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IMPACT OF UV-C RADIATION ON THE SENSORY PROPERTIES OF RED WINES

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ABSTRACT

This pilot study investigated the influence of ultraviolet-C (UV-C) radiation on the sensory properties of two red wine varieties, Dunaj from Slovakia and Lasina Crna from Croatia. The wines were exposed to three UV-C treatments and were compared to the untreated control samples using sensory evaluation, electronic eye color analysis. Descriptive sensory scoring showed a clear varietal response: Dunaj showed improved color scores in all treated variants and a slight aroma improvement after the longest exposure, whereas Lasina Crna showed reduced aroma quality and lower color intensity after shorter treatments. Electronic eye analysis confirmed strong varietal differentiation as well; principal component analysis (PCA) based on chromatic variables explained 98.46% of the total variance by PC1 and 1.2% by PC2. The initial alcohol and total acid contents were 12.45% and 4.90 g/L for Lasina Crna and 13.60% and 4.55 g/L for Dunaj variety confirming that selected wines represented different matrices for UV-C treatment evaluation. The results indicate that UV-C treatment may be useful for selected red wine matrices, but the treatment should be optimised separately for each variety due to the some exposure could negatively affect aroma and color quality of red wines.

Keywords: wine variety, chromatic profile, CIEL*a*b* coordinates, PCA, color of wines

INTRODUCTION

Food preservation primarily aims to reduce enzymatic and microbial activity while maintaining product quality and extending shelf life. Thermal processing has been widely used to preserve plant-based products, but it can also cause losses of heat-sensitive nutrients and quality attributes. Therefore, alternative non-thermal technologies are increasingly being investigated. Ultraviolet-C (UV-C) treatment has been shown to preserve quality and minimize nutrient degradation in selected vegetable-based liquid products **(Tchonkouang *et al.*, 2023)**. Continuous-flow UV-C treatment is also considered to be a promising alternative to heat treatments, although reactor design remains challenging because UV light has a low penetration depth in liquid foods with high absorbance, suspended particles and variable residence time distribution **(Gayan *et al.*, 2014)**.
The traditional approach for microbiological stabilisation of wine is the addition of sulfur dioxide, which acts both as an antimicrobial agent and as an antioxidant. However, alternative stabilisation methods are being investigated because sulfur dioxide can cause sensitivity reactions in susceptible consumers and because the market increasingly demands wines with reduced preservative addition. **Matias *et al.* (2016)** tested UV-C radiation as an innovative method that could help reduce sulfur dioxide application in red wines. In their study, red wine with a very low sulfur dioxide content was treated with UV-C doses of 424 J/L and 778 J/L and compared with a control wine supplemented with 30 mg/L sulfur dioxide during four months of storage. The lower UV-C dose was effective for microbiological control, increased color intensity and did not negatively affect wine flavour or taste **(Matias *et al.*, 2016)**.
Pachnowska *et al.* (2025) emphasized that controlling microorganisms during vinification is a critical factor for successful wine production and that novel methods for reducing sulfite application are needed. UV-C irradiation has been proposed as an alternative for reducing viable microbial counts in wine and grape juice, but it may also alter wine chemistry. They therefore examined iron oxide-silica core-shell nanomaterial functionalized with TiO_2 in UV-C treatment of white and red wines. Results showed that the nanomaterial can modulate the effects of UV-C treatment on yeast viability and polyphenol content, with treatment effectiveness depending on wine type. These findings indicate that UV-C-based technologies may be used in winemaking, but their impact on polyphenols and alcohol content must be controlled by the wine matrix **(Pachnowska *et al.*, 2025)**.
Diesler *et al.* (2019) investigated UV-C treatment for chemical and sensory wine properties as well. Their study showed that UV-C may affect aromatic compounds and color pigments, which is important when treatment is applied before or during winemaking **(Diesler *et al.*, 2019)**.
Red wines typically contain high levels of phenolic compounds and antioxidant capacity, and both can be modified by vinification techniques. **Tahmaz and Soylemezoglu (2017)** compared classical maceration, cold maceration combined with UV irradiation and thermovinification combined with UV irradiation. Total phenolic content (TPC), total anthocyanins (TA) and Trolox equivalent antioxidant capacity (TAA) were determined, selected components such as catechin, epicatechin, rutin, quercetin and resveratrol isomers were measured. The highest levels of most phenolic compounds, TPC, anthocyanins and TAA were determined in wines produced by thermovinification combined with UV treatment, indicating that UV-assisted vinification can affect phenolic extraction and antioxidant properties **(Tahmaz and Soylemezoglu, 2017)**.
UV-C treatment of grape must with an absorbed UV-C dose of 2 kJ/L and pasteurization of grape must, did not lead to an off-flavour formation in the resulting wines **(Golombek *et al.*, 2021)**. Changes in volatile compounds, such as terpenes and C13-norisoprenoids were observed. Model experiments showed that linalool was relatively stable, β-damascenone degraded. The identification of unknown products formed at UV-C induced reactions of β-damascenone is thought to be interesting for future studies. Although changes were significant only at high UV-C doses, they may act as indicator compounds for product stability. Formation of furan compounds, as an efficient cooling system avoiding overheating during UV-C treatment was another result of this research of **Golombek *et al.* (2021)**.
Several UV-treated foods are already approved for the market, including UV-treated milk. In this case, milk is exposed to ultraviolet radiation under turbulent-flow conditions, which increases vitamin D_3 concentration via 7-dehydrocholesterol conversion to cholecalciferol. In the European authorization, UV radiation is defined as treatment with ultraviolet light in the wavelength range from 200 nm to 310 nm and an energy input of 1,045 J/L **(Commission Implementing Decision (EU) 2016/1189)**.

The aim of this model study was to monitor selected sensory properties, namely color, aroma and oxidation, using a trained sensory panel and electronic-eye color analysis in two red wines of different varietal and geographic origin after UV-C irradiation treatment.

MATERIAL AND METHODS

Material

Two red wine varieties were selected for this pilot study: Dunaj originated from Slovakia and Lasina Crna from Croatia. These varieties were chosen because they represent different genetic, geographical and enological backgrounds and were expected to respond differently to UV-C exposure due to differences in color intensity, phenolic structure and aromatic profile. Wine batch of each variety was obtained directly from wine producers. In total, eight experimental wine variants were evaluated: two untreated controls and six UV-C-treated samples.

Dunaj

Dunaj is a Slovak red grape variety derived from the cross (Svatovavrinecke/Saint Laurent x Blauer Portugieser) x Alibernet.
It forms medium to large and moderately compact bunches with medium to large dark blue to almost black berries covered by a waxy layer.
The variety ripens medium-late, usually in late September, and is considered to be relatively tolerant to diseases and low temperatures, which makes it suitable for more northern wine-growing locations.
Dunaj wines are usually dark red, full-bodied and rich in extract and tannins, with aromas of wild berries, sour cherries and chocolate.

Lasina Crna (LC)

Lasina Crna is an indigenous Croatian red grape variety originating from northern Dalmatia, especially from the Skradin and Drnis area within the wider Skradin-Promina wine region. It is an old Dalmatian variety of presumed local selection, with no clearly identified parent varieties.
Lasina Crna forms medium-sized, compact and often irregular bunches with medium-sized dark red to bluish berries, thin skin and a pronounced waxy coating. The variety ripens from medium-late to late and is more sensitive to drought and diseases, which requires careful vineyard management and reduced yields.
The wine is generally light in color and alcohol than many other red wines, with pronounced freshness and aromas of cherry, raspberry and spice; it is sometimes described as the Dalmatian Pinot noir.

METHODS

For wine irradiation, a flow-through quartz germicidal UV-C lamp was used (LED UV6, Philips, the Netherlands; 6 W). The lamp was positioned in the center of the flow-through device, while the wine circulated around the lamp in a 5 mm liquid layer. Radiation energy was expressed in joules (J), by the formula $E = P \times t$, where P is lamp power in watts (W) and t is exposure time in seconds (s). The applied radiation energies were 4 950 J, 2 382 J and 1062 J.
The wine samples were treated with UV-C light at three exposure times. The sample codes were set up as follows: LASINA CRNA: sample 0 represents the sample with no irradiation, sample 1 (13.45 min. of irradiation), sample 2 (6.37 min.), sample 3 (2.57 min.). Similarly DUNAJ: sample A represents Dunaj sample with no irradiation, sample B (13.45 min.), sample C (6.37 min.), sample D (2.57 min.).

Sensory evaluation of wines was performed by a panel consisted of five trained and certified adult evaluators under controlled laboratory conditions at the Institute of Horticulture of the Faculty of Horticulture and Landscape Engineering, SUA. Age of evaluators was not used as an inclusion criterion for panel selection, which can be considered to be, together with the number of panelists a limitation of this pilot sensory design.
The assessment used a simplified difference-from-control protocol prepared for this pilot study, because its objective was to identify the direction and intensity of changes caused by UV-C treatment rather than to provide a full descriptive sensory profile. The variables color, aroma and oxidation were selected because they are directly related to the expected effects of UV-C irradiation on wine pigments, volatile compounds and photo-oxidative reactions **(Diesler *et al*., 2019; Cvetkova *et al*., 2024)**. Each treated sample was compared to its corresponding untreated control and scored on a scale from -5 to +5, where negative values indicated deterioration and positive values indicated improvement.

Analysis of color profiles by electronic eye

Color profiles were analysed using an IRIS VA 400 electronic eye (Alpha M.O.S., Toulouse, France) equipped with a complementary metal oxide semiconductor (CMOS) camera in a closed cabin under controlled light conditions. After automatic color calibration with a certified color checker, images of the wine samples placed in weighing boats were recorded in triplicate (n = 3). Only colors with a representation higher than 1% were included in further analysis.
Statistical analysis was applied to the electronic eye color data. Color spectra were statistically analysed using AlphaSoft software (Alpha M.O.S., Toulouse, France). The results were expressed as red-green-blue (RGB) values and as coordinates in the CIEL*a*b* color space, where L* represents lightness, a* represents the green-red axis and b* represents the blue-yellow axis (RGB Color Code Color converter). Principal component analysis (PCA) was used because the colorimetric dataset contained multiple correlated chromatic variables, whereas the sensory data were obtained as descriptive panel scores in a pilot design and were therefore interpreted separately.

FTIR Analyses

Alcohol content, total sugar, pH and total acidity, as the basic initial chemical parameters of wines, were determined using an ALPHA (FTIR) analyser (Bruker Optik GmbH, Ettlingen, Germany) with an attenuated total reflectance (ATR) measurement procedure. The analyser was calibrated for wine, using calibration data from more than 2,000 red and white wines, with technical support from OK Servis BioPro, Ltd. The calibration spectra and reference-value settings were provided by the accredited DAkkS Institute Heidger (Osann-Monzel, Germany. Before measurement, the flow-through cell was rinsed with deionized water and a blank was measured. Approximately 20 mL of each wine sample was injected into the flow-through cell, heated to 40 °C and analysed. FTIR results were used for the initial characterization of selected wines; 3 analytical measurements per each chemical parameter were determined.

RESULTS AND DISCUSSION

UV-C light is one of the non-thermal technologies investigated for liquid foods and grape-derived products because it can reduce microbial populations while avoiding heat treatment **(Gayan *et al*., 2014; Tchonkouang *et al*., 2023)**. Some studies showed that UV-C treatment can affect turbidity, aroma compounds, pigments and phenolic composition, so its application in wine should be evaluated according to the specific matrix and treatment dose **(Czako *et al*., 2017; Diesler *et al*., 2019; Pachnowska *et al*., 2025)**. **Czako *et al*. (2017)** tested the effect of UV-C radiation at 254 nm on turbidity, microbial count and sensory properties of grape juices. Their results indicated that UV-C treatment of grape juice can be problematic because higher UV-C intensity increased turbidity and negatively affected sensory properties, particularly smell and taste. Their results show that UV-C treatment should be optimised for each liquid matrix **(Czako *et al*., 2017)**.
The initial chemical characteristics of our two red wine varieties, selected for sensory model testing were different. Lasina Crna contained 12.45% alcohol, 4.90 g/L total acids, pH of wine was 3.27 and total sugar 4.45 g/L. In case of Dunaj variety, 13.60% alcohol and 4.55 g/L total acids were measured, pH was 3.59 and total sugar 2.05 g/L. These differences confirmed that two wines represented different matrices for UV-C treatment evaluation.

Sensory evaluation of wines

For Dunaj variety, UV-C treatment improved the color score in all treated variants compared to the untreated control (Figure 1). The strongest positive color effect was observed in sample B, corresponding to the longest exposure time of irradiation 13.45 min. Aroma also showed a slight positive shift in sample B, whereas two shorter treatments (sample C, D) obtained lower aroma scores. Also mild oxidation was observed in samples C,D, while B sample showed the lowest oxidation effect among treated Dunaj samples. These descriptive results suggest that the longest UV-C exposure used in this pilot study stabilized the visual impression of Dunaj with no negative sensory effect.

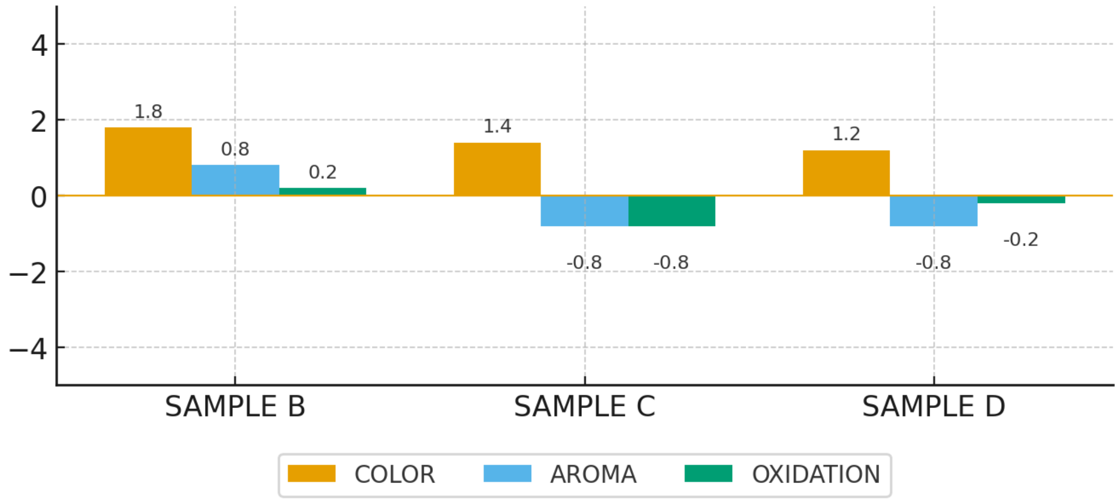

Figure 1 Dunaj variety: average deviations in sensory scoring compared to the untreated control.
*Note: Dunaj variety comparison of control sample with: **B sample** irradiated for 13.45 min., **C sample** 6.37 min., **D sample** 2.57 min.*

For Lasina Crna variety, UV-C treatment showed less favorable sensory response (Figure 2). In sample 1, it was proved only a slight positive color effect (+0.20), whereas samples 2 and 3 showed worse color impression than the untreated control (1). Aroma decreased in the shorter treatments (sample 2, 3), indicating that the aromatic profile of Lasina Crna was sensitive to UV-C exposure. This response may be related to photodegradation of volatile compounds such as terpenes, phenols or esters and to degradation or transformation of anthocyanins under UV-C light. Oxidation scores decreased in all treated samples.
The comparison of two selected varieties showed that UV-C radiation produced matrix-dependent effects. Dunaj responded with improved color intensity and slight aroma enhancement, especially during longer treatment, Lasina Crna showed aroma deterioration and reduced color intensity and only slight improvement of aroma and color during the longest treatment (sample 1). This supports the need for variety-specific UV-C protocols, because the same exposure regime can produce beneficial effects in one red wine matrix and negative sensory effects in another.

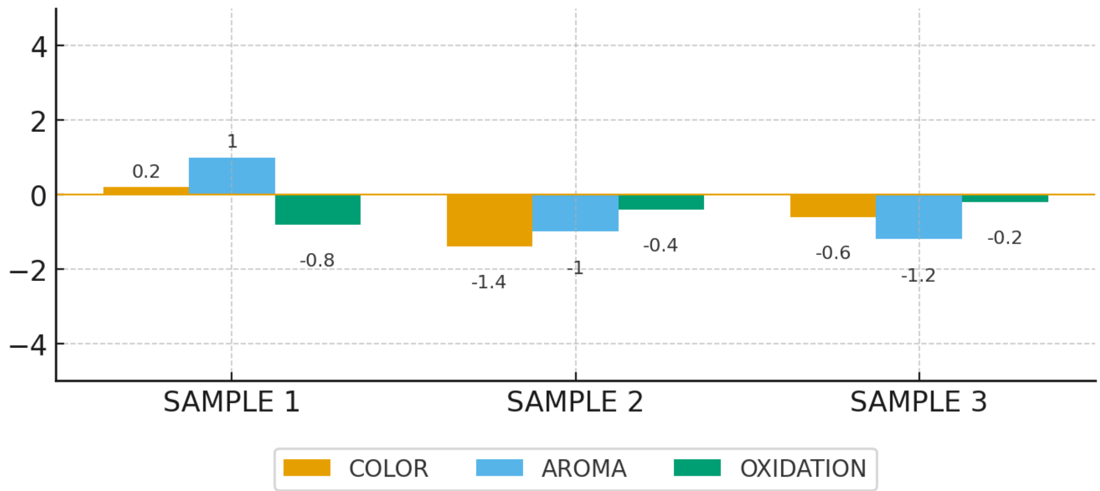

Figure 2 Lasina Crna variety: average deviations in sensory scoring compared to the untreated control
*Note: Lasina Crna variety comparison of control sample with: **sample 1** irradiated for 13.45 min., **sample 2** irradiated for 6.37 min, **sample 3** irradiated for 2.57 min.*

UV-C is a high-energy light source and can promote photo-induced oxidation reactions. Formation of reactive oxygen species during UV-C treatment of wine can be reduced by antioxidants that scavenge reactive oxygen species or interact with products of photo-induced oxidation reactions. **Cvetkova *et al.* (2024)** reported that UV-C doses higher than 1 kJ/L increased color intensity and oxidised and burnt odor attributes in white wines. Increasing UV-C doses promoted acetaldehyde and 2-aminoacetophenone formation and degradation of C13-norisoprenoids, higher alcohols, monoterpenes and esters. In that study, SO_2 did not act as an effective antioxidant during UV-C treatment, hydrolysable tannins reduced oxidation effects (**Cvetkova *et al.*, 2024**). It can help explain why UV-C treatment may improve visual properties while risking aroma deterioration.
Diesler *et al.* (2019) reported oxidative reactions in grape must after its UV-C treatment. UV-C-induced color bleaching indicated degradation of colors, and decreases in beta-damascenone and linalool content were detected in wines from UV-C-treated must. Trained sensory panels did not detect off-flavours at doses relevant for microbial inactivation between 1.0 kJ/L and 3.0 kJ/L. It can indicate that stabilisation and sensory preservation may be achievable only within a limited treatment.
Dunaj variety showed higher stability under UV-C effect and even a tendency toward improvement of selected sensory characteristics, especially color and aroma after 13.45 min. of UV-C treatment. This response may be associated with its darker color, richer extract and tannin structure, which can provide more resilient matrix for UV-C application. However, this interpretation should be treated as descriptive because phenolic composition was not measured in detail in the present pilot study. Anthocyanins are important compounds in wines, they strongly affect color and contribute to the perception of red wine quality. UV-C can induce secondary metabolism in grapes and may affect anthocyanin profiles. **Gindri *et al.* (2022)** exposed Cabernet Sauvignon grapes after harvest to 0, 2 or 3 kJ/m^2 UV-C radiation and detected that wine produced from grapes irradiated with 3 kJ/m^2 showed increased color. This effect was associated with increases in total anthocyanin monomers, pyranoanthocyanins, direct condensation products and acetaldehyde-mediated condensation products, and the treated wine received higher sensory scores for visual color, aroma and taste (**Gindri *et al.*, 2022**).

Results of color analysis of wines by electronic eye

Electronic eye color analysis of our results confirmed varietal differentiation as well. The color spectra of the analysed samples contained 10 to 15 colors with representation higher than 1%. The largest number of detected colors was detected in Lasina Crna /sample 1, namely 15 colors, while Dunaj samples (C, D) contained only 10 colors. In Lasina Crna samples treated with UV-C light, the most represented color was coded as 2116 (Cordovan). This color was also identified in the untreated control sample, but the most represented color in control (sample 0) was coded as 1860 (Deep coffee).

In the Dunaj samples, the main identified color was 1621 (Wenge), followed by 1877 (Pastel brown).

The CIEL*a*b* results in Table 1 show differences in a* and b* coordinates between varieties. Lasina Crna samples showed higher a* values, indicating stronger red components, and higher b* values, indicating stronger yellow components, than Dunaj samples.

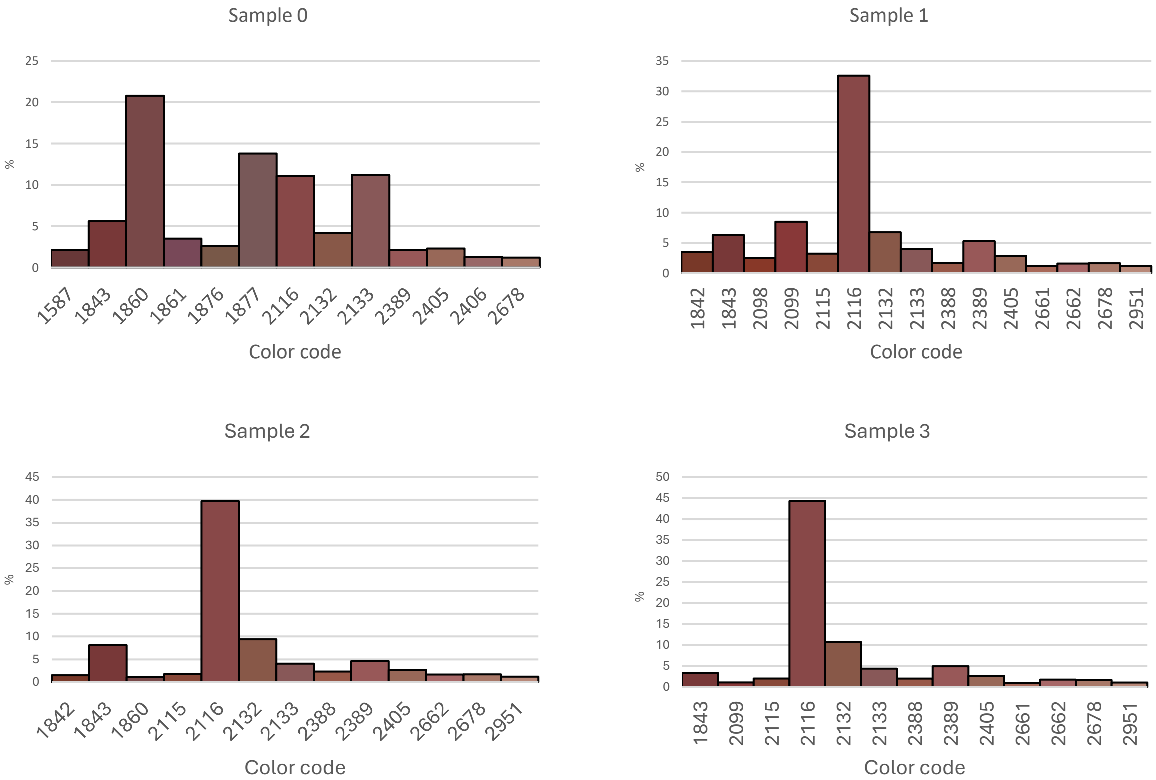

Figure 3 Color spectra of Lasina Crna irradiated samples (1-3) compared to the untreated control (sample 0)
*Note: Lasina Crna variety: the control (**0 sample**), **1 sample** irradiated for 13.45 min, **2 sample** 6.37 min. and **3 sample** 2.57 min.*

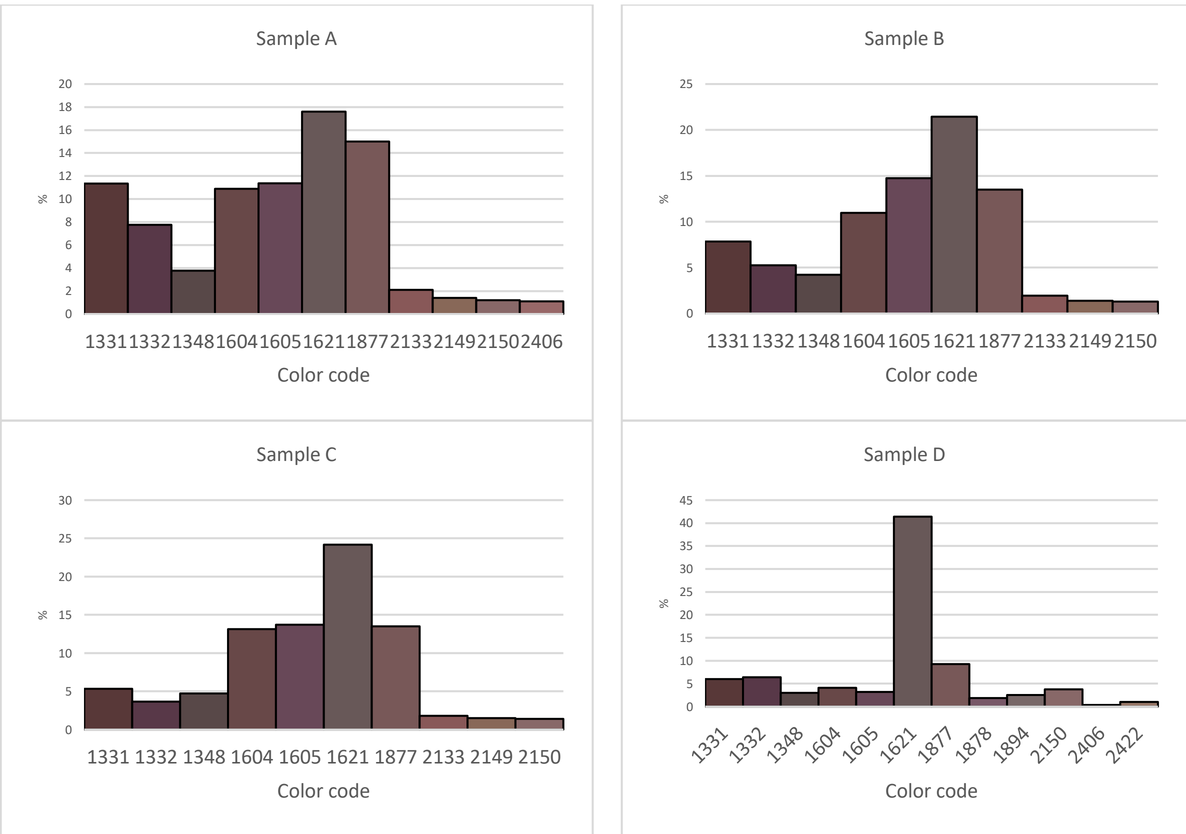

Figure 4 Color spectra of Lasina Crna irradiated samples (B-D) compared to the untreated control (sample A)
*Note: Dunaj variety: the control (**A sample**), **B sample** irradiated for 13.45 min., **C sample** 6.37 min. and **D sample** 2.57 min.*

Table 1 RGB and CIEL*a*b* coordinates of colors identified above 1%

Color code	R	G	B	L*	a*	b*	Color name *
1331	88	56	56	27.425	14.678	6.172	Dark lava
1332	88	56	72	27.843	16.637	-3.730	Purple taupe
1348	88	72	72	32.280	7.008	2.680	Liver
1587	104	56	56	29.800	21.795	9.880	Wine
1604	104	72	72	34.229	14.099	5.757	Rose ebony
1605	104	72	88	34.635	16.097	-3.770	Tuscan red
1621	104	88	88	39.015	6.759	2.558	Wenge
1842	120	56	40	32.130	27.591	23.589	Wine
1843	120	56	56	32.378	28.555	13.862	Wine
1860	120	72	72	36.400	21.060	9.162	Deep coffee
1861	120	72	88	36.774	22.730	-0.350	Tuscan red
1876	120	88	72	40.521	11.939	14.735	Raw umber
1877	120	88	88	40.843	13.619	5.449	Pastel brown
1878	120	88	104	41.238	15.634	-3.774	Old lavender
1894	120	104	104	45.555	6.553	2.461	Dim gray
2098	136	56	40	34.886	34.139	27.606	Burnt umber
2099	136	56	56	35.109	34.932	18.031	Cordovan
2115	136	72	56	38.487	26.666	22.278	Bole
2116	136	72	72	38.754	27.779	12.824	Cordovan
2132	136	88	72	42.562	18.983	17.872	Raw umber
2133	136	88	88	42.862	20.415	8.624	Rose taupe
2149	136	104	88	46.966	11.485	14.237	Pastel brown
2150	136	104	104	47.289	13.213	5.207	Mauve taupe
2388	152	88	72	44.766	25.820	21.233	Rose taupe
2389	152	88	88	45.045	27.046	12.035	Rose taupe
2405	152	104	88	48.886	18.346	17.206	Dark chestnut
2406	152	104	104	49.191	19.850	8.204	Copper rose
2422	152	120	104	53.265	11.105	13.821	Beaver
2661	168	104	88	50.953	25.064	20.382	Dark chestnut
2662	168	104	104	51.239	26.376	11.415	Copper rose
2678	168	120	104	55.089	17.797	16.653	Café au lait
2951	184	136	120	61.180	17.318	16.183	Light taupe

Note: *Color name according to https://rgbcolorcode.com/color/converter/

Principal component analysis (PCA) was performed only at the electronic-eye colorimetric measurements because these data provided a quantitative multivariate matrix suitable for PCA. Sensory results were based on descriptive difference from control scores and were therefore interpreted separately as result of a small certified panel representatives. The PCA map (Figure 5) showed clear separation of the two wine varieties along the first principal component (PC1), which explained 98.459% of the total variance. The second component (PC2) explained 1.203% of the variance and contributed only minimally to sample differentiation.
Dunaj samples were clustered on the negative side of PC1, whereas Lasina Crna samples, were located on the positive side. This separation indicates substantial differences in color profiles between two varieties (Fig. 5).
Colorimetric vectors overlaid on the PCA map identified four major color variables associated with the wine samples. Colors coded 2422 (Beaver) and 1620 (Umber) were mainly associated with Dunaj samples, indicating that these chromatic tones contributed to the separation of this group. Lasina Crna samples were primarily associated with color 2678 (Cafe au lait), confirming a distinct chromatic profile from the Dunaj group. The proximity of samples to their respective color vectors suggests relationship between selected color parameters and sample grouping, while tight clustering within each varietal group indicates high internal similarity among samples.
Overall, PCA demonstrated that electronic-eye color parameters can discriminate between two red wine matrices, with PC1 capturing nearly all variation attributed to their chromatic differences. Because PCA was based only on colorimetric data, the results should be interpreted together with sensory scores rather than as a complete quality assessment.
Pachnowska *et al*. (2025) compared nanomaterials, UV-C-assisted photolysis and hurdle technology and state that UV-C may reduce important phenolic compounds, affect antioxidant properties and sensory complexity. These results support the idea that UV-C treatment cannot be transferred directly without matrix-specific optimization.
Matias *et al*. (2016) reported that UV-C technology of red wine after four months of storage did not negatively affect physicochemical parameters or polyphenol content, and aroma and flavour were not adversely affected. Color stabilisation was promoted, supporting the potential use of UV-C as a tool for selected red wines when the dose is properly optimised.

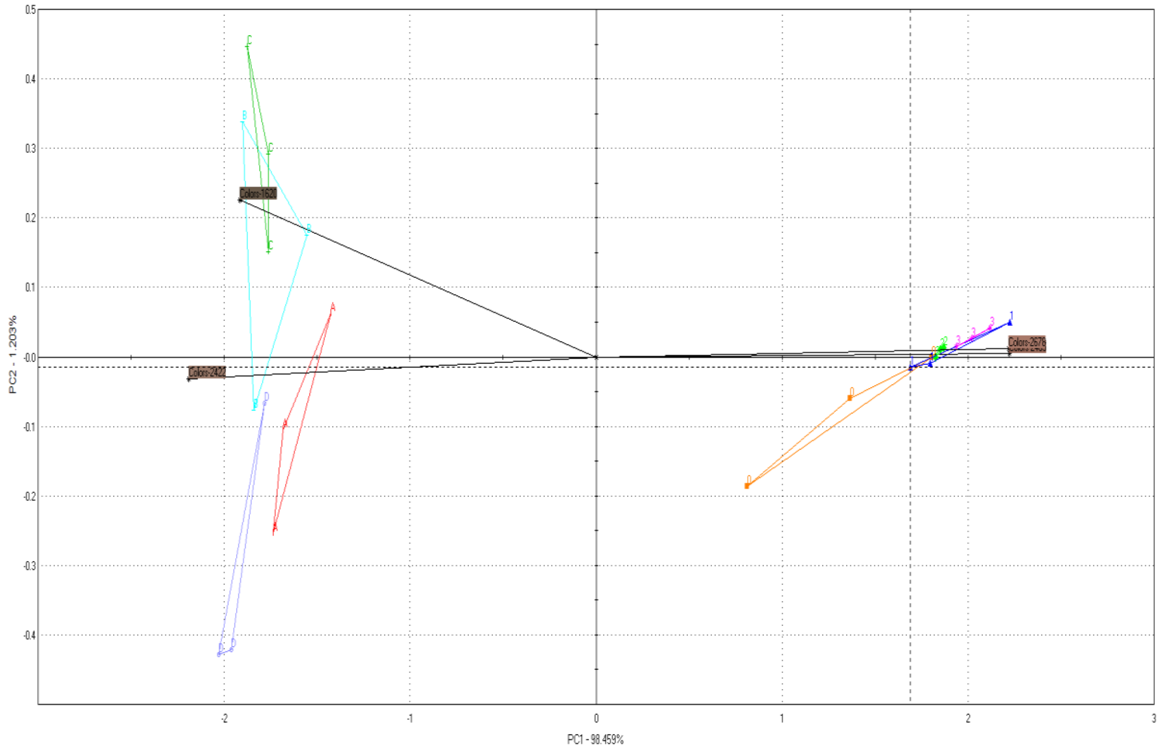

Figure 5 PCA map of electronic eye color analysis. *Note: Dunaj variety: the control (A sample), B sample irradiated for 13.45 min, C sample 6.37 min and D sample 2.57 min. Lasina Crna variety: the control (0 sample), 1 sample irradiated for 13.45 min, 2 sample 6.37 min and 3 sample 2.57 min. Colors: 2422 (Beaver),1620 (Umber), 2678 (Cafe au lait)*

CONCLUSION

This pilot study showed that UV-C irradiation can affect selected sensory properties of red wines, but the direction and intensity of the response depend on the wine variety. Dunaj showed to be more favorable to the UV-C treatment, with improved color scores in all treated samples and a slight aroma improvement after the longest exposure. Lasina Crna showed higher sensitivity, especially in aroma deterioration and weak color impression in the shorter treatments.

Electronic eye analysis supported the sensory results by demonstrating clear colorimetric differentiation between two varieties. PCA showed 98.459% of total variance by PC1 and separated Dunaj from Lasina Crna according to their chromatic profiles. Because this was a pilot study with a limited number of wine matrices, these results should be interpreted as preliminary and descriptive. Further research should include larger number of wine varieties and batches, detailed phenolic and volatile-compound analyses, full statistical testing and a broader sensory protocol. The findings nevertheless indicate that UV-C treatment may be technologically useful for selected red wines if variety-specific protocols are developed and if aroma and color stability are monitored together.

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