|--------------------------|-----------|
| Constant                 | 41.899    |
| Merlot vs Pinot noir     | -12.03    |
| Time                     | 0.3420    |
| Merlot : time            | 0.456     |

**Blue (%)**

|                          | Blue (%)  |
|--------------------------|-----------|
| Constant                 | 16.201    |
| Merlot vs Pinot noir     | 5.535     |
| Time                     | -0.2326   |
| Frankovka vs Merlot and Pinot noir | -3.400 |

Regression main effect terms are built from indicators of the indicated condition (1 if true and 0 otherwise). Main effect orthogonal contrasts (vs) are built from differences of multiples of indicators (such that the coefficient would be the difference in the means, when the other terms are orthogonal to the other contrasts). Interaction terms (marked with :) are built from products of these. Time as a continuous variable is also considered, with care in subset selection as it is not orthogonal to the other contrasts. Term selection is by preservation of strong significance ($p < 0.001$), set especially small to avoid large models and because we are not otherwise accounting for multiple comparisons. Three way interaction terms appear only when residual analysis of the best two way interaction model reveals large standardized residuals (magnitude > 3) at the corresponding measurement, such that no such large residuals occur in the final model. Terms are shown in bold when they correspond to time changes as a main effect or time changes in interaction with the type of packaging.