

Scifood

vol. 20, 2026, p. 472-485

<https://doi.org/10.5219/scifood.121>

ISSN: 2989-4034 online

<https://scifood.eu>

© 2026 Authors, License: CC BY-NC-ND 4.0

Received: 20.2.2026

Revised: 23.4.2026

Accepted: 30.4.2026

Published: 11.5.2026



Evaluation of the quality parameters of distillates and macerates produced from black chokeberry (*Aronia melanocarpa*)

*Lucia Ailer, Štefan Ailer, Martin Janás,
Adrián Selnekovič, Martin Molčan*

ABSTRACT

The study aimed to design an optimal technological process for preparing mash from black chokeberry (*Aronia melanocarpa*) for fruit distillate production. The cultivar Galicjanka (harvest 2024) was used. Three variants were evaluated: (1) mash with added sucrose and water, (2) mash without sucrose and water, and (3) maceration of pulp in apple distillate (52% vol. ethanol) without fermentation or distillation. The following parameters were analyzed: methanol content, non-volatile soluble substances, higher alcohols, and sensory quality. Technological interventions during mash preparation, particularly the addition of water, enzymes, and sucrose, significantly influenced distillate quality. The highest methanol content was found in the variant without sucrose and water (2.754 g/L a.a.), while the lowest was in the macerated sample (0.238 g/L a.a.). Non-volatile soluble substances were highest in the macerated variant (56.09 g/L a.a.) and lowest in the fermented variant without additives (<0.002 g/L a.a.). The highest sensory score was achieved by the macerated variant (42.5 points), followed by the variant with added sucrose and water (42.0 points), which also showed low methanol levels and a more balanced sensory profile. These findings support the broader use of chokeberry in distillate and macerate production and highlight the importance of optimizing technological parameters, especially when preserving bioactive compounds.

Keywords: black chokeberry, fermentation, distillate, maceration, methanol, sensory analysis

INTRODUCTION

The production of fruit distillates and macerates has a long tradition in Slovakia and is deeply rooted in the country's cultural and economic heritage. Traditional fruits such as plums, apples, and pears are commonly used in distillate production; however, in recent years, there has been growing interest in new and less conventional raw materials that possess unique sensory and nutritional properties. One such raw material is black chokeberry (*Aronia melanocarpa*), known for its high content of antioxidants, vitamins, polyphenols, and other bioactive compounds [1], [2]. Despite the exceptional properties of chokeberry, its use in distillate production remains relatively limited.

This may be due not only to its characteristic astringency but also to the insufficiently explored technological processes required to produce a harmonious and sensorially acceptable product. Therefore, optimizing the mash preparation process is essential for improving the quality of the final distillate and for effectively utilizing the potential of this unconventional raw material [3]. Since ancient times, the production of distillates and the process of distillation have been an integral part of human history—whether as a food product or as a component of medicinal preparations. The maceration of fruit and

herbs has long been a traditional method used in the creation of elixirs, tinctures, and plant extracts [4], [5]. Today, we are witnessing both the preservation and revival of traditional technological processes, as well as progress in formulations, technology, the application of scientific knowledge, and the definition of quality standards [6]. Chokeberry, in terms of its history in distillation, cannot be compared with traditional fruits such as plums, apples, or pears, as it has not been commonly used to produce fruit distillates in our region—although this is now beginning to change. To produce both macerates and distillates, chokeberry is an exceptionally valuable raw material, primarily due to its high content of antioxidants, vitamins, and its intense flavor [7].

Most of the chokeberry varieties cultivated in Slovakia belong to the species *Aronia melanocarpa*. Other distinct species include *A. prunifolia*, although *A. melanocarpa* remains the most widely grown. Chokeberry fruit is nutritionally valuable, containing approximately 198 kJ (47 kcal) of energy, 0.63 g of fat, 0.7 g of protein, 20.1 g of total carbohydrates (of which 7.5 g are sugars), 2.1 g of fiber, and 0.9 mg of sodium per 100 g of fresh weight [8]. The total amino acid content in chokeberries ranges from 558 to 1,580 mg/kg, with essential amino acids accounting for 56 to 128 mg/kg, ranking the fruit among moderately rich sources of amino acids compared to similar berry fruits. Chokeberry juice is considered one of the strongest natural antioxidants [9]. To ensure a high-quality fermentation process, the quality of the raw fruit at the time of harvest is crucial. The optimal raw material for mash preparation is fruit at technological ripeness—that is, at a stage when it contains the maximum amount of fermentable sugars and aromatic compounds [10]. Distillation is a physico-chemical process in which a mixture of liquids, or a liquid containing dissolved substances, is separated into individual components based on their different boiling points. It is primarily used for separating or purifying liquids and for extracting volatile compounds from mixtures [11], [12], [13], [14]. Maceration is the process of extracting compounds from fruit, seeds, berries, herbs, or their parts by soaking them in a distillate, alcohol, or alcohol diluted with water. The result of this process is a semi-finished product called a macerate, which carries the aroma and flavor characteristic of the raw materials used [15], [16].

According to the currently valid Regulation (EU) 2019/787 of the European Parliament and of the Council of 17 April 2019 on the definition, description, presentation, and labeling of spirit drinks, the maximum methanol content in fruit spirits is set at 1,000 grams per hectoliter of 100% alcohol (a.a.). Although different (often higher) limits are reported in the literature for specific categories of berry fruit distillates, black chokeberry (*Aronia melanocarpa*) is not explicitly defined as a separate category under current EU legislation and is therefore classified within the general category of fruit spirits. Consequently, the general legal limit of 1,000 g/hL a.a. is considered applicable in this study. Neither EU legislation nor Slovak national law defines limit values for non-volatile soluble substances [17].

Scientific Hypothesis

The technological process applied during the production of black chokeberry (*Aronia melanocarpa*) distillates and macerates significantly affects their chemical composition and sensory quality. It is assumed that the addition of water, sucrose, and enzymes during mash preparation leads to lower methanol content and improved sensory properties compared to mash prepared without these additives. Furthermore, it is hypothesized that maceration without fermentation results in significantly different levels of non-volatile soluble substances and higher alcohols compared to fermented variants. It is also assumed that the monitored parameters (methanol, higher alcohols, and non-volatile soluble substances) differ significantly among individual sub-variants within each technological group.

Objectives

The primary objective of this study was to design and experimentally verify an optimal technological process for the production of distillates and macerates from black chokeberry (*Aronia melanocarpa*), with an emphasis on improving their chemical composition and sensory quality. The study aimed to evaluate the effect of different technological treatments (addition of water, sucrose, enzymes, and yeast) on the fermentation process and resulting distillates, to compare fermented variants with a macerated variant, and to determine their influence on key quality parameters such as methanol content, higher alcohols, and non-volatile soluble substances. Furthermore, the sensory properties of the final products were assessed to identify the most suitable technological variant, and statistical analysis (ANOVA) was applied to determine significant differences between experimental variants. Secondary objectives included verifying the suitability of black chokeberry as a raw material and identifying technological factors that contribute to improved product quality and safety.

MATERIAL AND METHODS

Samples

Samples description: Samples consisted of distillates and macerates produced from black chokeberry (*Aronia melanocarpa*) cultivar ‘Galicjanka’. Three experimental variants were prepared: (1) fermented mash with the addition of water, sucrose, enzymes, and yeast (AVKES), (2) fermented mash without the addition of water and sucrose (ABKE), and (3) macerated chokeberry fruits in apple distillate (ADL).

Samples collection: Chokeberry fruits were hand-harvested at full technological ripeness on September 10, 2024, from a plantation located in Giraltovce, Slovakia. The samples were transported immediately after harvest and processed without prolonged storage under controlled conditions (18–22 °C).

Samples preparation: The fruits were crushed using a food-grade grinder and processed according to the experimental design. Fermented variants were prepared by adding enzymes and yeast, with or without sucrose and water adjustment. Macerated samples were prepared by immersing whole fruits in 52% (v/v) apple distillate. After fermentation and distillation, samples were collected at different stages of distillation or maceration and stored in sealed containers until analysis (Figure 1 and Figure 2).



Figure 1 Double-pot still distillery and rectification column unit.



Figure 2 Black chokeberry macerate (*Aronia melanocarpa*).

Number of samples analysed: A total of 18 distillate samples (0.5 L each) were collected from fermented variants, along with macerate samples taken at three time intervals (1, 3, and 6 months) (Figure 3). All analyses were performed in triplicate ($n = 3$).

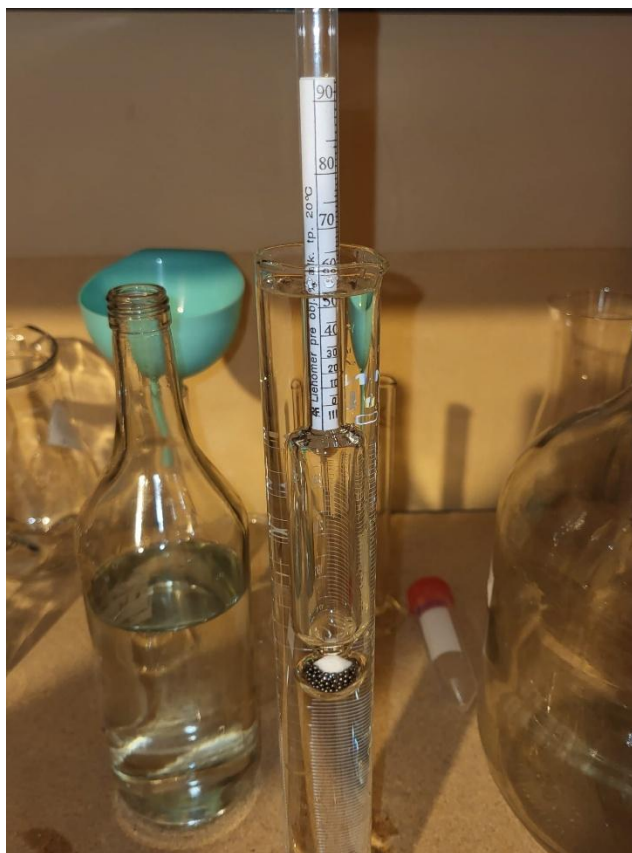


Figure 3 Black chokeberry distillate samples (*Aronia melanocarpa*).

Chemicals

All chemicals and reagents used in the study were of analytical grade quality.

Animals, Plants and Biological Materials

Plant material: *Aronia melanocarpa* (black chokeberry), cultivar ‘Galicjanka’.

Microorganism: *Saccharomyces cerevisiae* var. *bayanus* (commercial yeast strain, BS Vinařské potřeby, Czech Republic).

No animal material was used in this study.

Instruments

Optical refractometer (Haas Coolant, Germany) for sugar content determination.

Distillation apparatus BOSO PP/RK 350 (Slovakia).

Ebulliometer Dujardin-Salleron (France) for ethanol determination.

Analytical measurements were conducted in an accredited laboratory (CERTIPO spol. s r. o., Slovakia).

Laboratory Methods

Methanol content was determined according to STN 560 210 (ŠPP-19 method) with expanded measurement uncertainty $U (k = 2) = 6\%$. Higher alcohols and non-volatile soluble substances were determined using method ŠPP-20 STN 560 210-10. Ethanol content was measured by ebulliometry using a Dujardin-Salleron apparatus.

All analytical methods used were standardized and validated methods routinely applied in accredited laboratories. Measurements were performed in triplicate to ensure repeatability and reliability.

Description of the Experiment

Study flow: The experiment consisted of three main phases. In the first phase, chokeberry fruits (*Aronia melanocarpa*, cv. ‘Galicjanka’) were harvested at full technological ripeness and immediately processed into mash or macerates according to three technological variants. The initial soluble solids content of the crushed fruit was 22 °Bx, determined using an optical refractometer. Two fermented variants (AVKES and ABKES) and one macerated variant (ADL) were prepared. In the AVKES variant, 30 L of water was added per 100 kg of fruit, resulting in a total mash volume of 130 L. The soluble solids content was adjusted to 22 °Bx by the addition of food-grade sucrose prior to fermentation. In the ABKES variant, no water was added, and the ^{طبيعي} sugar content

(22 °Bx) was maintained without adjustment. A commercial pectinolytic enzyme preparation (Distizym® FM, Erbslöh) was applied at a dose of 40 mL per 100 kg of mash, diluted in water and homogenized into the mixture. Fermentation was initiated using a selected yeast strain *Saccharomyces cerevisiae* var. *bayanus* (BS14, BS Vinařské potřeby), applied at a dosage of 20 g per 100 L of mash. The yeast was pre-activated in a mixture of must and water (1:1) for 5 hours prior to inoculation. In the second phase, fermentation and maceration processes were conducted under controlled temperature conditions (18–22 °C). The pH of the mash was within the typical range for fruit fermentation (approximately 3.8–5.5), ensuring suitable conditions for yeast activity. Fermentation was carried out in sealed vessels equipped with airlocks to maintain anaerobic conditions. After completion of fermentation, the mash was distilled using a BOSO PP/RK 350 distillation apparatus. Distillates were collected at defined stages (after 0.5 L, 1.5 L, and 3 L of distillate) to monitor changes in composition during the distillation process. For the macerated variant (ADL), whole chokeberry fruits were immersed in 52% (v/v) apple distillate at a ratio of 5 kg fruit to 3 L distillate. Maceration was performed over different time intervals (1, 3, and 6 months), and samples were collected accordingly. In the final phase, physico-chemical analyses and sensory evaluation were performed, followed by statistical analysis to assess differences among variants. Sensory evaluation was performed using a 50-point scoring system assessing aroma, taste, harmony, aftertaste, and overall impression. The evaluation was carried out by a panel of trained assessors experienced in the analysis of fruit distillates. All samples were evaluated under controlled laboratory conditions. Samples were served at room temperature in standardized tasting glasses and coded with random three-digit numbers to ensure anonymity. The order of sample presentation was randomized for each assessor to minimize positional bias. Assessors were instructed to evaluate samples independently under standardized conditions, without communication during the session. Water was provided for palate cleansing between samples. Each sample was evaluated in triplicate to ensure repeatability of the results.

Quality Assurance

Number of repeated analyses: All analyses were performed in triplicate ($n = 3$).

Number of experiment replication: Each experimental variant was prepared in three independent replicates.

Reference materials: Standardized analytical procedures and calibrated laboratory instruments were used; no certified reference materials were explicitly stated.

Calibration: Instruments (e.g., refractometer) were calibrated prior to measurement using standard calibration solutions according to manufacturer instructions.

Laboratory accreditation: Analyses were performed in an accredited laboratory (CERTIPO spol. s r. o.) in accordance with ISO standards.

Data Access

Data are available from the corresponding author upon reasonable request.

Statistical Analysis

Statistical analysis was performed using Microsoft Excel and Python (SciPy v1.11.0). One-way analysis of variance (ANOVA) was used to evaluate statistically significant differences among experimental variants (AVKES, ABKE, and ADL) for the monitored parameters (methanol, higher alcohols, and non-volatile soluble substances). Each experimental variant was prepared in three independent replicates ($n = 3$), which were considered as biological replicates. Prior to ANOVA, the assumptions of normality and homogeneity of variances were assessed using the Shapiro–Wilk test and Levene’s test, respectively. When statistically significant differences were detected ($p < 0.05$), Tukey’s HSD post hoc test was applied to determine differences between individual groups. The significance level was set at $\alpha = 0.05$, and results were expressed as mean \pm standard deviation ($n = 3$).

Reporting and transparency statement

This study was experimental; randomization and blinding were not applied. The sample size was based on the experimental design with three replicates per variant. All samples were included in the analysis, and no data were excluded. The study design, analytical procedures, and statistical evaluation were conducted to ensure reproducibility and transparency.

RESULTS AND DISCUSSION

The measurement results revealed significant differences among the individual variants, as well as the fact that the method of mash preparation and the applied technology have a substantial impact on the overall parameters of the observed indicators. The measured ethanol content is presented in Table 1. Among the fermented variants, a lower methanol content was found in the AVKES sample, where both water and sucrose were added (Table 2). The measured higher alcohols content is presented in Table 3.

Table 1 Ethanol Content in Individual Variants (vol.%).

Sub-Variant	Stage of Distillation	Ethanol (% vol.)
AVKES 1	After distilling 0.5 L of distillate	83.0
AVKES 2	After distilling 1.5 L of distillate	82.0
AVKES 3	After distilling 3 L of distillate	74.6
ABKE 1	After distilling 0.5 L of distillate	67.0
ABKE 2	After distilling 1.5 L of distillate	59.6
ABKE 3	After distilling 3 L of distillate	50.6

Table 2 Methanol Content in Individual Variants (g/l a.a.).

Sub-Variant	Average \pm SD	p-value
AVKES 1	1.189 \pm 0.004	0.003*
AVKES 2	1.217 \pm 0.005	
AVKES 3	1.160 \pm 0.005	
ABKE 1	2.140 \pm 0.003	0.001*
ABKE 2	2.416 \pm 0.028	
ABKE 3	2.754 \pm 0.009	
ADL 1	0.701 \pm 0.002	0.001*
ADL 2	0.261 \pm 0.005	
ADL 3	0.238 \pm 0.002	

Note: * indicates that values are statistically significant at the 0.05 level; SD – standard deviation.

The markedly lower methanol level in the ADL variant is likely due to the absence of fermentation and distillation in its preparation process. All analyzed samples met the current EU legislative limits (Regulation (EU) 2019/787 of the European Parliament and of the Council) for methanol content in fruit spirits (maximum 1,000 g/hL of 100% alcohol, i.e., 10 g/L a.a.), confirming their safety for consumption and technological suitability [17]. It should be noted that Aronia is not explicitly defined as a separate category in this legislation and is therefore considered within the general category of fruit spirits.

Table 3 Content of higher alcohols in individual variants (g/l a.a.).

Sample	Average \pm SD	p-value
AVKES 1	4.100 \pm 0.005	p = 0.001*
AVKES 2	4.350 \pm 0.052	
AVKES 3	3.609 \pm 0.004	
ABKE 1	5.200 \pm 0.021	p = 0.001*
ABKE 2	4.133 \pm 0.021	
ABKE 3	3.165 \pm 0.010	
ADL 1	5.060 \pm 0.018	p = 0.001*
ADL 2	1.002 \pm 0.039	
ADL 3	0.546 \pm 0.001	

Note: * indicates that values are statistically significant at the 0.05 level; SD – standard deviation.

In terms of non-volatile soluble substances (Figure 4 and Figure 5), notable variation among the different variants was observed. In two cases—ABKE2 and AVKES3—the values were below the measurable threshold. Due to the different production processes, the ADL variant exhibited substantially higher levels of non-volatile compounds, which can be attributed to the extraction of sugars, polyphenols, organic acids, and other non-volatile constituents into the ethanol matrix during maceration. In contrast, fermented and distilled samples contained negligible amounts of these substances, as distillation removes most non-volatile components. The macerated variant (ADL) was therefore not intended to be directly comparable to fermented distillates in terms of compound formation, but rather to provide a reference for extraction-based processing, highlighting fundamental technological differences. From a technological perspective, these compounds contribute to body, mouthfeel, and astringency, and may influence product authenticity and stability. This observation is consistent with previous studies describing chokeberry as a fruit rich in polyphenolic compounds, particularly anthocyanins and proanthocyanidins, which significantly influence extraction efficiency and sensory perception [18], [19], [3].

The efficiency of extraction in the ADL variant is strongly influenced by ethanol concentration, which enhances solvent polarity and increases cell membrane permeability, facilitating the release of intracellular

compounds [20], [21]. In contrast, fermented and distilled samples contained negligible amounts of these substances, as distillation removes most non-volatile components. This phenomenon has been widely described in distillation processes, where only volatile compounds are transferred into the final distillate, while non-volatile substances remain in the residue [22]. The macerated variant (ADL) was therefore not intended to be directly comparable to fermented distillates in terms of compound formation, but rather to provide a reference for extraction-based processing, highlighting fundamental technological differences.

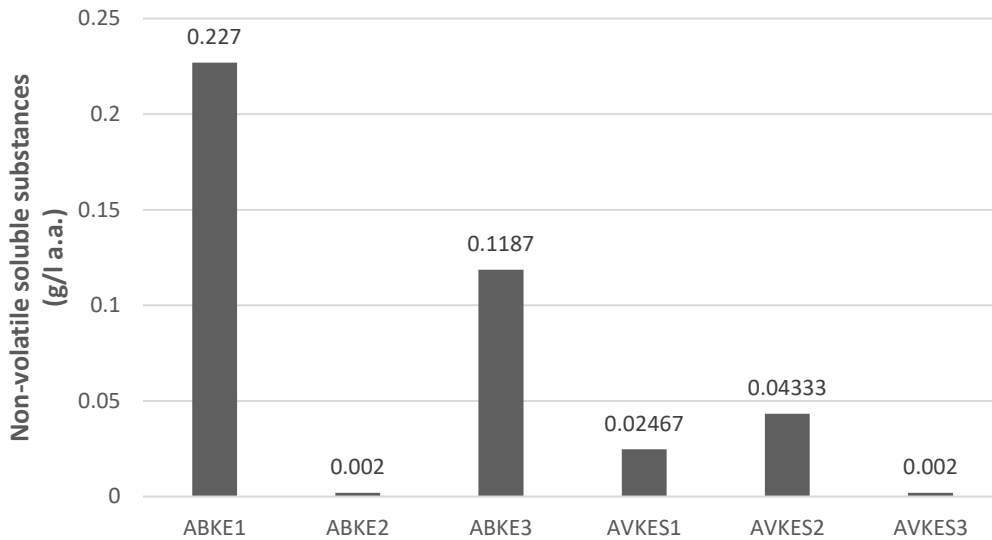


Figure 4 Content of non-volatile soluble substances in ABKE and AVKES variants.

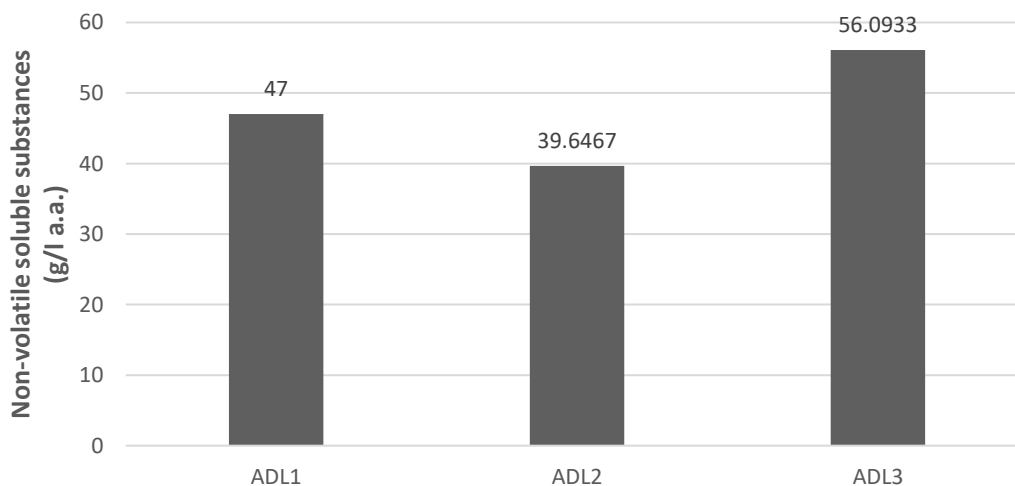


Figure 5 Content of non-volatile soluble substances in ADL variants.

From a technological perspective, non-volatile compounds play a key role in shaping sensory characteristics such as body, mouthfeel, and astringency, while also contributing to product authenticity and stability [23], [24]. High concentrations of these compounds, as observed in the ADL variant, may enhance sensory intensity but can also lead to less harmonious perception if not properly balanced.

Statistical analysis of key quality parameters—including methanol, higher alcohols, and non-volatile soluble substances—revealed significant differences among the sub-variants (1, 2, 3) within each technological group (AVKES, ABKE, ADL). One-way ANOVA confirmed that the differences in methanol concentration were statistically significant ($p < 0.01$), with the most pronounced variability observed in the ABKE group, where levels increased progressively from ABKE1 to ABKE3. This trend likely reflects the combined effect of mash density and fermentation conditions. Methanol formation in fermented samples is primarily associated with the enzymatic degradation of pectins present in fruit cell walls, particularly through the activity of pectin methylesterase [25], [26]. Higher methanol levels in the ABKE variant can therefore be explained by the absence of dilution, leading to a higher concentration of pectic substances and limited mass transfer. In contrast, dilution in the AVKES variant likely reduced substrate concentration and improved fermentation conditions, resulting in lower methanol formation [27].

In contrast, methanol concentrations in the AVKES and ADL variants decreased in later fractions, consistent with the selective separation of volatile compounds during distillation and the absence of fermentation-related methanol formation in macerated samples. The lowest methanol content was measured in ADL 3 (0.238 g/L a.a.), while the highest was recorded in ABKE 3 (2.754 g/L a.a.), despite all variants originating from identical raw material. These results indicate a substantial influence of processing conditions on methanol formation within the limits of this study. Hričovský et al. [28] reported methanol concentrations in blackcurrant distillates ranging from 2.67 to 5.95 g/L a.a., supporting the variability observed in our study.

Similarly, statistically significant differences in higher alcohol concentrations were confirmed across sub-variants within each group ($p < 0.001$). The highest value was detected in ABKE1 (5.20 g/L a.a.) and the lowest in ADL 3 (0.546 g/L a.a.). Higher alcohols are mainly formed via yeast metabolism through amino acid degradation pathways (Ehrlich pathway), and their formation is strongly influenced by fermentation conditions, nitrogen availability, and yeast strain selection [29], [30].

While the fermented variants showed decreasing trends across distillation fractions, reflecting the selective separation of volatile compounds, the ADL group exhibited a gradual decline over maceration time, indicating extraction kinetics and subsequent stabilization. Maceration is governed primarily by diffusion processes and solvent–matrix interactions, where extraction efficiency increases with time and ethanol concentration [24], [20].

The most pronounced differences were observed in the non-volatile soluble substance content, with ADL3 reaching a peak value of 56.09 g/L a.a., while ABKE2 displayed levels below the detection limit (<0.002 g/L a.a.). These findings reflect the fundamental impact of processing method—particularly maceration—on the extraction and retention of non-volatile compounds.

In the sensory evaluation, the macerated variant (ADL) achieved the highest average score (42.5 points), followed closely by the AVKES variant (42.0 points), while ABKE scored lower (39.75 points), particularly in aroma harmony and mouthfeel. Although ADL reached the highest overall score, the AVKES variant exhibited a more balanced and technologically desirable sensory profile, especially in terms of harmony and overall impression. The biplot (Figure 3) further supports these findings by illustrating the relationship between samples and sensory attributes. Similar relationships between chemical composition and sensory perception have been described in studies linking polyphenol content and volatile compounds with overall product acceptability [31], [3].

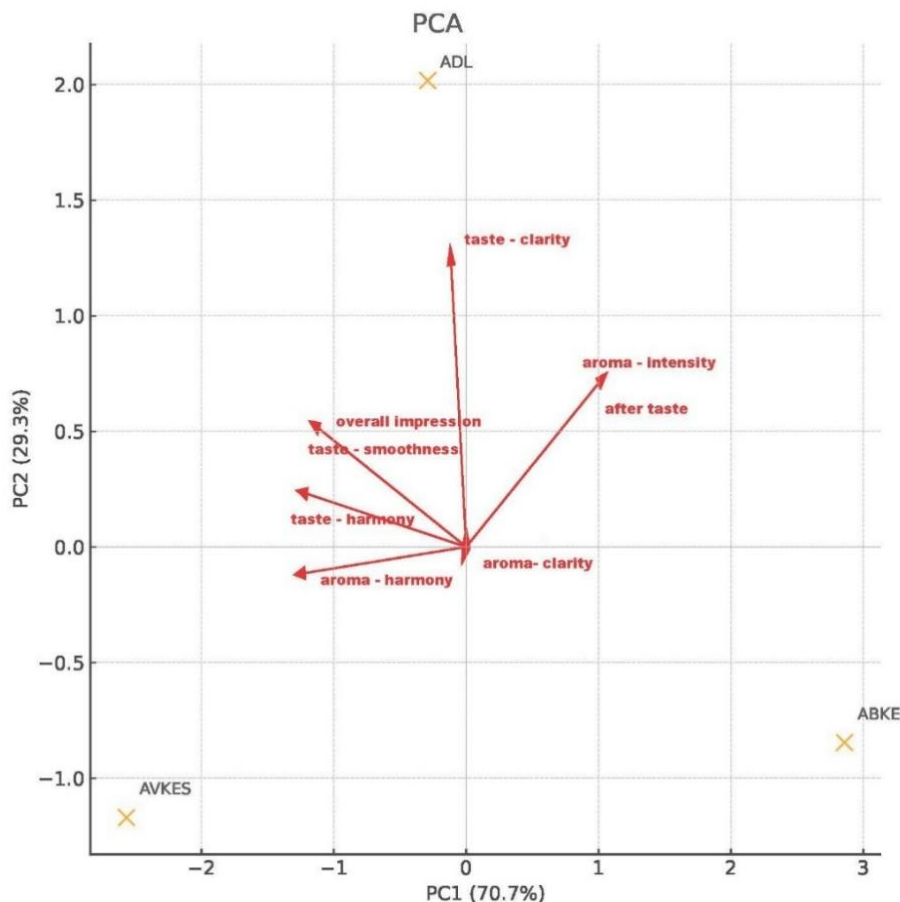


Figure 3 PCA of sensory profiles of samples.

The biplot (Figure 3) visualizes the spatial distribution of aronia samples (ABKE, ADL, AVKES) and their associated sensory descriptors in the principal component space. The first two principal components (PC1 and PC2) account for 100% of the total variance, with PC1 explaining 70.7% and PC2 29.3%, based on eigenvalues of 7.07 and 2.93, respectively. Sensory attributes are represented as vectors (arrows) indicating their direction and magnitude of influence. Attributes such as aroma harmony, taste harmony, aftertaste, and overall impression align strongly with PC1, indicating that this axis primarily captures flavor complexity and balance. On the other hand, appearance, taste smoothness, and aroma clarity contribute more prominently to PC2, which reflects perceptual differences in visual and mouthfeel characteristics. Sample AVKES is clearly positioned apart from the other two samples along the PC1 axis, suggesting a distinct sensory profile characterized by higher perceived harmony and flavor intensity. The alignment of AVKES with multiple positive sensory vectors further supports its favorable evaluation across key attributes. This biplot provides an intuitive overview of how samples differ based on their sensory characteristics and which variables are most responsible for these differences. It confirms PCA as an effective technique for reducing dimensionality and highlighting patterns in sensory evaluation data. It is evident that the high value measured in ADL3 is directly related to the maceration process used in the production of the distillate. In the sensory evaluation, ADL received the highest total score (42.5 points), showing the most balanced profile across all evaluated sensory attributes.

Several previous studies have explored the chemical and sensory characteristics of fruit-based distillates and macerates, offering useful comparisons to the findings presented in this work. Balcerek and Szopa [32] examined aronia distillates and identified isoamyl alcohol as a dominant volatile, which corresponds with the profile observed in the ABKE variant. Similarly, Vulić et al. [33] reported methanol concentrations ranging from 2.67 to 5.95 g/L a.a. in blackcurrant distillates, confirming the influence of raw material and technological procedure on methanol levels. Methanol formation across various fruit spirits has also been reviewed by Botelho et al. [34], who emphasized the significance of fermentation parameters and raw material integrity. Alonso et al. [35] analyzed berry distillates such as arbutus and blackcurrant, revealing that production method strongly influences volatile profiles, while Wojdyło et al. [36] showed that prolonged maceration enhances phenolic and aromatic complexity in berry products—consistent with the ADL3 macerate in our study. Schlosser [37] demonstrated that enzymatic mash treatment can improve aroma retention and reduce methanol formation during fruit fermentation. The findings of Abubakar and Haque [38] also support the use of maceration to preserve delicate aromatic compounds, which helps explain the high concentration of non-volatile substances in the ADL variant. Kanat et al. [39] and Uhrová [10] both highlighted the critical impact of sugar content, enzyme addition, and yeast selection on the overall chemical profile and fermentation quality of fruit mashes. Similarly, Sena Olcay et al. [40] explored innovative processing strategies for functional berry products, emphasizing the potential of maceration and cold extraction techniques. Nilson and Thorell [41] presented a comparison of traditional and modern distillation technologies, underlining how production style affects both composition and flavor. The role of extended maceration in enhancing sensory richness was demonstrated by Martínez-Moreno et al. [42], while Eglinton et al. [43] showed that fermentation with *Saccharomyces cerevisiae* var. *bayanus* yields cleaner, more aromatic fruit spirits. Finally, Huseynli et al. [44] underscored the importance of linking analytical composition with sensory perception to ensure balanced and appealing distillate profiles. Together, these studies support our findings and reinforce the idea that raw material quality, fermentation control, and the choice between maceration and distillation are decisive factors in producing high-quality aronia-based beverages. Overall, the results indicate that technological parameters such as mash dilution, enzyme application, fermentation conditions, and ethanol concentration play an important role in shaping the chemical composition and sensory properties of chokeberry-based products within the conditions of this study.

Limitations

The study has certain limitations that should be considered when interpreting the results. The experimental design was based on a limited number of replicates ($n = 3$), which is standard for this type of controlled technological study; however, increasing the number of replicates in future research could further strengthen the statistical robustness of the findings. The experiment was carried out under controlled conditions that ensured high reproducibility, although these conditions may not fully capture the variability present in large-scale industrial production. In addition, only one cultivar of black chokeberry (*Aronia melanocarpa* ‘Galicjanka’) and a single production season were included, which may influence the broader applicability of the results under different agronomic or climatic conditions. Finally, the study focused on key quality parameters relevant to distillate production, while more detailed profiling of minor compounds could provide additional insights in future research.

CONCLUSION

The results of this study clearly confirm that the applied technological process significantly influences the chemical composition and sensory quality of black chokeberry (*Aronia melanocarpa*) distillates and macerates. Statistically significant differences ($p < 0.05$) were observed among all experimental variants for key parameters, including methanol, higher alcohols, and non-volatile soluble substances. The highest methanol content was recorded in the ABKE variant (up to 2.754 g/L a.a.), confirming that the absence of water and sucrose leads to less favorable fermentation conditions and increased methanol formation. In contrast, the AVKES variant showed substantially lower methanol levels (as low as 1.160 g/L a.a.), demonstrating the positive effect of technological interventions such as dilution and sugar adjustment. The macerated variant (ADL) also exhibited very low methanol content (0.238 g/L a.a.), primarily due to the absence of fermentation. Significant differences were also found in higher alcohols, with the highest concentration in ABKE1 (5.20 g/L a.a.) and the lowest in ADL3 (0.546 g/L a.a.), indicating the strong influence of both fermentation conditions and maceration time. The most pronounced variability was observed in non-volatile soluble substances, where the ADL variant reached the highest values (up to 56.09 g/L a.a.), while fermented variants showed minimal or undetectable levels (< 0.002 g/L a.a.), highlighting the effect of maceration on compound extraction. From a sensory perspective, the highest score was achieved by the macerated variant (42.5 points), followed closely by AVKES (42 points), whereas ABKE showed the lowest acceptability (39.75 points). Although the macerated variant (ADL) achieved the highest sensory score, its profile was characterized by lower harmony compared to the AVKES variant, which exhibited a more balanced and technologically desirable sensory profile. PCA analysis further confirmed that AVKES samples were associated with the most favorable sensory attributes, particularly in terms of harmony and overall impression. Overall, the AVKES variant can be considered the most optimal for distillate production, as it achieved a balanced combination of low methanol content, acceptable levels of higher alcohols, and high sensory quality. The ADL variant proved highly suitable for macerate production due to its high content of non-volatile compounds and excellent sensory profile. These findings emphasize the importance of optimizing mash composition and processing parameters, particularly the addition of water, sucrose, and enzymes, to ensure both safety and quality of the final product.

REFERENCES

- Molčan, M. (2025). Design of an Optimal Procedure for the Preparation of Black Chokeberry Mash Intended for Distillation. [Bachelor theses, Slovak University of Agriculture in Nitra].
- Saracila, M., Untea, A. E., Oancea, A. G., Varzaru, I., & Vlaicu, P. A. (2024). Comparative Analysis of Black Chokeberry (*Aronia melanocarpa* L.) Fruit, Leaves, and Pomace for Their Phytochemical Composition, Antioxidant Potential, and Polyphenol Bioaccessibility. *Foods*, 13(12), 1856. <https://doi.org/10.3390/foods13121856>
- Xu, J., Li, F., Zheng, M., Sheng, L., Shi, D., & Song, K. (2024). A Comprehensive Review of the Functional Potential and Sustainable Applications of *Aronia melanocarpa* in the Food Industry. *Plants*, 13(24), 3557. <https://doi.org/10.3390/plants13243557>
- Petrovska, B. (2012). Historical review of medicinal plants' usage. *Pharmacognosy Reviews*, 6(11), 1. <https://doi.org/10.4103/0973-7847.95849>
- Surendra, G., Rao Kasula, R., Ramakrishna Reddy, M., Sharma, S., Kumari, S., Khan, S., Awasthi, A., & N Anjana Male, C. K. V. L. S. (2025). Comprehensive Review of Herbal Extracts: Modern Pharmaceutical Uses, Phytochemical Composition, Extraction Methods, Historical Legacy. *Journal of Neonatal Surgery*, 14(6S), 527–533. <https://doi.org/10.52783/jns.v14.2269>
- Poleć, W., & Murawska, D. (2021). The Social Constraints on the Preservation and Sustainable Development of Traditional Crafts in a Developed Society. *Sustainability*, 14(1), 120. <https://doi.org/10.3390/su14010120>
- Mendelova, A., Mendel, E., Solgajová, M., Golian, J., & Kolesárová, A. (2025). Process changes in polyphenolic substances after processing aronia into various food products. *Journal of Microbiology, Biotechnology and Food Sciences*, e12131. <https://doi.org/10.55251/jmbfs.12131>
- Gurčík, L., Bajusová, Z., Ladvenicová, J., Palkovič, J., & Novotná, K. (2023). Cultivation and Processing of Modern Superfood—*Aronia melanocarpa* (Black Chokeberry) in Slovak Republic. *Agriculture*, 13(3), 604. <https://doi.org/10.3390/agriculture13030604>
- Horváthová, J., Daško, E., Jelemenská, V., & Ciesarová, Z. (2020). Chokeberry – a source of amino acids in food. *Trendy v potravinárstve*, 51–55.
- Uhrová, H. (2015). Domáci výroba slovovice a ostatných destilátů, ovocných šťáv, sirupů a vín (2nd ed.). Český Těšín, 110.
- Gordon, C. M., Muldoon, M. J., Wagner, M., Hilgers, C., Davis, J. H., & Wasserscheid, P. (2008). Synthesis and purification ionic liquids in synthesis. In Wiley-VCH Verlag GmbH & Co. KGaA, 7–55.

12. Earle, M., Wasserscheid, P., Schulz, P., Olivier-Bourbigou, H., Favre, F., Vaultier, M., Kirschning, A., Singh, V., Riisager, A., Fehrmann, R., & Kuhlmann, S. (2007). Organic Synthesis. In *Ionic Liquids in Synthesis* (pp. 265–568). Wiley. <https://doi.org/10.1002/9783527621194.ch5>
13. Wasserscheid, P., & Welton, T. (Eds.). (2007). *Ionic Liquids in Synthesis*. Wiley. <https://doi.org/10.1002/9783527621194>
14. Reinert, L., Batouche, K., Lévêque, J.-M., Muller, F., Bény, J.-M., Kebabi, B., & Duclaux, L. (2012). Adsorption of imidazolium and pyridinium ionic liquids onto montmorillonite: Characterisation and thermodynamic calculations. *Chemical Engineering Journal*, 209, 13–19. <https://doi.org/10.1016/j.cej.2012.07.128>
15. Saravanabavan, N., Salwe, K. J., Sudar Codi, R., & Kumarappan, M. (2020). Herbal extraction procedures: need of the hour. *International Journal of Basic & Clinical Pharmacology*, 9(7), 1135. <https://doi.org/10.18203/2319-2003.ijbcp20202566>
16. Klahs, P. C., McMurchie, E. K., Nikkel, J. J., & Clark, L. G. (2023). A maceration technique for soft plant tissue without hazardous chemicals. *Applications in Plant Sciences*, 11(5). <https://doi.org/10.1002/aps3.11543>
17. Regulation (Eu) 2019/787 Of The European Parliament And Of The Council of 17 April 2019 on the definition, description, presentation and labelling of spirit drinks, the use of the names of spirit drinks in the presentation and labelling of other foodstuffs, the protection of geographical indications for spirit drinks, the use of ethyl alcohol and distillates of agricultural origin in alcoholic beverages, and repealing Regulation (EC) No 110/2008. PE/75/2018/REV/1. Ú. v. EÚ L 130, 17.5.2019, 1 – 54. <https://eur-lex.europa.eu/eli/reg/2019/787/oj?locale=sk>
18. Denev, P., Pencheva, D., Teneva, D., Ognyanov, M., & Todorova, Z. (2025). Development of Functional Fruit, Vegetable, and Herbal Beverages Enriched with Gamma-Aminobutyric Acid and Polyphenols: Is It Feasible? *Beverages*, 11(6), 176. <https://doi.org/10.3390/beverages11060176>
19. Saracila, M., Untea, A. E., Oancea, A. G., Varzaru, I., & Vlaicu, P. A. (2024). Comparative Analysis of Black Chokeberry (*Aronia melanocarpa* L.) Fruit, Leaves, and Pomace for Their Phytochemical Composition, Antioxidant Potential, and Polyphenol Bioaccessibility. *Foods*, 13(12), 1856. <https://doi.org/10.3390/foods13121856>
20. Chemat, F., Vian, M. A., & Cravotto, G. (2012). Green Extraction of Natural Products: Concept and Principles. *International Journal of Molecular Sciences*, 13(7), 8615–8627. <https://doi.org/10.3390/ijms13078615>
21. Ignat, I., Volf, I., & Popa, V. I. (2011). A critical review of methods for characterisation of polyphenolic compounds in fruits and vegetables. *Food Chemistry*, 126(4), 1821–1835. <https://doi.org/10.1016/j.foodchem.2010.12.026>
22. Douady, A., Puentes, C., Awad, P., & Esteban-Decloux, M. (2019). Batch distillation of spirits: experimental study and simulation of the behaviour of volatile aroma compounds. *Journal of the Institute of Brewing*, 125(2), 268–283. <https://doi.org/10.1002/jib.560>
23. Silva, M. E. dos S., de Oliveira, R. L., de Moraes, M. M., da Camara, C. A. G., Arruda, L. L. de A. L., Silva, S. P., & Porto, T. S. (2025). Impact of fermentation time on the bioactive and volatile composition of coffee: Insights for producers and researchers. *Food Chemistry*, 490, 145067. <https://doi.org/10.1016/j.foodchem.2025.145067>
24. Bouyahya, A., Omari, N. E., EL Hachlafi, N., Jemly, M. E., Hakkour, M., Balahbib, A., El Menyiy, N., Bakrim, S., Naceiri Mrabti, H., Khouchlaa, A., Mahomoodally, M. F., Catauro, M., Montesano, D., & Zengin, G. (2022). Chemical Compounds of Berry-Derived Polyphenols and Their Effects on Gut Microbiota, Inflammation, and Cancer. *Molecules*, 27(10), 3286. <https://doi.org/10.3390/molecules27103286>
25. Vázquez-Araújo, L. (2023). Analysis of Volatile Compounds during Food Fermentation. *Foods*, 12(19), 3635. <https://doi.org/10.3390/foods12193635>
26. Spigno, G., Tramelli, L., & De Faveri, D. M. (2007). Effects of extraction time, temperature and solvent on concentration and antioxidant activity of grape marc phenolics. *Journal of Food Engineering*, 81(1), 200–208. <https://doi.org/10.1016/j.jfoodeng.2006.10.021>
27. Balák, J., Drábová, L., Ilko, V., Maršík, D., & Jarošová Kolouchová, I. (2024). Preliminary Investigation of Fruit Mash Inoculation with Pure Yeast Cultures: A Case of Volatile Profile of Industrial-Scale Plum Distillates. *Foods*, 13(12), 1955. <https://doi.org/10.3390/foods13121955>
28. Hričovský, P., et al. (2023). Characterization of the ‘Galicjanka’ aronia cultivar for fermentative potential. *Slovak Journal of Horticultural Sciences*, 58, 13–21.

29. Procopio, S., Krause, D., Hofmann, T., & Becker, T. (2013). Significant amino acids in aroma compound profiling during yeast fermentation analyzed by PLS regression. *LWT - Food Science and Technology*, 51(2), 423–432. <https://doi.org/10.1016/j.lwt.2012.11.022>
30. Vidal, E. E., de Morais Junior, M. A., François, J. M., & de Billerbeck, G. M. (2014). Biosynthesis of higher alcohol flavour compounds by the yeast *Saccharomyces cerevisiae*: impact of oxygen availability and responses to glucose pulse in minimal growth medium with leucine as sole nitrogen source. *Yeast*, n/a-n/a. <https://doi.org/10.1002/yea.3045>
31. Pittari, E., Moio, L., & Piombino, P. (2021). Interactions between Polyphenols and Volatile Compounds in Wine: A Literature Review on Physicochemical and Sensory Insights. *Applied Sciences*, 11(3), 1157. <https://doi.org/10.3390/app11031157>
32. Balcersek, M., & Szopa, J. S. (2005). Optimization of the extraction technology of Aronia spirits – Part 2: Influence of the mixing conditions on the composition of the volatile contents. *Deutsche Lebensmittel-Rundschau*, 101, 16–19.
33. Vulić, T., Nikićević, N., Stanković, L., Veličković, M., Todosijević, M., Popović, B., Urošević, I., Stanković, M., Beraha, I., & Tešević, V. V. (2012). Chemical and sensorial characteristics of fruit spirits produced from different black currant (*Ribes nigrum* L.) and red currant (*Ribes rubrum* L.) cultivars. *Macedonian Journal of Chemistry and Chemical Engineering*, 31(2), 217. <https://doi.org/10.20450/mjce.2012.17>
34. Botelho, G., Anjos, O., Estevinho, L. M., & Caldeira, I. (2020). Methanol in Grape Derived, Fruit and Honey Spirits: A Critical Review on Source, Quality Control, and Legal Limits. *Processes*, 8(12), 1609. <https://doi.org/10.3390/pr8121609>
35. Alonso González, E., Torrado Agrasar, A., Pastrana Castro, L. M., Orriols Fernández, I., & Pérez Guerra, N. (2010). Production and Characterization of Distilled Alcoholic Beverages Obtained by Solid-State Fermentation of Black Mulberry (*Morus nigra* L.) and Black Currant (*Ribes nigrum* L.). *Journal of Agricultural and Food Chemistry*, 58(4), 2529–2535. <https://doi.org/10.1021/jf9037562>
36. Wojdyło, A., Figiel, A., & Oszmiański, J. (2014). Effects of extraction and maceration on phenolic content and aroma in berry products. *Food Chemistry*, 152, 78–84.
37. Schlosser, S. (2011). Distillation – from Bronze Age till today. In *Proceedings of the 38th International Conference of the Slovak Society of Chemical Engineering (SSCHE)*, Tatranské Matliare, Slovakia.
38. Abubakar, A. R., & Haque, M. (2020). Preparation of Medicinal Plants: Basic Extraction and Fractionation Procedures for Experimental Purposes. *Journal of Pharmacy and Bioallied Sciences*, 12(1), 1–10. https://doi.org/10.4103/jpbs.jpbs_175_19
39. Kanat, G., Gezer, B., Yılmaz, Z., & Akbal, Ü. (2020). Distillation: types and applications (Kinetics and Reactor Design Project). Unpublished. <https://doi.org/10.13140/RG.2.2.17874.99524>
40. Sena Olcay, H., Ceyhan, T., & Yildirim Yalcin, M. (2024). Sensory and color properties in new product development: Chokeberry (*Aronia melanocarpa*) sour concentrate and fruit leather (pestil). In *Proceedings of the Consumer and Sensory Sciences Conference*, Istanbul, Turkey.
41. Nilson, T., & Thorell, K. (2018). Cultural heritage preservation: The past, the present and the future. Halmstad University.
42. Martínez-Moreno, A., Toledo-Gil, R., Bautista-Ortin, A. B., Gómez-Plaza, E., Yuste, J. E., & Vallejo, F. (2024). Exploring the Impact of Extended Maceration on the Volatile Compounds and Sensory Profile of Monastrell Red Wine. *Fermentation*, 10(7), 343. <https://doi.org/10.3390/fermentation10070343>
43. Eglinton, J. M., McWilliam, S. J., Fogarty, M. W., Francis, I. L., Kwiatkowski, M. J., Høj, P. B., & Henschke, P. A. (2000). The effect of *Saccharomyces bayanus*-mediated fermentation on the chemical composition and aroma profile of Chardonnay wine. *Australian Journal of Grape and Wine Research*, 6(3), 190–196. <https://doi.org/10.1111/j.1755-0238.2000.tb00178.x>
44. Huseynli, L., Walser, C., Blumenthaler, L., Vene, K., & Dawid, C. (2025). Toward a Comprehensive Understanding of Flavor of Sunflower Products: A Review of Confirmed and Prospective Aroma- and Taste-Active Compounds. *Foods*, 14(11), 1940. <https://doi.org/10.3390/foods14111940>

Funds:

Research was funded by the Grant Agency of The Slovak University of Agriculture in Nitra, project number 03-GA-SPU-2025 Plant biostimulants as a tool for increasing quantitative and qualitative indicators of Slovak grape varieties (*Vitis vinifera*).

Acknowledgments:

We would like to thank Mr. Bc. Martin Molčan from FJM Group s.r.o. for providing the biological material and for enabling the research to be conducted under semi-operational conditions at the cider house in SK-08622 Kobyly, Slovak Republic.

Competing Interests:

No potential conflict of interest was reported by the authors.

Ethical Statement:

This article does not contain any studies that would require an ethical statement.

AI Statement:

No AI tools were used at any stage of this research, including data collection, data analysis, or manuscript preparation.

Contact Address:

Lucia Ailer

Affiliation: Slovak University of Agriculture in Nitra, AgroBioTech RC, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia

E-mail: lucia.benesova@uniag.sk

ORCID: <https://orcid.org/0000-0002-2321-6627>

Author contribution: software, data curation, writing – review & editing, visualisation.

Štedan Ailer

Affiliation: Slovak University of Agriculture in Nitra, Faculty of Horticulture and Landscape Engineering, Institute of Horticulture, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia

Tel.: +421 37 641 5804

E-mail: stefan.ailer@uniag.sk

ORCID: <https://orcid.org/0000-0001-8447-5377>

Author contribution: conceptualisation, methodology, validation, formal analysis, writing – original draft.

Martin Janás

Affiliation: Slovak University of Agriculture in Nitra, SUA University Farm, Ltd., Hlavná 561, 951 78 Kolíňany, Slovakia

Tel.: +421 37 641 4229

E-mail: xjanas@uniag.sk

ORCID: <https://orcid.org/0009-0003-5132-2747>

Author contribution: formal analysis, investigation, data curation, writing – original draft, visualisation.

Adrián Selnekovič

Affiliation: Slovak University of Agriculture in Nitra, Faculty of Horticulture and Landscape Engineering, Institute of Horticulture, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia

E-mail: xselnekovic@uniag.sk

ORCID: <https://orcid.org/0009-0007-4031-0184>

Author contribution: visualisation, project administration, funding acquisition.

Martin Molčan

Affiliation: FJM Group sro, SK-08622 Kobyly, Slovakia

ORCID: <https://orcid.org/0009-0008-4945-7753>

E-mail: cabernet5565@gmail.com

Author contribution: providing the biological material, realising the experiment under semi-operational conditions at the cider house FJM Group.

Corresponding author: **Štefan Ailer**

Copyright notice:

© 2026 The Author(s). Published by HACCP Consulting, Slovakia, European Union, on *Scifood* (<https://scifood.eu>), the official website of the journal. *Scifood* is owned and operated by HACCP Consulting s.r.o. (<https://www.haccp.sk>). This article is published as **Open Access** under the **Creative Commons Attribution–NonCommercial–NoDerivatives 4.0 International License** <https://creativecommons.org/licenses/by-nc-nd/4.0/> (CC BY-NC-ND 4.0). This license permits non-commercial use, sharing, distribution, and reproduction in any medium or format, provided that appropriate credit is given to the author(s) and the original publication, a link to the license is provided, and the work is not modified, adapted, or transformed.