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THE INFLUENCE OF MACERATION DURATION AND TEMPERATURE ON THE CHARACTERISTICS OF BLACKBERRY WINE

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Abstract

The production of fruit wines, particularly blackberry wine, is being improved to enhance the quality of the final product. This study aimed to investigate the influence of maceration duration and temperature on the characteristics of blackberry wine. Eight samples were prepared with the addition of a maceration enzyme, potassium metabisulfite, and yeast, with variations in sugar addition (0 and 20%), maceration temperature (20 and 25°C), and maceration duration (5 and 10 days). Analyses were performed on the prepared blackberry juice, must, and wines. Physicochemical properties were analyzed using standard methods recommended by the International Organization of Vine and Wine (OIV). Antioxidative properties included the determination of total phenolics, nonflavonoids, and flavonoids, as well as antioxidant activity (FRAP, DPPH, and ABTS assays). Antimicrobial activity was tested using the agar dilution method to determine the minimum inhibitory and bactericidal/fungicidal concentrations against selected bacteria (Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Bacillus cereus, Listeria monocytogenes), pathogenic yeast (Candida albicans), and probiotic cultures (Lactobacillus plantarum and Saccharomyces boulardii). Sensory evaluation of blackberry wines was conducted using the Buxbaum method. The results showed that prolonged maceration at lower temperatures and sugar addition increased the alcohol content, while higher maceration temperatures increased total acidity (6.23-10.60 g/L) and lower temperatures reduced volatile acidity (0.48-1.08 g/L). Shorter maceration at higher temperatures improved color intensity, whereas longer maceration at lower temperatures reduced color quality. The sample without added sugar, macerated for 5 days at 25 °C, showed the highest phenolic content and antioxidant activity, and all samples exhibited antibacterial activity, particularly against B. cereus and P. aeruginosa, but weak effects against yeast and probiotic cultures. Wines produced without sugar addition during fermentation were quite acidic and weak. By adding sugar, wines of good quality were obtained. Samples produced with sugar addition, shorter maceration, and lower temperature proved superior, and the alcohol content in these samples (>11 vol%) was considered satisfactory.

Key words: *blackberry wine, maceration time, maceration temperature, wine quality.*

INTRODUCTION

Blackberries (*Rubus fruticosus* L.) are seasonal fruits that, under the tested climatic conditions, reach their technological ripeness from mid-July to late September. They are grown worldwide due to their delicious taste, pleasant flavor, and excellent nutritional profile. Blackberries contain dietary fibers, vitamin C (ascorbic acid), vitamin A, vitamin E, potassium, and calcium, along with phenolic metabolites that may offer health benefits. Blackberry phenolics have been linked to potential anticancer, antiproliferative, antineurodegenerative, anti-inflammatory, antidiarrheal, antidiabetic, antimicrobial, and antiviral activities. These fruits are enjoyed fresh or processed into various products such as jam, wine, tea, ice cream, desserts, seedless jellies, and baked goods (Mikulic-Petkovsek et al., 2021; Savic et al., 2021).

Blackberry wine is one of the most common blackberry products and contains high levels of anthocyanins, polyphenols, and aromatic compounds that contribute to its color and aroma, as well as its antioxidant activity and potential to prevent chronic diseases (Wu et al., 2022). Nowadays, wines made from fruits other than grapes are gaining full acceptance in the market. The techniques used for fruit wine production are analogous to those applied for the production of grape wines and include alcoholic fermentation of fruit juice or pulp. The main steps of fruit wine production are: fruit reception, must preparation by crushing and

squeezing (pressing), maceration (pre-fermentation), clarifying, adjusting, spontaneous or inoculated fermentation (using selected wine yeasts), maturation, aging, and bottling (Velic et al., 2018).

The way the production process is carried out clearly affects the quality of the resulting wine. The preparation of fruit musts for wine production varies depending on the type of fruit. To correct imbalances in acidity or sugar levels, it is recommended to dilute the must with water to reduce acidity and to supplement it with sugar to achieve an appropriate balance (Velic et al., 2018). However, differences in raw materials often require special treatment techniques, distinguishing fruit winemaking from grape winemaking and affecting final quality (Tan et al., 2024). The maceration process plays an important role in the composition of the color and sensory properties of wine by facilitating the extraction of phenolic and aromatic compounds from fruits (Şener, 2018). Maceration duration strongly influences the phenolic composition and sensory attributes of red wines. Leaving the pulp in contact with the juice during the first week of maceration and fermentation intensifies the wine's body, character, and color, while extended maceration promotes the formation of polymeric pigments that enhance color stability (Feifel et al., 2025). Although 10-day maceration elevates overall phenolic content, it may also negatively affect sensory quality by intensifying astringency (Gu et al., 2025).

The efficiency of the maceration process is strongly dependent on temperature. Low-temperature prefermentative maceration (cold soaking at 10-15°C) is increasingly used to enhance wine color and aromatic expression (Sener and Yildirim, 2013), whereas increasing the maceration temperature from 15 to 35°C has been reported to raise phenolic concentrations by up to 300-fold (Varo et al., 2024). Although numerous studies have examined the effects of fermentation and maceration temperatures in grape wines, research addressing their influence in fruit-based winemaking remains comparatively limited.

As interest in fruit wines with enhanced functional attributes grows, evaluating technological factors such as maceration time and temperature is increasingly important for ensuring product quality. The optimization of these parameters is crucial for achieving a well-balanced sensory profile in blackberry wine, with emphasis on the preservation of its natural color, aroma, and antioxidant capacity. The present study aims to evaluate the effects of varying maceration times and temperatures on the quality properties of blackberry wine and to establish the optimal conditions for the production of a premium-quality final product.

MATERIALS AND METHODS

Blackberry fruit samples of the Loch Ness variety came from the Experimental and Educational Center of the Faculty of Agriculture, University of Banja Luka, Bosnia and Herzegovina.

Sample preparation and fermentation. The samples and maceration parameters used: temperature, duration, and percentages of added sugar are presented in Table 1. Eight samples were prepared with the addition of maceration enzyme (40 mg/L), potassium metabisulfite (100 mg/L), and wine yeast (300 mg/L). In four samples (W2, W4, W6, and W8) white sugar was added to make the total sugar content 20%. After the end of the maceration process, decantation and mild sulphiting (potassium metabisulfite - 50 mg/l) were performed, and all samples were further fermented.

Table 1. Samples and maceration parameters

	temperature	added sugar	duration (days)
W1	20	-	5
W2		up to 20%	
W3		-	10
W4		up to 20%	
W5	25	-	5
W6		up to 20%	
W7		-	10
W8		up to 20%	

The physicochemical parameters of blackberry juice (total soluble solids - TSS, °Brix, total titratable acidity (TTA), and pH value) and wines (relative density, alcohol content, total extract, reducing sugars, total acidity, volatile acids, pH value, ash content, wine color intensity, and shade) were carried out using standard methods prescribed by the International Organization for Vine and Wine (OIV, 2015).

The content of total phenolic compounds (TPC) was determined by the Folin-Ciocalteu method (Wolfe et al. 2003). The non-flavonoid content (TNF) was determined by the formaldehyde method (Alberto et al., 2006), whereas the flavonoid content (TF) was calculated as the difference between TPC and TNF. The ability to remove DPPH (1,1-diphenyl-2-picrylhydrazyl) radicals was determined by the method given by Liyana-Pathirana and Shahidi (2005). ABTS radical scavenging activity (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) was evaluated according to Re et al. (1999), while ferric reducing antioxidant power (FRAP) was performed according to the method developed by Benzie and Strain (1996).

The antimicrobial activity against five pathogenic bacteria *(Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus cereus*, *Staphylococcus aureus, and Listeria monocytogenes*), a pathogenic yeast (*Candida albicans*), and two probiotic strains (*Saccharomyces boulardii* and *Lactobacillus plantarum*) was tested by the agar dilution method according to Jovanović-Cvetković et al. (2025).

Sensory evaluation of blackberry wines was performed using the Buxbaum method (20-point scoring method) (Tešević et al. 2005). A commercial blackberry wine was used as the control sample.

Statistical analysis. The results were expressed as mean values of the individual results of three randomly selected product samples ± standard deviation (SD). The significance of arithmetic mean differences was determined by analysing the variance with one independent variable (One way ANOVA) and multiple interval tests (Tukey HSD – test) and expressed with 95% probability ($p<0.05$).

RESULTS AND DISCUSSIONS

The chemical composition of the fruit must play a key role and influence the quality of the wine. Among the most important parameters affecting wine quality are the soluble solids content, total acidity, and actual acidity (pH value). The results of the physicochemical parameters and antioxidative properties of blackberry juice are shown in Table 2.

Table 2. The physicochemical parameters and antioxidative properties of blackberry juice

		blackberry juice
TSS	°Brix	10.00
TTA	g/L	8.80
pH value		3.39
TPC	g GAE/L	3.262±0.175
TNF		1.988±0.042
TF		1.274±0.133
FRAP	mmol Fe^{2+}/L	20.67±0.194
DPPH	mmol TE/L	5.066±0.166
ABTS		10.688±0.621

The initial Brix was 10, which is in accordance with results obtained by Tosun et al. (2008). The obtained value of total acidity (8.8 g/L) is very high, and it is characteristic for fruits with emphasized freshness and stability (Clark and Finn, 2011). Tosun et al. (2008) stated that high acidity is important for the preservation of sensory characteristics in general, but also for its microbiological stability, because acids act as natural preservatives. Similar values of total acids in blackberry were recorded in the work of Milošević et al. (2012), which confirmed the consistency of the results obtained.

The real acidity (pH value) of blackberry juice indicated the balance between acidity and sweetness. The obtained pH value (3.39) is in accordance with the data of Basaran and Kepenek (2011), who emphasized the importance of the pH value in maintaining the stability and quality of fruit wines.

Blackberry juice used in this work showed good antioxidative properties, based on results obtained by FRAP, DPPH, and ABTS tests. Wang and Lin (2000) tested juice samples from several cultivated blackberry varieties and found higher antioxidant potential than in the tested juice samples from several varieties of strawberries, raspberries, cranberries, and blueberries. Koczka et al. (2018) found high degrees of correlation between the content of total polyphenols, flavonoids, and anthocyanins contained in blackberries and the antioxidant activity determined on the basis of various tests. Also, Monforte et al. (2018) proved high antioxidant activity of blackberry juice samples based on several antioxidant tests, and the activity trend based on potential was ORAC > TEAC > DPPH > FRAP.

The physicochemical parameters, including total soluble solids, total titratable acidity, and pH values, of the prepared blackberry musts are

summarized in Table 3. Based on the results obtained, it can be concluded that the addition of sugar (up to 20%) led to changes in the chemical composition of the blackberry must. The total acidity decreased by 3.8 g/L following sugar addition, while the pH value slightly increased from 3.35 to 3.45.

Table 3. The physicochemical parameters of blackberry musts

		blackberry must	
			after sugar addition
TSS	°Brix	10.00	20.00
TTA	g/L	8.80	5.00
pH value		3.35	3.45

The results of physicochemical parameters of blackberry wines are presented in Tables 4 and 5. The relative density values varied from 0.9931 (W2) to 1.0094 (W5). Amidžić Klarić et al. (2017) found that the relative density of blackberry wine samples ranged from 1.0017 to 1.0660 g/mL. The same authors stated that higher values might indicate a higher content of sugar, alcohol, and extract, which significantly affected the relative density of the wine. Also, there might be a difference in the raw material itself (e.g. blackberry variety, ripeness), as well as in the production technology (length of time and temperature of maceration).

The highest alcohol content was measured in sample W4 (11.56% vol), which was macerated for 10 days at 20°C, with the addition of sugar up to 20%. The lowest alcohol content was measured in sample W7 (3.49% vol), which was macerated at 25°C for 10 days and to which no sugar was added. Prolonged maceration and lower maceration temperature influenced the increase in alcohol content, but an indispensable factor that influenced the increase in alcohol content is the addition of sugar (up to 20%). Samples to which no sugar was added had a significantly lower alcohol content. Amidžić Klarić et al. (2017) stated that the alcohol content in blackberry wine ranged from 9.37 to 14.78% vol. Johnson and Gonzalez de Mejia (2012) compared blackberry wines from Illinois and found that the ethanol content ranged from 9.5 to 12.4% vol.

Table 4. Relative density, alcohol content, extract without sugar, reducing sugars, and ash content of blackberry wines

	relative density (g/mL)	alcohol content (%vol)	extract without sugar (g/L)	reducing sugars (g/L)	ash (g/L)
W1	1.0087	4.06^{a} ±0.05	34.7^{a} ±0.0	3.75^{a} ±0.00	-
W2	0.9931	11.47^{b} ±0.00	21.4^{b} ±0.0	0.60^{b} ±0.00	1.80^{a} ±0.01
W3	1.0080	3.97^{a} ±0.07	32.9^{c} ±0.1	3.49^{c} ±0.07	3.70^{b} ±0.02
W4	0.9936	11.56^{b} ±0.00	21.2^{b} ±0.0	2.74^{d} ±0.00	1.94^{c} ±0.06
W5	1.0094	3.52^{c} ±0.00	35.1^{a} ±0.0	3.39^{c} ±0.00	-
W6	0.9939	11.26^{d} ±0.06	22.4^{d} ±0.1	1.44^{e} ±0.00	1.95^{c} ±0.01
W7	1.0089	3.49^{c} ±0.05	33.3^{c} ±0.2	3.78^{a} ±0.04	3.87^{d} ±0.03
W8	0.9959	9.99^{e} ±0.06	23.5^{e} ±0.1	1.64^{f} ±0.00	2.19^{e} ±0.02

(a–f) Different letters within the same column indicate statistically significant differences between samples at a significance level of $p < 0.05$.

The obtained results indicated that the addition of sugar affected the extract content of the extract, while the samples without the addition of sugar had a higher extract content of the extract. The content ranged from 21.4 g/L in sample W2 (with added sugar) to 37.5 g/L in samples W1 and W5 (without sugar added). Alepza et al. (2014) stated that the total extract content for blackberry wines ranged from 44.3 to 174.9 g/L.

The content of reducing sugars in all samples was relatively low, and all tested samples belong to the group of dry wines. The lowest content of reducing sugars was measured in sample W2, which was produced at a lower temperature and with a shorter duration of maceration, and was 0.6 g/L. Sample W7 had the highest content of reducing sugars (3.78 g/L), to which no sugar was added. The content of reducing substances (sugar) was relatively low in all tested samples. The average value for the content of reducing sugars was 2.6 g/L, which is in accordance with the OIV definition for the content of reducing sugars for dry wines - from 0.5 to 5 g/L. Petravić-Traminac et al. (2013) found that the content of reducing sugars in blackberry wines after fermentation was 1.416 g/L.

The samples with longer maceration and at a higher temperature had a higher ash content. Sample W7 had the highest (3.87 g/L), and sample W2 had the lowest ash content (1.80 g/L). The average ash content of the examined samples in this research was 2.58 g/L, which is in accordance with the results obtained in research conducted by Amidžić Klarić et al. (2017). On the other hand, higher-quality wine implies a higher content of minerals and ash.

Based on the results presented in Table 5, it can be concluded that the increase in maceration temperature influenced the increase in total acidity. The highest total acidity is found in sample W7, which was macerated at a temperature of 25°C for 10 days and was 10.6 g/L. The lowest total acidity is found in sample W2, which was macerated at a temperature of 20°C for 5 days and was 6.23 g/L. So, it can be concluded that all samples with sugar added had lower total acidity, which varied from 6.23 g/L to 6.69 g/L, regardless of the temperature and duration of maceration.

Table 5. Total acidity, volatile acidity, and pH value of blackberry wines

	total acidity (malic acid g/L)	volatile acidity (g acetic acid /L)	pH value
W1	$10.26^{a}\pm0.00$	$0.48^{a}\pm0.02$	$3.20^{a}\pm0.00$
W2	$6.23^{b}\pm0.02$	$0.50^{a}\pm0.00$	$3.32^{b}\pm0.00$
W3	$10.20^{a}\pm0.00$	$0.48^{a}\pm0.01$	$3.25^{c}\pm0.00$
W4	$6.37^{c}\pm0.00$	$0.60^{b}\pm0.00$	$2.99^{d}\pm0.00$
W5	$10.52^{d}\pm0.00$	$0.50^{a}\pm0.00$	$3.55^{e}\pm0.00$
W6	$6.69^{e}\pm0.04$	$0.57^{b}\pm0.00$	$3.38^{f}\pm0.00$
W7	$10.60^{f}\pm0.02$	$1.08^{c}\pm0.01$	$3.42^{g}\pm0.00$
W8	$6.72^{e}\pm0.00$	$0.60^{b}\pm0.01$	$3.48^{h}\pm0.01$

(a–g) Different letters within the same column indicate statistically significant differences between samples at a significance level of $p<0.05$.

This is consistent with other studies that reported that the total acidity of blackberry wines ranged from 3.3 g/L to 8.1 g/L (Johnson and Gonzalez Mejia, 2012). Alpeza et al. (2014) reported that the total acidity for all their blackberry wines varied between 8.0 g/L and 16.0 g/L.

The low content of volatile acids is an important indicator of microbiological stability during wine storage. In this regard, all analyzed samples had a satisfactory low volatile acidity, except sample W7, which was subjected to a longer duration and a higher temperature of maceration, and without the addition of sugar. A lower maceration temperature had a positive effect on reducing the content of volatile acids. Volatile acid content varied from 0.48 g/L to 1.08 g/L, with an average of 0.61 g/L acetic acid. Alpeza et al. (2014) in their study, found that volatile acidity, expressed in g/L of acetic acid, for all wines varied between 0.3 and 1.5 g/L, which is in accordance with the results of this research. Examined wine samples had a rather low pH value. Lower wine pH values were recorded in samples that were subjected to a lower maceration temperature (20°C). The lowest measured pH value was in sample W4, to which sugar was added, and was 2.99. The highest pH value was in sample W5, without added sugar, and was 3.55, which is in line with results obtained by Alpeza et al. (2014) - from 3.11 to 3.99. Chromatic characteristics are one of the main parameters taken into account when evaluating the quality of blackberry wine, and the results are given in Table 6.

Table 6. Chromatic characteristics of blackberry wines

	color intensity	shade
W1	$7.09^{a}\pm0.01$	$0.88^{a}\pm0.00$
W2	$5.90^{b}\pm0.02$	$1.06^{b}\pm0.01$
W3	$10.35^{c}\pm0.11$	$0.77^{c}\pm0.00$
W4	$5.20^{d}\pm0.11$	$0.89^{ad}\pm0.00$
W5	$10.51^{c}\pm0.00$	$0.82^{e}\pm0.00$
W6	$7.43^{e}\pm0.08$	$0.85^{f}\pm0.00$
W7	$9.32^{f}\pm0.04$	$0.76^{g}\pm0.00$
W8	$6.50^{g}\pm0.03$	$0.90^{d}\pm0.00$

(a–g) Different letters within the same column indicate statistically significant differences between samples at a significance level of $p<0.05$.

From the presented results, it can be concluded that shorter duration of maceration (5 days) had a positive effect on increasing the wine's color intensity and shade of the wine. A higher maceration temperature (25°C) also had a positive effect on higher color intensity. In contrast to the color intensity, increasing the maceration temperature negatively affected the color shade. The color intensity of blackberry wines in this study ranged from 5.20 to 10.51. Color intensity values reported in the literature for blackberry wines ranged from 1.80 to 13.19 (Amidžić Klarić et al., 2017), and 2.7–8.4 for Andean blackberry wine (Arozarena et al., 2012). Shades of color ranged from 0.755 (W7) to 1.062 (W2), which was similar to the results obtained in the work of Amidžić Klarić et al. (2017) (0.763-1.740), while lower values are reported by Arozarena et al. (2012) (0.42- 0.63).

An overview of the phenolic content and antioxidant activity of blackberry wines is provided in Table 7. Sample W2, which was macerated at a lower temperature and with added sugar, had the lowest content of total phenolics, 0.960 g GAE/L. The highest content of total phenolics is found in sample W5, which was macerated at a higher temperature, without the addition of sugar, and was 1.485 g GAE/L. Ortiz et al. (2013) reported that the content of total polyphenols in blackberry wine varied from 1.122 to 1.400 g GAE/L, which was in line with the results of this study.

Table 7. Phenolic content (total phenolics, non-flavonoids and flavonoids) and antioxidant activity (FRAP, DPPH, ABTS)

	TPC	TNF	TF	FRAP	DPPH	ABTS
	g GAE/L			mmol Fe^{2+}/L	mmol TE/L	
W1	1.37^{a} ±0.01	0.98^{a} ±0.03	0.39^{ab} ±0.02	18.69^{a} ±0.18	4.60^{ab} ±0.05	16.94^{ab} ±0.29
W2	0.96^{b} ±0.04	0.64^{b} ±0.09	0.32^{a} ±0.05	11.11^{b} ±0.06	3.86^{c} ±0.01	13.38^{c} ±0.23
W3	1.37^{a} ±0.02	0.95^{a} ±0.01	0.42^{ab} ±0.011	17.36^{ac} ±0.31	5.09^{dc} ±0.03	19.03^{bc} ±0.07
W4	1.07^{c} ±0.02	0.65^{b} ±0.04	0.42^{abc} ±0.06	13.52^{d} ±0.78	3.97^{c} ±0.10	13.84^{cd} ±1.09
W5	1.49^{d} ±0.02	0.89^{a} ±0.01	0.59^{d} ±0.00	20.98^{e} ±0.76	5.18^{e} ±0.01	19.96^{e} ±0.20
W6	1.051^{e} ±0.029	0.579^{b} ±0.017	0.47^{bcd} ±0.012	10.89^{b} ±0.23	3.40^{c} ±0.01	14.47^{cd} ±0.27
W7	1.31^{a} ±0.01	0.87^{a} ±0.04	0.44^{abc} ±0.05	16.66^{c} ±0.64	4.88^{ad} ±0.01	17.61^{ab} ±0.17
W8	1.17^{e} ±0.01	0.62^{b} ±0.01	0.55^{cd} ±0.02	14.47^{d} ±0.48	4.44^{b} ±0.12	16.02^{ad} ±0.14

* a-e mean values with different letters in the same column differ statistically significantly with 95% probability ($p < 0.05$)

The strongest antioxidant activity is shown by sample W5 (20.98 mmol Fe^{2+}/L for the FRAP test, 5.18 mmol TE/L for the DPPH test, and 19.96 mmol TE/L for the ABTS test), which was subjected to maceration for 5 days at 25°C. On the other hand, sample W6 showed the weakest antioxidant activity under identical maceration conditions.

The antioxidant activity of wine is directly related to the content of phenolic compounds. This is consistent with findings reported by Amidžić Klarić et al. (2020), who confirmed that the antioxidant activity of blackberry wines is proportional to the concentration of bioactive phytochemicals. Notably, Mudnić et al. (2012) observed that some blackberry wines exhibited lower total phenolic content relative to red grape wines, yet demonstrated stronger antioxidant capacity, attributing this to a higher content of non-flavonoid compounds, most notably gallic acid, in blackberry wines. Higher maceration temperature of the samples without the addition of sugar had a positive effect on the increase in antioxidant activity. Varo et al. (2022) reported that the maceration process increased the concentration of phenolic compounds and the antioxidant activity values measured by the DPPH assay; however, extended maceration times may reduce these values due to phenolic compound involvement in polymerization, copigmentation, degradation, pyranoanthocyanin formation, and reactions between anthocyanins and tannins.

The results of measuring the antimicrobial activity of blackberry wines, expressed as MIC/MBC/MFC values (%) are presented in Table 8.

Table 8. Antimicrobial activity (MIC, MBC, and MFC) of blackberry wine samples in %

MIC/ MBC/MFC	W1	W2	W3	W4	W5	W6	W7	W8
E. coli	20	20	20	20	20	20	20	20
	30	30	30	30	30	30	30	30
P. rugissante	20	20	20	20	20	10	20	10
	30	30	30	30	30	30	30	30
B. cereus	10	10	<5	10	10	10	<5	10
	>30	>30	>30	>30	>30	>30	>30	*>30*
S. aureus	20	20	20	20	10	20	20	20
	>30	>30	>30	30	20	>30	>30	30
L. monocy-togenes	30	30	20	30	20	30	20	30
	>30	>30	>30	>30	30	>30	>30	>30
C. albicans	>30	>30	>30	>30	>30	>30	>30	>30
	>30	>30	>30	>30	>30	>30	>30	>30
S. boulardii	>30	>30	>30	>30	>30	>30	>30	>30
	>30	>30	>30	>30	>30	>30	>30	>30
L. plantarum	>30	>30	>30	>30	>30	>30	>30	>30
	>30	>30	>30	>30	>30	>30	>30	>30

*MIC - minimum inhibitory concentration; MBC - minimum bactericidal concentration; MFC - minimum fungicidal concentration.

The blackberry wines tested in this work showed pronounced antimicrobial activity against all tested bacteria, except for the probiotic bacterium *L.* plantarum. Also, blackberry wate at the tested concentrations had no effect against yeasts, *C. albicans* and *S. boulardii*. The best inhibitory effect, with the lowest MIC value, was shown by blackberry wine against *B. cereus*, where all samples had an MIC of 10%, and samples W3 and W7 <5%. At the same time, the highest tested concentration of 30% had no bactericidal effect on this bacterium. The best bactericidal activity, according to the tested cforcentrations of wine, was obtained for *P.*

aeruginosa, where two samples had an MIC of 10%, and the bactericidal effect was manifested in all samples at 30%. *E. coli* and *S. aureus* showed similar sensitivity, with sample W5 inhibiting *S. aureus* better, and all samples having a bactericidal effect on *E. coli* at a concentration of 30%. Among the samples, sample W5 exhibited the best inhibitory effect, inhibiting Gram-positive *B. cereus*, *S. aureus* and *L. monocytogenes* better than Gram-negative *E. coli* and *P. aeruginosa*. The samples W3, W4 and W7 also had a more pronounced antimicrobial effect. Czyżowska et al. (2020) investigated the content of phytochemicals and bioactive components in dealcoholized wines from bilberry, blackberry, cranberry, elderberry, raspberry, and strawberry and found that blackberry wine has the best antioxidant activity (by ABTS and FRAP methods), which cannot be associated with the highest content of total phenolics. The authors believe that this activity, in addition to the content of phenolic components, is also related to the content of other non-phenolic components with antioxidant activity, such as ascorbic acid. Similarly, dealcoholized blackberry wine only inhibited the growth of Gram-positive bacteria, *B. cereus* and *L. monocytogenes*, while it had no effect on Gram-negative bacteria, *E. coli* and *Salmonella enteritidis*. Fruit wines are complex systems containing alcohol, various phenolic compounds, organic acids, minerals, and vitamins. The antimicrobial activity of red wines has been extensively researched, and its antimicrobial activity is associated with the combination of organic acids and alcohol (Møretrø and Daeschel, 2004), the combination of alcohol, organic acids, pH, and phenolic components (Kim et al., 2014). Boban et al. (2010) concluded that wine is a complex system and that that its components act synergistically on the inhibition of microorganisms. This is also confirmed by the comparison of the antimicrobial activity of blackberry wine in this research and dealcoholized wine in the research of Czyżowska et al. (2020).

Sensory analysis revealed that wines produced without sugar addition were characterised by pronounced acidity and a thin body, which is consistent with the naturally high titratable acidity of blackberry must.

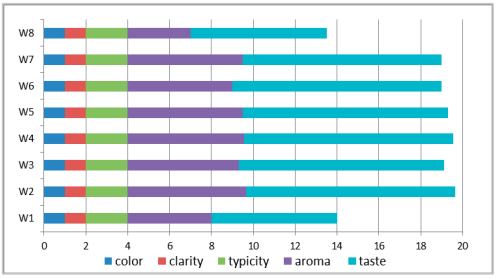

Figure 1. Sensory analysis results

Varo et al. (2022) found that longer maceration or fermentation times decreased the concentration of all compounds, including acids, which resulted in wines with high acidity. The addition of sugar up to 20% yielded wines of markedly improved quality, and samples macerated and fermented at 20°C received superior sensory scores, and the amount of alcohol in the samples (about 12% vol) proved to be satisfactory. With respect to maceration duration, samples subjected to a 5-day maceration period performed better overall - the wines were slightly lighter in color, but exhibited a more acceptable taste profile, characterized by reduced acidity and bitterness. Extended maceration promotes the extraction of high-molecular-weight tannins from seeds, which can lead to pronounced bitterness and astringency in the final product (Varo et al., 2022). Longer maceration can cause a probable negative effect on wine color and sensory properties (Gutiérrez-Escobar et al., 2021).

CONCLUSIONS

The results demonstrated that maceration conditions significantly affect wine composition and quality. Samples macerated at lower temperatures with the addition of 20% sugar exhibited higher alcohol content, whereas higher maceration temperatures combined with sugar addition resulted in increased total acidity. In most cases, lower maceration temperatures were associated with lower volatile acidity. Shorter maceration at higher temperatures enhanced color intensity, while prolonged maceration at lower temperatures reduced color intensity. Wines produced without added sugar showed the highest total phenolic content and the strongest antioxidant activity, with elevated temperatures further enhancing antioxidant

potential. The sample W5, macerated for 5 days at 25°C without sugar addition, exhibited the highest phenolic content and antioxidant capacity. However, wines produced without sugar addition were sensorially less acceptable due to pronounced acidity and low alcohol content. The addition of sugar up to 20% improved overall wine quality, with the best sensory evaluation achieved in the sample macerated for 5 days at 20°C. Overall, the findings confirm that both physicochemical and sensory properties of blackberry wine are strongly dependent on maceration temperature, duration, and sugar addition.

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