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IDENTIFYING THE FACTORS AFFECTING THE EXTRACTION OF PHENOLIC COMPOUNDS IN WINE PRODUCTION

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The object of the study is red grape varieties rich in phenolic compounds, the wine samples obtained from them, and the physicochemical and mechanical means used during the extraction process. Although several studies have been conducted on the extraction of phenolic compounds into juice and wine, the impact of mechanical methods-based on maceration for different durations, alcoholic extraction at various degrees of darkness, thermal treatment, enzyme preparations, and agitation-on extraction, as well as the effect of different storage conditions on the total content of phenolic compounds and anthocyanins, has not been studied.

In the case of the Khindogni variety, during alcoholic treatment of the pomace up to 6% alcohol, phenolic compounds were not distinctly perceptible. The experimental wine material showed higher color intensity in pomace treated with 10% and 18% alcohol than the control. Comparison of different methods (thermal, enzyme preparations, etc.) indicated that enzymatic treatment (Trenol Color DF, dose 2.0 mg/dm^3) provided more efficient extraction. Agitation increased the extraction of phenolic compounds by more than 1.24 times. During 6 months of storage, the mass concentration of phenolic compounds in Syrah wine material decreased by 21.3%, and anthocyanins decreased by 16.4%.

The problem of producing red wines rich in phenolic compounds and anthocyanins is addressed through the application of physicochemical and mechanical methods, including alcoholic extraction of pomace for varying maceration periods, thermal treatment, enzyme and agitation effects, and storage under different conditions. The obtained results can be applied in winemaking operations

Keywords: mash temperature, maceration, polyphenols, polyphenol extraction, antioxidants, tannins, catechins, inert gas, anthocyanins

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1. Introduction

Tannins and pigments in red grape varieties, together with other compounds, determine the high organoleptic qualities of wine, including body, smoothness, flavor harmony, color intensity, as well as biological value.

Phenolic compounds are mainly concentrated in the solid parts of the grape. Pigments are mostly located in the skin of the berries, and in some varieties, also in the pulp. The technological potential of phenolic compounds varies among grape varieties. Their extraction depends on the technological methods used to transfer these compounds from the solid phase to the liquid phase. Such methods include storing juice with pomace, fermenting the pomace, thermal treatment, alcoholic extraction, and others.

Processing enterprises still largely rely on technologies based on pressing using screw-type presses. This approach is not entirely efficient, as some grape varieties have hard skins that are difficult to press. Often, only 40–45 dal of high-quality juice can be obtained from one ton of such grapes. When grapes are processed using the "white method," anthocyanins, phenolic, and bioactive compounds remain in the pomace (with 20–25 dal of juice still present) and are later lost with the marc, which is not economically advantageous, as more value could be extracted from the raw material.

The extraction of phenolic compounds and anthocyanins from aboriginal and introduced red grape varieties-Khindogni, Tavkveri, Cabernet Sauvignon, Syrah, and Saperavi is effectively addressed through different maceration periods, alcohol content, thermal and mechanical effects, and enzyme treatments. This topic is current and holds scientific and practical significance.

2. Literature review and problem statement

The paper [1] presents research results on the effects of acid type, particle size intervals, temperature, time, and pH on the extraction yield and physicochemical parameters of pectin from grape pomace. It is shown that, depending on particle size, temperature, and other factors, the amount of extracted pectin can be increased. However, several unresolved issues arise regarding the applied treatments of grape pomace, particularly the effects of mechanical treatments and other processing methods, which have not been investigated. This is mainly due to objective difficulties associated with testing a large number of methods simultaneously. One possible way to overcome these challenges is the use of new solvents.

This approach was applied in the paper [2], where research results on the use of the green solvent dimethyl carbonate (DMC) as a more effective solvent for the extraction of oleanolic acid, detected at a concentration of 0.45 mg/g in grape juice, are presented. It is shown that this solvent can be a better alternative to fossil-based solvents. However, other extraction methods, particularly thermal treatment, were not considered in this study.

The paper [3] presents research results related to the use of enzymes capable of degrading structural components for extraction purposes. It is shown that, in addition to enzymes, extraction agents, temperature, and extraction methods can be considered as factors influencing extraction efficiency. Nevertheless, mechanical treatments based on vibration of the pomace for 1–5 minutes are not addressed.

The paper [4] presents research results related to oil extraction from pomace. It is shown that using temperatures above 26°C and injecting 5% water can increase extraction yield and reduce oil losses from pomace. However, unresolved issues and unexplored aspects remain regarding oil loss reduction and extraction efficiency. Investigating alternative oil production methods, particularly mechanical methods, could be one way to overcome these challenges.

The paper [5] presents research results on hot water extraction. It is shown that the use of hot water enables the extraction of insoluble dietary fiber from apple pomace and provides a higher dietary fiber yield. However, due to objective limitations, other alternative methods, including the effects of alcohol and other solvents, were not investigated.

The paper [6] reports results of a study using hot water as a solvent. It is shown that this method plays a key role in increasing the amount of L-ascorbic acid extracted from rosehip pomace. However, the parameters of hot water usage are not considered as alternatives to other solvents.

The paper [7] provides generalized conclusions on the main components of grape pomace and their utilization. It is shown that the proposed extraction methods are superior with respect to green extraction approaches. However, in vivo and in vitro studies are not included.

The paper [8] presents research results related to improving bioactivity using SSF fungi. It is shown that soluble phenolic compounds and bioactivity in grape processing by-products, particularly seeds, are enhanced through SSF fungi. However, unresolved issues remain concerning other parts of the pomace. The lack of investigation of grape skins, which are rich in bioactive compounds, is a limitation of this study.

One way to overcome these challenges is the total extraction of phenolic compounds from grape pomace (GP). This approach was applied in the paper [9], where efficient use of heating technology combined with hydroethanolic extraction enhanced the extraction of bioactive compounds from pomace and revealed its potential for functional food applications. However, other alternative methods capable of extracting phenolic compounds were not considered.

The paper [10] presents a strategy to simplify the utilization of pomace extracts in various industries. It is shown that extraction followed by encapsulation of extracts obtained from grape processing residues facilitates their future application in the food, cosmetic, and pharmaceutical industries. Nevertheless, several unresolved issues remain, mainly due to the theoretical nature of the proposed approaches and insufficient experimental validation.

The paper [11] presents research results on the use of microwave-assisted extraction. It is shown that this method provides high yields, efficient extraction of polyphenols from grape processing residues, and minimal environmental impact. However, from an economic perspective, industrial implementation of this treatment presents certain challenges.

The paper [12] presents research results on the extraction of compounds with cardioprotective activity. It is shown that adjusting solvent polarity is an effective approach for extracting cardioprotective compounds and plays a significant role in the antioxidant capacity of tomato pomace extracts. However, mechanical treatment of pomace and the effects of enzyme preparations were not investigated.

The paper [13] presents research results on ultrasound-assisted extraction. It is shown that ultrasound-based procedures are effective for extracting polyphenols from carrot pomace, and the antioxidant properties of individual phenolic compounds are evaluated. However, efficient solutions for implementing this technology under industrial conditions are not addressed.

The paper [14] presents research results on the effects of drying methods on nutrient extraction from pomace. It is shown that oven drying at 40°C provides better results compared to freeze-drying, with improved preservation of phenolic compounds. However, unresolved issues remain regarding the economic evaluation of these methods. In addition, alternative extraction routes for phenolic compounds were not considered, and no extraction process was performed.

The paper [15] presents research results on the effects of oxidation on phenolic content and antioxidant and antimicrobial properties. It is shown that oxidation affects phenolic content as well as antioxidant and antimicrobial properties in a model system containing different ratios of catechin and grape seed tannin. However, the model system does not fully mimic the extract environment obtained from pomace, making the results less applicable in practice.

The paper [16] presents research results on the use of ultrasound for extraction and as a fermentation inhibitor. It is shown that ultrasound-assisted extraction enables the recovery of phenolic compounds from grape pomace, supporting their use as effective fermentation inhibitors with pharmaceutical and health benefits. In addition, the use of chitosan films enriched with the extract as food packaging material is proposed. However, practical studies on the health effects of the obtained extracts are not included.

The paper [17] presents research results on the reaction between cork stoppers and phenolic compounds in bottled wine during storage. It is shown that in horizontally stored Vintage Port wines, reactions between cork components and wine phenolic compounds lead to the formation of ellagitannin-derived compounds. However, unresolved issues remain, as changes in phenolic and anthocyanin contents during storage are not addressed.

The paper [18] presents research results on the role of cork stopper selection in wine quality. It is shown that proper cork selection significantly influences the normal progression of chemical processes during wine aging and overall wine quality. However, studies on the extraction and transformation of phenolic compounds are not included.

One way to address these shortcomings is to study changes in the phenolic profile and the factors affecting them. This approach was applied in the paper [19], where the effects of storage vessel, aging time, and initial wine composition on the phenolic profile of Merlot wine were investigated. However, unresolved issues remain, as changes in anthocyanin content and color intensity were not considered.

The paper [20] presents research results on wine enrichment using wine-alcohol extracts. It is shown that the addition of wine–alcohol extract to dark wine samples produced from the Bayanshira grape variety using the “white method” increases phenolic compound content. However, this process also increases the content of other extractive substances, complicating process control.

The paper [21] presents research results on increasing phenolic compound extraction. It is shown that preliminary thermal treatment of rosehip fruits and their residues enhances phenolic compound extraction. However, a reduction in ascorbic acid content – one of the main beneficial components is observed, and methods to prevent this loss are not proposed.

The paper [22] presents research results on the effects of cultivation conditions on the phenolic content and antioxidant properties of juice and wine samples. It is shown that the physicochemical composition and antioxidant properties of juices and wines vary depending on the cultivation region. However, phenolic compound extraction and influencing factors are not investigated.

The paper [23] presents research results on the effects of maceration forms on phenolic compound content. It is shown that seeded and seedless skin maceration of the Madrasa grape variety significantly affects wine composition and phenolic compound levels. However, unresolved issues remain, as alternative phenolic extraction methods are not considered.

Especially in the indigenous and introduced grape varieties Khindogni, Tavkveri, Cabernet Sauvignon, Syrah, and Saperavi, the problem of extracting phenolic compounds and anthocyanins has not yet been resolved. At the same time, the effect of different maceration periods of the crushed grape mass, as well as treatment with alcohol, heat, enzyme preparations, and mechanical influences, and the storage of wine on the quantity of phenolic compounds has not been studied. As can be seen, there is a scientific problem in this field that requires a solution.

3. The aim and objectives of the study

The aim of the study is to identifying the factors affecting the extraction of phenolic compounds in order to improve wine quality.

To achieve this aim, the following objectives were accomplished:

– to study the effect of various processing methods on the extraction of phenolic compounds;

– to examine the impact of mechanical treatments and storage on the content of phenolic compounds.

4. Materials and methods

The study focuses on red grape varieties rich in phenolic compounds and the physical, chemical, and mechanical factors used during their extraction.

The extraction of phenolic compounds is influenced by different processing methods, including the duration of maceration, the amount of alcohol added to the crushed grapes, the use of enzyme preparations, the temperature of thermal treatment, mass transfer, and the intensity of mechanical shaking. Determining the optimal levels of these factors can significantly improve the extraction of phenolic compounds, as well as enhance the organoleptic and antioxidant properties of the resulting wine.

It is assumed that phenolic compounds are mainly located in the grape skin, seeds, and stems; the grape raw material is of the same variety, similar ripeness, and chemical composition; the yeast used in fermentation has stable activity and does not directly affect the adsorption or degradation of phenolic compounds; and the analytical methods used provide accurate and reproducible results.

The effects of oxidation and polymerization on the amount of phenolic compounds, as well as the interactions of proteins, polysaccharides, and other wine components with phenolic compounds, are not considered. Mechanical shaking is assumed to only affect the extraction of phenolic compounds and not other components. The added ethanol is considered to only influence the extraction of phenolic compounds without interacting with other compounds. Temperature is assumed to be evenly distributed throughout the crushed grape mass.

The wine material belonged to the previous season and was prepared according to the following scheme: grape crushing and destemming; partial fermentation; sulfiting the pomace at 60 mg/dm^3; alcoholic treatment at 6–10–18% alcohol; storing the treated pomace with juice for 12, 24, 48, 72 hours (at 18–20°C); separation of wine from pomace; alcoholic treatment of all samples up to 18%; 30-day storage; separation from sediment.

The control sample was prepared according to factory-accepted technology: fermentation of the pomace until residual sugar reached 10%; separation of fermented juice; alcoholic treatment of the juice up to 18%. Each grape variety was represented by 13 wine material variants.

Comparative technological evaluation of anthocyanin and phenolic compound extraction efficiency from grape skins was performed. The pomace was processed in a CDG-20A centrifugal crusher-destemmer. Before fermentation, the pomace was heated to 50–60°C. Enzymatic treatment used Trenolin Opti and Trenolin Color DF (Germany) at a dose of 1.5–2.0 mg/dm^3.

Mechanical treatments were applied in two ways: stirring with a mixer every 8 hours (control) and low-frequency agitation (50 Hz, amplitude 4 mm) for 3–5 minutes. A model device (Fig. 1) was used to apply agitation for 1, 3, and 5 minutes. The control variant followed factory-accepted stirring (4 times per day).

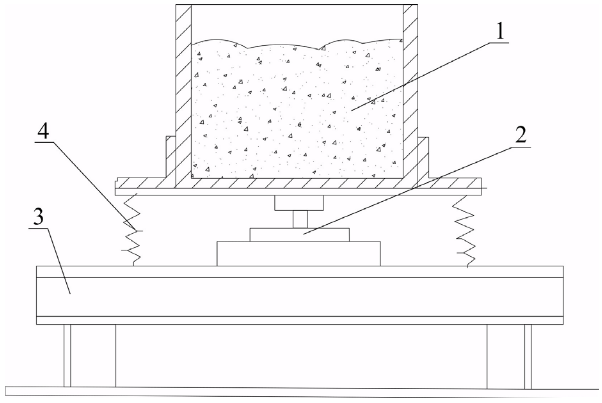

Fig. 1. Schematic diagram of the vibration device (model apparatus) for marc extraction: 1 – container with marc; 2 – electromagnet; 3 – frame of the vibration device; 4 – spring

The physicochemical and organoleptic characteristics of raw materials, semi-finished, and finished products were determined using standard enochemical analytical methods [24, 25]. In the obtained samples, the optical density was measured on a СФ-4А spectrophotometer at 10 nm intervals over a wavelength range of 400–650 nm. Based on these measurements, optical density graphs were constructed, and according to these, the color characteristics of wine were determined using the Südro method: intensity (D420 + D520) and hue (D420:D520); brightness, clarity, and dominant wavelength using the arbitrage method; and the angle formed by the tangent connecting the points corresponding to D420 and D520 on the spectrophotometric curve. This angle characterizes hue in the express-method.

The mass concentration of phenolic compounds in wine was determined using the Folin-Ciocalteu method. The Folin-Ciocalteu reagent oxidizes phenolic groups in wine, forming a blue complex. The color intensity is proportional to the concentration of phenolic compounds. The total content of phenolic compounds and pigments was determined both during the experiment and after storing the wine material in sealed glass bottles at 18–20°C for 5 months.

Modern analytical techniques, including high-performance liquid chromatography (HPLC), as well as statistical analyses and calculations, were performed using IBM SPSS Statistics 18.0 (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.) and MS Excel 2007 (USA). Statistical significance was accepted at $p < 0.05$.

Mean ± standard deviation values are presented in the descriptive statistics of the variables included in the study. To compare measurements obtained at different time points for control and experimental samples, ANOVA and t-tests were used. The Tukey method was applied for pairwise comparisons of variables showing significant differences between groups. Repeated measures ANOVA and paired t-tests were also used to compare measurement values of control and experimental samples at different time points [26, 27].

5. Results on the identifying of factors affecting the extraction of phenolic compounds in wine production

5. 1. Effect of various processing methods on the extraction of phenolic compounds

The mass concentration of phenolic compounds and anthocyanins as the technological potential was investigated in certain red grape varieties (Fig. 2).

As shown in Fig. 2, the technological potential of phenolic compounds in the investigated red grape varieties ranged from 4330 to 5790 mg/dm^3, while the technological potential of anthocyanins ranged from 1360 to 1680 mg/dm^3. Among the varieties, Saperavi had the highest technological potential, with phenolic compounds reaching 6041 mg/dm^3 and anthocyanins 1760 mg/dm^3. The next highest values were observed in Cabernet Sauvignon, with phenolic compounds and anthocyanins at 5790 mg/dm^3 and 1680 mg/dm^3, respectively. The lowest values were recorded for Tavkveri, with phenolic compounds at 4330 mg/dm^3 and anthocyanins at 1360 mg/dm^3. In Khindogni, these values were 4970 mg/dm^3 and 1540 mg/dm^3, respectively, and in Merlot, they were 5450 mg/dm^3 and 1590 mg/dm^3, respectively.

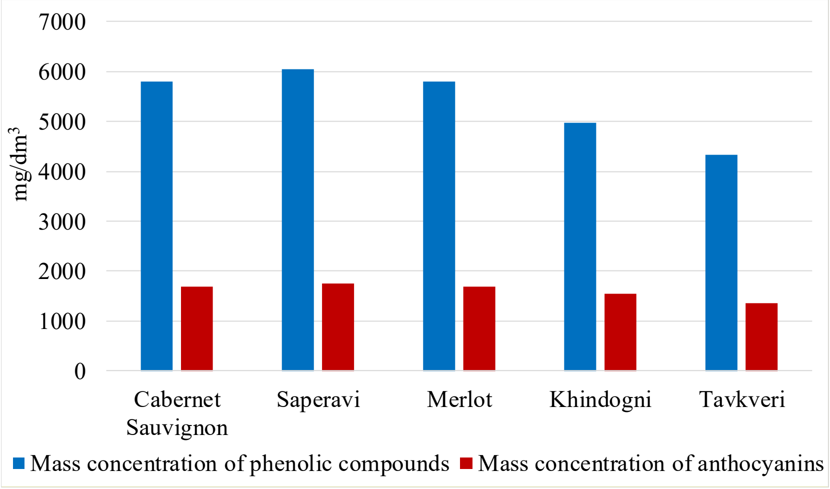

Fig. 2. Technological potential of phenolic compounds and anthocyanins in different grape varieties

Based on the data presented in the figure, the studied grape varieties can be ranked according to the technological potential of phenolic compounds as follows: Saperavi, Cabernet Sauvignon, Merlot, Khindogni, and Tavkveri. A similar trend is observed for anthocyanin content.

The effect of maceration duration and alcoholic treatment at different levels (6, 10, and 18% vol.) on the extraction process was studied in the Khindogni variety. The results for the Khindogni variety are presented below (Tables 1–3).

Pomace samples subjected to maceration for different durations were alcoholized up to 6% vol. In the control variant, no storage was applied. As observed, with increasing maceration time, the total content of phenolic compounds also increased. After storage, a decrease in this content was observed across all samples.

If the total phenolic content in the control sample before storage was 2.45 g/dm^3, a decrease was noted for maceration durations of 12, 24, and 48 hours, while a slight increase occurred after 72 hours of maceration. However, after storage, the total phenolic content did not show a tendency to increase with longer storage times. A similar trend was observed for pigment content. In the control sample, the pigment content after storage was 246 mg/dm^3, while after 12 hours of maceration it was 361 mg/dm^3,after 24 hours 472 mg/dm^3, after 48 hours 579 mg/dm^3, and after 72 hours 583 mg/dm^3.

Alcoholization of samples subjected to maceration for different durations up to 10% vol. caused greater changes in both the total content of phenolic compounds and pigment content compared to 6% vol. After storage, an increase of up to 1.25 g/dm^3 in total phenolic content was observed in the sample macerated for 72 hours compared to the control. A similar trend was observed in pigment content: in samples macerated for 48–72 hours, pigment content increased approximately 2.5–3 times compared to the control.

Table 2

Effect of pomace maceration duration and 10% alcohol treatment on the extraction of phenolic compounds (Khindogni variety)

No.	Indicators	10% alcohol by volume				
		Control	12 hours	24 hours	48 hours	72 hours
1	Total amount of phenolic compounds, g/dm^3					
1. 1	Before storage	2.45	2.32	2.72	2.93	3.42
1. 2	After storage	1.95	2.25	2.65	2.85	3.30
2	Coloring substances, mg/dm^3					
2. 1	Before storage	586	518	658	738	648
2. 2	After storage	246	492	660	710	618
3	Color characteristics before storage					
3. 1	Intensity	20.9	19.	24.2	27.6	24.2
3. 2	Hue, D_{420}/D_{520}	0.998	0.667	0.582	0.605	0.669
3. 3	Brightness, %	10.4	18.9	11.6	8.7	11.7
3. 4	Clarity, %	32	21	28	33	33
3. 5	Dominant wavelength, nm	638	493	495	495	493
3. 6	Hue (angle)	0°05^1	20°45^1	32°30^1	34°10^1	25°30^1

Table 3

Effect of pomace maceration duration and 18% alcohol treatment on the extraction of phenolic compounds (Khindogni variety)

No.	Indicators	18% alcohol by volume				
		Control	12 hours	24 hours	48 hours	72 hours
1	Total amount of phenolic compounds, g/dm^3					
1.1	Before storage	2.45	2.52	3.43	3.89	3.66
1.2	After storage	1.95	2.40	3.35	3.75	3.50
2	Coloring substances, mg/dm^3					
2.1	Before storage	586	656	880	884	715
2.2	After storage	246	610	825	783	660
3	Color characteristics before storage					
3.1	Intensity	20.9	26.2	33.4	35.2	29.8
3.2	Hue, D_{420}/D_{520}	0.998	0.845	0.749	0.725	0.732
3.3	Brightness, %	10.4	12.8	6.6	6.4	8.6
3.4	Clarity, %	32	39	47	52	40
3.5	Dominant wavelength, nm	638	618	700	633	625
3.6	Hue (angle)	0°05^1	12°20^1	25°30^1	29°10^1	24°40^1

Table 1

Effect of pomace maceration duration and 6% alcohol treatment on the extraction of phenolic compounds (Khindogni variety)

No.	Indicators	6% alcohol by volume				
		Control	12 hours	24 hours	48 hours	72 hours
1	Total amount of phenolic compounds, g/dm^3					
1. 1	Before storage	2.45	2.13	2.18	2.31	2.66
1. 2	After storage	1.95	2.05	2.10	2.25	2.55
2	Coloring substances, mg/dm^3					
2. 1	Before storage	586	389	502	615	590
2. 2	After storage	246	361	472	579	583
3	Color characteristics before storage					
3. 1	Intensity	20.9	16.9	14.7	19.7	24.6
3. 2	Hue, D_{420}/D_{520}	0.998	0.640	0.884	0.669	0.618
3. 3	Brightness, %	10.4	22.7	29.8	18.6	10.8
3. 4	Clarity, %	32	22	19	22	30
3. 5	Dominant wavelength, nm	638	493	620	493	495
3. 6	Hue (angle)	0°05^1	20°30^1	5°10^1	21°15^1	30°

Although in samples treated with 18% alcohol a slight increase in the total content of phenolic compounds and pigments was observed compared to 10% alcohol samples, this increase was not significant.

Based on the above, it can be noted that in the experimental samples obtained using alcoholic treatment and subsequent storage, the content of phenolic compounds was higher than in the control samples. In the control samples, the pomace was not alcoholized, and fermentation proceeded more intensively. The best results in the experimental variants were obtained with pomace treated with 10% and 18% alcohol. At 6% alcohol, the phenolic compounds were not distinctly perceptible. Compared to the control, the color intensity of pigments was higher in the pomace treated with 18% alcohol and stored for 24–48 hours. The color intensity of experimental wine materials was higher in the variants treated with 10% and 18% alcohol compared to the control.

With increasing alcohol content, the degree of extraction of phenolic compounds and pigments, as well as wine color intensity, also increased. For the Khindogni variety, the optimal regime for alcoholic treatment of juice with pomace is: alcohol content – 18%, storage – 24–48 hours; for Tavkveri: alcohol – 18%, storage – 48–72 hours; and for Saperavi: alcohol – 18%, storage – 48 hours.

Thus, the results of the study indicate that a differentiated technological approach is required for extraction in each variety.

Tannin preparations obtained from grape seeds and stems are similar in catechin composition but differ in the amounts of individual catechins. Both catechin content and the titration coefficient of the tannin preparation, as determined in the study, can be used to improve wine quality and guide technological enhancements.

Efficient use of tannins and pigments in red grape varieties was studied, and it was determined that during alcoholic treatment of pomace, increasing the alcohol content enhances the extraction of phenolic compounds and pigments. The best variant was found to be 18% alcohol, with storage of juice on pomace for 48–72 hours depending on the variety.

Various processing methods were used, including thermal treatment of pomace at different temperatures, different doses of enzyme preparations, classical fermentation of pomace, fermentation in a CO_2 environment, and agitation for different durations (Table 4).

Analysis of the obtained data shows that among the compared variants, the most effective extraction method is the enzymatic (fermentative) method using Trenilor Color DF at a dose of 2.0 mg/dm^3. Good results were also obtained when the pomace was thermally treated (60°C), subjected to mechanical effects (periodic stirring and low-frequency vibration), or fermented in a carbon dioxide environment. However, considering resource and energy efficiency, as well as the economic aspects of the technological process of extraction, the analysis indicates that optimal results can be achieved by applying mechanical effects to the pomace using CO_2 gas energy.

To study the effect of thermal treatment on the dynamics of phenolic compound extraction, pomace from Cabernet Sauvignon, Saperavi, and Merlo grapes at the technical maturity stage was used. The pomace was obtained using a CDG-20A centrifugal crusher-destemmer. Before fermentation, the pomace was thermally treated at 50, 60, and 70°C. The results of the study are presented in Table 5.

Table 5

Degree of extraction of phenolic and pigment compounds during thermal treatment of pomace

Experimental variant	Total phenolic compounds			Anthocyanins		
	Grape variety			Grape variety		
	Saperavi	Merlot	Cabernet Sauvignon	Saperavi	Merlot	Cabernet Sauvignon
Initial amount, g/dm^3	1.540	1.395	1.845	0.875	0.795	1.210
Heating up to 50°C	0.862	0.865	0.842	0.356	0.327	0.220
Heating up to 60°C	0.901	0.817	0.913	0.458	0.278	0.385
Heating up to 70°C	0.713	0.643	0.789	0.323	0.226	0.350
Stirring (control)	0.629	0.638	0.594	0.165	0.122	0.245

Mathematical processing of the experimental data allowed obtaining the following general regression equations for the studied grape varieties, describing the dependence of the extraction degree of phenolic and pigment compounds (as a fraction of their technological potential) on temperature.

Degree of phenolic compound extraction versus temperature

$$F = 0{,}6190 + 0{,}01445T - 0{,}0001832T^2. \tag{1}$$

Coefficient of determination $R^2 = 0.81$.

Table 4

Extraction of phenolic compounds and anthocyanins from pomace using various processing methods

Experimental variant	Cabernet Sauvignon		Saperavi		Merlot	
	Phenolic compounds	Anthocyanins	Phenolic compounds	Anthocyanins	Phenolic compounds	Anthocyanins
Heating the mash up to 50°C	0.821	0.625	0.876	0.717	0.840	0.764
Heating the mash up to 60°C	0.848	0.673	0.894	0.792	0.886	0.792
Trenol Opti (1.5 mg/dm^3 at a dose of) treatment with an enzyme preparation	0.874	0.684	0.912	0.830	0.890	0.863
Trenol Opti (2.0 mg/dm^3 at a dose of) treatment with an enzyme preparation	0.923	0.716	0.956	0.906	0.938	0.901
Trenol Color DF (1.5 mq/dm^3 at a dose of) treatment with an enzyme preparation	0.883	0.698	0.929	0.868	0.895	0.887
Trenol Color DF (2.0 mq/dm^3 at a dose of) treatment with an enzyme preparation	0.927	0.731	0.965	0.943	0.938	0.906
Fermentation of the mash with a settled “cap”	0.826	0.622	0.867	0.660	0.829	0.840
Fermentation of the mash with a floating “cap”	0.786	0.585	0.850	0.566	0.786	0.755
Fermentation of the mash in a carbon dioxide environment	0.821	0.615	0.876	0.623	0.833	0.802
Treatment with vibration for 3 minutes	0.797	0.582	0.788	0.491	0.781	0.717
Treatment with vibration for 5 minutes	0.828	0.615	0.805	0.509	0.824	0.750
Periodic stirring of the mash (production experiment) – control	0.808	0.618	0.823	0.528	0.819	0.783

Degree of anthocyanin extraction versus temperature

$$A = 0{,}1760 + 0{,}005537T - 0{,}00004992T^2. \quad (2)$$

Coefficient of determination $R^2 = 0.49$.

Here, F – degree of extraction (release) of phenolic compounds, units; A – degree of extraction of anthocyanins, units; T – heating temperature of the mash, °C.

Analysis of the research results shows that the most effective method for intensifying the extraction of phenolic and coloring substances from the grape berry skin is heating the mash to 60°C.

5. 2. Effect of mechanical impacts and storage on the amount of phenolic compounds

During the course of the study, it was determined that as the duration of vibrational treatment applied to the mash increases, the mass concentration of phenolic and coloring substances in the juice and wine material also increases (Tables 6, 7). Compared to the control, 1 minute of vibrational processing of the mash increases the mass concentration of phenolic compounds in the juice and wine material by up to 3.4%, and anthocyanins by up to 12.1%, depending on the grape variety. When the duration of vibrational treatment is extended to 3 minutes, the mass concentration of phenolic compounds increases by 8.2–10.1%, while anthocyanins increase by 49.9–86.6%.

When the duration of vibrational impact is 5 minutes, the mass concentration of phenolic compounds increases by 12.3–35.9%, and the mass concentration of anthocyanins increases by 46.4–81.8%, depending on the grape variety. It was also determined that different grape varieties are affected by low-frequency vibrations to different extents. Maximum extraction of phenolic compounds from the grape berry skin is observed in the Cabernet Sauvignon variety, and the lowest extraction is noted in the Merlot variety. Nevertheless, more intensive extraction of coloring substances is recorded in the Merlot and Saperavi varieties.

When comparing the mass concentration values of phenolic compounds and the technological potential in the control and experimental juice samples across grape varieties, it was found that mixing (in the control variant) ensured extraction up to 59.4% of the technological potential in Cabernet Sauvignon and up to 63.8% in Merlot. Under 5 minutes of vibrational treatment, these indicators reached 72% for Saperavi and 81% for Cabernet Sauvignon. Vibrational impact intensifies the extraction of phenolic compounds by more than 1.24 times. Compared to the control, higher concentrations of extracted substances were recorded in the experimental samples. Such increases were also observed in the finished wine materials.

The evaluation of the effectiveness of vibrational treatment of the mash was carried out based on the degree of extraction (share of technological potential) of phenolic and coloring substances. The results are presented in Table 8.

Table 6

Changes in the mass concentration of phenolic compounds during the processing of the mash under different regimes

Mechanical treatment method of the mash	Grape variety					
	Saperavi		Merlot		Cabernet Sauvignon	
	At the beginning of fermentation	Fermented wine material	At the beginning of fermentation	Fermented wine material	At the beginning of fermentation	Fermented wine material
Initial amount, g/dm^3	1.540		1.400		1.840	
1-minute vibration	0.970	0.805	0.900	0.730	1.130	0.310
3-minute vibration	1.050	0.900	0.980	0.820	1.200	1.130
5-minute vibration	1.110	0.980	1.000	0.900	1.490	1.285
Stirring (control)	0.970	0.900	0.890	0.710	1.095	1.070

Table 7

Changes in the mass concentration of anthocyanins during the processing of the mash under different regimes, mg/dm^3

Mechanical treatment method of the mash	Grape variety					
	Saperavi		Merlot		Cabernet Sauvignon	
	At the beginning of fermentation	Fermented wine material	At the beginning of fermentation	At the beginning of fermentation	Fermented wine material	At the beginning of fermentation
1-minute vibration	160	100	150	90	260	240
3-minute vibration	215	150	180	100	320	315
5-minute vibration	205	150	200	140	340	330
Stirring (control)	140	90	110	50	200	170

Table 8

Degree of extraction of phenolic compounds and anthocyanins from mash under different processing methods

Technological method	Total phenolic compounds			Anthocyanins		
	Saperavi	Merlot	Cabernet Sauvignon	Saperavi	Merlot	Cabernet Sauvignon
Initial amount, g/dm^3	1.540	1.395	1.845	0.845	0.795	1.210
1-minute vibration	0.629	0.645	0.614	0.183	0.183	0.132
3-minute vibration	0.681	0.703	0.649	0.247	0.227	0.184
5-minute vibration	0.720	0.717	0.807	0.235	0.252	0.114
Stirring (control)	0.629	0.638	0.594	0.165	0.122	0.245

When evaluating the effect of mechanical treatment methods, the use of low-frequency vibrations for processing the mash draws particular attention. Compared to the control variant, it can be seen that the mass concentration of phenolic compounds during extraction is 1.21 times higher, while the mass concentration of anthocyanins is 1.24 times higher.

Thus, the conducted experimental research established that intensifying the extraction of phenolic and coloring substances from the skins of red grape varieties becomes significantly more effective when low-frequency mechanical oscillations (vibrations) are applied to the mash. This leads to the release of larger amounts of these compounds and helps shorten the duration of the process.

Based on the use of low-frequency vibrations (with a treatment duration of 5 minutes), heating of the mash (to 60°C), and the application of the enzyme preparation "Trenol Opti" (at a dose of 2 mg / dm^3), complex technological methods were proposed to intensify the extraction of phenolic and coloring substances. The application of these methods makes it possible to increase the degree of extraction (in terms of the share of technological potential) of phenolic compounds and anthocyanins up to 85–94%.

It was determined that during fermentation of the mash, the mass concentration of phenolic and coloring substances depends exponentially on the mash heating temperature and the duration of vibrational exposure.

Since phenolic substances precipitate during barrel storage of wine materials, leading to a decrease in their mass concentration, the dynamics of changes in phenolic and coloring substances during storage were studied for the variant with maximum extraction. The results of the study are presented in Table 9.

Table 9

Changes in the mass concentration of phenolic and coloring compounds during the storage period of wine material

Indicators	Grape variety	Initial material	After 4 months	After 5 months	After 6 months
Mass concentration of phenolic compounds (total), mg/dm^3	Cabernet Sauvignon	1298	1231	1223	1207
	Syrah	471	412	396	383
Mass concentration of anthocyanins, mg/dm^3	Cabernet Sauvignon	239	223	222	210
	Syrah	201	182	181	168

The obtained values show that over 6 months, the mass concentration of phenolic compounds in the wine material of the Syrah grape variety decreased by 21.3%, while anthocyanins decreased by 16.4%. In the control variant (Cabernet Sauvignon), the corresponding decreases were 7.01% and 12.13%. As can be seen from the obtained results, the decrease in coloring substances in the control wine material is relatively small and is around 12–13%. It should be noted that although the reduction in the mass concentration of phenolic compounds in the control wine material is approximately three times greater compared to the Syrah wine material, the decrease in the mass concentration of coloring substances is quite similar-within the range of 12.13–14.4%.

The dynamics of changes in the mass concentration of phenolic compounds and anthocyanins during storage in the control and experimental wine materials are shown in Fig. 3, 4.

The conducted study allows to conclude that wine material obtained from Syrah grapes can be used both in blending and as varietal wine material, making it possible to expand the assortment of red acidic table wines.

Mathematical processing of the experimental values made it possible to determine the correlation and regression dependencies among the studied parameters: mass concentration of phenolic compounds (φk), anthocyanins (αk), and storage duration of wine materials (τ).

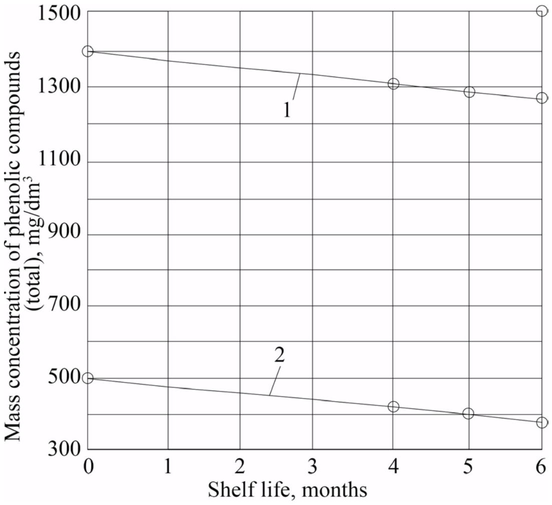

Fig. 3. Changes in the mass concentration of phenolic compounds during the storage period of wine samples: 1 — cabernet sauvignon; 2 — Syrah

For the wine material of the Cabernet Sauvignon grape variety:

$$\varphi_k = \varphi_0(10000 - 113.8 \cdot 10^{-4}\tau - 1.1966 \cdot 10^{-4}\tau^2),\ R^2 = 0.997;\ \tau = -0.998; \quad (3)$$

$$\alpha_k = \alpha_0(10000 - 161.9 \cdot 10^{-4}\tau - 6.050 \cdot 10^{-4}\tau^2),\ R^2 = 0.996;\ \tau = -0.982. \quad (4)$$

For the wine material of the Syrah grape variety:

$$\varphi_k = \varphi_0(10000 - 295.7 \cdot 10^{-4}\tau - 3.044 \cdot 10^{-4}\tau^2),\ R^2 = 0.996;\ \tau = -0.998; \quad (5)$$

$$\alpha_k = \alpha_0(10000 - 194.6 \cdot 10^{-4}\tau - 7.206 \cdot 10^{-4}\tau^2),\ R^2 = 0.966;\ \tau = -0.982. \quad (6)$$

Here φ_k – mass concentration of phenolic compounds in the wine material, mg/dm^3;

φ_0 – mass concentration of phenolic compounds in the wine material before storage mg/dm^3;

α_k – concentration of anthocyanins in the wine material, mg/dm^3;

α_0 – mass concentration of anthocyanins in the wine material before storage, mg/dm^3;

τ – storage duration, months.

The obtained mathematical expressions can be used to determine the dynamics of changes in the mass concentrations of phenolic compounds and anthocyanins when storing red table wine materials.

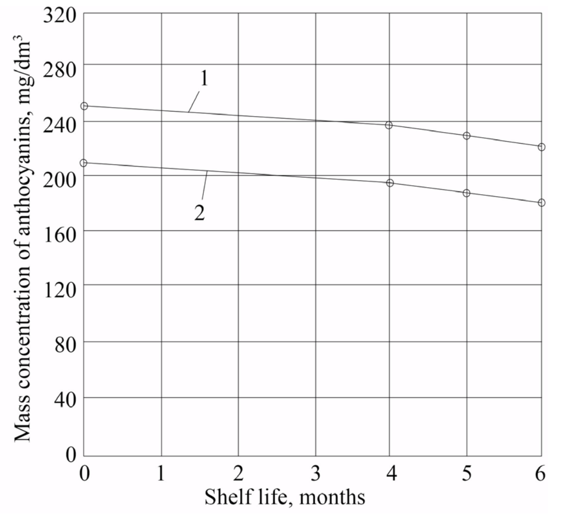

Fig. 4. Changes in the mass concentration of anthocyanins during the storage period of wine material: 1 — cabernet sauvignon; 2 — Syrah

During storage, wine undergoes significant physicochemical changes. It should be noted that when wine is stored in barrels, over time, the mass concentrations of titratable and volatile acids and ethyl acetate increase, while the astringency of the wine decreases. Such conditions lead to a decline in wine quality, resulting in the loss of body and smoothness. This is directly related to insufficient astringency and low acidity. Therefore, storing wine in barrels for more than two years is not recommended.

Study shows that storage of red wine in contact with air significantly reduces the concentration of coloring substances. It is recommended to store red table wines in conditions isolated from air (in bottles or tightly sealed tanks) at a temperature of 20°C. If the wine is in contact with air (e.g., in barrels), the recommended storage temperature is 15°C. Temperatures above these levels lead to a significant decrease in the mass concentration of coloring substances. A decrease in the mass concentration of anthocyanins also corresponds to a reduction in wine color intensity.

Subsequent studies focused on examining changes in the physicochemical properties of red table wine from Cabernet Sauvignon under various storage methods.

The research material was red table wine prepared from Cabernet Sauvignon grapes using the following technologies: maceration of the mash at 35–40°C for one day; fermentation of the juice in the mash at 25–28°C in a sulfur dioxide environment with periodic stirring; and residual fermentation at 15–16°C. Storage was carried out in two variants: 1 year in a barrel followed by 1.5 years in bottles, and 2 years entirely in a barrel. In both variants, the storage temperature was 14–18°C. The results are presented in Table 10.

Analysis of the obtained values showed that the storage method has a significant effect on the physicochemical properties of the wine.

Comparison of storing wine in a barrel for 2 years with the variant of storing 1 year in a barrel followed by 1.5 years in bottles showed that in the first variant, some quality indicators decreased significantly. Specifically, the ethanol volume fraction decreased by 14.7%, free sulfur dioxide by 10.7%, total sulfur dioxide by 24.7%, phenolic compounds: total – 14.5%, monomers – 11.3%, polymers – 18.7%, and coloring substances – 6.7%. Additionally, the mass concentration of total extract decreased by 9.5%, and the extracted extract decreased by 10.3%. A slight reduction in optical characteristics of the wine was observed: color intensity – 1.8%, color hue – 5.2%. Meanwhile, the following increases in mass concentration were noted: titratable acids – 8.5%, volatile acids – 16.7%.

Table 10

Effect of storage conditions on the physicochemical composition of Cabernet Sauvignon wine material

Indicators	Storage for 1 year in a barrel and 1,5 years in a bottle	Storage for 2 years in a barrel
Ethanol volume fraction, %	13.08	11.17
Mass concentration of titratable acids, g/dm^3	6.1	6.5
Mass concentration of volatile acids, g/dm^3	1.2	1.3
Mass concentration of sulfurous acid, mg/dm^3		
Free	27	26
Total	165	127
Mass concentration of phenolic compounds, mg/dm^3		
Total	2580	2200
Monomer	832	776
Polymer	1746	1409
Coloring	181	170
Mass concentration of extract, g/dm^3		
Total	19.2	17.1
Fixed	17.5	15.5
Optical characteristics		
Color intensity:	0.990	0.981
Color hue:	0.465	0.437
Mass concentration, mg/dm^3		
Potassium	1030	1021
Sodium	23	28
Calcium	55	79
Magnesium	100	99
Zinc	0.31	0.17
Iron	1.40	1.04
Copper	0.22	0.18

Producing high-quality, low-oxidized table wines requires creating optimal oxidation-reduction conditions, with oxygen playing a crucial role. It should be noted that in most cases, direct contact with air negatively affects the stability and organoleptic properties of wine. The highest oxidation occurs when wine is stored in partially filled barrels. In partially filled containers, oxygen from the air above diffuses into the wine until full saturation is reached. It is known that at 12°C, 200 mg of oxygen diffuses per 1 m^2 of wine surface in 1 hour. As the wine volume in the barrel increases, the oxygen concentration in the air above decreases, which increases gas diffusion. To prevent the negative effect of air oxygen on wine quality, inert gases are used. Accordingly, various storage methods using inert gases (e.g., nitrogen) have been studied for their impact on physicochemical indicators.

Wine storage was carried out for 3 months under two variants: full barrels and half-full (50%) barrels under inert gas (nitrogen). Nitrogen was supplied from below through barbotage. The microbiological condition of the samples was studied using microscopy in 10 fields of view under a centrifuge. The results showed that in both storage variants, physicochemical indicators did not differ, and sensory evaluation was the same. Microbiologically, lactic acid bacteria were found in the control variant, which is consistent with regulatory standards, while in the experimental variant the wine remained biologically stable.

The studies demonstrated the high efficiency of storing wine under nitrogen. Even in half-full (50%) barrels, the wine remained stable after 3 months compared to the control variant.

Wine color depends on the grape variety, cluster growth conditions, agrotechnical practices, grape maturity, and winemaking technology. Grapes grown in the republic have sufficient anthocyanin concentrations. The study used experimental wine materials prepared under production conditions in local wine factories. The results are presented in Table 11. Analysis of the obtained values shows that wines and wine materials prepared from Cabernet Sauvignon, Merlot, and Saperavi grape varieties were intensely colored. The positive effect of intensive extraction methods on the color of wine materials should also be noted.

Mathematical processing of the physicochemical analysis results of production and experimental wine samples from 2021–2023 made it possible to establish a relationship between color intensity and the mass concentrations of total phenolic compounds and anthocyanins. It was determined that there is a moderate correlation between color intensity and the mass concentration of anthocyanins, with a correlation coefficient of $\tau = 0.661$.

The dependence between the quality indicators of red wine materials is expressed by a first-degree regression equation

$$Int. = 0.4878 + 17.68 \cdot 10^{-4}\alpha_k, \qquad (7)$$

Int. – color intensity of the wine material;

α_k – mass concentration of anthocyanins, mg/dm^3;

R^2 – 0.43, significance level, $\alpha = 0.021$.

The correlation coefficient between the color intensity of red wines and the mass concentration of total phenolic compounds is relatively low, with a value of $\tau = 0.576$. The relationship between these indicators is expressed by a second-degree regression equation

$$Int. = 3{,}5070 - 24{,}88 \cdot 10^{-4}\varphi_k + 5{,}6078 \cdot 10^{-7}\varphi_k^2. \qquad (8)$$

Here: φ_k – mass concentration of total phenolic compounds, mg/dm^3;

R^2 – 0.54, significance level, $\alpha = 0.031$.

Using the obtained dependencies, it is possible to predict, with a certain probability, the color intensity of wine based on known mass concentrations of total phenolic compounds and anthocyanins. These results can be applied in the development of new wine brands.

Thus, as a result of the conducted study, technological schemes for intensifying the extraction process of phenolic and coloring substances have been proposed, as well as new methods for mash processing and a new fermentation device based on a specially designed extractor and periodic lifting of the “cap.”

6. Discussion of the results of studying factors affecting the extraction of phenolic compounds in winemaking

Unlike the study [1] devoted to factors affecting pectin extraction yield and physicochemical parameters from grape mash, in this study, the technological potential of phenolic compounds was determined for some aboriginal and introduced red grape varieties, and their ranking from high to low was established as follows: Saperavi, Cabernet Sauvignon, Merlot, Khindogni, and Tavkveri (Fig. 2).

Table 11

Physicochemical composition of wine materials prepared according to various technological schemes

Wine material, year of production	Optical density at D_{420}	Optical density at D_{520}	$Int = D_{420} + D_{520}$	Total phenolic compounds, mg/dm^3	Anthocyanins, mg/dm^3
Khindogni red table wine, 2021	0.220	0.409	0.629	2418	131
Khindogni red table wine, 2022	0.300	0.691	0.991	2903	229
Khindogni red table wine, 2023	0.295	0.665	0.960	2798	274
Saperavi red table wine, 2023	0.221	0.604	0.825	1853	221
Cabernet Sauvignon red table wine, 2021	0.264	0.581	0.845	2743	191
Cabernet Sauvignon red table wine, 2022	0.285	0.640	0.925	2853	169
Cabernet Sauvignon red table wine, 2023	0.271	0.611	0.882	2526	263
Madrasa red table wine, 2022	0.230	0.542	0.772	2264	148
Madrasa, red table wine, fermented in a CO_2 environment, 2022	0.230	0.466	0.696	2420	221
Merlot red table wine, 2023	0.198	0.470	0.668	2232	163
Merlot, red table wine, with 5-minute vibration treatment, 2023	0.264	0.618	0.882	2261	190
Merlot, red table wine, with periodic “cap” punching-down, 2023	0.300	0.710	1.01	2688	237

To study the effect of parameters on extraction characteristics, unlike the study [3] based on the application of enzymes capable of breaking down structural components, this study comparatively analyzed the physicochemical properties of samples that were either unfortified with alcohol or macerated at various alcohol strengths for different durations. An increase in alcohol content (%) led to an increase in the amount of phenolic compounds and anthocyanins. It was found that in experimental samples treated and stored with alcohol, the amount of phenolic compounds exceeded that of the control. In the control samples, the mash was not fortified with alcohol, resulting in faster and more intense fermentation. The best results were obtained when the mash was treated with 10% and 18% alcohol. At 6% alcohol, phenolic compounds were less evident. Color substances were observed during maceration of the mash treated with up to 18% alcohol for 24–48 hours. The color intensity corresponded to the variants treated with 10% and 18% alcohol (Tables 1–3).

Unlike the study [2], which recommended dimethyl carbonate (DMC), a green solvent, as a better alternative to fossil-based solvents for oleanol extraction, this study used various processing methods, including hot treatment of the mash at different temperatures, different doses of enzyme preparations, classical mash fermentation in a CO_2 environment, and vibrational treatment of different durations. During these processes, the total amount of phenolic compounds and the degree of anthocyanin extraction (relative to the initial amount) were investigated across different grape varieties (Tables 4, 5).

Unlike the study [11] claiming that microwave extraction is the best method to extract polyphenols from processing residues, in this work it was found that increasing the duration of vibrational treatment of the mash increases the mass concentration of phenolic and coloring substances in the wine material. Increasing the duration of vibrational impact up to 3 minutes resulted in an increase in the mass concentration of phenolic compounds by 8.2–10.2% and anthocyanins by 49.9–86.6% compared to the control (Tables 6–8).

Unlike the study [17], which reported the formation of ellagitannin-derived compounds in Vintage Port wines stored horizontally due to reactions between cork components and phenolic compounds in the wine, this work investigated changes in the mass concentrations of phenolic and coloring compounds during the storage of wine samples. It was found that over 6 months, in Syrah wine material, the mass concentration of phenolic compounds decreased by 21.3% and anthocyanins by 16.4%. A similar trend was observed in Cabernet Sauvignon wine material (Table 9, Fig. 3, 4).

Unlike the study [18] examining the effect of cork on chemical processes during wine aging, in this work, Cabernet Sauvignon wine material was stored under two variants for different durations. Comparison of storage in barrels for 2 years with the mixed storage variant (1 year in a barrel and 1.5 years in bottles) showed a significant decrease in quality indicators in the first variant (Table 10).

Unlike the study [19], which linked changes in the phenolic profile of Merlot wine during aging to the container, duration, and initial wine composition, in this work, the wine was stored for 3 months under two variants: fully filled barrels and half-full (50%) barrels under an inert gas atmosphere. The studies demonstrated the high efficiency of storing wine under a nitrogen atmosphere. Even in half-full (50%) barrels, the wine remained stable after 3 months compared to the control variant.

Experimental wine samples prepared under production conditions were investigated. It was found that wine samples made from Cabernet Sauvignon, Merlot, and Saperavi grapes were more intensely colored compared to their analogs, and the positive effect of intensive extraction methods on coloring was noted (Table 11).

The main limitation of this study is that, since the phenolic composition exhibits varietal specificity, the obtained results cannot be directly applied to other grape varieties. Another limitation is related to the fact that the fermentation process was carried out under microvinification conditions. Under industrial winemaking conditions, the regulation of temperature and other influencing factors is more complex, and therefore the extraction process may be characterized by different outcomes. In addition, during the course of the study, only the total content of phenolic compounds, including anthocyanins, was determined, while the evaluation of individual phenolic fractions was not performed.

The absence of a comparative analysis of yeast strains used during fermentation can be considered a shortcoming of this study. Furthermore, another drawback is the lack of organoleptic evaluation during the extraction process aimed at increasing the phenolic content. This is particularly important because an increase in phenolic compounds does not necessarily have a positive effect on organoleptic quality. In future studies, the influence of different yeast strains on the adsorption of phenolic compounds should be taken into account. In addition to chemical analyses, sensory characteristics, including the evaluation of taste, color, and bouquet, may also be assessed.

In future research, the study may be further developed by focusing on individual classes of phenolic compounds, such as flavan-3-ols, tannins, and related fractions. In this context, one of the main challenges is the large number of variables involved and the resulting complexity of mathematical models. From an experimental point of view, achieving full standardization of fermentation conditions and ensuring reproducibility of results may present difficulties. When scaling up to industrial production, technological and economic constraints must also be taken into consideration.

7. Conclusion

1. During the alcohol treatment of the pomace, increasing the ethanol content led to a higher extraction of phenolic compounds and coloring substances. The optimal condition was determined to be an ethanol concentration of 18% (v/v) and a pomace maceration time of 48–72 hours, depending on the grape variety. Hot processing of the pomace (60°C) combined with mechanical action (periodic stirring and low-frequency treatment), as well as fermentation under a carbon dioxide atmosphere, produced favorable results. However, from a resource- and energy-saving perspective, applying mechanical action to the pomace using the carbon dioxide generated during fermentation could be considered a more optimal approach.

2. Compared to the control, applying 1 minute of vibration-based mechanical treatment to the pomace increased the mass concentration of phenolic compounds in the juice and wine by up to 3.4% and anthocyanins by up to 12.1%, depending on the grape variety. Extending the vibration treatment to 3 minutes increased the mass concentration

of phenolic compounds by 8.2–10.1% and anthocyanins by 49.9–86.6%. With a 5-minute vibration treatment, depending on the grape variety, the mass concentration of phenolic compounds increased by 12.3–35.9%, and anthocyanins by 46.4–81.8%. During storage, a decrease in the mass concentration of phenolic compounds and anthocyanins was observed in both control and experimental wine samples.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

Use of artificial intelligence tools

The authors confirm that they did not use artificial intelligence technologies in creating the submitted work.

Authors' contributions

Hasil Fataliyev: Writing – review & editing, Project administration, Writing – original draft; **Elnur Heydarov:** Conceptualization, Investigation, Writing – original draft; **Mehman Ismayilov:** Validation, Investigation, Writing – review & editing; **Natavan Gadimova:** Investigation, Methodology, Conceptualization; **Konul** Baloghlanova**:** Investigation, Methodology, Conceptualization; **Shabnam Fataliyeva:** Conceptualization, Methodology, Investigation.

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