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Original article

Does u.v. light affect the total phenolic compound, anthocyanin, antioxidant capacity, and sensory profiles in wines?

Hande Tahmaz[1*] & **Damla Yüksel Küskü**[2]

1 Department of Horticulture, Faculty of Agriculture, Ankara University, Ankara 06110, Turkey
2 Landscape and Ornamental Plants, Vocational High School, Bilecik Seyh Edebali University, Bilecik 11230, Turkey

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Summary In the study, by applying ultraviolet (u.v.) lights (254 nm) for 45 min to red wines from fermented Cabernet Franc, Cabernet Sauvignon, Merlot, and Petit Verdot (*Vitis vinifera* L.) grapes, we examined the total phenolic compound, total anthocyanin, and antioxidant capacity by four different methods, *trans*-resveratrol, (+)-catechin, gallic acid content, and the change in tasting profiles of the wines after application. According to the results of the research, the u.v.-C application has caused an increase in all parameters examined. If we talk about averages without distinguishing between varieties, after the application the total phenolic compound content of 3206 increased to 3356 mg gallic acid equivalent (GAE) per L and after u.v.-C application, the total anthocyanin content increased from 411 to 780 mg L^{-1}, the ABTS [2,2′-azinobis(3-ethyl-benzothiazoline-6-sulphonic acid)] value increased from 30 to 33 μmol trolox mL^{-1}, the DPPH ((2,2-diphenyl-1-picrylhydrazyl) level increased from 13 to 16 μmol trolox mL^{-1}, the FRAP (ferric reducing antioxidant power) level increased from 15 to 16 μmol trolox mL^{-1}, and the CUPRAC (cupric reducing antioxidant capacity) level increased from 40 to 45 μmol trolox mL^{-1}. The u.v. application affected *trans*-resveratrol the most among the phenolic compounds and an average increase of 12.99% was obtained. The rate of increase after u.v. application was 3.33% in (+)-catechin and 5.57% in gallic acid. The highest correlation between antioxidant activity measurement methods was measured to be 0.998 between FRAP and DPPH. In addition, u.v.-C application has had a positive effect on taste-based sensory profiles. In recent years, the search for a diet with a high antioxidant content has become even more important.

Keywords Antioxidant capacity, red wine, total anthocyanin, total phenolic compound, u.v.-C.

Introduction

The most important feature that distinguishes wine from other alcohols is the phytochemicals it contains. Phenolic compounds, especially found in red wines, have proven to have positive effects on human health. Among the most intensively studied of these effects, we could list their protective effects on the cardiovascular system (Haseeb *et al.*, 2017; Castaldo *et al.*, 2019), metabolic health (Fragopoulou *et al.*, 2018; Gerardi *et al.*, 2020), skin health (Wurz, 2019), and the intestinal–digestive system (Le Roy *et al.*, 2020), their protective effect against cancer (Dybkowska *et al.*, 2018; Sharma *et al.*, 2018), microbial infections (Sánchez *et al.*, 2019; Abedini *et al.*, 2021), neurological diseases (Granzotto & Zatta, 2014; Lange, 2018), diabetes (Bahadoran *et al.*, 2013), and obesity (Castro-Barquero *et al.*, 2018) and their effect on improving cognitive performance (Kennedy *et al.*, 2010).

In addition to their health benefits, phenolic compounds also contribute to the sensory character of wines. Grapes and their amounts in wines vary according to the type of grapes, cultivation and vinification techniques, and terroir effect (Lopez-Velez *et al.*, 2003; Tahmaz & Söylemezoğlu, 2017). Ageing of wines is also one of the factors affecting phenolic compound levels (Peri *et al.*, 2015). In addition, wine contains more phenolic compounds than in harvested grapes. This is due to the fact that significant changes in phenolic composition are dissolved in the process of vinification, especially during maceration, and get transferred into the must.

The transition of phenolic compounds from grapes to wine occurs in the early stages of fermentation and during the ageing of wine (Tahmaz & Söylemezoğlu,

*Correspondent: Hande Tahmaz; e-mail: tahmazhande@gmail.com

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2017). Wine, especially red wine, is a rich source of antioxidants. The antioxidant capacity of phenolic compounds is due to the ease with which one hydrogen atom from an aromatic hydroxyl group can be donated to the free radical and the ability of the phenolic compound to support unmatched electrons (Balasundram *et al*., 2006).

In recent years, the importance of health and healthy eating has been on the agenda. Society has turned to foods with a high antioxidant content. This trend is manifested in wine production technology, with studies aimed at obtaining a wine with a high organoleptic quality and a higher amount of antioxidant phenolic compounds. For example, reducing the fermentation temperature and prolonging the maceration (Panprivech *et al*., 2015), increasing the fermentation temperature with thermovinification (Lisov *et al*., 2021), cryoextraction procedures (Ruiz-Rodríguez *et al*., 2020), saignée method (Lukić *et al*., 2017), and enzyme application (Osete-Alcaraz *et al*., 2019) techniques are applied to increase the extraction of phenolic compounds to wine.

The u.v. application is also an application that is known to increase phenolic compound synthesis in grape and wine. Stilbene synthase and chalcon synthase enzymes, which are responsible for phenolic compounds in grapes, are known to increase with u.v. light application and stimulate the phenolic synthesis (Versari *et al*., 2001). In the literature, u.v. lights have been implemented on grapes post-harvest (Freitas *et al*., 2015). U.v.-C lights, which are between 100 and 280 nm wavelengths, are known to increase the phenolic compound and nutrition value of the post-harvest grapes. Similarly, the u.v.-C application on post-harvest table grapes is known to increase the gene level responsible for the synthesis of phenolic compounds and thus result in the increase in phenolic compound levels (Sheng *et al*., 2018).

Scanning through literature, u.v. application during the vinification process is limited. The colour intensity, total phenolic compound content, and polyphenol indexes that are extracted from the Tempranillo grapevines which are exposed to u.v. rays have been reported to be higher compared to grapes that were not exposed to u.v. rays (Del-Castillo-Alonso *et al*., 2020). As we said before, there are almost no research studies in which wine is exposed to u.v. light. In our previous research, we have exposed wines to u.v.-C light during the maceration process and we have observed a profound increase in the total phenolic compound, total anthocyanin, and antioxidant capacity values (Tahmaz & Söylemezoğlu, 2017). In this study, it was aimed to observe the effects of total phenolic compounds, antioxidant capacity, and total anthocyanin amounts and application on sensory profiles by applying u.v.-C to red wines that have completed fermentation and to add information in this direction to the literature. In addition, the changes in the levels of *trans*-resveratrol, catechin, and gallic acid, which are beneficial phenolic compounds to human health, with u.v. application were also investigated. The biggest question of the research is whether it is possible to obtain both healthier and better taste wine with the application of u.v. lights, which is a practical application.

Materials and methods

Materials

In this study, red wines produced from Cabernet Franc (Clone 393), Cabernet Sauvignon (Clone 169), Merlot (Clone 181), and Petit Verdot (Clone 400) (*Vitis vinifera* L.) grape varieties were used as materials. The vineyards of the grapes belong to a private winery called Chateau Kalpak and are located in Şarköy Tekirdağ-Turkey. In 2020, grapes harvested during optimum technological maturity were vinated with the addition of yeast (Laffort FX10) in fermentation tanks on the same day in the winery after destemming and crushing. At the end of maceration, malolactic fermentation was initiated by pressing. After the malolactic fermentation was completed and racking, samples were taken from the wines during the maturation phase and put together with nitrogen gas in transparent bottles of 500 mL and sent to Ankara University Faculty of Agriculture for analysis.

Methods

U.v. application

U.v.-C lights (254-nm) were applied to Cabernet Franc, Cabernet Sauvignon, Merlot, and Petit Verdot (*Vitis vinifera* L.) wines in 500 mL glass bottles for 45 min by turning the bottles on a horizontal axis and from a height of 15 cm, every five min. The u.v. lights consisted of a total of 4 lamps (Philips TUV PL-L) with a power of 36 W each and the u.v. irradiation of 1 lamp was 140 $\mu W\ cm^{-2}$. Analysis of application wines was carried out immediately within 1 h after u.v.-C application.

General grape analysis

On the day of harvest, brix, total acidity, pH, and density measurements of grapes were made (OIV, 2011).

General wine analysis

Before u.v.-C application, in addition to total acidity, alcohol, sugar, volatile acid, free SO_2 and total SO_2

analyses (OIV, 2011), chemical age 1–2, ionisation of anthocyanin (%), total anthocyanin (mg L^{-1}), colour density (AU), hue (no units), SO_2-resistant pigment (AU) analyses according to Mercurio *et al.* (2007), anthocyanins (mg L^{-1}) with bisulphite bleaching method according to Mercurio & Smith (2008), tannins (g L^{-1}) by the acid hydrolysis method according to Iland *et al.* (2000), colour density and colour hue according to Cliff *et al.* (2007), and copigmented anthocyanins, monomeric anthocyanins, polymeric anthocyanins, and total anthocyanins again according to Cliff *et al.* (2007) were carried out on the wines. All analyses using spectrophotometer were performed with Shimadzu u.v.-1208 model u.v.-vis spectrophotometer.

Total phenolic compound, total anthocyanin, and antioxidant capacity analysis for the determination of u.v.-C treatment

After u.v.-C application of wines, changes in total phenolic compound, total anthocyanin, and antioxidant capacity (through ABTS, DPPH, FRAP, and CUPRAC methods) were examined. All wines were filtered through polyvinylidene fluoride (PVDF) membrane filters of 0.45-μm pore size before analysis. Total phenolic compound, total anthocyanin, antioxidant capacity, *trans*-resveratrol, catechin, and gallic acid analyses were performed within 1 h following u.v. application.

Total phenolic compound

The total phenolic compound content of the wines was determined according to Singleton & Rossi (1965) and the results were expressed as mg L^{-1} gallic acid equivalent (GAE). Measurements were performed at a wavelength of 765 nm and R^2 =0.9989 gallic acid curve was used to express the results as gallic acid equivalent (GAE).

Total anthocyanin

The pH differential method of Giusti & Wrolstad (2001) was used to determine the total amounts of anthocyanin. The total amount of anthocyanin was expressed as mg L^{-1} in malvidin-3-monoglucoside, which is predominant in red wines. The measurements were made at 520 and 700 nm and the results were calculated according to the following formula.

$$\text{Total anthocyanin(mg/L)} = [(A) \times (\text{MW}) \times (\text{DF}) \times 1000]/[(\epsilon) \times (L)]$$

A: Difference of sample absorbance between pH 1.0 and 4.5, MW: molecular weight, DF: dilution factor, ϵ: molar absorbance coefficient, L: pathlength (cm).

Antioxidant capacity

Changes in the antioxidant capacities of wines were examined by ABTS, DPPH, FRAP, and CUPRAC methods and all results were given as trolox equivalent (μmol trolox mL^{-1}). The ABTS [2,2′-azinobis(3-ethylbenzothiazoline-6-sulphonic acid)] method was applied according to Re *et al.* (1999) and the inhibition rate was calculated according to the following formula.

$$\text{Inhibition rate}(\%) = (\text{Initial absorbance value} - \text{Final absorbance value})/\text{Initial absorbance value}$$

The average percentage inhibition values obtained were transferred to a graph against sample volumes (10, 20, and 30 {L) and linear regression analysis was applied to these data to reach the curve and the equation that defines this curve.

Antioxidant activity by the DPPH (2,2-diphenyl-1-picrylhydrazyl) method was performed according to Katalinić et al. (2004). DPPH free radicals were dissolved in 96% ethanol and 3 mL of this solution was mixed with a 0.2 mL sample. After 15 min, a reading was performed against blank at 517 nm.

FRAP (ferric reducing antioxidant power) method was applied according to Benzie & Strain (1996). For this purpose, respectively, 300 mM sodium acetate with pH 3.6, 10 mM TPTZ (2,4,6-Tris(2-pyridyl)-s-triazine) diluted in 40 mM hydrochloric acid, and 20 mM $FeCl_3 \times 6H_2O$ were mixed at a rate of 10:1:1 and heated to 37 °C. In addition, the 3 mL of FRAP standard was mixed with 0.2 L sample. After 15 min, the absorbance values were measured at 593 nm.

Finally, antioxidant activity was measured according to Özyürek *et al.* (2011) with CUPRAC (cupric reducing antioxidant capacity) method. As much as 10 mM $CuCl_2 \times 2H_2O$ solution, 7.5 mM neocuproine solution, and 1 M ammonium acetate solution were prepared with pH 7.0. A sample of 0.2 mL of wine was mixed with 1 mL and 3.9 mL of distilled water from each standard. The change of colour was measured at 450 nm after 30 min.

Trans-resveratrol, (+)- catechin, and gallic acid

The *trans*-resveratrol, (+)- catechin, and gallic acid quantities of the wines were determined by Shimadzu HPLC-DAD (diode array detector) device according to Downey & Rochfort (2008). The identification of phenolic compounds was obtained by using authentic standards and by comparing the retention times and their visible spectra, while quantification was performed by external calibration with standards. Standard solutions were prepared at 1–50 ppm (parts per million) concentrations, standard curves were formed, and phenolic compound amounts of samples were

used. Gemini Phenomenex C18 (CA, USA): 4.6 mm × 260 mm column was used at two different mobile phases: 10% formic acid in water (solvent A) and 10% formic acid in methanol (solvent B). The flow rate of solvents was 1.0 mL min^{-1} and the gradient conditions were 0 min 18% B, 14 min 29% B, 16 min 32% B, 18 min 41% B, 18.1 min 30% B, 29 min 41% B, 32 min 50% B, 34.5 min 100% B, and 35–38 min 18% B. The results were stated as mg L^{-1}.

Sensory profiles

The organoleptic profiles of control wines and u.v.-C-applied wines were made by 20 expert tasters (10 males, 10 females, 25–45 years old) with blind tasting according to Jakson (2002). The panellists tested the wines in terms of harmony, astringency, astringency aftertaste, bitterness, sourness, sweetness, body, flavour, and colour and evaluated each criterion on a horizontally prepared scale of 10 cm. Wine samples are presented in a completely randomised order. The results of the panellists were collected and interpreted after variance analysis.

Data analysis

The data were subjected to variance analysis in the Minitab18 computer package program. The differences between averages were grouped according to the Tukey test. IBM SPSS version 20.0 was used for Pearson's correlation coefficients' calculation. Each application and analysis was performed in three repetitions and the results were given in the form of standard errors ± average.

Results and discussion

General grape analysis

Brix, total acidity, pH, and density results for the wine after harvest are given in Table 1. The brix values of the grapes were determined in the range of 26.0–24.1, the total acidity values in the range of 6.48–4.52, the pH values in the range of 3.50–3.32, and the density of the grape juices was determined in the range of 1.116–1.105. The values are suitable for a ripe red wine grape.

General wine analysis

pH, total acidity, alcohol, residual sugar, volatile acid, free SO_2, and total SO_2 values of wines given in Table 2 were measured at the intervals of 3.86–3.41, 6.94–5.70, 14.9–14.3, 2.6–1.8, 0.43–0.50, 29–24, and 41–33 from the lowest to the highest respectively. The results of the general analysis of Merlot, Cabernet Franc, Cabernet Sauvignon, and Petit Verdot wines are consistent with the literature (Sartor *et al.*, 2017; Zemzemoglu *et al.*, 2021).

Table 1 General composition of must

Grape varieties	%Brix	Total acidity (mg mL^{-1})*	pH	Density
M	24.1 ± 0.1c	6.47 ± 0.03a	3.36 ± 0.03bc	1.105 ± 1.0b
CF	25.0 ± 0.1b	4.52 ± 0.02c	3.50 ± 0.01a	1.106 ± 0.5b
CS	26.0 ± 0.2a	5.39 ± 0.06b	3.40 ± 0.01b	1.116 ± 0.6a
PV	24.1 ± 0.1c	6.48 ± 0.11a	3.32 ± 0.01c	1.105 ± 0.6b

Different letters in the same column indicate statistical differences at the $P < 0.05$ level. CF, Cabernet Franc; CS, Cabernet Sauvignon; M, Merlot; PV, Petit Verdot.
*In terms of tartaric acid.

Spectrophotometric wine quality analysis

Spectrophotometric wine quality analysis is not only quick and easy to apply but also gives a general idea of the phenolic compounds of wines. Table 3, which provides spectrophotometric wine quality analysis results for Merlot, Cabernet Franc, Cabernet Sauvignon, and Petit Verdot wines, is examined, chemical age 1–2, colour density, colour density SO_2 corrected, ionisation of anthocyanin, acid hydrolysis assay, colour density, monomeric and polymeric anthocyanin parameters were measured at the highest in Merlot wine. This showed that Merlot has more polymeric anthocyanin pigments and that these polymeric forms are resistant to SO_2 bleaching. Compared to the other three varieties, Merlot wine is thought to contain more anthocyanin than expected, which is thought to be associated with the deterioration of anthocyanins with more stable pigment formation as pyranoanthocyanins. Modified Somers assay results of four wine varieties are in the intervals of 0.625–0.465 NU for chemical age 1, 0.085–0.038 NU for chemical age 2, 1614–949 mg L^{-1} for total anthocyanin, 17.327–8.400 AU for colour density, 12.684–10.203 AU for colour density SO_2, 0.743–0.618 NU for hue, SO_2 4.833–3.025 for resistant pigments, and 6.5–5.4% for ionisation of anthocyanin, respectively. The highest tannin content was obtained from Merlot and the lowest from Cabernet Sauvignon wine with the acid hydrolysis method, the highest amount of anthocyanin was obtained from Merlot and the lowest from Petit Verdot wine with the bisulphite bleaching method, colour density was obtained at the highest from Merlot, and at the lowest from Cabernet Franc wine, colour hue was obtained at the highest from Cabernet Sauvignon, and at the lowest from Merlot wine, copigmented anthocyanins were obtained at the highest from Petit Verdot, and at the lowest from Cabernet Franc wine, monomeric

Table 2 General composition of wines

Wines	pH	Total acidity (mg mL^{-1})*	Alcohol (% v/v)	Residual sugar (g L^{-1})	Volatile acidity** (g L^{-1})	Free SO_2 (mg L^{-1})	Total SO_2 (mg L^{-1})
M	3.41 ± 0.01c	6.94 ± 0.06a	14.5 ± 0.0b	2.3 ± 0.1a	0.50 ± 0.02a	26 ± 0.4b	36 ± 2.7b
CF	3.69 ± 0.01b	6.46 ± 0.02b	14.3 ± 0.1c	1.8 ± 0.2b	0.43 ± 0.03b	24 ± 0.7b	33 ± 0.8c
CS	3.86 ± 0.02a	5.70 ± 0.01c	14.8 ± 0.1a	2.6 ± 0.2a	0.50 ± 0.02a	29 ± 1.1a	41 ± 2.5a
PV	3.72 ± 0.01b	5.73 ± 0.03c	14.9 ± 0.1a	2.2 ± 0.2ab	0.45 ± 0.02b	25 ± 0.4b	37 ± 1.9b

Different letters in the same column indicate statistical differences at the $P < 0.05$ level. CF, Cabernet Franc; CS, Cabernet Sauvignon; M, Merlot; PV, Petit Verdot.
*In terms of tartaric acid.
**In terms of sulphuric acid.

Table 3 Spectrophotometric wine quality analysis results of wines

Analysis		Wines			
		M	CF	CS	PV
Modified Somers assay	Chemical age 1 (NU)	0.625 ± 0.002a	0.490 ± 0.005c	0.556 ± 0.001b	0.465 ± 0.004d
	Chemical age 2 (NU)	0.085 ± 0.003a	0.043 ± 0.001c	0.051 ± 0.001b	0.038 ± 0.001d
	Total anthocyanin (mg L^{-1})	949 ± 1.6d	1265 ± 0.8b	1221 ± 1.0c	1614 ± 0.4a
	Colour density (AU)	17.327 ± 0.352a	8.400 ± 0.030d	13.381 ± 0.047c	14.437 ± 0.026b
	Colour density SO_2 corrected (AU)	12.684 ± 0.004a	10.203 ± 0.021d	10.603 ± 0.011c	11.474 ± 0.007b
	Hue (NU)	0.618 ± 0.003c	0.743 ± 0.001a	0.736 ± 0.007a	0.672 ± 0.002b
	SO_2-resistant pigments	4.833 ± 0.006a	3.025 ± 0.056d	3.385 ± 0.079b	3.225 ± 0.004c
	Ionisation of anthocyanin (%)	6.5 ± 0.07a	5.8 ± 0.02b	5.4 ± 0.01c	5.4 ± 0.01c
Acid hydrolysis assay	Tannins (g L^{-1})	3.12 ± 0.04a	1.90 ± 0.05b	1.80 ± 0.02c	1.92 ± 0.01b
Bisulphite bleaching method	Anthocyanins (mg L^{-1})	205.625 ± 1.4a	182 ± 1.0b	97.125 ± 0.8c	34.125 ± 0.4d
Colour determinations	Colour density	2.857 ± 0.010a	1.758 ± 0.015d	1.917 ± 0.023c	1.998 ± 0.002b
	Colour hue	0.553 ± 0.002d	0.648 ± 0.003b	0.689 ± 0.003a	0.594 ± 0.004c
Copigmented, monomeric, polymeric, and total anthocyanin determination	Copigmented anthocyanins	7.851 ± 0.007b	7.178 ± 0.076c	7.218 ± 0.085c	8.248 ± 0.003a
	Monomeric anthocyanins	4.215 ± 0.005a	2.282 ± 0.0563c	2.649 ± 0.0728b	2.553 ± 0.005b
	Polymeric anthocyanins	0.839 ± 0.006a	0.515 ± 0.001d	0.552 ± 0.003b	0.536 ± 0.007c

Different letters in the same line indicate statistical differences at the $P < 0.05$ level.
AU, Absorbance units; CF, Cabernet Franc; CS, Cabernet Sauvignon; M, Merlot; NU, No units; PV, Petit Verdot.

anthocyanin was obtained at the highest from Merlot, and at the lowest from Cabernet Franc wine ($P < 0.05$). The results are in line with previous research results (Cliff *et al.*, 2007; Basalekou *et al.*, 2017). The analyses in Table 3 are practical analyses that are often used especially in wineries, and via this general ideas about the quality of wines can be reached. Today, there are a number of analytical methods for the analysis of grape and wine phenolics in the literature. However, the results may vary significantly depending on the analytical methods used, and a direct comparison between the methods is not possible. In our research, analysis of Table 3 was carried out to give an overview of wines, and more detailed methods specified in the method section were used to determine the effects of u.v. application on total phenolic compound, antioxidant capacity, and anthocyanin levels.

Total phenolic compound, total anthocyanin, and antioxidant capacity analysis

In Merlot, Cabernet Franc, Cabernet Sauvignon, and Petit Verdot wines, total phenolic compound, total anthocyanin, and antioxidant capacity levels were examined before and after application in order to determine the effect of u.v.-C radiation.

As can be seen from Fig. 1, the highest total phenolic compound content in the control group was detected in Cabernet Sauvignon (3507 mg GAE per L) wine and the lowest in Cabernet Franc (2912 mg GAE per L) wine ($P < 0.05$). The 45-min u.v.-C application resulted in an increase in the total phenolic compound levels of all wines ($P < 0.05$). The highest post-application increased rate was observed in Merlot wine with 8.14%, and the lowest increased rate was observed in Petit Verdot wine with 0.51% ($P < 0.05$).

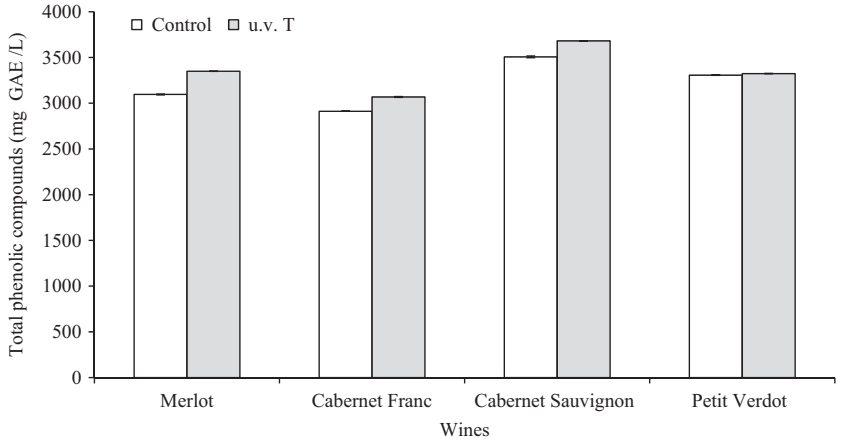

Figure 1 Total phenolic compounds of control and treatment wines (mg gallic acid equivalent (GAE) L^{-1}) $P < 0.05$ level. u.v. T:45-min ultraviolet (u.v.) treatment.

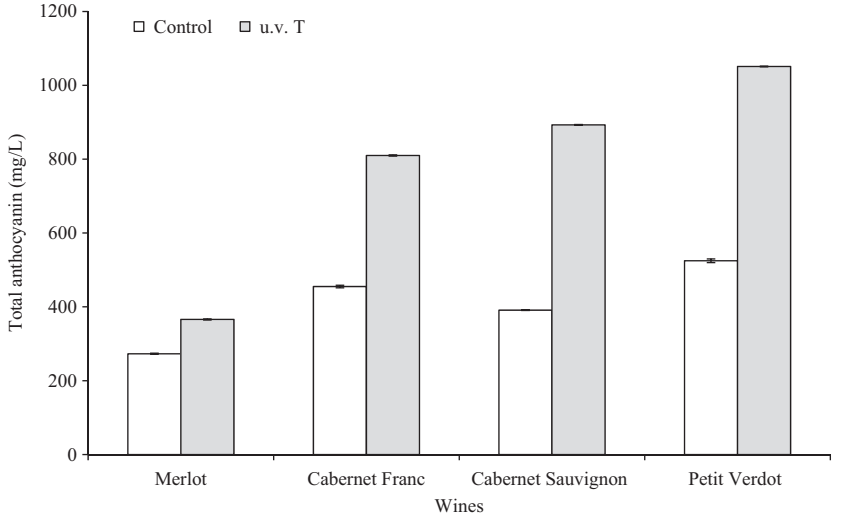

Figure 2 Total anthocyanin of control and treatment wines (mg L^{-1}) $P < 0.05$ level. u.v. T:45-min u.v. treatment.

Ginjom *et al*. (2010) measured total phenolic compound contents as 1886–3610 mg L^{-1} in Merlot wines, as 2739–1673 mg L^{-1} in Cabernet Sauvignon wines; Di Profio *et al*. (2011) measured it as 2544–1071 mg L^{-1} in Cabernet Franc wines and Padilha *et al*. (2017) measured it as 2144 mg L^{-1} in Petit Verdot wines. In our research, all values, except of Merlot, were found to be higher in control wines and u.v.-applied wines than in previous research. It is known that the total phenolic compound content varies due to differences in the method of analysis, ecology, cultivation, and vinification techniques.

As with the total phenolic compound results, the contents of total anthocyanins showed impressive increases as a result of u.v.-C application (Fig.2). Anthocyanin levels in the range of 525 (Petit Verdot)–273 mg L^{-1} before u.v.-C application increased to 1051 (Petit Verdot)–366 (Merlot) mg L^{-1} after u.v. application ($P < 0.05$). The highest increase was observed in Petit Verdot wine by 100%, while the lowest increase was observed in Merlot wine, even so a high increase of 34% ($P < 0.05$).

Antioxidant capacity results measured by ABTS, DPPH, FRAP, and CUPRAC methods can be examined from Table 4. Like increases in total phenolic compound and anthocyanin levels, antioxidant capacity levels increased after u.v.-C application ($P < 0.05$). In all four methods, the highest antioxidant activity value was measured in Cabernet Sauvignon wines, as in the total phenolic compound content. It was also reported by Ivić *et al*. (2021) that the antioxidant content of samples with a high total phenolic compound content is also high. ABTS levels of control wines which were out of the application were measured to be in the range of 32.48–28.64 μmol trolox mL^{-1}, DPPH levels in the range 15.21–11.9 μmol trolox mL^{-1}, FRAP levels in the range of 7.61–3.21 μmol trolox mL^{-1}, and CUPRAC levels in the range of

Table 4 ABTS [2,2′-azinobis(3-ethyl-benzothiazoline-6-sulphonic acid)], DPPH ((2,2-diphenyl-1-picrylhydrazyl), FRAP (ferric reducing antioxidant power), and CUPRAC (cupric reducing antioxidant capacity) of control and ultraviolet (u.v.) treatment wines

	ABTS (μmol trolox mL^{-1})		DPPH (μmol trolox mL^{-1})		FRAP (μmol trolox mL^{-1})		CUPRAC (μmol trolox mL^{-1})	
Wines	**Control**	**U.v. T**	**Control**	**U.v. T**	**Control**	**U.v. T**	**Control**	**U.v. T**
M	29.55 ± 0.41Ab	33.21 ± 0.05Ab	14.02 ± 0.90Bb	17.85 ± 0.15Ab	6.28 ± 0.98Bb	7.93 ± 0.24Ab	43.09 ± 1.11Ba	48.12 ± 0.81Ab
CF	29.03 ± 1.00Bb	30.89 ± 0.73Ac	12.10 ± 0.21Bc	15.61 ± 0.88Ac	4.21 ± 0.32Bc	6.87 ± 0.53Ac	37.38 ± 0.50Ab	40.18 ± 0.29Ac
CS	32.48 ± 0.68Ba	35.98 ± 0.84Aa	15.21 ± 0.91Ba	18.02 ± 0.93Aa	7.61 ± 0.84Ba	9.09 ± 0.92Aa	43.85 ± 1.67Ba	51.64 ± 0.92Aa
PV	28.64 ± 0.15Bb	30.61 ± 0.58Ac	11.90 ± 0.24Bc	12.30 ± 0.68Ad	3.21 ± 0.59Bd	3.88 ± 0.71Ad	36.23 ± 1.02Bb	39.47 ± 0.61Ac

Different lowercases in the same column and uppercases in the same line indicate statistical differences at the $P < 0.05$ level. U.v. T:45-min ultraviolet (u.v.) treatment. CF, Cabernet Franc; CS, Cabernet Sauvignon; M, Merlot; PV, Petit Verdot.

43.85–36.23 μmol trolox mL^{-1}. On the other hand, after UV application, ABTS levels increased to the range of 35.98–30.61 μmol trolox mL^{-1}, DPPH levels increased to the range of 18.02–12.30 μmol trolox mL^{-1}, FRAP levels increased to the range of 9.09–3.88 μmol trolox mL^{-1}, and CUPRAC levels increased to the range of 51.64–39.47 ($P < 00.05$).

Proportionally, the highest increase was observed in Merlot by 12% in ABTS, 29% in Cabernet Franc in DPPH method, 63% in Cabernet Franc, and 18% in CUPRAC method in Cabernet Sauvignon.

Previous studies carried out on the same varieties as our research determined phenolic compound contents as 4230–32 mg GAE L^{-1}, the total anthocyanin content as 930–167 mg L^{-1} (Hogan *et al*., 2009; Vujovic *et al*., 2016; Jiang & Zhang, 2018; St Minkova *et al*., 2019); the antioxidant capacity level was determined to be 25.4–24.2 trolox Eq. mM with the ABTS method, 24.9–21.2 Fe^{2+}Eq with the FRAP method (Garaguso & Nardini, 2015); and at the level of 196 mg of vitamin C equivalent (VCE)/100 g with the DPPH method (Floegel *et al*., 2011). Our results are in the same trend as the literature.

Correlation analysis was performed between antioxidant capacity parameters for each type analysed and the results are given in Table 5. With the ABTS method, it is understood that all correlation coefficients, except FRAP and CUPRAC, are important at $P < 0.01$. Correlation analysis results showed that these methods are almost comparable and interchangeable in characterising the antioxidant capacities of wines. Other research studies using antioxidant capacity measurement methods have also shown a high correlation (Alañón *et al*., 2011; Jiang & Zhang, 2012).

Table 5 Pearson's correlation coefficients of antioxidant capacity (ABTS [2,2′-azinobis(3-ethyl-benzothiazoline-6-sulphonic acid)], DPPH (2,2-diphenyl-1-picrylhydrazyl), FRAP (ferric reducing antioxidant power), and CUPRAC (cupric reducing antioxidant capacity)

	ABTS	**DPPH**	**FRAP**	**CUPRAC**
ABTS	1			
DPPH	0.901†	1		
FRAP	0.885†	0.988*	1	
CUPRAC	0.780†	0.971*	0.976*	1

*Correlation is significant at the 0.01 level.
†Correlation is significant at the 0.05 level.

Trans-resveratrol, (+)-catechin, and gallic acid

As seen from Table 6, u.v.-treated wines had a higher content of all phenolic compounds compared to the control ($P < 0.05$). *Trans*-resveratrol was measured in the range of 1.53–2.93 mg L^{-1} in control wines and 1.69–3.25 mg L^{-1} in u.v. treatment wines. After UV treatment, *trans*-resveratrol contents increased by 10.46%, 16.47%, 14.12%, and 10.92% in M, CF, CS, and PV wines compared to the control group, respectively. The highest increase was from Cabernet Franc wine. Catechin contents increased by 13.41%, 10.87%, 6.45%, and 3.33% in M, CF, CS, and PV wines compared to the control group, respectively. This time, the highest increase in catechin content was seen in Merlot wine. And finally, gallic acid contents increased by 7.14%, 4.59%, 4.06%, and 6.48% in M, CF, CS, and PV wines compared to the control group. As can be seen from the increased percentages, the phenolic compound most affected by the UV application is *trans*-resveratrol. Petit Verdot wine is the one that contains the most phenolic compounds among wine varieties. *Trans*-resveratrol, (+)-catechin, and gallic acid levels, which are known to be beneficial to health and increase in their amounts with stress factors, have increased significantly in our study. Consumers especially prefer to drink red wine because of its resveratrol content. Indeed, in our study, even higher resveratrol levels were obtained without disturbing the sensory profile. The results of the control group phenolic compound content of the research are in the same trend as the literature (Dimitrov *et al*., 2019; Balanov *et al*., 2021).

According to the results of the study, u.v.-C application was found to be effective on total phenolic compound, total anthocyanin, antioxidant capacity, and individual phenolic compounds. U.v., especially u.v.-C

Table 6 *Trans*-resveratrol, (+)-catechin, and gallic acid content of control and ultraviolet (u.v.) treatment wines

	Trans-resveratrol (mg L^{-1})		(+)- Catechin (mg L^{-1})		Gallic acid (mg L^{-1})	
Wines	**Control**	**U.v.**	**Control**	**U.v.**	**Control**	**U.v. T**
M	1.53 ± 0.30Bd	1.69 ± 0.05Ad	28.04 ± 0.70Bc	31.80 ± 0.17Ad	42.57 ± 0.80Bc	45.61 ± 0.34Ad
CF	1.70 ± 0.70Bc	1.98 ± 0.73Ac	32.20 ± 0.20Bb	35.70 ± 0.80Ac	45.71 ± 0.30Bb	47.81 ± 0.63Ac
CS	2.62 ± 0.59Bb	2.99 ± 0.84Ab	35.21 ± 0.80Bb	37.48 ± 0.85Ab	46.99 ± 0.80Bb	48.90 ± 0.80Ab
PV	2.93 ± 0.16Ba	3.25 ± 0.58Aa	39.92 ± 0.28Ba	41.25 ± 0.72Aa	49.50 ± 0.39Ba	52.71 ± 0.91Aa

Different lowercases in the same column and uppercases in the same line indicate statistical differences at the $P < 0.05$ level. U.v. T:45-min UV treatment. M, Merlot; CF, Cabernet Franc; CS, Cabernet Sauvignon; PV, Petit Verdot.

lights, is a stimulating abiotic stress factor for vines and adaptation to stress factors is achieved by increasing the synthesis of phenolic compounds (Wrzaczek *et al*., 2011). The stimulating effects of u.v.-C on plant secondary metabolism have been linked to the stimulation of the production of reactive oxygen species (ROS) with this light (Urban *et al*., 2016). Therefore, in order to prevent cell damage, even death, it is imperative that the enzymatic antioxidant substance balance the excess ROS produced. Another reason why UV application causes an increase in phenolic compounds is that the genes involved in phenylpropanoid, flavonoid pathway, and stilbene biosynthesis increase in activity in response to u.v. (Sheng *et al*., 2018) and therefore the amount of phenolic compounds increases as observed in our research results.

Unfortunately, there are no studies in the literature examining the effect of u.v.-C on wine. Only in our previous research, we applied u.v.-C to red wines during maceration and detected an increase in the same parameters (Tahmaz & Söylemezoğlu, 2017). U.v. applications in the literature are usually focused on post-harvest and a small part of it is on grape juice. Sheng *et al*. (2018) kept table grapes for 28 days after u.v. application and stated that the application caused an increase in phenolic compounds. Another study said wines made from UV-applied grapes would have a higher amount of phenolic compounds (Cantos *et al*., 2003). Kaya *et al*. (2018) and Müller *et al*. (2014) stated that the application of u.v.-C to grape juices can inactivate the enzyme polyphenol oxidase (PPO), so that it can be used to prevent microbial and enzymatic deterioration with loss of taste, appearance, and nutritional values caused by the PPO enzyme. Our research results have shown that u.v.-C can be used in winemaking technology to increase the bioactive compound content of wines and therefore their taste and colour character.

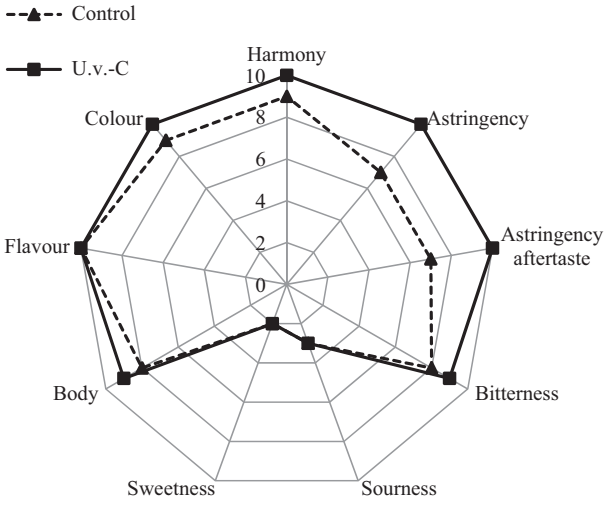

Figure 3 Sensory profile of Cabernet Franc in control and u.v.-C treatment wines. All data are expressed as mean value. Significance at $P < 0.05$.

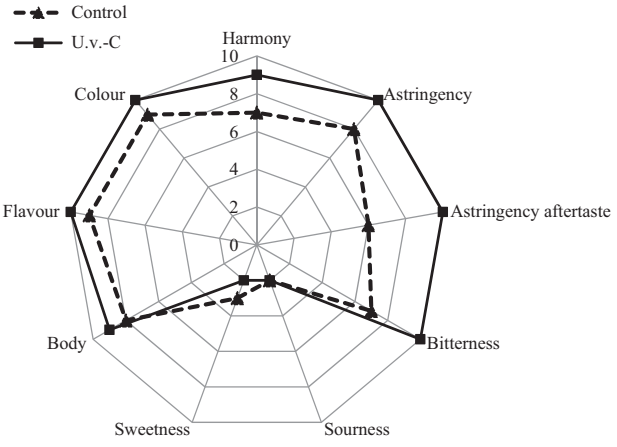

Figure 4 Sensory profile of Cabernet Sauvignon in control and u.v.-C treatment wines. All data are expressed as mean value. Significance at $P < 0.05$.

Sensory profiles

The change in organoleptic profiles of wines with the u.v.-C effect is given in Fig. 3 for Cabernet Franc, Fig. 4 for Cabernet Sauvignon, Fig. 5 for Merlot, and Fig. 6 for Petit Verdot. Using nine identifiers, the sensory profiles results of control wines and u.v.-C-applied wines were transferred to a spider graph.

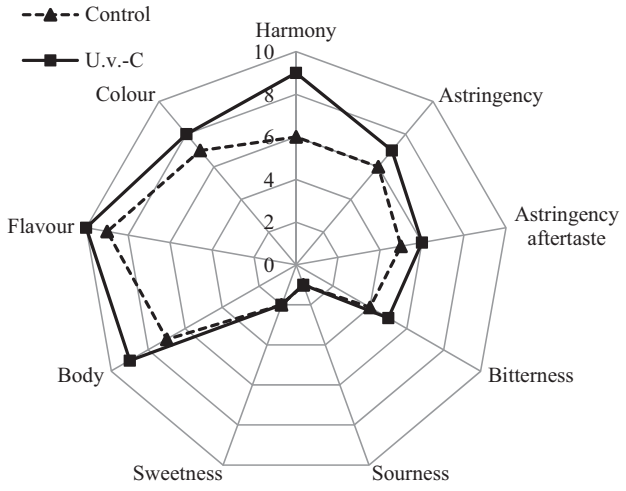

Figure 5 Sensory profile of Merlot in control and u.v.-C treatment wines. All data are expressed as mean value. Significance at $P < 0.05$.

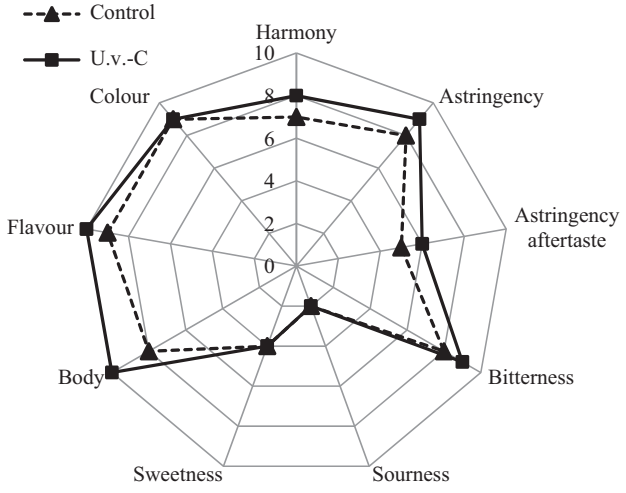

Figure 6 Sensory profile of Petit Verdot in control and u.v.-C treatment wines. All data are expressed as mean value. Significance at $P < 0.05$.

Panelists concluded that harmony, astringency, astringency aftertaste, bitterness, and body parameters increased in all wine varieties as a result of u.v. application. The criteria for sourness and sweetness did not change after application in all 4 wines. In addition, after u.v. application, colour criteria did not change in Cabernet Sauvignon and Petit Verdot. According to the analysis, u.v.-C application has a positive effect on the organoleptic quality parameters preferred by the tasters ($P < 0.05$).

Conclusions

As far as we know, this research is the first to examine changes in *trans*-resveratrol, (+)-catechin, and gallic acid content, total phenolic compound, total anthocyanin, and antioxidant capacity with ABTS, DPPH, FRAP, and CUPRAC methods by applying u.v.-C to wines that have completed fermentation. Today, an increase in the orientation to foods and beverages, which contain more intense antioxidant compounds, is an inevitable fact. Consumers prefer products that are beneficial to health in addition to being flavourful. The results show that u.v.-C application gave the intended results by causing an increase in all parameters examined. In addition to examining the contents of phenolic compounds by spectrophotometric and HPLC methods, sensory analyses were carried out with blind tasting of wines and the wines that attracted the attention of tasters were wines with u.v.-C applied method. In this way, wines that contain more antioxidant compounds and are preferred as organoleptics have been obtained in all four varieties. It is thought that both sensory profiles and wines with increased health-beneficial compounds obtained as a result of the research will be the first choice of consumers. Testing future research on wines from other grape varieties and then performing it on more individual phenolic compounds may provide a better understanding of the u.v.-C effect. Additionally, the possibility of market development in this direction can also be explored by organising blind tasting panels, where u.v.-applied wines are offered to the consumer as an option.

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Ethical guidelines

Ethics approval was not required for this research.

Author contribution

Hande Tahmaz: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Funding acquisition (lead); Investigation (lead); Methodology (lead); Resources (lead); Supervision (lead); Writing – original draft (lead); Writing – review & editing (lead). **Damla Yüksel Küskü:** Investigation (supporting).

Peer review

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Data availability statement

The data that support the findings of this study are openly available in [repository name e.g. "figshare"] at http: //doi.org/[doi], reference number [reference number].

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