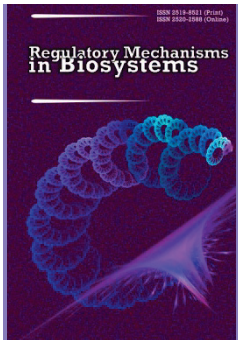

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Chemical composition of craft hard cheeses from raw goat milk during the ripening process

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Craft goat cheeses have unique taste characteristics and are in high consumer demand. The production of goat cheeses from raw milk forms an authentic dynamic microbiome that determines their structure and chemical composition. Therefore, the research aimed to determine the physicochemical parameters of Caciotta and Canestrato goat cheeses during long-term ripening. Caciotta and Canestrato cheeses were made according to the recipe, and wheels weighing 2.3–2.5 kg were laid down for ripening for 24 and 12 months. During the ripening period of up to 24 months, Caciotta cheese lost moisture from 44.4% to 25.1%, which contributed to an increase in fat content from 27.0% to 36.5%, protein from 23.8% to 33.2%, and ash from 3.4% to 4.3%, while hardness decreased from 60.8% to 39.5%. The fat-to-protein ratio did not depend on the age of the Caciotta cheese and ranged from 1.10 to 1.24, reaching a maximum at 12 months of ripening. The structure of Caciotta cheese changed with age from plastic (10 days and 1 month) to slightly brittle (12 months) and brittle (24 months). The size, number, and arrangement of eyes in the cut of Caciotta cheese depended on the ripening period. As the Caciotta cheese aged, the rind hardened and changed color from milky to amber, and from 12 to 24 months, the degree of damage caused by the mite *Acarus siro* increased. The moisture content in Canestrato cheese from 10 days to 12 months of ripening decreased from 38.0% to 33.5%, the fat content increased by 3.8% at 12 months of ripening, while the protein and ash content did not depend on age. The hardness of Canestrato cheese during the ripening period fluctuated between 50.8–51.3% and the paste was characterized by a plastic homogeneous structure with varying sizes and locations of eyes depending on the ripening period. The rind of Canestrato cheese darkened from milky to amber with increasing ripening time and showed signs of damage by the mite *A. siro* starting from the age of 6 months. The results of the research on the dynamics of physicochemical processes can be used to determine the authenticity and criteria for the ripening of craft cheeses from unpasteurized goat milk.

Keywords: Caciotta; Canestrato; protein; fat; ash; moisture; cheese paste; rind.

Introduction

Goat milk is a unique product in terms of its chemical composition and biological properties, rich in protein, lipids, calcium, phosphorus, trace elements, niacin, and thiamine (Riskó & Csapó, 2019). Due to the smaller size of fat globules and casein, goat milk is easier for the human body to digest and absorb compared to cow's milk (Razali et al., 2021). It is consumed raw or used for cheese production. Goat cheese is a valuable and popular gelatinous dairy product worldwide. Cheese is a dairy product that has played a key role in human nutrition for centuries, and most of its properties depend on the chemical composition of the milk, as well as the method and depth of its processing (Bayer et al., 2017a; Gámbaro et al., 2017; Kukhtyn et al., 2024).

The wide range of goat cheeses is primarily due to the ecological characteristics of each region, and therefore, the production technologies that are constantly being improved. The production of goat milk cheeses on small farm enterprises ensures their uniqueness, which is determined by the breed of goats, their diet, the quality and botanical composition of the pasture grasses, and the cheese production technology. For the production of such craft cheeses, minimal processing is applied, or raw milk is used, which ensures its authenticity and is characterized by unique flavor and aroma shades compared to cheeses made using industrial technologies (Anedda et al., 2021; Psomas et al., 2023). Craft goat cheeses remain relatively expensive products, synonymous with taste enjoyment, which depends on many factors, such as chemical composition, including protein, fat, and salt content, as well as the presence and ratio of biologically active compounds that are present or formed during the ripening process. The characteristics of mature cheese are influenced by the milk components and microorganisms present in it throughout the ripening period (Bayer et al., 2017c; Delgado et al., 2023), as well as the ripening conditions (water activity, salt concentration and diffusion, temperature, and relative humidity of the environment).

One of the most important phenomena during cheese ripening is the evaporation of moisture from the core and rind and its redistribution from the core to the surface of the cheese wheel. Meanwhile, a series of biochemical processes occur in the cheese, ensuring its maturation, including lactose, citrate, and lactate metabolism, lipolysis, fatty acid metabolism, proteolysis, and amino acid catabolism. The main agents of these biochemical transformations are the enzymes of milk, starter cultures, and natural microorganisms, as well as the coagulant (Slyvka et al., 2018; Cipolat-Gotet et al., 2020). Among the components of cheese that determine its quality are the fat and protein content, as well as several aromatic and biologically active compounds: methanethiol, free fatty acids, acetoin, diacetyl, acetate, ethanol, and propionate. Various factors influence the chemical composition and quality of cheese: the conditions of animal husbandry and feeding (Mylostyvyi et al., 2023), the microbiological and chemical composition of milk (Bayer et al., 2017b), the production technology, and the terms and conditions of cheese ripening (Duru et al., 2018; Uzun et al., 2020).

The protein and fat content in milk can vary depending on the species, breed, season, health status, lactation stage, and diet of the animals (Manuelian et al., 2017; Manzocchi et al., 2021). Additionally, the type of starter culture used in cheese production can alter the overall protein, fat, ash content, and fatty acid profile due to the different activity and specificity of proteolytic and lipolytic enzymes (Taboada et al., 2015; Özcan et al., 2019).

Most studies on the determination of physicochemical characteristics of craft cheeses during ripening present data where cow's milk, various blends with other types of milk (Ramírez-López & Vélez-Ruiz, 2018; Hovjecki et al., 2022), pasteurized goat milk (Pappa et al., 2022), or raw goat milk for short-ripened cheeses (Levak et al., 2023) have been used. However, information on the physicochemical indicators of long-ripened cheeses from raw goat milk (12 and 24 months) is insufficient to reveal the main parameters of their authenticity. Therefore, the research aims to determine the physicochemical properties of craft hard cheeses Caciotta, and Canestrato from raw goat milk during long-term ripening.

Materials and methods

Two batches of craft cheeses from raw goat milk, Caciotta, and Canestrato, were produced for the research, each consisting of 20 wheels with an average weight of 2.3–2.5 kg at the "Zhuravka" Eco Farm in Kyiv region. The milk used for cheese production came from Anglo-Nubian goats. For the production of Caciotta cheese, a lactic acid bacteria starter culture MA 4001 (Danisco France SAS, France) was used. The starter culture included the following microorganisms: *Lactobacillus lactis*, *Lactococcus cremoris*, *L. diacetylactis*, and *Streptococcus thermophilus*. The starter culture was applied to milk heated to 37 °C, mixed, and left for 45–60 minutes. Then, liquid rennet enzyme Rennet Liquid 92/8 (Pamir Service, Kyiv, Ukraine) was added and evenly distributed throughout the milk. After adding the enzyme, the milk was left for 35–40 minutes to coagulate and then the curd was cut into 1.5–2.0 cm cubes. The curd was slowly and thoroughly mixed for 25 minutes, maintaining a temperature of 37–39 °C. After separating the whey, it was drained to cover the surface of the curd. The curd was placed in a mold, creating a warm chamber (stufatura) for it with a temperature of 47 °C. For the next 1.0–1.5 hours, the temperature of the cheese in the mold was maintained at 32–38 °C to ensure the necessary conditions for the enzymatic activity of thermophilic streptococci. After the holding period, the cheese was removed from the chamber and left to cool at room temperature for 2–3 hours, turning every half hour. After this, the cheese was placed on a draining mat in the refrigerator for 8–10 hours. The cheese was salted using a 25% solution of table salt at a rate of ~ 3–4 hours per 500 g of cheese. After salting, the cheese was removed from the brine and placed in a ripening chamber at 12–15 °C and 85–90% humidity for 24 months.

For chemical composition analysis, average samples from 5 wheels of Caciotta cheese were taken at ripening stages: 10 days, 1 month, 12 months, and 24 months, each weighing 200 g.

For the production of Canestrato cheese, a thermophilic starter culture TA 45 (Danisco France SAS, France) containing *Streptococcus thermophilus* was used. The starter culture was added to milk heated to 32 °C and thoroughly mixed. Liquid rennet enzyme Rennet Liquid 92/8 (Pamir Service, Kyiv, Ukraine) was then added, evenly distributed throughout the milk, and left for 45 minutes to coagulate. The resulting curd was cut into small cubes of 5–7 mm, the mass was stirred with a special whisk to break down the pieces, and the curd was left for 10 minutes to settle. After settling, the curd was heated to 46 °C, the whey was drained, and the curd was pressed for 15 minutes. After pressing, the cheese in the mold was immersed in whey heated to 65–71 °C and cooled for 24 hours at room temperature, turning every 12 hours. A 20% brine solution was prepared from the whey for salting the cheese, which was performed for 24 hours. The salted cheese was placed in a ripening chamber at 12–15 °C and 80–85% humidity for 12 months.

For analysis, samples from 5 wheels of Canestrato cheese were taken at different ripening stages: 10 days, 3 months, 6 months, and 12 months, each weighing 200 g. Starting from the 6-month maturation period, the wheels of Caciotta and Canestrato cheeses were washed with artesian water every 2–3 months, depending on the intensity of infestation by the mite *Acarus siro* (Linnaeus, 1758), genus *Acarus* (Linnaeus, 1758), family Acaridae (Latreille, 1802).

The chemical composition analysis of the cheeses was conducted at "Biolights Expert Center" LLC in Ternopil and the Transcarpathian Regional State Laboratory of the State Consumer Service in Uzhhorod. The cheese was analyzed for moisture, ash, protein, and fat content.

The moisture content in the cheese was determined by successively weighing and drying of samples in a drying oven SESH ZMU (Olis LLC, Ukraine). The nitrogen content in the cheese was determined using the Kjeldahl method, with sample mineralization conducted using a Speed-Digester K-439 (DONAU LAB, Moldova). Ammonia distillation was performed with a automatic steam distillation unit KjelFlex K-360 (DONAU LAB, Moldova). The protein content in the cheese was calculated using a conversion factor from the nitrogen content. The ash content in the cheese was determined by incinerating samples in a Nabertherm L9 muffle furnace (Germany). The fat content in the cheese was determined using the Gerber method. The hardness of the cheeses was calculated as the ratio of the mass of moisture in the cheese sample to the difference between the mass of the sample and the mass of fat in the sample, expressed as a percentage.

Statistical analysis of the results was performed using regression and correlation analysis with ANOVA software. Data in the tables are presented as x ± SD (mean ± standard deviation). Differences between groups were considered significant using the Tukey test with $P < 0.05$, taking into account the Bonferroni correction.

Results

The moisture content in Caciotta cheese did not differ significantly on the 10th day and the first month of maturation, but by the 12th month, it had decreased by 12.8% compared to the 10th day and by 13.6% compared to the first month (Table 1). By the 24th month of maturation, there was an even greater loss of moisture, which amounted to 19.3% compared to the 10th day, 20.1% compared to the first month, and 6.0% compared to the 12th month.

The fat content in Caciotta cheese did not significantly differ within the 10-day and one-month maturation periods. However, by 12 months, there was an increase in fat content by 8.0% compared to the 10 days and by 9.7% compared to the one month. The fat content in Caciotta reached its maximum from 12 to 24 months of age. There was a significant increase in fat content in 24-month-old cheese compared to the 10-days by 9.6% and compared to the one-month maturation period by 10.6%.

The protein content in Caciotta cheese showed similar fluctuations to the dry matter content: it did not change on the 10th day and the first month of maturation but increased by 4.4% by the 12th month. The protein content in Caciotta increased by 9.4% compared to the 10 days, by 9.6% compared to the one month, and by 5.0% compared to the 12-month maturation period by the 24th month.

The ash content in Caciotta cheese also increased with age: by the 24th month of maturation, the ash content was 0.8% higher compared to the 10 days, 0.4% higher compared to the one month, and 0.3% higher compared to the 12 months.

Table 1
Chemical composition of Caciotta goat cheese during the ripening process (%, x ± SD, n = 5)

Indicator	Cheese maturation period			
	10 days	1 month	12 months	24 months
Moisture	44.44 ± 0.54^a	45.21 ± 1.51^a	31.60 ± 1.25^b	25.09 ± 0.56^c
Fat	26.96 ± 1.32^a	25.95 ± 0.76^a	34.98 ± 0.48^b	36.53 ± 0.65^b
Protein	23.76 ± 0.55^a	23.63 ± 0.71^a	28.18 ± 0.26^b	33.21 ± 0.43^c
Ash	3.45 ± 0.09^a	3.89 ± 0.09^b	3.94 ± 0.03^b	4.28 ± 0.07^c

Note: different superscript letters indicate significantly different values in the same row of the table ($P < 0.05$) based on the Tukey test with Bonferroni correction.

Correlation and regression analysis indicate that the moisture content in Caciotta cheese had a strong inverse correlation with the maturity period ($r = –0.977 \pm 0.097$, $P < 0.01$). The regression line shows a linear inverse relationship between moisture content and maturity period in Caciotta cheese (Fig. 1). There is also a strong direct correlation between protein content in Caciotta cheese and the maturity period (r = 0.991 ± 0.103, P < 0.01), and a strong inverse correlation between protein content and moisture content in the cheese (r = –0.978 ± 0.092, P < 0.01). The regression line confirms the direct linear relationship between protein content and maturity period (Fig. 2) and the inverse linear dependence between protein content and moisture content in Caciotta cheese (Fig. 3).

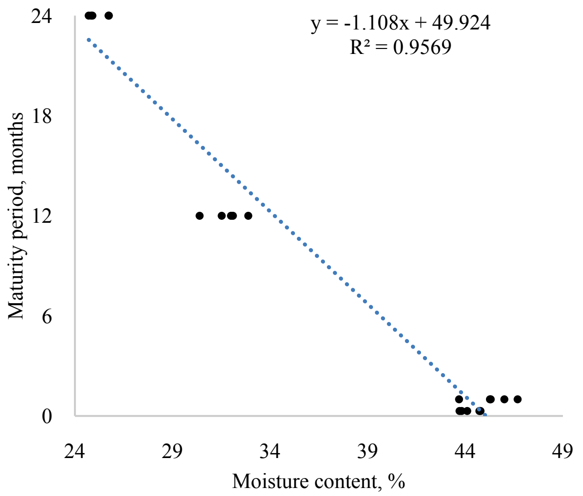

Fig. 1. Dependence of moisture content in Caciotta cheese on ripening time, n = 20

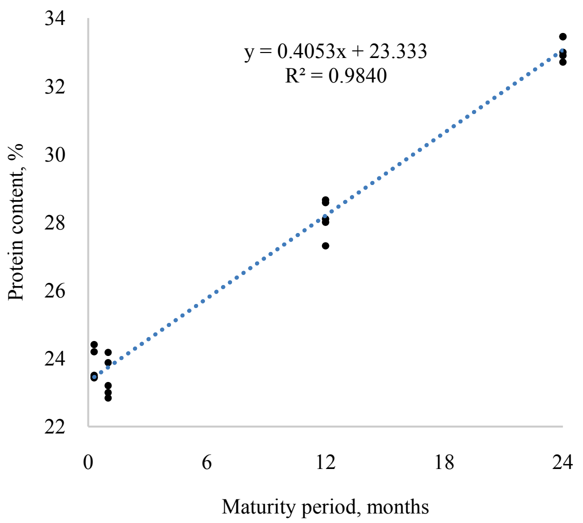

Fig. 2. Dependence of protein content in Caciotta cheese on maturity period, n = 20

The fat and protein content in the dry matter of Caciotta cheese did not depend on the maturity period except for the 24th month, when the protein content increased by 1.6% compared to the 10-day maturity period and by 3.1% compared to the 12-month period. The fat-to-protein ratio in Caciotta cheese during maturity for 10 days, one month, and 24 months did not differ significantly, but at the age of 12 months, it increased by 0.11 units compared to the 10-day period and by 0.14 units compared to the 24-month period (Table 2).

Hardness reached its maximum value in young Caciotta cheese (aged 10 days and one month). During further maturation, it decreased: at 12 months, hardness was reduced by 12.2% compared to 10-day old cheese and by 13.3% compared to one-month-old cheese. At 24 months, the hardness of Caciotta cheese was the lowest, being 9.1% lower than that of 12-month old cheese, 22.3% lower than that of one-month-old cheese, and 21.3% lower than that of 10-day old cheese. The hardness of Caciotta cheese was characterized by a strong inverse correlation with the maturation period (r = –0.987 ± 0.106, P < 0.01). Regression analysis showed an inverse linear dependence between the hardness of Caciotta cheese and its maturation period (Fig. 4).

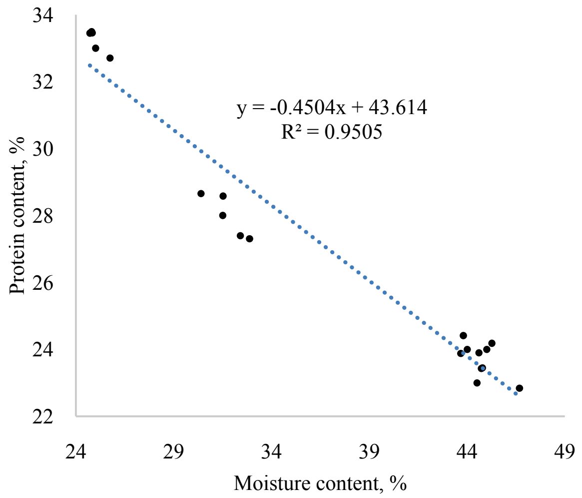

Fig. 3. Dependence between protein content and moisture content in Caciotta cheese during ripening, n = 20

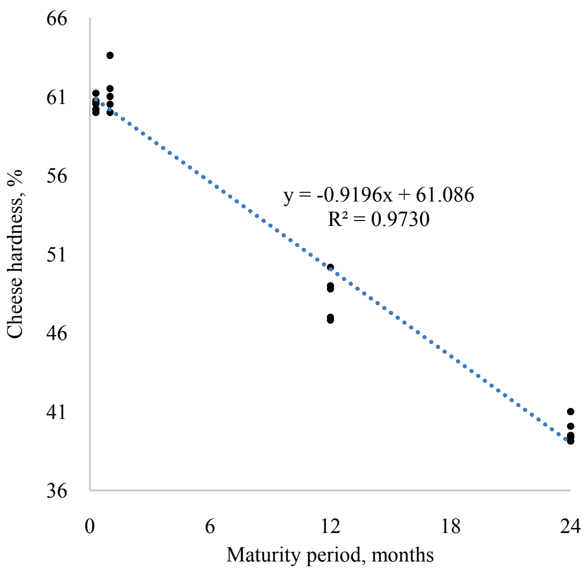

Fig. 4. Dependence between hardness and maturity period of Caciotta cheese, n = 20

Table 2
Physico-chemical indicators of dry matter in Caciotta cheese during maturation (%, x ± SD, n = 5)

Indicator	Cheese maturation period			
	10 days	1 month	12 months	24 months
Fat	48.50 ± 1.85[a]	49.20 ± 0.85[a]	51.14 ± 1.67[a]	48.76 ± 0.51[a]
Protein	42.76 ± 0.59[a]	43.14 ± 0.92[ab]	41.20 ± 0.52[a]	44.33 ± 0.25[b]
Fat/Protein Ratio	1.13 ± 0.03[a]	1.14 ± 0.04[ab]	1.24 ± 0.02[b]	1.10 ± 0.01[a]
Hardness	60.84 ± 0.34[a]	61.88 ± 1.58[a]	48.59 ± 1.69[b]	39.53 ± 0.48[c]

Note: see Table 1.

Caciotta cheese matured without artificial coating, with the surface of the wheels covered by a milk-colored rind. At 10 days of age, the rind had a smooth relief surface and was the same color as the cheese mass (Fig. 5a, 5b). When cutting a 10-day old Caciotta cheese, the mass was plastic and homogeneous, with round, oval, and irregularly shaped and sized holes unevenly distributed over the cut surface. In one month old Caciotta cheese, the mass was plastic and homogeneous, with small round, oval, and irregularly shaped holes evenly distributed over the cut surface. From the age of one month, the Caciotta cheese rind acquired a yellow color, standing out against the cheese mass (Fig. 5c, 5d).

Twelve month old Caciotta cheese wheels had an amber-colored rind with traces of small pores and whitish-gray exfoliation due to damage by the mite *A. siro*. On the cut, the rind was hard and clearly stood out against the cheese mass. The cheese mass was homogeneous, slightly brittle, with irregularly shaped holes more concentrated in the core of the wheel (Fig. 5e, 5f). At 24 months, Caciotta cheese had an amber-colored rind that, in places, lost its surface relief and was covered with large pores with whitish-gray exfoliation and flakes due to the activity of the mite *A. siro*. On the cut, the cheese mass had a uniform color, was brittle, with irregularly shaped holes unevenly distributed over the cut surface (Fig. 5g, 5h).

Fig. 5. Caciotta cheese aged 10 days (*a* – wheel, *b* – slice), 1 month (*c* – wheel, *d* – slice), 12 months (*e* – wheel, *f* – slice), 24 months (*g* – wheel, *h* – slice)

The moisture content in Canestrato cheese during maturation from 10 days to 6 months did not change. At the 12th month of maturation, the moisture content in Canestrato cheese decreased by 4.4% compared to 10 days old cheese, by 3.5% compared to 3 month old cheese, and by 3.2% compared to 6 month old cheese (Table 3). Regarding the fat content in Canestrato cheese, no significant difference was found between cheeses aged 10 days, 3 months, and 6 months. Only in 12 month old cheese did the fat content exceed that of 10 day old cheese by 3.8%.

The maturation period did not affect the protein and ash content in Canestrato cheese (Table 3). A strong inverse correlation was found between the moisture content in Canestrato cheese and its maturation period ($r = -0.913 \pm 0.101$, $P < 0.01$). The regression line confirms that there is an inverse linear relationship between the moisture content and the maturation period of Canestrato cheese (Fig. 6).

The fat and protein content in the dry matter of Canestrato cheese did not depend on the maturation period (Table 4). Accordingly, the fat-to-protein ratio did not significantly depend on its age, except for the cheese aged 12 months, where this ratio was higher by 0.18 units compared to the 10-day-old cheese.

Table 3
Chemical composition of Canestrato cheese during maturation (%, $x \pm SD$, $n = 5$)

Indicator	Cheese maturation period			
	10 days	3 months	6 months	12 months
Moisture	37.94 ± 0.29^{a}	37.07 ± 1.31^{a}	36.78 ± 0.43^{a}	33.54 ± 0.39^{b}
Fat	30.82 ± 0.91^{a}	32.15 ± 0.80^{ab}	32.79 ± 1.57^{ab}	34.63 ± 0.51^{b}
Protein	25.65 ± 0.34^{a}	26.34 ± 2.10^{a}	24.50 ± 0.29^{a}	25.08 ± 0.11^{a}
Ash	4.15 ± 0.16^{a}	4.26 ± 0.13^{a}	3.97 ± 0.26^{a}	4.09 ± 0.12^{a}

Note: see Table 1.

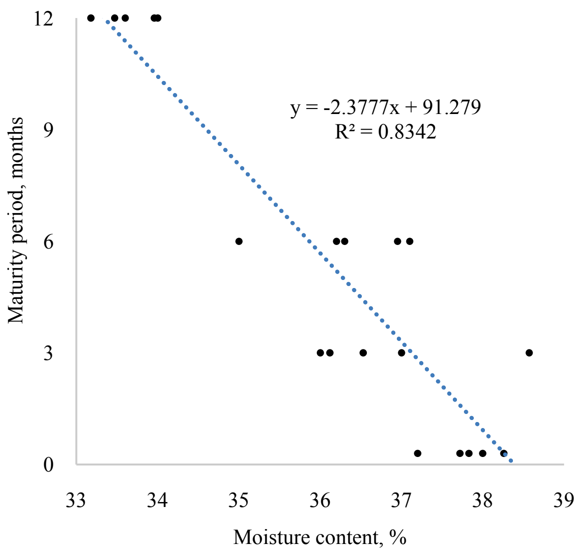

Fig. 6. Dependence of moisture content in Canestrato cheese on the maturation period, $n = 20$

A decrease in the hardness of Canestrato cheese was observed with an increase in the maturation period, particularly by 3.5% at the 12th month compared to 10-day-old cheese, by 3.3% compared to 3 months old cheese, and by 3.4% compared to 6 months old cheese.

Table 4
Physico-chemical indicators of dry matter in Canestrato cheese during maturation (%, $x \pm SD$, $n = 5$)

Indicator	Cheese maturation period			
	10 days	3 months	6 months	12 months
Fat	49.66 ± 1.61^{a}	51.12 ± 2.30^{a}	51.87 ± 2.26^{a}	52.11 ± 0.52^{a}
Protein	41.33 ± 0.39^{a}	41.91 ± 4.25^{a}	38.75 ± 0.25^{a}	37.74 ± 0.09^{a}
Fat/Protein ratio	1.20 ± 0.05^{a}	1.22 ± 0.07^{ab}	1.34 ± 0.04^{ab}	1.38 ± 0.02^{b}
Hardness	54.82 ± 0.31^{a}	54.66 ± 0.24^{a}	54.74 ± 0.41^{a}	51.31 ± 0.29^{b}

Note: see Table 1.

Canestrato cheese matured without artificial coating, similar to Caciotta cheese. On the 10th day of maturation, the surface of Canestrato cheese wheels was covered with a milk-colored rind, with a smooth and intact surface, indistinguishable from the cheese mass color (Fig. 7a, 7b). When cutting a 10-day-old Canestrato cheese wheel, the mass was plastic and homogeneous, with very small, scattered, round holes on the cut surface. By the third month of maturation, the surface of Canestrato cheese wheels was covered with a continuous yellow rind, which stood out from the cheese mass on the cut. At this stage, Canestrato cheese had a characteristic plastic and homogeneous mass, with small, scattered, round and oval holes unevenly distributed over the cut surface (Fig. 7c, 7d). Six-month-old Canestrato cheese wheels had an amber-colored rind. On the cut, the rind was hard and clearly stood out against the cheese mass. Small, irregularly placed pores with yellowish-gray exfoliations, identified as damage caused by the mite *A. siro*, were found on the rind surface. The cheese mass was homogeneous, slightly brittle, with small and medium-sized round, oval, and irregular holes distributed throughout the cheese cut (Fig. 7e, 7f). At 12 months, Canestrato cheese had a hard, amber-colored rind. The rind surface had characteristic traces of the mite *A. siro,* manifested as small pores with whitish-gray exfoliations around the wheel's perimeter. On the cut, the cheese mass had a uniform color, was slightly brittle, with irregularly shaped holes unevenly distributed over the cut surface (Fig. 7g, 7h).

Discussion

In Europe, nearly all goat's milk is processed into cheese, accounting for 35% of the world's goat cheese production (Sepe & Argüello, 2019). Caciotta is a semi-hard cheese made from a mixture of whole raw sheep, goat, and cow milk. It belongs to the large family of typical Italian agricultural cheeses, such as "Caciotta della Lunigiana," "Caciotta della Sabina," "Caciotta di pecora Toscana," and the protected designation of origin (PDO) "Caciotta d'Urbino," which has a maturation period of 2 months (Fusco et al., 2019). Canestrato is a hard cheese made from a mixture of sheep and goat milk, produced in artisanal conditions in Italy. It has a cylindrical shape and a maturation period ranging from 2 months (young type) to 12 months (matured type) (Trani et al., 2016). The originality of the craft production of Caciotta and Canestrato cheeses in our experiment consists in the use of only unpasteurized goat's milk and extending the maturation period of Caciotta cheese to 24 months.

It is known that physical, biochemical, and microbiological changes during maturation correlate with the quality, safety, and stability of cheese (Kliks et al., 2022). Lactic acid bacteria, which dominate in cheese and exhibit enzymatic activity affecting its structure formation, play an important role in this process (Blaya et al., 2018; Musiy et al., 2020; Proust et al., 2020). The stability of desirable properties is closely related to the presence and state of water in cheese (Tomaszewska-Gras et al., 2019). The state and dynamics of water present in products in the form of free and bound water largely determine the properties of food products, including cheeses. The presence and state of water affect the shelf life and quality of cheeses, as well as the course of all chemical reactions involving microbial enzymes during their maturation (Małkowska-Kowalczyk et al., 2024). As is evident from our research results, Caciotta and Canestrato cheeses significantly lost moisture during maturation starting from the 12th month. During this period, both cheeses showed an increase in fat content proportional to the increase in dry matter. Meanwhile, in Caciotta cheese, the decrease in moisture content was also associated with an increase in protein content, whereas in Canestrato cheese, this dependence was not observed.

The increase in protein and fat content during cheese maturation may be due to partial water evaporation (Manuelian et al., 2017; Nurliyani et al., 2020). The typical fat-to-protein ratio in cheeses ranges from 0.70 to 1.15, which influences its sensory characteristics. Lipkowitz et al. (2018) demonstrated that the higher the fat content in the dry matter of cheese, the more pronounced its flavor properties and consumer appeal. The fat-to-protein ratio in Caciotta and Canestrato cheeses was highest at 12 months, exceeding the upper limit of the typical ratio in both cases, indicating the formation of authentic flavor characteristics during this period.

It is believed that the maturation stage significantly affects the increase in dry matter content, nitrogen solubility, and the reduction of fat content in cheese, although the latter was not confirmed in our research. The maturation period is related to the melting properties and hardness of cheese (Młynek et al., 2018). As the maturation period of Caciotta cheese increased to 12 months and older, its hardness decreased, whereas this pattern was not observed in Canestrato cheese, which is related to the different intensity of water loss by these cheeses during maturation. It has been shown that cheese made from goat's milk has poor rennet process kinetics, which explains its lower hardness and higher brittleness (Wang et al., 2023). It should be noted that the hardness of Caciotta and Canestrato cheeses was calculated according to national regulatory documents and may not reflect the characteristics of cheeses with a long maturation period, which is 12 months or more, and is characteristic of Parmesan-type cheeses. Such cheeses are classified as ultra-hard, having a brittle structure (D'Incecco et al., 2020). Studies on Kope cheeses with a maturation period of 187 days are consistent with our research results and indicate that the maturation period of cheeses affects their chemical composition and sensory properties.

a b c d e f g h

Fig. 7. Canestrato cheese aged 10 days (*a* – wheel, *b* – slice), 3 months (*c* – wheel, *d* – slice), 6 months (*e* – wheel, *f* – slice), 12 months (*g* – wheel, *h* – slice)

Esmaeilzadeh et al. (2021) classify cheeses based on maturation time into three groups: early-ripened cheeses with a salty taste, waxy to cheesy odor, and rubbery texture; medium-ripened cheeses with a sweet taste and cheesy odor; and late-ripened cheeses with a bitter taste, cheesy or sharp odor, and hard and brittle texture. Caciotta cheese at 10 days and one month of maturation and Canestrato cheese at 10 days and 3 months of maturation exhibited sensory characteristics similar to early-ripened cheeses, except for the salty taste. Caciotta cheese aged 12 and 24 months and Canestrato cheese aged 12 months corresponded more closely to the characteristics of late-ripened cheeses.

Cheeses are also classified by moisture content into three classes: hard cheeses with moisture content <35%, semi-hard cheeses with moisture content 35–45%, and soft cheeses with moisture content >45% (Manuelian et al., 2017). Bintsis (2021) further divides cheeses by moisture content into seven categories: 1) hard (moisture content less than 43%), 2) semi-hard (moisture content 44–55%), 3) soft (moisture content above 56%), including soft pasta-filata and whey cheeses, 4) white brined cheeses, 5) surface-ripened cheeses, 6) surface-ripened cheeses with bacterial cultures, and 7) blue cheeses. Caciotta cheese at 10 days and one month, and Canestrato cheese at 10 days, 3 months, and 6 months can be classified as semi-hard cheeses based on moisture content, but at 12 months and older, they can be classified as hard cheeses. A similar pattern of moisture loss in goat cheeses during maturation was found by Gámbaro et al. (2017). In this study, the moisture content of goat cheese ranged from 28.1% to 55.9%. The lowest moisture content – 30.2% – was found in cheese with a maturation and/or storage period of over 60 days, while in fresh cheese, the average moisture content was 46.6%. The results of the physicochemical analysis of artisanal Minas Canastra cheese showed that its moisture content ranged from 18.4% to 28.2%, fat content from 20.5% to 40%, sodium chloride content was 0.9%, and pH ranged from 5.2 to 5.5 (Aragão et al., 2022). Similar data on the chemical composition of cheeses produced in Xinjiang (China) were obtained by Zhang et al. (2022), who reported that the moisture content of such cheeses ranged from 23.2% to 59.2%, and the salt content ranged from 1.1% to 4.8%.

The chemical composition of cheese is influenced by the weight of the wheel, maturation period, and the rate of rind formation, which protects the cheese from moisture evaporation. A study of the chemical composition of Provolone del Monaco cheese, made from raw cow's milk (Naples, Italy), showed that the moisture content in freshly made cheese ranged from 43.8% to 47.0%. Specifically, the moisture percentage in the core of a 3 kg cheese was 46.2% and in a 5 kg cheese 47.0%, while under the rind it was 43.8% and 45.8%, respectively. The greatest moisture loss was observed in cheese on the 90th day of maturation, when its content decreased to 40.0% and 42.9% in the core and to 31.6% and 36.9% under the rind in cheeses weighing 3 kg and 5 kg, respectively. After 90 days of maturation, moisture loss was less noticeable, likely due to the final formation of the rind (Manzo et al., 2019). Our data are consistent with these results; however, during the maturation of Caciotta and Canestrato cheeses weighing 2.3–2.5 kg, the greatest moisture loss was noted in the 12th month of maturation. At the same time, the intensity of moisture loss in Caciotta cheese at 12 months of maturation was on average 10.4% higher than in Canestrato cheese, which may be related to the characteristics of the protective rind formation.

The concentration of minerals in cheese depends on the origin and blend of the milk, the cheese-making recipe, and the moisture content, which can significantly differentiate cheeses of the same name produced using different technologies (de Oliveira Filho et al., 2022). It is believed that the mineral composition of cheese is influenced by the salt content. Salt not only contributes to the cheese's saltiness but can also enhance the intensity of its flavor. Additionally, it can mask undesirable flavors, such as bitterness (Møller et al., 2013). The total mineral content significantly increased when the moisture content of the cheese decreased (Manuelian et al., 2017). The analysis of the mineral composition of Caciotta cheese confirms an increase in mineral content in the form of ash with a decrease in moisture content, whereas the ash content in Canestrato cheese did not change throughout the maturation period against the background of slow moisture loss.

The microbiome can influence the taste or color of cheese through the secretion of volatile compounds or the biosynthesis of pigments (Walsh et al., 2020). The color changes of the rind and core of Caciotta and Canestrato cheeses observed during their maturation are likely caused by enzymatic processes involving the microbiome and the *A. siro* mite, whose population inhabits the surface of cheese wheels from 6 months of age. These changes are particularly noticeable in long-aged cheeses, 12 months and older.

Our research results in the analysis of Caciotta and Canestrato cheeses are consistent with data obtained by other scientists, emphasizing the regional characteristics of cheese production and supplementing information on the dynamics of physicochemical processes in long-aged cheeses made from unpasteurized goats' milk in artisanal production.

Conclusions

The physical and chemical characteristics of Caciotta and Canestrato cheeses made from raw goat milk varied with their maturation period. Over the course of aging up to 24 months, the moisture content in Caciotta decreased from 44.4% to 25.1%. The greatest moisture loss during Caciotta aging occurred at 12 months and was between 19.3% and 20.1%. During the maturation process, Caciotta showed an increase in fat content from 27.0% to 36.5%, protein from 23.8% to 33.2%, and ash from 3.4% to 4.3%, while its firmness decreased from 60.8% to 39.5%. The moisture content in Caciotta had a strong inverse relationship with the maturation period. There was also a strong inverse dependence between protein content and moisture content, and a direct dependence between protein content and the aging period of Caciotta. The fat-to-protein ratio remained stable, ranging from 1.10 to 1.24, peaking at 12 months. Caciotta develops a crumbly texture over time, with a rind that hardens and changes color from milky white to amber with varying degrees of damage from the mite *A. siro*.

For Canestrato cheese, the moisture content decreased with aging, from 38.0% to 33.5% by 12 months. The greatest moisture loss in Canestrato occurred between 6 and 12 months, at 4.4%. The protein and ash content in Canestrato did not depend on the aging period, while the fat content increased by 3.8% only at 12 months. Firmness of Canestrato decreased at 12 months. The cheese had a plastic, homogeneous texture with varying sizes and distribution of eyes depending on age. The rind changed color from milky white to amber, with signs of mite *A. siro* activity. These findings can be used as criteria for assessing the ripening duration and authenticity of artisanal cheeses made from raw goat milk.

The authors declare that they have no potential conflict of interest.

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