NUTRITIONAL AND SENSORY EVALUATION OF WHEY CHEESE PRODUCED WITH DRIED BLACK CHOKEBERRY POMACE

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Abstract

The integration of fruit by-products into dairy products is a chance to improve nutritional value and sensory attractiveness while promoting sustainable food production. This study examines the nutritional and sensory assessment of cheese made with the incorporation of dried black chokeberry (*Aronia melanocarpa*) pomace. Nutritional analyses concentrated on proximate composition, dietary fiber, phenolic compounds, and antioxidant capacity, contrasting enriched cheeses with control samples. The results revealed a substantial enhancement in total polyphenols (4.45 ± 0.27-9.13 ± 0.31 mg GAE/g dw), dietary fiber, and antioxidant activity (26.43 ± 0.24-48.94 ± 0.34 µmol TE/g dw) in cheeses fortified with chokeberry pomace, underscoring its potential as a functional ingredient. Sensory evaluation demonstrated that moderate incorporation of pomace was positively perceived, particularly through improvements in colour and appearance, whereas higher inclusion levels were associated with a slight reduction in overall flavour acceptability. The results indicate that dried black chokeberry pomace can be effectively employed in cheese production to enhance nutritional attributes while preserving acceptable sensory qualities, hence facilitating the creation of value-added functional dairy products.

Keywords: Aronia Pomace, Anthocyanins, Antioxidant activity, Cheese Enhancement, Consumer Acceptance

The nutraceutical and dietary supplement industries are seeing swift growth. There is a growing focus on utilising commodities formerly seen as trash, like pomace, seeds, and leaves, in the quest for useful raw materials. This strategy aligns with the European Union's zero-waste objectives established for 2025 and aids in the progression of the United Nations Sustainable Development Goals. Recent studies have highlighted the significant importance of fruit by-products, which are especially abundant in bioactive chemicals linked to various health benefits (Saracila *et al.,* 2024). Presently, researchers and the food industry are concentrating on the development of functional food formulations and nutraceuticals, so aligning this study with global trends (Tamkutė *et al.,* 2021).

Black chokeberry, or aronia (*Aronia melanocarpa*), is a shrub belonging to the *Rosaceae* family, indigenous to North America and introduced to Europe approximately a century ago. The edible components of black chokeberry consist mostly of its fruits, which are small, dark, cherry-like berries. Black chokeberry is widely recognized as one of the richest natural sources of bioactive compounds, particularly anthocyanins, flavonoids, and other phenolic constituents (Sidor *et al.,* 2019). These phytochemicals are associated with strong antioxidant activity, anti-inflammatory effects, and potential health-promoting properties, including cardiovascular protection, improved glucose metabolism, and immune modulation (Martins *et al.,* 2024).

Raw, unrefined black chokeberry fruits are infrequently ingested due to their astringent flavour; yet, they are extensively utilised in the food sector for the production of juices, syrups, jams, fruit teas, and dietary supplements (Jurendic *et al.,* 2021). By-products generated during fruit processing, particularly pomace, are increasingly being valorized for food applications. Chokeberry pomace consists of approximately 28–35% skin, 60–70% seeds, and about 10% pulp. It represents a valuable source of polyphenols, vitamins, and dietary fiber, while being relatively low in calories (Sarv *et al.,* 2021).

Studies have shown that pomace contains higher levels of procyanidins compared to juices and fresh fruits, highlighting its potential as a rich source of natural antioxidants (Raczkowska *et al.,* 2022). Chokeberry pomace may serve as a component for the formulation of antioxidant-rich meals and nutraceuticals. Although considerable research has been conducted on the valorization of

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agro-industrial by-products, including fruit pomace, the utilization of juice-pressing residues from certain fruit species remains insufficiently explored (Repajić *et al.,* 2025). Dried and powdered pomace has been reported to function as a versatile ingredient in various products, such as bakery items, confectionery, functional foods, and teas (Raczkowska *et al.,* 2012).

The incorporation of fruit by-products into dairy products has gained considerable attention as part of sustainable food system strategies that aim to reduce waste, enhance nutritional value, and improve functional properties. In the dairy sector, several studies have successfully demonstrated the incorporation of fruit by-products into yogurts, cheeses, and fermented milk products, leading to improved antioxidant activity, extended shelf life, and enhanced consumer appeal (Tarchi *et al.,* 2024). Whey cheese, a traditional dairy product valued for its high protein content and unique texture, provides an excellent matrix for fortification with plant-derived bioactive ingredients. Such approaches not only enhance the nutritional profile of cheese but also contribute to the development of innovative functional foods that align with consumer demand for healthier diets (Dodan *et al.,* 2025).

The present study focuses on the nutritional and sensory evaluation of whey cheese enriched with dried black chokeberry pomace(BCP). By examining its phytochemical composition, phytochemical, antioxidant capacity, color, texture….and sensory performance, this research seeks to demonstrate the potential of chokeberry pomace as a natural, value-adding ingredient for the dairy industry, while simultaneously promoting sustainable utilization of fruit by-products.

MATERIAL AND METHOD

Fresh black chokeberry fruits (*Aronia melanocarpa* L.) were purchased in August 2024 from a local supermarket in Iași County, Romania, and processed immediately after sorting. Pomace, obtained as a by-product during laboratory juice extraction, was frozen at –30 °C and subsequently freeze-dried for 48 h at 42 °C under a pressure of 0.10 mBar using a CHRIST Alpha 1–4 LD plus freeze-dryer (Germany) until a dry weight of approximately 98% was achieved. The resulting freeze-dried pomace was ground into a fine powder and stored in glass jars at room temperature, in the dark, until further analysis.

Two hundred liters of cow's milk were supplied by the Rediu Iași Research Station of the University of Life Sciences.

Folin–Ciocalteu reagent, 1% citric acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), ethanol, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS), potassium chloride solution, sodium hydroxide, sodium nitrite, gallic acid, sodium acetate solution, aluminum chloride, and sodium carbonate were purchased from Sigma-Aldrich (Steinheim, Darmstadt, Germany). All other reagents used in the experiments were of analytical grade.

Bioactive compounds were extracted from BCP powder using the ultrasound-assisted method described by Saracila *et al.* (2023), with slight modifications. Briefly, 1 g of BCP powder was mixed with 10 mL of 70% ethanol acidified with 1% citric acid solution at an acid-to-solvent ratio of 1:9. The mixture was sonicated in an ultrasonic bath (Elmasonic S 180 H, Elma, Singen, Germany) for 42 min at 40 kHz and 40 °C, followed by centrifugation at 6000 rpm for 10 min at 4 °C. The obtained supernatant was collected and subjected to phytochemical characterization.

The determination of bioactive compounds and antioxidant activity of BCP extract.

The total anthocyanin content of the extract was quantified spectrophotometrically using an Analytik Jena UV-Vis spectrophotometer (Specord 210 Plus, Jena, Germany) following the modified method of Cacak-Pietrzak *et al.* (2023). 200 µL of each sample was mixed with 800 µL of buffer solutions at pH 1.0 and pH 4.5 in spectrophotometer cuvettes. After a 15 min incubation in the dark to allow reaction, absorbance readings were recorded at 520 nm and 700 nm. The results were expressed in milligrams cyanidin 3-glucoside equivalents (C3G) per 100 grams of dry weight (d.w.).

Total flavonoid content was determined according to the method of Cacak-Pietrzak *et al.* (2023), with slight modifications. 0.25 mL of extract solution was mixed with 0.075 mL of 5% sodium nitrite and 2 mL of distilled water. After 5 min, 0.15 mL of 10% aluminum chloride solution was added, and the mixture was left to react for 6 min. Subsequently, 0.5 mL of 1 M sodium hydroxide was added, and the absorbance of the final solution was immediately recorded at 510 nm. Results were expressed as mg catechin equivalents (CE) per g dry weight (d.w.) based on a standard calibration curve prepared with catechin.

Total polyphenol content was determined using the Folin–Ciocâlteu colorimetric method as described by Cacak-Pietrzak *et al.,* (2023). 0.20 mL of extract was mixed with 15.8 mL of distilled water and 1 mL of Folin–Ciocâlteu reagent. After 10 min, 3 mL of 20% (w/v) sodium carbonate solution was added, and the mixture was incubated for 60 min at room temperature. Absorbance was subsequently measured at 765 nm. Results were expressed as mg gallic acid equivalents (GAE) per g dry weight (d.w.) based on a calibration curve constructed with gallic acid standards.

Antioxidant activity (DPPH and ABTS methods). The antioxidant activity of the dried BCP sample was evaluated using the DPPH radical scavenging assay. Briefly, 0.1 mL of BCP extract was mixed with 3.9 mL of 0.1 M methanolic DPPH solution and incubated in the dark at room temperature for 30 min. The absorbance of the reaction mixture was then measured at 515 nm using a UV–Vis spectrophotometer (Biochrom Libra S22, Cambridge, UK).

The antioxidant activity of the dried BCP sample was also assessed using the ABTS radical cation ($ABTS^{\bullet +}$) decolorization assay. The $ABTS^{\bullet +}$ solution was generated by reacting 7 mM ABTS with 2.45 mM potassium persulfate and incubating the mixture for 16–24 h at room temperature in the dark. The resulting stock solution was diluted with ethanol to obtain an absorbance of 0.700 at 734 nm. For the assay, 50 µL of extract was mixed with 1.95 mL of the adjusted $ABTS^{\bullet +}$ solution and incubated for 2 h at room temperature in the dark. Absorbance was then measured at 734 nm. Results were expressed as µmol Trolox equivalents (TE) per gram of dry weight (d.w.). (Cacak-Pietrzak *et al.,* 2023).

Cheese manufacturing. The functionality of whey cheese was evaluated by supplementing it with black chokeberry pomace (BCP) powder at two concentrations, 10% and 20%. The control group (WC) consisted of whey cheese without powder addition.

Whey-type cheese was produced from whey obtained during cheese manufacture, following the technological process. The whey was first normalized with citric acid to an acidity of 11° Thörner (ºT) and heated to 60–65 °C, after which whole milk (3.9% fat) was added. The mixture was then heated to 72 °C and maintained for 5 min to promote albumin denaturation. Heating was resumed until the temperature reached 84–85 °C, at which point 250 mL of DAIRSAL+ was added. The process was continued until 88–90 °C, after which heating was stopped and the curd was collected in baskets to drain and cool. The cooled whey cheese was divided into three batches: WC (control), WCBCP1 (10% BCP), and WCBCP2 (20% BCP). The powder was incorporated by mixing, followed by dosing into thermo-welded plastic cups, which were stored at 4–6 °C until analysis.

The physicochemical properties of the supplemented cheese samples—including moisture, dry matter, pH, protein, fat, carbohydrates, fiber, ash, salt, and energy content—were determined according to the Association of Official Analytical Chemists (AOAC, 2000) and Gavril *et al.,* (2024).

The texture of the samples was evaluated using a Mark-10 ESM 300 texturometer (New York, NY, USA) fitted with a 7i-50 series digital dynamometer with a range of 0 to 1000 N, and a resolution of 0.2 N. Compression tests were performed with a cylindrical probe (model TA4) measuring 38.1 mm in diameter and 20 mm in height. The samples, prepared in a cylindrical form (30 mm diameter × 40 mm height), were subjected to a double compression cycle with a penetration speed of 1 mm/s, producing characteristic force–time curves. The maximum penetration force of the samples was recorded and the mechanical work or energy required to section the sample was calculated.

Mineral analysis. For mineral determination, 1 g of each sample was digested with nitric acid (HNO_3) and hydrochloric acid (HCl) in an 8:2 ratio at 180 °C for 40 minutes. The digested material was diluted to 25 mL with deionized water in a volumetric flask. The concentrations of P, K, Mg, Zn, Cu, Fe, and Na were quantified using Atomic Absorption Spectrophotometry, following the method described by Stoica *et al*. (2024).

Color analysis. Color measurements of black chokeberry pomace and BCP-enriched cheese samples were performed using the CIELAB system (L, a, b*) with a MINOLTA Chroma Meter CR-410 (Konica Minolta, Osaka, Japan), following the procedure described by Dag *et al.* (2017). From these primary values, Chroma ($\sqrt{(a^*)^2 + (b^*)^2}$), Hue angle (180 + arctan(b*/a*) for quadrant IV (+a*, -b*),), and total color difference (ΔE=$\sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2}$), were calculated to further characterize color attributes.

Sensorial analysis. Sensory evaluation of the enriched cheese samples was conducted by a panel of twenty untrained assessors. Prior to participation, panelists were informed about the objectives of the study and the procedures for handling personal data. Each panelist evaluated 10 sensory descriptors: visual appearance, odor, aroma, color, taste, aftertaste, hardness, adhesiveness, chewability, and overall acceptability. Attributes were scored on a seven-point hedonic scale, where 1 represented "extremely low" and 7 indicated "extremely high." The evaluation was performed in accordance with the specifications outlined in ISO 13299.

Statistical Analysis. All analyses were performed in duplicate, and results are presented as mean values ± standard deviations. Data were subjected to one-way analysis of variance (ANOVA) after verifying normality and homoscedasticity assumptions. Post-hoc comparisons were carried out using Tukey's test at a 95% confidence interval, with differences considered statistically significant at $p < 0.05$. Statistical analyses were performed using Minitab software, version 18 (Minitab Inc., State College, PA, USA).

RESULTS AND DISCUSSIONS

BCP powder is produced from the solid by-products that remain after juice processing of *Aronia melanocarpa* berries. BCP powder is recognized as a valuable source of bioactive compounds, particularly anthocyanins and other flavonoids, which contribute to its strong antioxidant capacity.

Table 1

Phytochemical content of the BCP extract

Parameters	***Sample* BCP**
Total anthocyanins (mg/100g d.w.)	84.26±1.08
Total flavonoids (mg CE/g d.w.)	5.46±0.09
Total polyphenols (mg GAE/g d.w.)	10.68±0.15
DPPH (µmol TE/g d.w.)	14.68±0.13
ABTS (µmol TE/g d.w.)	1055.83 ±4.82
L*	23.57±0.04
a*	13.08±0.09
b*	4.01±0.05

The phytochemical analysis of the BCP extract in *Table 1* revealed that it is particularly rich in bioactive compounds, with anthocyanins representing the dominant fraction. The total anthocyanin content was 84.26 mg/100 g d.w., confirming the extract as a concentrated source of natural pigments, consistent with the characteristic deep purple coloration of chokeberry products. In addition, appreciable levels of total flavonoids (5.46 mg CE/g d.w.) and total polyphenols (10.68 mg GAE/g d.w.) were recorded, indicating that the extract contains a diverse spectrum of phenolic compounds that may contribute synergistically to its bioactivity. According to Saracila *et al.* (2024), black chokeberry pomace is characterized by a relatively high total polyphenol content (22.94 mg GAE/g), while exhibiting a comparatively low total flavonoid content (1.89 mg CE/g).

The antioxidant potential of the extract was notably high, as demonstrated by the radical scavenging assays. The DPPH value reached 14.68 µmol TE/g d.w., while ABTS activity exceeded 1055 µmol TE/g d.w., reflecting a strong capacity to neutralize free radicals. This antioxidant strength aligns with the high phenolic content, particularly anthocyanins, which are well recognized for their redox properties.

Colorimetric measurements (L*, a*, b*) further characterized the extract's visual properties. A relatively low lightness value (L* = 23.57) confirmed its dark appearance, while the positive a* value (13.08) and low b* value (4.01) positioned the extract within the red–purple region of the CIELab color space, consistent with its anthocyanin-rich profile.

Taken together, these results demonstrate that the BCP extract is a highly pigmented, anthocyanin-dense matrix with strong antioxidant activity, making it a promising functional ingredient for food fortification and value-added product development.

Table 2

Phytochemical profile of the control and BCP-supplemented Cheeses

Parameters	***Type of* Cheese**		
	WC	**WCBCP1**	**WCBCP2**
Total anthocyanins (mg/100g d.w.)	-	27.48±1.23^{b}	46.59±1.68^{a}
Total flavonoids (mg CE/g d.w.)	1.16±0.11^{c}	2.98±0.10^{b}	7.41±0.13^{a}
Total polyphenols (mg GAE/g d.w.)	1.43±0.13^{c}	4.45±0.27^{b}	9.13±0.31^{a}
DPPH (µmol TE/g d.w.)	12.67±0.22^{c}	26.43±0.24^{b}	48.94±0.34^{a}
ABTS (µmol TE/g d.w.)	482.92±2.13^{c}	687.86±4.18^{b}	929.93±8.29^{a}

Values within a row that do not share a common letter differ significantly at $p < 0.05$.

The phytochemical composition of the cheeses showed a clear enrichment effect following supplementation with black chokeberry pomace. As expected, no anthocyanins were detected in the control (WC), whereas both supplemented samples contained significant amounts, reaching 27.48 mg/100 g d.w. in WCBP1 and 46.59 mg/100 g d.w. in WCBP2. This confirms the effective incorporation of chokeberry-derived pigments into the cheese matrix, with concentrations increasing proportionally to the supplementation level. Total flavonoids and total polyphenols also increased markedly with pomace addition: flavonoids rose from 1.16 mg CE/g d.w. in the control to 2.98 and 7.41 mg CE/g d.w. in WCBP1 and WCBP2, respectively, while polyphenols increased more than six-fold, from 1.43 mg GAE/g d.w. in the control to 4.45 in WCBP1 and 9.13 in WCBP2.

The antioxidant activity, measured by DPPH and ABTS assays, followed the same trend. DPPH values more than doubled in WCBP1 (26.43 µmol TE/g d.w.) and nearly quadrupled in WCBP2 (48.94 µmol TE/g d.w.) compared to the control (12.67 µmol TE/g d.w.). Similarly, ABTS values increased significantly from 482.92 µmol TE/g d.w. in the control to 687.86 µmol TE/g d.w. in WCBP1 and 929.93 µmol TE/g d.w. in WCBP2. These results demonstrate that chokeberry pomace supplementation markedly enhances the functional potential of cheese, particularly by enriching it with anthocyanins, flavonoids, and polyphenols that directly contribute to higher antioxidant activity.

Overall, the data indicate that the phytochemical and antioxidant properties of cheese are strongly dependent on the level of pomace incorporation, with WCBP2 exhibiting the most pronounced improvements. This confirms the suitability of chokeberry pomace as a functional ingredient for the development of value-added dairy products. These findings are consistent with those of Lucera *et al.* (2018), who reported that the incorporation of grape pomace powder into cheese resulted in a significant enhancement of total phenolic content, flavonoids, and antioxidant activity relative to the control cheese.

Table 3

Chemical composition of the control and BCP-supplemented Cheeses

Parameters	***Type of Cheese***		
	WC	**WCBCP1**	**WCBCP2**
Total dry matter (%)	22.53±0.15^{c}	28.78±0.16^{b}	35.19±0.18^{a}
Fat (%)	5.05±0.04^{a}	4.79±0.03^{ab}	4.48±0.02^{b}
Protein (%)	11.13±0.014^{a}	10.68±0.13^{b}	10.21±0.12^{b}
Crude fiber (%)	0.00±0.00^{c}	4.76±0.03^{b}	9.57±0.06^{a}
Carbohydrate (%)	5.23±0.10^{c}	7.21±0.14^{b}	9.59±0.15^{a}
Moisture (%)	77.23±0.26^{a}	71.02±0.24^{b}	64.42±0.23^{c}
Ash (%)	1.11±0.02^{a}	1.22±0.03^{a}	1.31±0.03^{a}
Salt (%)	0.92±0.04^{a}	0.85±0.03^{a}	0.78±0.02^{a}
pH	5.86 ± 0.10^{a}	5.76 ± 0.09^{a}	5.61 ± 0.10^{a}
Energy value (Kcal/100 g)	110.89 ±0.06^{c}	124.19±0.07^{b}	138.66±0.08^{a}

Values within a row that do not share a common letter differ significantly at $p < 0.05$.

Table 4

Mineral composition of the control and BCP-supplemented Cheese samples

Parameters	***Type of Cheese***		
	WC	**WCBCP1**	**WCBCP2**
Sodium (Na, mg/100 g)	20.32 ± 0.28^{c}	39.67 ± 0.43^{b}	54.75 ± 0.52^{a}
Phosphorus (P, mg/100 g)	5.70 ± 0.21^{c}	9.84 ± 0.29^{b}	14.29 ± 0.33^{a}
Potassium (K, mg/100 g)	99.82± 0.81^{c}	125.38± 0.89^{b}	140.20 ± 0.92^{a}
Magnesium (Mg, mg/100 g)	61.18 ± 0.52^{c}	73.49 ± 0.63^{b}	81.30 ± 0.79^{a}
Zinc (Zn, mg/100 g)	0.45 ± 0.04^{c}	1.53 ± 0.11^{b}	2.41 ± 0.12^{a}
Copper (Cu, mg/100 g)	0.05± 0.01^{c}	0.11± 0.02^{b}	0.15± 0.03^{a}
Iron (Fe, mg/100 g)	0.61± 0.01^{c}	1.84± 0.09^{b}	2.44± 0.14^{a}

Values within a row that do not share a common letter differ significantly at $p < 0.05$.

Incorporation of BCP into the cheese samples markedly improved their chemical composition compared with the control as was seen in *Table 3*. BCP addition significantly increased dry matter, fiber, carbohydrate, and energy values, while reducing protein, fat (slightly), and moisture.

Ash, salt, and pH remained unaffected, showing BCP incorporation does not alter mineral content or acidity.

Statistically, all parameters with different superscript letters differ at $p < 0.05$. The clearest dose-dependent trends were observed in dry matter, fiber, carbohydrate, moisture, and energy value.

Gaglio *et al.* (2021) developed a novel fresh ewe's milk pressed cheese ("primosale") by incorporating 1% (w/w) grape pomace powder and employing selected Lactococcus lactis strains resistant to the main grape phenolic compounds. The fortified cheese demonstrated a reduced fat content, increased protein levels, enhanced antioxidant activity, and a higher degree of secondary lipid oxidation compared to the control.

The textural properties of whey cheese (WC) were significantly influenced by supplementation with black chokeberry pomace

(BCP) powder at two concentrations (10% WCBCP1 and 20% WCBCP2). The control sample (WC) exhibited the highest maximum penetration force (17.76 N) and mechanical work (90.01 mJ), indicating a firmer and more resistant structure. In contrast, the addition of BCP powder led to a progressive reduction in both parameters, with WCBCP1 showing 13.01 N and 30.83 mJ, while WCBCP2 displayed the lowest values, 8.36 N and 22.61 mJ, respectively. These results suggest that BCP incorporation softens the cheese matrix, reducing cutting resistance and structural compactness in a concentration-dependent manner. The observed effect may be attributed to the high fiber content of the pomace, which interferes with protein-protein interactions and alters the microstructure of the cheese, resulting in a more tender texture.

Abd Elhamid (2016) investigated the effect of supplementing Egyptian “Kariesh” cheese with varying levels of wheat bran (0.1–0.5% *w/w*) as a prebiotic source on its physicochemical, rheological, and sensory properties. The fortified cheeses showed an increased yield and moisture content, accompanied by reductions in pH, protein concentration, and textural firmness compared with the control. *Table 4* summarizes the mineral composition of the analyzed samples. The incorporation of BCP powder into whey cheese significantly enhanced its mineral content in a dose-dependent manner. Compared to the control, WCBCP1 and WCBCP2 showed progressive increases in sodium (from 20.32 to 39.67 and 54.75 mg/100 g), phosphorus (from 5.70 to 9.84 and 14.29 mg/100 g), potassium (from 99.82 to 125.38 and 140.20 mg/100 g), and magnesium (from 61.18 to 73.49 and 81.30 mg/100 g). Similarly, trace elements such as zinc, copper, and iron were substantially higher in fortified samples, with iron increasing from 0.61 mg/100 g in the control to 2.44 mg/100 g in WCBCP2. These results confirm that BCP supplementation is an effective strategy to improve the mineral profile of whey cheese, potentially enhancing its nutritional value and functional properties. Color evaluation of the control and BCP-supplemented Cheese samples were shown in *table 5*.

The colorimetric analysis revealed substantial differences between the control (WC) and the cheeses supplemented with black chokeberry pomace (WCBP1 and WCBP2). The lightness value (L*) decreased sharply from 82.61 in the control to 44.62 and 29.95 in WCBP1 and WCBP2, respectively, indicating that pomace supplementation produced significantly darker cheeses, with the effect being more pronounced at higher levels.

Table 5

Color evaluation of the control and BCP-supplemented Cheese samples

Parameters	***Type of Cheese***		
	WC	**WCBCP1**	**WCBCP 2**
L*	82.61±0.13[a]	44.62±0.25[b]	29.95±0.18[c]
a*	1.09±0.04[a]	12.27±0.11[b]	13.66±0.13[c]
b*	13.56±0.09[c]	-0.96±0.03[b]	-0.62±0.08[a]
Chroma	13.60±0.10[c]	12.30±0.07[b]	13.67±0.06[a]
Hue angle	1.49±0.02[a]	359.90±0.01[b]	359.95±0.01[b]
ΔE	-	42.18±0.03[b]	55.97±0.09[c]

Values within a row that do not share a common letter differ significantly at $p < 0.05$.

The redness index (a*) showed the opposite trend, increasing markedly with pomace addition, particularly in WCBP2 (13.66), which demonstrates a strong red hue compared with the nearly neutral value in the control (1.09). The chokeberry pomace natural pigments, predominantly anthocyanins, impart attractive red–purple hues that can improve product appearance and consumer appeal.

The b* coordinate shifted from a positive value in the control (13.56), indicative of yellow tones, to negative values in both supplemented samples, confirming the loss of yellow coloration and dominance of purple–red tones derived from chokeberry pigments. The redness parameter (a*) rose sharply from 1.09 in the control to 12.27 and 13.66 in WCBP1 and WCBP2, respectively, while the yellowness parameter (b*) changed from a strongly positive value (13.56) in the control to negative values (–0.96 and –0.62). This shift places the pomace-supplemented cheeses within Quadrant IV of the CIELab color space (+a, –b), which corresponds to red–bluish hues, in contrast to the yellowish tones of the control.

Chroma values decreased slightly in WCBP1 but were restored in WCBP2, suggesting more intense and saturated colors at higher supplementation. Similarly, the hue angle shifted from 1.49 in the control to approximately 360° in the supplemented cheeses, reflecting the transition from yellowish tones to a red-dominated hue. The total color difference (ΔE) between the control and supplemented cheeses was very high, reaching 42.18 for WCBP1 and 55.97 for WCBP2, confirming that pomace incorporation induced visually perceptible and substantial color modifications. Overall, these results indicate that chokeberry pomace supplementation strongly enhances the red coloration of cheese, with higher addition levels producing more intense pigmentation but also leading to darker and less luminous products.

Sensory evaluation scores of control and BCP-supplemented Cheeses. Figure 1 illustrates the mean values of the sensory scores. The sensory evaluation demonstrated that the incorporation of dried black chokeberry pomace improved most quality attributes of the cheese compared to the control. In terms of appearance, odour, aroma, and taste, the sample with moderate supplementation (WCBP1) consistently achieved the highest scores, suggesting that a balanced level of pomace addition enhanced overall sensory perception without overpowering the product.

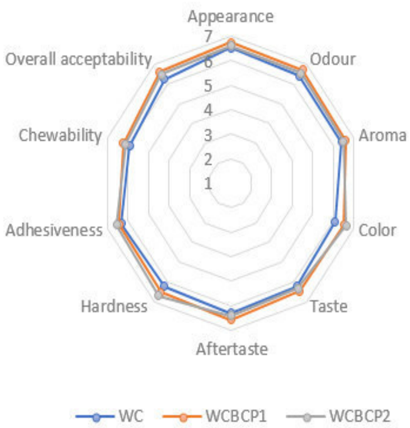

Figure 1. **Comparative diagram of the sensory attributes specific to analyzed cheeses**

Color was markedly improved in both supplemented cheeses (Figure 2), with the highest value observed for WCBP2, reflecting the strong pigmentation potential of chokeberry pomace. Textural attributes also benefited from pomace incorporation, as hardness and adhesiveness were most pronounced in WCBP2, while chewability reached its optimum in WCBP1. Regarding aftertaste, both enriched samples outperformed the control, with WCBP1 again recording the best score. Overall acceptability followed the same trend, with WCBP1 being the most preferred cheese, indicating that moderate supplementation offered the most favorable balance across sensory attributes. By contrast, the higher pomace concentration (WCBP2) enhanced visual and structural properties but slightly diminished flavour-related acceptance, reflecting the trade-off between nutritional enrichment and sensory preference. The incorporation of dried black chokeberry pomace improved most sensory attributes compared to the control. WCBP1 (moderate addition) achieved the highest scores across odour, aroma, taste, aftertaste, chewability, and overall acceptability, suggesting it represents the optimal supplementation level. WCBP2 (higher addition) particularly enhanced color, hardness, and adhesiveness, though with a slight reduction in taste- and aroma-related attributes. Mileriené *et al.* (2021) employed liquid whey protein, a common by-product of the dairy industry, to develop an edible coating enriched with 0.3% Chinese cinnamon extract aimed at extending the shelf life of Eastern European curd cheese. Application of the coating effectively enhanced the color and appearance of the cheese, while leaving its sensory attributes unaffected. Overall, chokeberry pomace enhances both visual and functional sensory properties of cheese, with moderate levels being most consumer-preferred.

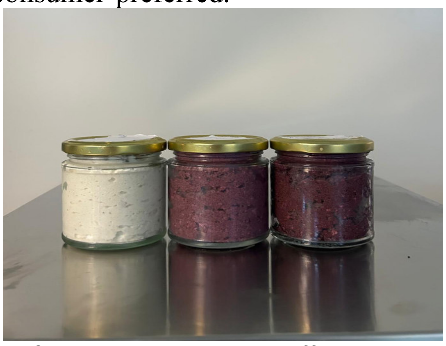

Figure 2. **Cheese samples with different percentages of BCP: WC (control), 10% (WCBCP1), and 20% (WCBCP 2)**

CONCLUSIONS

The present study demonstrated that the incorporation of dried black chokeberry pomace into whey cheese significantly enhanced its nutritional, functional, and sensory properties. The pomace-supplemented cheeses exhibited markedly higher levels of anthocyanins, flavonoids, and total polyphenols compared to the control, which translated into improved antioxidant capacity as confirmed by DPPH and ABTS assays. Instrumental color analysis revealed a clear shift from the light-yellow tones of the control to the red-purple hues of supplemented cheeses.

Incorporation of dried black chokeberry pomace into whey cheese led to a marked increase in dry matter, fiber, minerals, and carbohydrate contents, while simultaneously enhancing the cheese's color, texture, and overall phytochemical profile. Sensory evaluation further confirmed the potential of chokeberry pomace as a value-adding ingredient. Moderate supplementation (WCBP1) yielded the highest scores for odor, aroma, taste, aftertaste, chewability, and overall acceptability, suggesting that this concentration provided the most balanced improvement without negatively impacting flavor.

Overall, these findings highlight dried black chokeberry pomace as a promising functional ingredient for the dairy industry, offering both nutritional enrichment and sensory enhancement while contributing to sustainable by-product utilization. Future research should further explore consumer acceptance, shelf-life stability, and the bioavailability of chokeberry-derived bioactive compounds in dairy matrices.

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