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ARONIA ENHANCED CACIOTTA AS A DAIRY ALTERNATIVE WITH IMPROVED FUNCTIONAL PROPERTIES

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Abstract

The study aimed to assess the impact of incorporating 5% aronia powder on the physicochemical and functional properties of two varieties of caciotta: one with homogenized aronia powder and another with aronia powder layered throughout. The results indicated an overall decrease in fat and crude protein content for both aronia variations compared to the control, while carbohydrate levels exhibited a slight increase. A substantial enhancement in antioxidant activity was seen in both varieties of enhanced caciotta (40.61 ± 0.32 µMol Trolox/g dw for the homogenized version and 39.3 ± 0.30 µMol Trolox/g dw for the layered variety) in comparison to the control (2.7 ± 0.52 µMol Trolox/g dw). Anthocyanins varied between 0.91 ± 0.014 mg C3G/g dw (homogenized) and 0.82 ± 0.01 mg C3G/g dw (layered), whereas polyphenols increased from 1.1 ± 0.01 mg GAE/g dw to 3.4 ± 0.01 mg GAE/g dw. Consequently, the integration of aronia powder into caciotta is an effective approach for creating a functional product with antioxidant properties and beneficial health effects, aiding in the mitigation of oxidative stress and the prevention of chronic diseases.

Key words: *antioxidant activity, dairy products, functional yogurt, plum pomace, pigments.*

INTRODUCTION

Currently, there is an increasing public interest in health-promoting foods, particularly health-promoting dairy products, which have substantial popularity among consumers.

Cheese is typically a nutrient-rich, and easily digestible fermented milk product appreciated globally, the beneficial effects of its consumption being continuously discussed. Cheese is a major source of quality proteins, fats, vitamins, minerals, probiotics, and bioactive compounds, which can provide considerable health benefits (Zhang et al., 2023). Conversely, cheese possesses elevated levels of saturated fats and sodium, which are regarded as detrimental dietary factors for cardiovascular health (Givens, 2022).

The term Caciotta originates from the Italian word "cacio", a colloquial designation for cheese (Mucchetti et al., 2006). The organoleptic characteristics of this cheese may differ based on the traditions of the many regions of the country in which it is manufactured (Gobbetti et al., 2018). Caciotta is typically classified as a semi-soft cheese with a short to medium maturation period, weighing approximately 1 kg, and is made from either pasteurized whole cow's milk exclusively or a blend of cow's and ewe's milk. The taste of caciotta might differ based on the production region, maturation period, and type of milk chosen. The aroma profiles of cow, ewe, and goat milk are distinct, with cow milk recognized as having the smallest variety and number of aroma components (Bancalari et al., 2020).

The production of dairy products enhanced with natural additives offers a natural appealing to these types of products (Granato et al., 2018). These supplements, in addition to being widely acknowledged as safe, enhance the flavour and colour of dairy products (Andersen et al., 2023). Vegetable by-products have confirmed significant amounts of carotenoids, fibers,

polyphenols, vitamins, tocopherols, as well as other nutrients. The by-products have environmental costs and, more importantly, possess unexploited ability to provide nutritional enhancement (Lipșa et al., 2023).

The functional properties of these compounds can improve foods and satisfy customer demands for products with fewer artificial ingredients, higher authenticity and increased levels of nutrients (Abou-Zeid, 2016). In the present study, we enhanced a caciotta cheese model by incorporating aronia powder. The choice of this substrate was supported by research regarding its several potential bioactive benefits for human health, including antidiabetic, antiobesity, and antioxidant capabilities, as well as its impact on cardiac, hepatic, and neuroprotective functions (Ren et al., 2022).

As mentioned by Ren et al. (2022), phenolic substances, including anthocyanins, cyanidins, phenolic acids, proanthocyanidins, triterpenoids, and their derivatives, have been recognized as the primary active constituents of Aronia berries. The study aimed to evaluate the impact of incorporating 5% aronia powder on the characteristics of caciotta cheese by comparing two distinct technological methods of incorporation (homogenization and stratification) regarding the physicochemical, phytochemical, color characteristics, and textural quality of the final product, in comparison to a control sample.

MATERIALS AND METHODS

Raw milk received from the Rediu, Iași Research Station of the University of Life Sciences underwent specific physicochemical analyses (pH, moisture, fat, protein, total solids, solid non-fat) employing the Association of Official Analytical Chemists (AOAC) procedures (Rațu et al., 2021).

This study employed some of the following reagents and chemicals: Folin-Ciocalteu reagent, acetone, methanol, hexane, ethanol, 6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox), 2,2-diphenyl-1-picrylhydrazyl (DPPH), sodium acetate solution, gallic acid, sodium carbonate and aluminum chloride. All the chemicals were purchased from Sigma Aldrich, Steinheim (Darmstadt, Germany).

Origin and preparation of aronia pomace powder (AP)

The aronia berries were harvested at the end of August 2024, with the color and flavor of the fruits serving as indicators of ripening. They were effortlessly separated from the clusters, exhibited an intense black-violet hue, and a mildly astringent flavor with a sweet-sour undertone. The fruits were manually harvested, and the conditioning procedure was conducted at a temperature of 2-4°C until they were processed. The aronia juice was extracted using a Bosch MES3500 juicer (Philips Consumer Lifestyle B.V., Drachten, Netherlands) shortly after the berries were washed with distilled water to remove impurities. The resulting pomace was retained for further processing. The particles were then ground in a laboratory mill for 60 seconds to achieve a size of 450 µm, and the drying process was conducted using heated air convection at a temperature of 45°C for 15 hours through a food dehydrator. In addition, the powder was sterilized with a UV lamp to prevent potential microbiological contamination.

Extraction of biologically active compounds from AP

Biologically active substances were extracted from aronia powder (AP) via ultrasound-assisted extraction. Specifically, 1.0 g of AP was mixed with 10 mL of a 70% ethanol solution, acidified with citric acid in an 8:2 (v/v) ratio, and then underwent an ultrasound treatment for 30 minutes at 42°C and 40 kHz using an Elmasonic S 180 H sonication water bath (Elma, Germany). The obtained supernatant was collected and centrifuged for 5 minutes at 6000 rpm and 4°C. The AP extract was subsequently used to assess the antioxidant activity of phytochemicals, including anthocyanins, polyphenols, and flavonoids.

Antioxidant activity (DPPH)

The extract's antioxidant activity was evaluated using the DPPH radical technique, as described by Lipsa et al. (2024). This mixture was obtained by combining 100 µL of extract and 3.9 mL of a 0.1 M DPPH reagent. The solution was kept at 25°C for 30 minutes in dark conditions. The absorbance of the mixture was measured at a wavelength of 515 nm utilizing a UV–vis spectrophotometer (Analytik Jena-Specord 210

Plus, Germany). The blank solution was obtained by mixing 3.9 mL of 0.1 M DPPH reagent with 100 µL of methanol, and the absorbance of the mixture was evaluated accordingly. The results were reported as µmol Trolox equivalents (TE)/g dry weight, derived from a curve of calibration. The radical scavenging activity was subsequently quantified as a percentage of inhibition utilizing the following formula:

$$I(\%) = \frac{A_b - A_s}{A_b} \times 100,$$

where A_b is the absorbance of the blank solution and A_s is the absorbance of the analyzed sample.

Total monomeric anthocyanin content

The total monomeric anthocyanin concentration was determined using a modified pH differential method, as outlined by Lipsa et al. (2024). Prior to analysis, the samples were diluted at a ratio of 1:10. The absorbance of the diluted extracts was measured at two specific wavelengths, respectively 520 nm and 700 nm, utilizing a UV-Vis spectrophotometer (Analytik Jena - Specord 210 Plus, Jena, Germany). For each measurement, 200 µL of extract and 800 µL of buffer solution at pH 1 and pH 4.5 were employed. The results were quantified in milligrams of cyanidin-3-glucoside (C3G) per gramme of dry weight (dw).

Total polyphenolic content

The total polyphenol content of AP extract was quantified using the Folin-Ciocalteu technique, as outlined by Gavril et al. (2024), alongside spectrophotometric analysis. Consequently, 200 µL of the extract was combined with 15.8 mL of distilled water and 1 mL of Folin-Ciocalteu reagent. After 10 minutes, 3 mL of a 20% sodium carbonate (Na_2CO_3) solution was added. The acquired solution was maintained at room temperature in dark conditions for 60 minutes. The absorbance was afterwards measured at a wavelength of 765 nm using a UV-Vis spectrophotometer (Analytik Jena Specord 210 Plus, Germany). The results were quantified in milligrams of gallic acid equivalents per gramme of dry matter (mg GAE/g dw).

Total flavonoid content

The total flavonoid content of the chokeberry powder extract was quantified by applying the aluminum chloride spectrophotometric technique as outlined by Lipsa et al. (2024). The procedure involved the preparation of a mixture by combining 0.25 mL of extract with 2 mL of distilled water, thereafter, adding 0.075 mL of a 5% sodium nitrite ($NaNO_2$) solution. After 5 minutes, 0.15 mL of aluminum chloride ($AlCl_3$) solution was added, followed by the addition of 0.5 mL of 1 M sodium hydroxide (NaOH) solution after another 6 minutes. The absorbance of the analyzed solution has been measured at a wavelength of 510 nm, utilizing a UV-Vis spectrophotometer (Analytik Jena Specord 210 Plus, Germany). The total flavonoid content was quantified in milligrams of catechin equivalents per gramme of dry weight (mg CE/g dw).

Preparation of caciotta enhanced with AP

Caciotta cheese was produced by adapting a technological workflow as described in Figure 1. The process started with the quantitative and qualitative reception of fresh milk, followed by filtration and pasteurization at 60°C for 30 minutes. The milk was chilled to 36°C after pasteurization and subsequently inoculated with an aromatic mesophilic starter culture of the LD type (*Lactococcus lactis* ssp. *lactis, Lactococcus lactis* ssp. *cremoris*).

The microbial rennet (CHY-Max M Liquid) was introduced after inoculation and homogenization, as determined by the specific quantity. Coagulation took place at 36°C for 35-40 minutes. To facilitate the dehydration of the curd, the curd was initially cut into small pieces and subsequently partially removed approximately 30% of the whey. Subsequently, the curd was slowly heated to 42°C while being continuously stirred for 10-15 minutes. After this phase, an additional 30% of the whey was removed. At this point, 3 batches of caciotta cheese were formed (caciotta without AP - *CWAP*, homogenized AP caciotta - *CHAP* and layered AP caciotta - *CLAP*).

The inclusion of aronia powder (5%) was accomplished through either homogenization or stratification, dependent upon the experimental variant. For CHAP variant, the powder was subsequently incorporated directly into the forms during the curd pouring process.

For the CLAP, the curd was poured into cylindrical forms in two phases for the caciotta with aronia powder in layers, with the

introduction of aronia powder between the two layers. All variants were subjected to a pressure of 3-6 kg/kg cheese and rotated 2 times during the 14-hour pressing process. Immersion in a 12% saline solution for 36 hours was the method of salting (Figure 1).

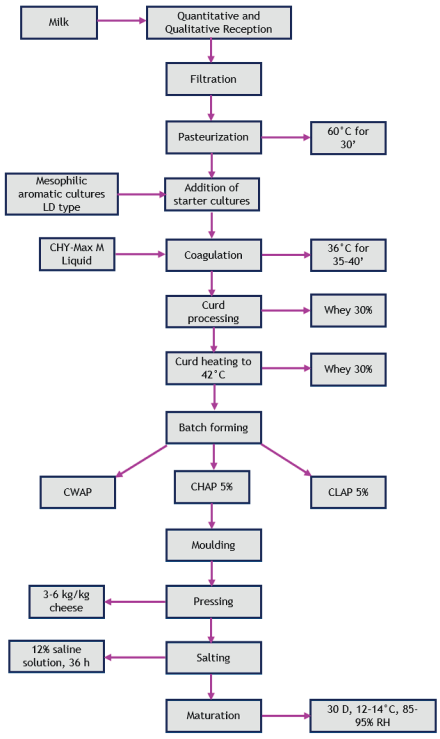

Figure 1. Flow diagram of aronia enhanced caciotta

After the salting process, the cheeses were dried at ambient temperature and subsequently matured for 30 days in spaces with a relative humidity of 85-95% and temperatures of 12-14°C. The cheeses were rotated every 4-6 days during the maturation process. For specific mold development, the cheeses were rinsed with brine three times per week.

The methods suggested by the AOAC were utilized to evaluate the samples' pH, fat, ash, moisture content, and total protein (Usturoi et al., 2017).

Colour analysis

The colour of the aronia powder and control caciotta was evaluated using the portable colorimeter C-MINOLTA Chroma Meter CR-410 (Konica Minolta, Osaka, Japan). The color parameters determined were L*, a*, and b*. Each sample was represented by three different replicates.

Statistical Analysis

The data were statistically analyzed with Minitab 19 and the data analysis toolbox in Microsoft Excel. Experiments were conducted in triplicate, and standard deviations were employed to compute mean values.

RESULTS AND DISCUSSIONS

The measured values for the phytochemical and colorimetric composition of aronia powder indicate a profile abundant in bioactive components with antioxidant properties (Table 1). The total concentration of monomeric anthocyanins was 1.08±0.02 mg C3G/g d.w., indicating a significant presence of anthocyanin pigments. The overall flavonoid concentration (9.85±0.3 mg CE/g d.w.) underscores the significant role of these secondary phenolic compounds in enhancing product stability and providing protection against oxidative stress.

The total polyphenol concentration (20.90±0.1 mg GAE/g d.w.) indicates the functional properties of aronia powder, underscoring its potential as a nutritionally beneficial addition in food products.

Table 1. Phytochemical and colorimetric features of the AP powder

Parameters	AP Powder
Total anthocyanin content (mg C3G/g d.w.)	1.08±0.02
Total flavonoid content (mg CE/g d.w.)	9.85±0.3
Total polyphenol content (mg GAE/g d.w.)	20.90±0.1
Antioxidant activity (DPPH, µmol TE/g d.w.)	23.65±0.10
Inhibition, %	87.55±0.03
L*	24.1±0.18
a*	12.65±0.05
b*	3.44±0.03

The antioxidant activity assessed via the DPPH technique (23.65 ± 0.10 µmol TE/g d.w.) and the notable inhibition percentage (87.55 ± 0.03%) indicate a significant capacity for free radical neutralization, implying a high biological value of aronia powder. The colour indices L*

(brightness – 24.1), a* (red – 12.65), and b* (yellow – 3.44) denote a deeply dark hue, characterized by a predominance of red-purple, typical of aronia fruits abundant in anthocyanins. The disparity between the elevated values of a* and the minimal values of b* underscores the predominance of cold hues, thereby elucidating the visual influence of aronia powder on the food matrix in which it is incorporated, as well as its efficacy as a natural colouring agent.

Table 2. Values of quality parameters in raw milk

Parameters	Mean
Water (%)	87.20±0.06
Fat (%)	3.80±0.08
Protein (%)	3.30±0.04
Total Solids (%)	12.80±0.08
Solid-non fat (%)	9.00±0.07
pH	6.60±0.02

The primary chemical quality indicators for raw milk have been established to assess its quality attributes. Table 2 displays the chemical composition values of bovine milk samples. The raw milk had an average pH of 6.60±0.02, a water content of 87.20±0.06%, and a total solids content of 12.80±0.08%. The mean solid-non-fat content was 9.00±0.07%, while the mean fat content was 3.80±0.08%. The mean protein concentration was 3.30±0.04%. The findings demonstrate that every raw milk quality parameter satisfies the standards for evaluating the milk's overall quality.

The phytochemical profile and DPPH free radical scavenging capacity obtained from both caciotta varieties (homogenized and layered) and simple caciotta reveal that the incorporation of aronia powder positively influences the phytochemical composition of caciotta cheese (Table 3).

Table 3. The phytochemical composition and antioxidant activity of aronia - enhanced caciotta

Parameters	**Type of caciotta**		
	CWAP	**CHAP**	**CLAP**
Total anthocyanin content (mg C3G /100 g d.w.)	-	0.91±0.014	0.82±0.01
Total flavonoid content (mg CE/g d.w.)	0.55±0.05	2.10±0.007	2±0.01
Total polyphenol content (mg GAE/g d.w.)	1.1±0.01	3.4±0.01	3.17±0.02
Antioxidant activity (µmol TE/g d.w.)	2.7±0.52	40.61±0.32	39.3±0.30

The control sample (CWAP), without of aronia powder, displayed a diminished phytochemical profile, characterized by a low concentration of flavonoids (0.55±0.05 mg CE/g d.w.) and total polyphenols (1.1±0.01 mg GAE/g d.w.), with anthocyanins being absent. Concerning the caciotta versions enhanced with aronia powder (CHAP and CLAP), a significant enhancement of these parameters was noted (Table 3). A monomeric anthocyanin level of 0.91±0.014 mg C3G/100 g d.w. was observed in CHAP cheese, which is slightly higher than the 0.82±0.01 mg C3G/100 g d.w. found in CLAP. The findings indicate that the uniform integration of the powder facilitates a more effective distribution of bioactive components within the cheese matrix.

An approximate fourfold increase in total flavonoid content was noted in the two variants with the incorporation of aronia powder compared to the control batch: 2.10±0.007 mg CE/g d.w. (CHAP) and 2.00±0.01 mg CE/g d.w. (CLAP), thereby underscoring the powder's potential as a valuable functional source of phenolic compounds. A similar pattern was observed with total polyphenols, with CHAP cheese exhibiting a value of 3.4±0.01 mg GAE/g d.w., in contrast to CLAP, which recorded 3.17±0.02 mg GAE/g d.w., and the control batch, which showed just 1.1±0.01 mg GAE/g d.w. The values obtained for total polyphenols support the idea that the approach employed in the integration process impacts the fortification level of the final product.

The antioxidant activity levels for the CHAP variations (40.61±0.32 µmol TE/g d.w.) and CLAP (39.3±0.30 µmol TE/g d.w.) were almost 15 times more than that of the control cheese (2.7±0.52 µmol TE/g d.w.). The substantial enhancement in antioxidant activity underscores the efficacy of incorporating aronia powder in improving free radical scavenging capability, with a marginally elevated value for the homogenized aronia variety.

The evaluation of the chemical composition of the three caciotta cheese variants reveals

significant disparities between the control batch (CWAP) and the two enhanced variants containing 5% aronia powder (CHAP and CLAP), particularly regarding moisture, fiber content, carbohydrates, and dry matter (Table 4).

Table 4 Chemical composition of aronia - enhanced caciotta compared to control batch

Parameters	Type of caciotta		
	CWAP	CHAP	CLAP
Moisture (%)	43.70±0.041	44.01±0.007	43.66±0.009
Total solid (%)	12.68±0.031	55.99±0.007	56.34±0.009
Fat (%)	27.99±0.027	25.67±0.01	25.97±0.01
F/NFS (%)	49.71±0.32	45.84±0.006	46.09±0.008
Protein (%)	23.55±0.019	21.80±0.01	21.61±0.01
Ash (%)	3.69±0.024	3.56±0.009	3.79±0.02
Carbohydrates (%)	1.07±0.001	1.57±0.01	1.60±0.04
Fiber (%)	-	3.39±0.009	3.37±0.02

The moisture content for all three analyzed types was comparable, ranging from 43.66% to 44.01%, indicating a consistent level of hydration characteristic for semi-soft cheeses. The dry matter (total solids) was 55.99% for CHAP and 56.34% for CLAP, slightly higher than the control sample's 56.30%.

The results reinforced the stability of the basic formula, demonstrating that the incorporation of aronia powder did not significantly affect the moisture/dry matter ratio of the final product.

A minor decrease in fat content was noted in the samples with the addition of aronia powder (CHAP – 25.67%, CLAP – 25.97%) compared to the control batch (27.99%), which can be attributed to the diluting effect of including a fiber-rich vegetable element, hence increasing the amount of dry matter.

The fat to dry matter ratio (F/NFS) was reduced in CHAP (45.84%) and CLAP (46.09%) samples relative to the control batch (49.71%), indicating that cheeses incorporating aronia powder may possess a more balanced lipid profile and could be healthier than those lacking this addition (Table 4).

The control sample had a higher protein content (23.55%) than the CHAP (21.80%) and CLAP (21.61%) variants. The reduction in protein level in the caciotta batches with aronia powder can be attributed to the diluting effect of the vegetable addition, without adversely affecting the nutritional quality of the enhanced types of cheese.

The ash content for all three types was comparable, ranging from 3.56% to 3.79%, signifying a consistent mineral composition. The somewhat elevated value for CLAP can be explained by the localized concentration of the powder in specific layers.

In terms of carbohydrates, the cheeses supplemented with aronia powder exhibited marginally elevated values (1.57% – CHAP and 1.60% – CLAP) relative to the control batch (1.07%), attributable to the naturally occurring sugars in the aronia powder.

The most significant contribution is from dietary fiber, which is lacking in the control sample but is present in both variants with added powder, in comparable amounts (3.39% for CHAP and 3.37% for CLAP) (Table 4).

Table 5 outlines the results for the colour parameters and the impact of incorporating chokeberry powder on the visual characteristics of the two varieties of Caciotta containing chokeberry powder. The CIELAB colorimetric system (L*, a*, b*) was employed to objectively assess the colour modifications resulting from the enhancement of the examined food matrix with functional ingredients.

Table 5. Colors of CWAP, CHAP, and CLAP types

Caciotta type	Parameters		
	L	a*	b*
CWAP	85.51±0.15	-3.23±0.62	28.89±0.20
CHAP	45.74±0.026	14.97±0.057	3.25±0.039
CLAP	69.33±0.080	8.11±0.10	1.96±0.070

Consequently, the L* parameter (brightness) exhibits significant variation among the examined samples. The control sample (CWAP) exhibited a value of 85.51 ± 0.15, signifying a very light colour characteristic of dairy products without of vegetable additions. For the remaining two types of caciotta, the L* value exhibited a notable decline, particularly in the homogenized sample (CHAP – 45.74 ± 0.026), indicating a clear darkening of the colour.

The value for the layered caciotta (CLAP – 69.33 ± 0.080) was deemed intermediate, indicating a localized distribution of the pigment, attributable to the sample's layered structure. The a* parameter, indicating a propensity towards red (positive values) or green (negative values), was negative for the control sample (–3.23 ± 0.62), signifying a marginally greenish background characteristic of white cheeses. Positive values were observed for CHAP (14.97 ± 0.057) and CLAP (8.11 ± 0.10), indicating a particular inclination towards red, attributable to the presence of anthocyanins in the aronia powder. The observed difference was deemed conclusive evidence of the efficacy of integrating natural pigments, exhibiting a higher intensity in the homogenized caciotta type. The b* parameter (yellow vs. blue) exhibited elevated values in the control sample (28.89 ± 0.20), indicating the subtle yellow tint of the cheese, which arises from its natural fat content and lactic pigments, without any additional ingredients.

The samples incorporating aronia powder exhibited a significant reduction in b* values (CHAP – 3.25 ± 0.039; CLAP – 1.96 ± 0.070), signifying a decrease in the yellow component and a prevalence of cool hues (red-violet), characteristic of pigmentation associated with anthocyanins.

Table 6 illustrates the assessment of the textural profile and the modifications seen in the mechanical properties of caciotta cheese after the incorporation of aronia powder. The results indicated a distinct trend of enhanced hardness and uniformity in the CHAP and CLAP samples compared to CWAP.

Table 6 Texture of enhanced caciotta compared to control batch

Parameter	CWAP Mean ± SD	CHAP Mean ± SD	CLAP Mean ± SD
Hardness, N	4.70 ± 0.21	5.90 ± 0.26	6.50 ± 0.30
Adhesiveness, mJ	0.40 ± 0.09	0.55 ± 0.11	0.53 ± 0.09
Cohesiveness, -	0.37 ± 0.06	0.50 ± 0.06	0.47 ± 0.05
Springiness, -	1.60 ± 0.13	1.85 ± 0.16	1.95 ± 0.16
Gumminess, N	0.75 ± 0.07	0.87 ± 0.09	0.95 ± 0.10
Chewiness, N	0.60 ± 0.06	0.68 ± 0.07	0.73 ± 0.07

The hardness was 4.70 ± 0.21 N for the control sample and increased up to 5.90 ± 0.26 N for the homogenized sample with addition of powder (CHAP). The CLAP sample had the highest hardness value, with an average measurement of 6.50 ± 0.30 N. The observable increase indicates that the aronia powder facilitated the consolidation of the protein network in the samples containing the powder, with a more pronounced effect in the layered sample, where the powder can form denser and more compact sections. The adhesiveness exhibited marginally elevated values in the caciotta with powder addition (0.55 ± 0.11 mJ – CHAP and 0.53 ± 0.09 mJ – CLAP) relative to the control batch (0.40 ± 0.09 mJ), suggesting an inclination towards enhanced resistance to separation, a phenomenon potentially influenced by the presence of vegetable fibers that retain a higher percentage of water within the cheese's microstructure.

The product's resistance to deformation (cohesiveness) exhibited markedly elevated values in samples containing aronia powder (0.50 ± 0.06 – CHAP and 0.47 ± 0.05 – CLAP) in comparison to the control batch (0.37 ± 0.06), underscoring an enhanced structural integrity of the final product. The newer formulations exhibited higher springiness values (1.85 ± 0.16 – CHAP and 1.95 ± 0.16 – CLAP) in comparison to the control batch (1.60 ± 0.13), signifying an enhanced ability to recover post-deformation, which is a favorable sensory characteristic that enhances the perception of freshness. Gumminess and chewiness exhibited a comparable increase. Gumminess: CWAP: 0.75

± 0.07 N→ CHAP: 0.87 ± 0.09 N→ CLAP: 0.95 ± 0.10 N. Chewiness: CWAP: 0.60 ± 0.06 N → CHAP: 0.68 ± 0.07 N→CLAP: 0.73 ± 0.07 N. These findings indicate that the incorporation of aronia powder improves the mechanical structure of the caciotta and enhances its consistency and chew resistance. The CLAP version often had the highest values for most textural characteristics, suggesting that the cheese's layering promotes the development of more compact and resistant sections in contrast to the homogenized varaint (CHAP), which provides a balance between hardness and homogeneity.

CONCLUSIONS

The findings demonstrated the beneficial effect of including 5% aronia powder on the physicochemical, textural, colorimetric, and antioxidant properties of caciotta cheese.

In comparison to the control batch, the caciotta variants enriched with aronia (both homogenized and layered) exhibited an enhanced phytochemical composition, characterized by elevated levels of polyphenols, flavonoids, and anthocyanins, as well as superior antioxidant activity. From a nutritional perspective, the incorporation of aronia powder markedly enhanced the dietary fiber content and diminished the fat level in relation to the dry matter, indicating an increased functional potential of the final product. The colorimetric changes revealed an enhancement of the red-violet hues in the experimental batches, with a more significant visual effect observed in the homogenized variant. Textural assessment demonstrated enhancements in firmness, elasticity, cohesiveness, and chewiness, hence demonstrating the hypothesis that aronia powder favorably impacts the overall protein structure of caciotta.

Consequently, including aronia powder in Caciotta cheese manufacturing may serve as an effective approach to enhance the nutritional and functional attributes of the final product, while preserving its physicochemical and sensory properties. The findings of this study encourage the incorporation of this natural ingredient into the formulation of novel dairy products that may offer health benefits to consumers.

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