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# Antioxidant Activity and Phenolic Components of *Cabernet Sauvignon* Red Wines At Different Storage Conditions

Esma Nur GEÇER[1*], Nilüfer VURAL[2], Rahmi Ertan ANLI[3]

**ABSTRACT:** In the present study, *Cabernet sauvignon* (*Vitis vinifera* L.) wines were stored at four different temperatures at 4-5°C, 8-10°C, 12-14°C and 18-20°C for 24 months. Effects of storage temperatures and durations on pH, total acidity, antioxidant activity, total phenolics content and phenolics distribution of the wines were investigated. Analyzes were carried out at the beginning of storage and at three-month intervals. At the end of the 24 months storage period, total phenolics decreased at all temperatures. At initial storage, the greatest decrease was 17.05 % at 12-14 °C in *Cabernet sauvignon* wines. Moreover, the antioxidant effect was decreased during the storage period. Quantitative analysis of natural compounds in wines was carried out by HPLC. The greatest catechin content of *Cabernet sauvignon* wine was measured as 71.59 $mgL^{-1}$ at the 24$^{th}$ month of storage. 12-14°C and the lowest catechin content of *Cabernet sauvignon* wine was observed at 0.43 $mgL^{-1}$ at the 15$^{th}$ month of storage and 8-10 °C. Principles and related components of *Cabernet sauvignon* wine for different storage temperatures and durations conditions were determined with the aid of Principle Component Analysis. Cluster analysis was carried out to determine the main clustering relationships of *Cabernet sauvignon* wine at different storage temperatures and durations.

**Keywords:** Red wine, *Cabernet sauvignon*, phenolic compounds, antioxidant activity, storage and temperature

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## INTRODUCTION

Wine contains alcohol, organic acids, nitrogenous components, sugar, amino acids, glycerol, mineral salts, colorants, enzymes, olisaccharides, polypeptides and colloidal substances in its chemical composition, as well as polyphenol compounds that have a significant effect on human health (Anlı, 2011).

Researchers have recently focused on red wine because of rich phenolics, antioxidant, anti-cancerogenic anti-inflammatory, antibacterial and antiviral biological activities of red wines (Faustino et al., 2003; Gambelli and Sanatorini, 2004; Anlı and Vural, 2009; Coman et al., 2012; Garrido and Borges, 2013; Ravishankar et al., 2013; Romano et al., 2013; Ferreira-Lima et al., 2016; Newair et al., 2018; Vicente and Boscaiu, 2018).

Storage conditions and durations have significant effects on wine quality. However, improper storage conditions or excessive storage durations have various negative impacts on wine quality. The optimum temperature and relative humidity conditions throughout the storage improve wine quality (Scrimgeour et al., 2015).

Temperature, light incidence, bottle position, oxygen content and time-like factors influence specific growth rates of the wines throughout the storage. However, wine stability during the storage period is largely related to the initial chemical composition and phenolics of the wines (Saucier, 2010; Burin et al., 2011; Kumar and Pandey, 2013; Panceri and Bordignon-Luiz, 2017).

Phenolic compounds, as a source of antioxidants, have various pharmacological and biochemical activities including antiviral, antibacterial, antidiabetic, antiinflammatory, hepatoprotective, neuroprotective and cardioprotective effect and they are commonly used as health promoters, disease prevention, and diet supplement (Middleton et al., 2000; Garrido and Borges, 2013; Kumar and Pandey, 2013; Romano et al., 2013; Vicente and Boscaiu, 2018; Todorova et al., 2018).

*Cabernet sauvignon*, one of the leading black grape varieties of French and world winemaking, is the variety with the highest percentage in the composition of the wines obtained in the Bordeaux region. *Cabernet sauvignon*, which is also found in the Languedoc-Rousillon and Loire valleys apart from 'Bordeaux' in France, is widely grown in Europe, America, Australia and New Zealand and is generally used in the production of one kind of wine. It has the potential to exceed the least average quality in almost every region. For this reason, *Cabernet sauvignon* is considered the most common and important black wine variety in the world (Anlı, 2011).

This is the first report that presents the changes in phenolic compounds and antioxidant propertes of the wines produced from *Cabernet sauvignon* grape cultivars throughout the storage condition such as temperature and duration. Since the climate, altitude, soil, cultivar condition, and harvested period affect the phenolic contents of the plants, the grapes cultivated in Vasfi Diren Farm in Tokat will contain the phenolic compounds in different quantities than the other cultivars. Hence, different phenolic compounds and different quantities will affect the biological activity directly.

## MATERIALS AND METHODS

### Materials

Grapes harvested from the vineyards of "Vasfi Diren Farm" of Dimes Corporation, Tokat in 2015 were used as the primary material of the present study. Wine production was performed in the facilities of Dimes Corporation under the supervision and control of the research team. Wine production was conducted under controlled fermentation conditions (20-23 °C) with the use of *Saccharomyces cerevisiae* as a starter culture yeast (Zymaflore RX60, Laffort; Zymaflore F83, Laffort; Lalvin ICV D

254, Lallemand). *Cabernet sauvignon* wines were placed into 750 mL dark colour glass bottles. Wine bottles were stored in light-proof Vestel VLP-4000 brand wine coolers at 85% relative humidity and 4 different temperatures (4-5 °C, 8-10 °C, 12-14 °C and 18-20 °C). Analyses were conducted at the beginning of storage and every three months ($0^{th}$, $3^{rd}$, $6^{th}$, $9^{th}$, $12^{th}$, $15^{th}$, $18^{th}$, $21^{st}$ and $24^{th}$ month) and phenolics composition of the wines were investigated.

## Methods

### pH

Wine pH was measured directly with a glass-electrode pH meter (Hanna brand) (Ough and Amerine, 1988).

### Total Acidity

For total acidity, a 10 mL wine sample was mixed with 20 mL distilled water and the resultant mixture was titrated with 0.1 N NaOH solution until a pH of 8.2. Results were expressed in g $L^{-1}$ tartaric acid equivalent (Ough and Amerine, 1988; Anonymous, 1990).

### Free radical scavenging activity

The Free radical scavenging activity of the wine samples was determined spectrophotometrically with the use of DPPH method. About 100 µl wine samples were diluted with MeOH at a 1/10 ratio. Diluted samples were supplemented with 2.9 ml DPPH solution, 30 minutes later, sample absorbance was read in a spectrophotometer at 517 nm. The % inhibition was calculated with the use of the following equation (Nixdorf and Hermosin-Gutierez, 2010);

$$\%\ \text{Inhibition} = [(\text{Abs DPPH} - \text{Abs wine}) / \text{Abs DPPH})] \times 100$$

### Total Phenolic Content (TPC)

The TPC was determined with the use of the Folin-Ciocalteu method. TPC corresponding to sample absorbance was determined with the use of standard graph drawn with the use of gallic acid and results were expressed in mg $L^{-1}$ gallic acid equivalent (GAE) (Ough and Amerine, 1988; Ribereau-Gayonet al., 2000).

### Multivariate Calibration of Phenolic Compounds Analyzed by High-Pressure Liquid Chromatography (HPLC)

### High-Pressure Liquid Chromatography (HPLC)

Cinnamic acids (caffeic acid, hydroxycinnamic acid, ferulic acid, coumaric acid), benzoic acids (gallic acid) and flavanols (catechin, gallocatechin, epicatechin, kaempferol and resveratrol) were determined quantitatively with the use of the modified HPLC method (Özkan and Göktürk Baydar, 2006).

Phenolic compound standards and methanol (MeOH) were supplied from Sigma-Aldrich Co. For all standards, stock solutions were prepared in MeOH:$H_2O$ (80:20 v/v) mixture as to have 1 mgm$L^{-1}$. For calibration curve, standard calibration solutions were prepared with MeOH at 5 different concentrations ranging from 1-100 mg $L^{-1}$. Standards were held at -18°C at dark. Quantitative analysis of phenolic compounds was conducted based on chromatograms of the wavelengths with maximum absorbance.

About 100 mL wine sample was filtered through 0.45 µm (Millex-HV) membrane filter and 50 µL filtrate was injected into HPLC device.

## Chromatographic conditions

The HPLC conditions required for chromatographic separation of phenolic compounds are provided in Table 1, gradient operational conditions are provided in Table 2 and maximum absorbance operation wave lengths and chromatographic retention times are provided in Table 3.

**Table 1.** HPLC conditions required for phenolic compounds

| | |
|---|---|
| Equipment | Shimadzu |
| Degasifier | DGU-20 A5 Prominence (gradient valf) |
| Pump | 1C-20 AT Prominence |
| Control unit | CBM-20A Prominence |
| Detector | SPD-M10AVP DAD |
| Automatic Sample İnjection Unit | SIL-10AXL |
| Column Furnace | CTO-10A |
| Column | Intersil ODS-3 Ters Faz (5 µm-25x4.6 mm) |
| Solvent A: | Methanol |
| Solvent B: | % 2 Acetic Acid |

**Table 2.** Gradient system solvent flow concentration for phenolic compounds

| Time (min) | A solution (% h/h) | B solution (% h/h) |
|---|---|---|
| 0 | 0 | 100 |
| 3 | 5 | 95 |
| 18 | 20 | 80 |
| 25 | 20 | 80 |
| 30 | 25 | 75 |
| 35 | 30 | 70 |
| 40 | 40 | 60 |
| 55 | 50 | 50 |
| 65 | 60 | 40 |
| 67 | 0 | 100 |
| 68 | 0 | 100 |

**Table 3.** Phenolic acid standards retention times, maximum absorbance values and $R^2$ values obtained by the used method

| Phenolic acid standards | Retention times (min) | Maximum absorbance values (nm) | $R^2$ values |
|---|---|---|---|
| Gallic Acid | 5.00 | 280 | 0.9990 |
| Gallocatechin | 17.20 | 280 | 0.9970 |
| Caffeic Acid | 18.90 | 320 | 0.9999 |
| Coumaric Acid | 23.42 | 320 | 0.9996 |
| Ferulic Acid | 24.49 | 280 | 0.9999 |
| Resveratrol | 28.28 | 320 | 0.9995 |
| Hydroxycinnami Acid | 30.39 | 280 | 0.9990 |
| Kaempferol | 34.48 | 280 | 0.9598 |
| Catechin | 35.21 | 280 | 0.9990 |
| Epicatechin | 61.32 | 280 | 0.9977 |

## Statistical Analysis

All experimental and sensory analyses were repeated three times and results were expressed in mean ± standard deviation (sd). General, spectrophotometric and chromatographic analysis results obtained through the analyses of *Cabernet sauvignon* wines at different storage temperatures and storage durations were subjected repeated to one-way nested ANOVA, Kruskal Wallis comparison analysis, Cluster analysis and Principal component analysis (PCA) with the use of Minitab 17 software.

For sensory analysis results, factor analysis was conducted with the use of SPSS 20 software. Samples were assessed in 20-point scale and resultant data were determined through variance analysis at factorial design. There are 4 levels of temperature factor (4-5 °C, 8-10 °C, 12-14 °C and 18-20 °C) and 1 level of cultivar factor *Cabernet sauvignon*. Different groups were identified with the use of Duncan's test ($p<0.05$).

## RESULTS AND DISCUSSION

### Chemical Analysis

### pH

In *Cabernet sauvignon* wines, initial pH at the beginning of storage was measured 3.57, 3.53 and 3.68 respectively. In *Cabernet sauvignon*, the greatest pH (3.70) was observed in 24-month storage at 18-20 °C storage temperature conditions and the lowest pH (3.48) in 18-month storage at 18-20 °C storage temperature conditions (Table 4). Unlike our results in the literature, according to the results of the study performed on *Rose sparkling* wines, differences were not observed in pH values compared to the initial pH values with 3, 6 and 9 months of storage at 5 °C and 30 °C storage temperatures (Benucci, 2020).

**Table 4**. pH results of *Cabernet sauvignon* wine

| Time (month) | pH | | | |
|---|---|---|---|---|
| **0** | 3.57±0.000 | | | |
| | **4-5 °C** | **8-10 °C** | **12-14 °C** | **18-20 °C** |
| **3** | 3.50±0.014$^{Aa}$ | 3.50±0.007$^{Aa}$ | 3.51±0.007$^{Aa}$ | 3.51±0.007$^{Aa}$ |
| **6** | 3.57±0.000$^{Ca}$ | 3.58±0.000$^{Ca}$ | 3.56±0.000$^{Ba}$ | 3.56±0.000$^{Ba}$ |
| **9** | 3.53±0.000$^{Ba}$ | 3.54±0.000$^{Ba}$ | 3.55±0.007$^{Ba}$ | 3.56±0.007$^{Ba}$ |
| **12** | 3.63±0.007$^{Da}$ | 3.66±0.007$^{Db}$ | 3.67±0.007$^{Cb}$ | 3.68±0.007$^{Cb}$ |
| **15** | 3.51±0.000$^{Aa}$ | 3.52±0.007$^{Aa}$ | 3.51±0.000$^{Aa}$ | 3.53±0.000$^{Aa}$ |
| **18** | 3.51±0.007$^{Ab}$ | 3.50±0.000$^{Ab}$ | 3.49±0.007$^{Aa}$ | 3.48±0.000$^{Aa}$ |
| **21** | 3.52±0.007$^{Aa}$ | 3.53±0.000$^{Ba}$ | 3.53±0.000$^{Aa}$ | 3.55±0.007$^{Bb}$ |
| **24** | 3.67±0.007$^{Ea}$ | 3.68±0.007$^{Da}$ | 3.69±0.007$^{Cb}$ | 3.70±0.007$^{Cb}$ |

### Total Acidity

In *Cabernet sauvignon* wines, initial total acidity at the beginning of storage was measured as 4.72 $gL^{-1}$. The greatest total acidity (5.44 $gL^{-1}$) was observed in 21-month storage at 18-20 °C storage temperature and the lowest (4.65 $gL^{-1}$) in 3-month storage at 12-14 °C and 24-month storage at 4-5 °C storage temperatures (Table 5).

**Table 5**. Total acidity results of *Cabernet sauvignon* wine

| Time (month) | Total Acidity (g/L tartaric acid) | | | |
|---|---|---|---|---|
| **0** | 4.72±0.000 | | | |
| | **4-5 °C** | **8-10 °C** | **12-14 °C** | **18-20 °C** |
| **3** | 4.80±0.106$^{Ab}$ | 4.84±0.053$^{Ab}$ | 4.65±0.000$^{Aa}$ | 4.95±0.000$^{Ab}$ |
| **6** | 5.36±0.053$^{Cb}$ | 5.21±0.053$^{Ba}$ | 5.33±0.106$^{Cb}$ | 5.21±0.053$^{Ba}$ |
| **9** | 5.25±0.000$^{Ba}$ | 5.33±0.000$^{Bb}$ | 5.18±0.000$^{Ba}$ | 5.33±0.000$^{Bb}$ |
| **12** | 4.95±0.106$^{Ba}$ | 5.03±0.000$^{Aa}$ | 4.91±0.053$^{Aa}$ | 5.06±0.053$^{Aa}$ |
| **15** | 5.10±0.000$^{Ba}$ | 5.25±0.000$^{Bb}$ | 5.21±0.053$^{Bb}$ | 5.29±0.053$^{Bb}$ |
| **18** | 5.10±0.000$^{Ba}$ | 5.21±0.053$^{Bb}$ | 5.14±0.053$^{Ba}$ | 5.33±0.106$^{Bc}$ |
| **21** | 4.84±0.053$^{Aa}$ | 4.99±0.053$^{Ab}$ | 5.06±0.053$^{Bb}$ | 5.44±0.053$^{Cc}$ |
| **24** | 4.65±0.106$^{Aa}$ | 4.91±0.053$^{Ab}$ | 4.95±0.000$^{Bb}$ | 5.36±0.159$^{Bc}$ |

### Free radical scavenging activity

In *Cabernet sauvignon* wines, initial antioxidant activity at the beginning of storage was measured as 80.95%. The highest antioxidant activity (77.13%) was obtained from 6-month storage at 8-10 °C storage temperatures and the lowest (59.38%) from 21-month storage at 18-20 °C storage temperatures (Table 6).

Marquez et al. (2014) stored *Merlot*, *Shiraz* and *Tempranillo* wines at 18-20 °C temperature for 12 months and determined total antioxidant capacity in 0$^{th}$, 3$^{rd}$, 6$^{th}$, 9$^{th}$ and 12$^{th}$ months with the use of DPPH method. Initial total antioxidant capacity was determined as 6.09 mmol TE $L^{-1}$ for *Tempranillo* wines, 5.91mmol TE $L^{-1}$ *Merlot* wines and 4.16 mmol TE $L^{-1}$ for *Shiraz* wines; the values at the end of 12-month storage were respectively measured as 6.09 mmol TE $L^{-1}$, 6.23 mmol TE $L^{-1}$ and 3.78 mmol

TE $L^{-1}$. Those findings indicated that antioxidant capacity did not change significantly throughout the storage.

**Table 6.** DPPH free radical scavenging activity of *Cabernet sauvignon* wine

| Time (month) | DPPH (% inhibition) | | | |
|---|---|---|---|---|
| **0** | 80.95±0.000 | | | |
| | **4-5 °C** | **8-10 °C** | **12-14 °C** | **18-20 °C** |
| **3** | 69.06±0.123$^{Bb}$ | 69.58±0.123$^{Bb}$ | 70.10±0.123$^{Bb}$ | 66.03±0.000$^{Ba}$ |
| **6** | 75.84±0.108$^{Eb}$ | 77.13±0.000$^{Ec}$ | 75.53±0.108$^{Db}$ | 72.94±0.108$^{Ea}$ |
| **9** | 72.41±2.734$^{Cc}$ | 70.91±0.124$^{Ba}$ | 71.62±0.124$^{Cb}$ | 71.88±0.000$^{Db}$ |
| **12** | 75.48±2.113$^{Eb}$ | 74.87±0.994$^{Db}$ | 72.14±4.847$^{Ca}$ | 71.62±1.118$^{Da}$ |
| **15** | 68.54±0.746$^{Ba}$ | 72.14±0.373$^{Cc}$ | 69.42±1.491$^{Ba}$ | 68.98±6.089$^{Ca}$ |
| **18** | 71.35±5.468$^{Cb}$ | 70.47±0.000$^{Ba}$ | 72.14±0.373$^{Cb}$ | 69.51±2.361$^{Ca}$ |
| **21** | 61.26±0.133$^{Ab}$ | 64.00±0.000$^{Ac}$ | 59.57±0.133$^{Aa}$ | 59.38±0.133$^{Aa}$ |
| **24** | 73.87±0.105$^{Db}$ | 72.91±0.209$^{Cb}$ | 71.13±0.209$^{Ca}$ | 70.69±0.209$^{Da}$ |

## Total phenolics content (TPC)

In *Cabernet sauvignon* wines, initial TPC at the beginning of the storage was measured as 2766.75 mg $L^{-1}$ GAE. The greatest value (3420.00 mg $L^{-1}$ GAE) was observed in 12-month storage at 4-5 °C storage temperatures and the lowest (1878.33 mg $L^{-1}$ GAE) in 21-month storage at 4-5 °C storage temperatures (Table 7). Decreases in phenolics were observed at the end of storage at all temperatures. Such a case could be explained by oxidation and polymerization reactions of free phenols between each other or with free anthocyanins.

**Table 7**. Total phenolic content results of *Cabernet sauvignon* wine

| Time (month) | Total Phenolic Content ($mgL^{-1}$ gallic acid) | | | |
|---|---|---|---|---|
| **0** | 2766.75±0.000 | | | |
| | **4-5 °C** | **8-10 °C** | **12-14 °C** | **18-20 °C** |
| **3** | 2774.17±5.893$^{Eb}$ | 2720.00±11.785$^{Fb}$ | 2907.50±5.893$^{Ec}$ | 2457.50±5.893$^{Ca}$ |
| **6** | 2540.83±5.893$^{Cb}$ | 2420.00±11.785$^{Ba}$ | 2382.50±5.893$^{Ca}$ | 2428.33±0.000$^{Ca}$ |
| **9** | 2032.50±5.893$^{Ba}$ | 2449.17±5.893$^{Bd}$ | 2174.17±17.678$^{Bb}$ | 2299.17±5.893$^{Bc}$ |
| **12** | 3420.00±11.785$^{d}$ | 2686.67±11.785$^{Ea}$ | 2903.33±11.785$^{Ec}$ | 2774.17±17.678$^{Db}$ |
| **15** | 1974.17±17.678$^{Ba}$ | 2365.83±17.678$^{Bc}$ | 2145.00±0.000$^{Bb}$ | 2457.50±17.678$^{Cd}$ |
| **18** | 2453.33±11.785$^{Cb}$ | 2595.00±0.000$^{Dc}$ | 2461.67±0.000$^{Db}$ | 2390.83±5.893$^{Ba}$ |
| **21** | 1878.33±0.000$^{Aa}$ | 2036.67±11.785$^{Ac}$ | 1982.50±5.893$^{Ab}$ | 1978.33±0.000$^{Ab}$ |
| **24** | 2695.00±11.785$^{Dd}$ | 2465.83±5.893$^{Cc}$ | 2295.00±0.000$^{Ca}$ | 2378.33±11.785$^{Bb}$ |

Burin et al. (2011) investigated the effects of storage temperatures and durations on TPC of the *Cabernet sauvignon* wines and reported that initial TPC of 2114 $mgL^{-1}$ decreased by about 35-40% at the end of 11-month of storage at 5 °C temperature. Arapitsas et al. (2014) stored Sangiovese wines at varying temperatures (20-27 °C) and reported that formation of pinotin A-like pigments and hydrolysis of flavanol glycosides were faster in relatively stable cellar temperatures (15-17 °C).

## Individual phenolic compounds

In *Cabernet sauvignon* wines, initial gallic acid content was measured as 12.45 $mgL^{-1}$. The greatest gallic acid content (212.66 $mgL^{-1}$) was determined in 24-month storage at 12-14 °C storage temperatures and the lowest (160.74 $mgL^{-1}$) in 21-month storage at 4-5 °C storage temperatures, initial gallocatechin content was measured as 8.13 $mgL^{-1}$. The greatest gallocatechin content (7.16 $mgL^{-1}$) was determined in 9-month storage at 12-14 °C storage temperatures and the lowest (1.01 $mgL^{-1}$) in 12-month storage at 8-10 °C storage temperatures.

In *Cabernet sauvignon* wines, initial ferulic acid content was determined as 1.51 $mgL^{-1}$. The greatest ferulic acid content (8.65 $mgL^{-1}$) was defined in 21-month storage at 12-14 °C temperatures and the lowest (0.64 $mgL^{-1}$) in 12-month storage at 12-14 °C temperatures, initial hydrocinnamic acid content was measured as 1.53 $mgL^{-1}$. The greatest hydrocinnamic acid content (23.96 $mgL^{-1}$) was

determined in 24-month storage at 4-5 °C storage temperatures and the lowest (0.20 $mgL^{-1}$) in 15-month storage at 4-5 °C storage temperatures (Table 8).

**Table 8**. Hydrocinnamic acid results of *Cabernet sauvignon* wine

| Time (month) | Hydroxycinamic acid ($mgL^{-1}$) | | | |
|---|---|---|---|---|
| **0** | 1.53±0.060 | | | |
| | **4-5 °C** | **8-10 °C** | **12-14 °C** | **18-20 °C** |
| **3** | 1.83±0.059$^{Ba}$ | 1.63±0.187$^{Ba}$ | 1.53±0.056$^{Ba}$ | 2.24±0.056$^{Ba}$ |
| **6** | 2.82±0.345$^{Ca}$ | 11.04±1.621$^{Ec}$ | 12.07±1.527$^{Ed}$ | 3.88±0.423$^{Cb}$ |
| **9** | 1.91±0.152$^{Ba}$ | 6.32±1.164$^{Cd}$ | 4.29±0.528$^{Cc}$ | 3.06±0.296$^{Cb}$ |
| **12** | 1.85±0.234$^{Bc}$ | 0.68±0.119$^{Ab}$ | 0.38±0.063$^{Aa}$ | 0.50±0.062$^{Ab}$ |
| **15** | 0.20±0.034$^{Aa}$ | 0.24±0.033$^{Aa}$ | 0.37±0.008$^{Aa}$ | 0.30±0.031$^{Aa}$ |
| **18** | 8.03±0.131$^{Da}$ | 14.64±0.079$^{Fc}$ | 8.39±0.141$^{Da}$ | 12.68±0.187$^{Db}$ |
| **21** | 12.60±0.045$^{Eb}$ | 9.43±0.216$^{Da}$ | 12.73±0.213$^{Fb}$ | 12.71±0.155$^{Db}$ |
| **24** | 23.96±0.500$^{Fd}$ | 21.04±0.190$^{Gc}$ | 11.72±0.149$^{Ea}$ | 15.22±0.300$^{Eb}$ |

In *Cabernet sauvignon* wines, initial kaempferol content was measured as 19.04 $mgL^{-1}$. The greatest kaempferol content (29.06 $mgL^{-1}$) was determined in 24-month storage at 8-10 °C temperatures and the lowest (1.14 $mgL^{-1}$) in 15-month storage at 4-5 °C temperatures, initial epicatechin content was measured as 9.36 $mgL^{-1}$. The greatest epicatechin content (34.20 $mgL^{-1}$) was determined in 6-month storage at 12-14 °C storage temperatures and the lowest (1.14 $mgL^{-1}$) in 18-month storage at 12-14 °C temperatures.

In *Cabernet sauvignon* wines, initial catechin content was calculated as 94.41 $mgL^{-1}$. The greatest catechin content (71.59 $mgL^{-1}$) was determined in 24-month storage at 12-14 °C temperatures and the lowest (0.43 $mgL^{-1}$) in 15-month storage at 8-10 °C storage temperatures (Table 9), initial caffeic acid content was measured as 2.70 $mgL^{-1}$. The greatest caffeic acid content (6.10 $mgL^{-1}$) was determined in 9-month storage at 12-14 °C storage temperatures and the lowest (0.31 $mgL^{-1}$) in 15-month storage at 4-5 °C storage temperatures.

**Table 9**. Catechin of *Cabernet sauvignon* wine

| Time (month) | Catechin ($mgL^{-1}$) | | | |
|---|---|---|---|---|
| **0** | 94.41±0.615 | | | |
| | **4-5 °C** | **8-10 °C** | **12-14 °C** | **18-20 °C** |
| **3** | 1.10±0.088$^{Aa}$ | 0.84±0.092$^{Ba}$ | 0.91±0.149$^{Aa}$ | 1.40±0.158$^{Aa}$ |
| **6** | 0.46±0.106$^{Aa}$ | 1.69±0.070$^{Cc}$ | 1.41±0.167$^{Ab}$ | 1.22±0.182$^{Ab}$ |
| **9** | 1.11±0.102$^{Aa}$ | 2.29±0.162$^{Cb}$ | 3.34±0.360$^{Bc}$ | 2.52±0.386$^{Bc}$ |
| **12** | 1.26±0.169$^{Aa}$ | 1.51±0.389$^{Cb}$ | 1.25±0.127$^{Aa}$ | 1.10±0.075$^{Aa}$ |
| **15** | 0.52±0.039$^{Ab}$ | 0.43±0.018$^{Aa}$ | 0.67±0.005$^{Ab}$ | 0.57±0.084$^{Ab}$ |
| **18** | 22.51±0.161$^{Cd}$ | 18.66±0.220$^{Db}$ | 19.95±0.500$^{Dc}$ | 8.58±0.273$^{Ca}$ |
| **21** | 18.46±0.330$^{Bb}$ | 22.87±0.371$^{Ec}$ | 18.61±0.390$^{Cb}$ | 13.73±0.193$^{Da}$ |
| **24** | 26.61±0.548$^{Da}$ | 41.24±0.445$^{Fb}$ | 71.59±0.549$^{Ed}$ | 68.82±0.392$^{Ec}$ |

In *Cabernet sauvignon* wines, initial coumaric acid content was measured as 4.72 $mgL^{-1}$. The greatest coumaric acid content (5.21 $mgL^{-1}$) was determined in 18-month storage at 4-5 °C storage temperatures and the lowest (0.86 $mgL^{-1}$) in 12-month storage at 12-14 °C storage temperatures, initial resveratrol content was measured as 2.87 $mgL^{-1}$. The greatest resveratrol content (17.50 $mgL^{-1}$) was determined in 24-month storage at 4-5 °C storage temperatures and the lowest (1.59 $mgL^{-1}$) in 15-month storage at 4-5 °C storage temperatures.

Gomez-Gallego et al. (2013) stored *Cencibel, Bobal, Moravia Agria* and *Tortosi* wines at 12 °C for 24 months and investigated changes encountered in hydrocinnamic acid derivates. While decreases were determined in caftaric acid and coutaric acid concentrations of all wines, gradual and significant increases were determined in caffeic and coumaric acid concentrations. Increase in coumaric acid contents of *Cencibel, Bobal* and *Tortosi* wines during the second half of the storage was more remarkable. Increasing coumaric acid contents were related to hydrolysis of tartaric acid esters (caftaric

acid and coutaric acid) and hydrolysis of the other compounds, especially of coumarin-form anthocyanins (Somers et al., 1987; Monagas et al., 2005; Gomez-Gallego et al., 2013).

**Principle component analysis**

Figure 1a and Figure 1b are biaxial graphs summarizing cumulative total variance on duration and temperature axes for *Cabernet sauvignon* wines. Principle component analysis revealed that eigen value was defined on PC4 and two principal components explained 82.3% of total variation (PC1 explaining 44.7% and PC4 explaining 37.6%). Figure 1a and 1b revealed that PC1 was effective on storage durations and PC4 was effective on storage temperature. Epicatechin, pH, gallocatechin, catechin, caffeic acid, hydroxycinnamic acid, kaempferol, coumaric acid, resveratrol, gallic acid and ferulic acid showed a strong correlation for storage time. The parameters on which storage temperature was effective were identified as DPPH, TPC and total acidity. According to principal component analysis, epicatechin and pH were distinctively separated in $0^{th}$ month; gallocatechin and catechin in $24^{th}$ month at 12-14 ºC and in $24^{th}$ month at 18-20 ºC; caffeic acid and hydroxycinnamic acid in $24^{th}$ month at 4-5 ºC and in $24^{th}$ month at 8-10 ºC. Storage temperatures and durations were effective on kaempferol, coumaric acid and resveratrol in $18^{th}$ month at 4-5 ºC, $18^{th}$ month at 8-10 ºC, $18^{th}$ month at 12-14 ºC, $21^{st}$ month at 8-10 ºC and $21^{st}$ month at 12-14 ºC; on gallic acid and ferulic acid in $18^{th}$ month at 18-20 ºC, $21^{st}$ month at 4-5 ºC and $21^{st}$ month at 18-20 ºC. Total acidity was remarkable in $3^{rd}$ month at 4-5 ºC, $3^{rd}$ month at 8-10 ºC, $3^{rd}$ month at 12-14 ºC, $3^{rd}$ month at 18-20 ºC, $9^{th}$ month at 4-5 ºC, $15^{th}$ month at 4-5 ºC, $15^{th}$ month at 8-10 ºC, $15^{th}$ month at 12-14 ºC and $15^{th}$ month at 18-20 ºC. Storage temperatures and durations were effective on DPPH and TPC in $6^{th}$ month at 4-5 ºC, $6^{th}$ month at 8-10 ºC, $6^{th}$ month at 12-14 ºC, $6^{th}$ month 18-20 ºC, $9^{th}$ month at 8-10 ºC, $9^{th}$ month at 12-14 ºC, $9^{th}$ month at 18-20 ºC, $12^{th}$ month at 4-5 ºC, $12^{th}$ month at 8-10 ºC, $12^{th}$ month at 12-14 ºC and $12^{th}$ month at 18-20 ºC.

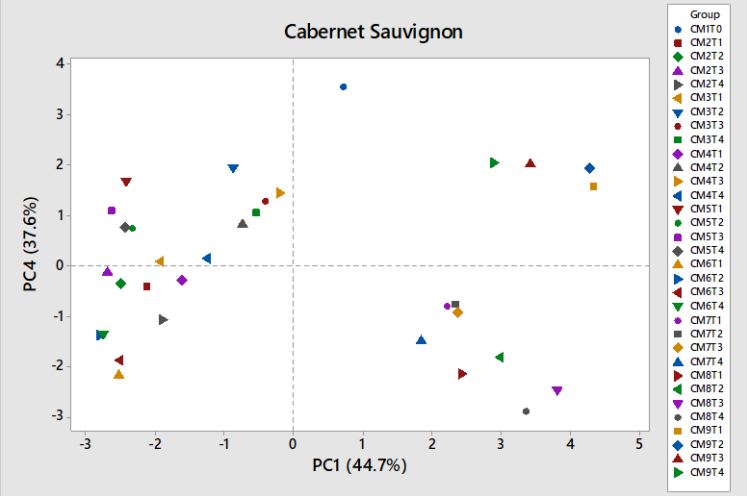


**Figure 1a.** Principal component analysis score plot for antioxidant activity, individual phenolic compounds, TPC and chemical properties

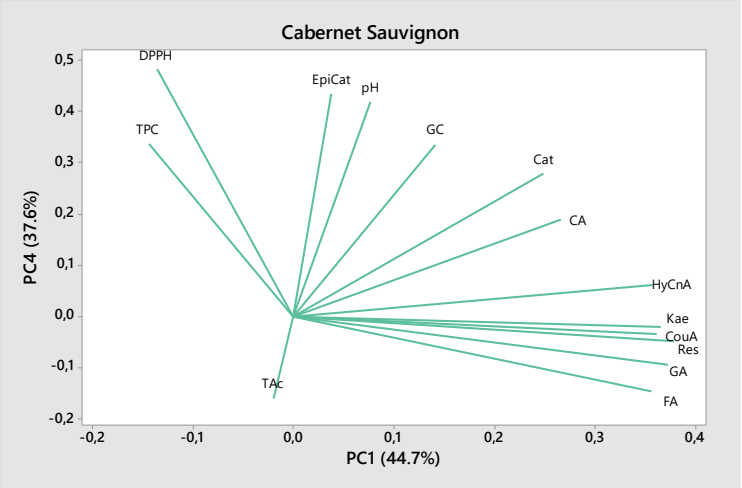


**Figure 1b.** Principal component analysis loading plot for antioxidant activity, individual phenolic compounds, TPC and chemical properties

## Cluster analysis

For cluster analysis, among the hierarchical clustering analysis methods, fully connected clustering was used. Clustering was performed based on Euclidean distances and non-hierarchical k-means methods was selected. Sequential phases of the clustering were presented with the use of dendrogram. Results of clustering analysis for *Cabernet sauvignon* wines are presented in dendrograms given in Figure 2.

In the dendrogram presented in Figure 2 for *Cabernet sauvignon* wines, there are two main clusters and 14 sub-clusters. The first main cluster under the effect of storage temperatures had 4 sub-clusters (pH, epicatechin, DPPH, TPC) and the second main cluster under the effect of storage durations had 10 sub-clusters (total acidity, gallic acid, resveratrol, coumaric acid, kaempferol, ferulic acid, hydroxycinnamic acid, gallocatechin, caffeic acid, catechin). These findings comply with the results of PCA (Figure 2). The closest (100%) variables were identified as gallic acid– resveratrol and the furthest (24.24%) variables were identified as pH -total acidity. In Figure 2, 14 variables were included in different clusters related to each other.

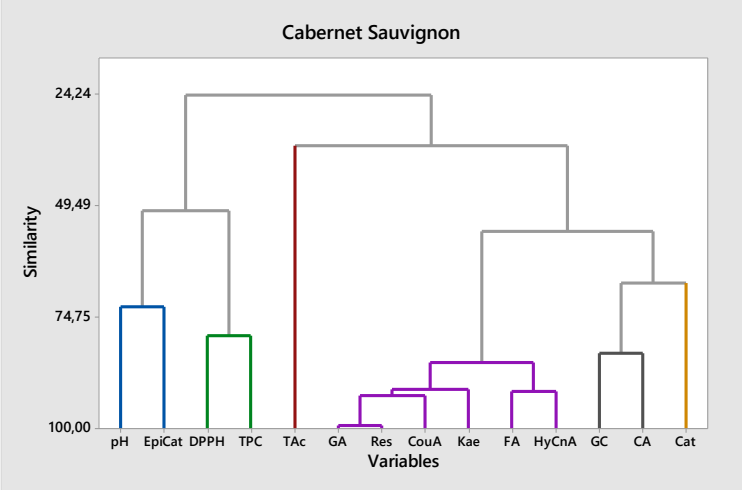


**Figure 2.** Cluster analysis of *Cabernet sauvignon* wine

## CONCLUSION

Present findings revealed that storage temperatures and durations influenced phenolics and antioxidant characteristics of the wines produced from *Cabernet sauvignon* grape cultivar and indicated

the significance of storage temperature for preservation of taste, aroma and color compounds of the wines and prevention of the effects of early development on quality traits. For this reason, both producers and consumers should pay attention to the storage and maturation conditions of wine quality.

**Conflict of Interest**

The article authors declare that there is no conflict of interest between them.

**Author's Contributions**

The authors declare that they have contributed equally to the article.

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