Regulatory Mechanisms in Biosystems

ISSN 2519-8521 (Print)
ISSN 2520-2588 (Online)
Regul. Mech. Biosyst.

Influence of the ripening period on the content of macroelements and microelements in craft soft goat cheeses

V. A. Davydovych*, L. V. Shevchenko*, S. V. Shulyak**, V. M. Mykhalska*, I. V. Kalinin*, D. V. Lisohurska***, O. V. Lisohurska***

**National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine*
***State Scientific and Research Institute of Laboratory Diagnostics and Veterinary and Sanitary Expertise, Kyiv, Ukraine*
****Polissia National University, Zhytomyr, Ukraine*

Article info

Received 01.12.2025
Received in revised form 30.12.2025
Accepted 21.01.2026

National University of Life and Environmental Sciences of Ukraine, Heroiiv Oborony st., 15, Kyiv, 03041, Ukraine. Tel.: +38-050-193-10-29. E-mail: shevchenko_laris@ukr.net

State Scientific and Research Institute of Laboratory Diagnostics and Veterinary and Sanitary Expertise, Donetska st., 30, Kyiv, 03151, Ukraine. Tel.: +38-066-402-30-29. E-mail: dia_sveta_@ukr.net

Polissia National University, Staryi Blvd., 7, Zhytomyr, 10008, Ukraine. Tel.: +38-096-964-10-03. E-mail: lisogurskadina@gmail.com

Davydovych, V. A., Shevchenko, L. V., Shulyak, S. V., Mykhalska, V. M., Kalinin, I. V., Lisohurska, D. V., & Lisohurska, O. V. (2026). Influence of the ripening period on the content of macroelements and microelements in craft soft goat cheeses. Regulatory Mechanisms in Biosystems, 17(1), e26006. doi:10.15421/0226006

The growing demand for cheeses as components of healthy nutrition is associated with minimal processing of raw milk and the preservation of biologically valuable constituents. These include soft cheeses such as Feta and Chevre, which are produced from unpasteurized goat milk and therefore require assessment of quality and safety based on their mineral composition during ripening. The study was carried out using optical emission spectrometry. It was found that during the ripening of brined Feta cheese, the content of calcium, zinc, and iron did not change, while the levels of phosphorus (by 11.0%), sodium (by 23.5%), potassium (by 13.5%), magnesium (by 36.5%), manganese (by 2.32 times), molybdenum (by 1.95 times), and lead (by 21.4%) decreased. In contrast, by the 30th month of ripening, the content of copper in Feta cheese had increased by 2.04 times and cobalt by 1.54 times. Essential elements in Feta cheese were arranged by concentration as follows: Na > Ca = P > K > Mg > Zn > Fe > Mn = Cu > Mo > Co > Se. The accumulation of heavy metals, in particular aluminum, nickel, chromium, cadmium, and mercury, in Feta cheese did not depend on its age and did not reach the maximum permissible concentrations. According to their content in Feta cheese, heavy metals were distributed as follows: Al > Pb = Ni > Cr > Cd > Hg > As = Sb. The mineral composition of Chevre cheese, which ripens with the participation of white noble mold, significantly depended on its age. On the 40th day of ripening, Chevre cheese showed an increase in the content of calcium (by 1.57 times), sodium (by 9.4%), potassium (by 22.1%), magnesium (by 1.47 times), iron (by 2.00 times), manganese (by 1.53 times), copper (by 1.52 times), and cobalt (by 1.45 times), against the background of stable levels of phosphorus, zinc, molybdenum, lead, nickel, chromium, and cadmium. Macro- and microelements in Chevre cheese were arranged in descending order of concentration as follows: Na > P > K > Ca > Mg > Zn > Fe > Mn = Cu > Mo > Co > Se. The aluminum content in Chevre cheese increased by 25.5%, and mercury by 38.5% by the 40th day of ripening. Concentrations of heavy metals in Chevre cheese decreased in the following sequence: Al > Pb > Ni > Cr > Cd > Hg > As = Sb. The content of selenium, arsenic, and antimony in both cheeses remained below the detection limit throughout the ripening period. The results of the study demonstrated that soft Feta and Chevre cheeses made from unpasteurized goat milk are characterized by a unique macro- and microelement composition, which confirms their biological value and safety with respect to heavy metal content. The mineral composition of craft goat cheeses Feta and Chevre may serve as one of the components of the criteria for their authenticity and the environmental well-being of the region.

Keywords: brined Feta cheese; Chevre cheese with noble mold; quality; safety; mineral composition; authenticity.

Introduction

Milk and dairy products are indispensable foods throughout the entire human lifespan. They are an accessible and rich source of nutrients and biologically active substances for the body, ensuring human growth and development from early childhood (Iakubchak et al., 2024; Savchenko et al., 2024). Among dairy products in the consumer basket, cheeses occupy an important place, as they contain significant amounts of mineral components, including macro- and microelements that are essential for respiration, digestion, reproduction, and the maintenance of homeostasis. Up to 58% of calcium, 32% of phosphorus, 23% of zinc, 17% of potassium and sodium, and 15% of magnesium entering the human body come through cheese consumption (Shkembi & Huppertz, 2021). The mineral composition of cheeses also includes essential trace elements (iron, copper, selenium, cobalt, and manganese), which are present in low doses but are vital for human physiological functions (Santarcangelo et al., 2022).

In addition, cheeses contain a number of elements classified as heavy metals, in particular aluminum (Al), chromium (Cr), nickel (Ni), arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb), which pose direct and potential risks to human health (Motas et al., 2021; Basaran, 2025; Moon et al., 2025). These elements may exhibit cumulative activity in tissues and lead to dangerous long-term consequences (Carmona et al., 2021; Grassi & Perna, 2025). Moreover, their presence in food products, including cheeses, even at low concentrations, can cause serious health problems in humans (Maruszewska et al., 2021). Some adverse effects of heavy metals on the human body include kidney failure, genetic mutations, and disorders of the nervous system. They may also cause cardiovascular problems, various types of cancer, respiratory disorders, weakening of the immune system, and infertility (Abd Elnabi et al., 2023).

The mineral composition of milk and dairy products, including cheeses, has long been the focus attention from researchers; however, most available data have been obtained from analyses of traditional cheeses produced using industrial technologies from pasteurized milk. Currently, increasing attention is being paid to craft cheeses made from unpasteurized milk of large and small ruminants, particularly goats that graze on pastures (Kaczyński, 2024; Chwastowska-Siwiecka et al., 2025a). Of particular value are refined soft cheeses, including brined cheeses such as Feta and cheeses ripened with the participation of white noble mold, such as Brie, Camembert, and Chevre.

Craft soft cheeses made from unpasteurized goat milk are characterized not only by a unique combination of refined flavors and aromas but also by a fatty acid profile that is beneficial for cardiovascular health. Therefore, the craft cheese market continues to expand, supported by the establishment of small eco-farms where milk production, processing, and the sale of cheeses and other dairy products take place. This is especially important from the perspective of food chain traceability “from farm to table” and is consistent with the development of the new Km 0 concept, also known as “zero-kilometer” marketing or “short food supply chains,” which usually do not exceed 100 km (Martínez-Vérez & Lucini Baquero, 2025). Such cheeses are sold both at local markets and in delicatessen stores (Chwastowska-Siwiecka et al., 2025b). It is believed that craft cheeses produced from the milk of grazing ruminants, especially goats, have characteristic differences in mineral composition compared with cheeses produced using industrial technologies, where animals are kept under intensive systems (de Oliveira Filho et al., 2022).

The mineral composition of soft cheeses made from unpasteurized goat milk has been investigated to a limited extent, and these studies have mainly been conducted to monitor contamination of dairy raw materials with toxic components. In such studies, attention has generally been paid only to the assortment of cheeses available on the retail market, whereas the dynamics of the mineral composition of soft cheeses made from raw milk during the ripening process have been practically unexplored. In many regions of the world, cheeses such as low-salt soft Feta cheese and soft Chevre cheese with noble white mold are widely consumed; however, they remain insufficiently studied in terms of their content of essential and toxic mineral components, which highlights the need for a comprehensive analysis of their safety (Herrera et al., 2025). On the other hand, the spread of gastronomic tourism requires authentication of refined cheeses made from unpasteurized goat milk.

Therefore, the aim of this study was to determine the effect of the ripening period on the mineral composition of brined Feta cheese and Chevre cheese ripened with the participation of noble white mold, produced from unpasteurized goat milk.

Materials and methods

Two types of soft craft cheeses made from unpasteurized goat milk were used in the experiment: five batches of brined Feta cheese, 5 kg each, and 15 wheels of Chevre cheese with noble white mold, each weighing 180–200 g. The cheeses were produced at the eco-farm “Zhuravka” in the Kyiv region (Ukraine) according to a previously described recipe (Davydovych et al., 2025b). The study was conducted from May 2022 to December 2024. The cheeses were produced from the milk of Anglo-Nubian goats kept under a barn–pasture management system. The goats’ diet consisted of concentrated, rough, and succulent feeds and met their requirements for nutrients and biologically active substances.

For mineral composition analysis, composite samples of Feta cheese were collected on the 7th day, and at the 18th and 30th months of storage, with 200 g taken from each of five containers. Composite samples of Chevre cheese were collected for analysis on the 3rd, 20th, and 40th days of ripening, with five cheese wheels sampled at each time point. Determination of mineral element content in the craft goat cheeses was carried out at the testing center of the State Scientific Research Institute for Laboratory Diagnostics and Veterinary and Sanitary Expertise, Kyiv, Ukraine, which is accredited by the National Accreditation Agency of Ukraine in accordance with the requirements of DSTU EN ISO/IEC 17025:201.

Sample preparation was carried out using a closed-vessel mineralizer, Microwave Laboratory Systems, Milestone (Bergamo, Italy, 2015). The content of calcium, phosphorus, sodium, potassium, magnesium, copper, zinc, iron, manganese, molybdenum, cobalt, lead, cadmium, chromium, aluminum, nickel, selenium, antimony, and arsenic in the samples was determined using an inductively coupled plasma optical emission spectrometer (ICP-OES) PlasmaQuant PQ 9000, Analytik Jena (Jena, Germany, 2015). The mercury content in cheese samples was determined using a Milestone DMA 80 mercury analyzer (Milan, Italy, 2018). Refrigeration and freezing units from Liebherr (Bühl, Switzerland, 2015) were used for sample storage.

The determination of mineral elements – calcium, phosphorus, sodium, potassium, magnesium, copper, zinc, iron, manganese, molybdenum, cobalt, lead, cadmium, mercury, chromium, aluminum, nickel, selenium, antimony, and arsenic – in the samples was performed in accordance with the working instruction PV.DNDILDVSE 7.2-1/1-21 (Determination of micro- and macroelements in food products, feeds, premixes, and vitamin supplements for animals and poultry by inductively coupled plasma optical emission spectrometry). The limits of detection were 5.0 µg/kg for calcium, 3.0 µg/kg for phosphorus, 1.0 µg/kg for sodium, 5.0 µg/kg for potassium, 5.0 µg/kg for magnesium, 2.0 µg/kg for copper, 5.0 µg/kg for zinc, 5.0 µg/kg for iron, 2.0 µg/kg for manganese, 0.1 µg/kg for molybdenum, 0.01 µg/kg for cobalt, 1.0 µg/kg for lead, 0.1 µg/kg for cadmium, 0.1 µg/kg for chromium, 2.0 µg/kg for aluminum, 1.0 µg/kg for nickel, 1.0 µg/kg for selenium, 1.0 µg/kg for antimony, and 1.0 µg/kg for arsenic. Analytical signals were processed automatically using the spectrometer software, applying calibration curves with background correction and, when necessary, correction for mutual interferences among the analyzed elements. To control fluctuations in ICP-OES analytical sensitivity, an internal standard solution containing indium at 20 µg/L (Roti®Star) was used.

The mercury content in the cheese samples was determined by a direct method in accordance with ISO 11212-2:1997(E), Part 2: Mercury content was determined by atomic absorption spectrometry. The limit of detection for mercury in samples was 0.01 µg/kg.

Statistical analysis of the obtained results was performed using one-way analysis of variance (ANOVA). The content of macro- and microelements and heavy metals in Feta and Chevre goat cheeses was compared within each cheese type depending on the ripening period. Data in the tables are presented as $x \pm SD$ (mean ± standard deviation). Differences between variants were considered statistically significant at $P < 0.05$ using Tukey’s test.

Results

Analysis of the macronutrient content in brined Feta cheese showed that the calcium content was practically independent of the ripening period, in contrast to phosphorus, sodium, potassium, and magnesium, the content of which decreased with increasing age. Thus, by the 30th month of ripening, the phosphorus content in this cheese had decreased by 11.0%, sodium by 23.5%, potassium by 13.5%, and magnesium by 36.5% compared with 7-day-old cheese (Table 1).

Table 1
Content of macro- and microelements in brined goat Feta cheese depending on the ripening period ($x \pm SD$, n = 5)

Parameter	Ripening period: 7 days	18 months	30 months
	Macroelements		
Ca, mg/kg	45.56 ± 3.14^a	40.85 ± 2.80^a	42.98 ± 4.25^a
P, mg/kg	45.01 ± 2.02^a	42.99 ± 2.41^{ab}	40.06 ± 1.02^b
Na, g/kg	4.17 ± 0.22^a	3.72 ± 0.58^{ab}	3.19 ± 0.26^b
K, mg/kg	17.11 ± 1.94^a	14.98 ± 1.11^b	14.79 ± 1.25^b
Mg, mg/kg	3.70 ± 0.30^a	2.86 ± 0.44^b	2.35 ± 0.21^b
	Microelements		
Zn, mg/kg	0.21 ± 0.03^a	0.17 ± 0.02^a	0.18 ± 0.01^a
Fe, µg/kg	25.22 ± 3.11^a	22.21 ± 1.48^a	22.63 ± 3.21^a
Mn, µg/kg	3.37 ± 0.58^a	2.94 ± 0.41^a	1.45 ± 0.28^b
Cu, µg/kg	2.36 ± 0.35^a	3.94 ± 0.34^b	4.82 ± 0.29^c
Mo, µg/kg	0.41 ± 0.09^a	0.23 ± 0.06^b	0.21 ± 0.04^b
Co, µg/kg	0.033 ± 0.003^a	0.047 ± 0.008^b	0.051 ± 0.010^b
Se, µg/kg	< 1.00	< 1.00	< 1.00

Note: different superscript letters indicate values that differ significantly within the same row ($P < 0.05$) based on Tukey’s test.

The content of most microelements in Feta cheese also changed during the ripening process. In particular, the content of zinc and iron in Feta cheese was independent of its age, whereas by the 30th month of ripening the content of manganese and molybdenum had decreased by 2.32 and 1.95 times, respectively, compared with cheese at the 7th day of ripening. In contrast, the content of copper and cobalt in Feta cheese increased with age, and by the 30th month of ripening exceeded that of young cheese by 2.04 and 1.54 times, respectively. The selenium content in Feta cheese remained below the detection limit throughout the entire ripening period. Thus, according to concentration, the macro- and microelements in Feta cheese can be arranged in the following order: Na > Ca = P > K > Mg > Zn > Fe > Mn = Cu > Mo > Co > Se. The calcium-to-phosphorus ratio in Feta cheese did not change during the ripening period and remained at 1:1.

Most heavy metals in Feta cheese – aluminum, nickel, chromium, cadmium, and mercury – remained at stable levels throughout the entire ripening period. Aluminum was present at the highest concentration, while arsenic and antimony were below the detection limit (Table 2). With regard to lead concentration, its content in long-ripened Feta cheese was 21.4% lower compared with 7-day-old cheese.

Table 2
Content (µg/kg) of heavy metals in brined goat Feta cheese depending on the ripening period (x ± SD, n = 5)

Parameter	Ripening period		
	7 days	18 months	30 months
Al	18.88 ± 0.41[a]	20.39 ± 1.39[a]	19.22 ± 2.11[a]
Pb	2.71 ± 0.21[a]	2.58 ± 0.27[ab]	2.13 ± 0.09[b]
Ni	2.25 ± 0.35[a]	2.31 ± 0.46[a]	2.29 ± 0.45[a]
Cr	1.09 ± 0.07[a]	0.97 ± 0.06[a]	0.93 ± 0.11[a]
Cd	0.22 ± 0.03[a]	0.18 ± 0.02[a]	0.17 ± 0.01[a]
Hg	0.018 ± 0.003[a]	0.021 ± 0.002[a]	0.023 ± 0.005[a]
As	< 1.00	< 1.00	< 1.00
Sb	< 1.00	< 1.00	< 1.00

Note: see Table 1.

The accumulation of heavy metals in Feta cheese can be arranged in the following order: Al > Pb = Ni > Cr > Cd > Hg > As = Sb.

The determination of macro- and microelements in Chevre cheese showed a direct dependence on the ripening period, with the exception of phosphorus, zinc, and molybdenum, whose content remained unchanged (Table 3). By the 40th day of ripening, the calcium content in Chevre cheese had increased by 1.57 times, sodium by 9.4%, potassium by 22.1%, and magnesium by 1.47 times compared with one-day-old cheese. The calcium-to-phosphorus ratio in Chevre cheese decreased with age, ranging from 1:2.24 to 1:1.56.

The content of iron in Chevre cheese increased by 2.00 times, manganese by 1.53 times, copper by 1.52 times, and cobalt by 1.45 times compared with one-day-old cheese. As in Feta cheese, the selenium content in Chevre cheese did not exceed the detection limit.

Table 3
Content of macro- and microelements in Chevre goat cheese depending on the ripening period (x ± SD, n = 5)

Parameter	Ripening period of cheese, days		
	1	20	40
	Macroelements		
Ca, mg/kg	12.73 ± 2.38[a]	19.80 ± 2.83[b]	19.93 ± 1.20[b]
P, mg/kg	28.54 ± 4.27[a]	30.83 ± 2.92[a]	32.08 ± 1.43[a]
Na, mg/kg	103.56 ± 5.19[a]	108.48 ± 8.40[ab]	113.26 ± 5.63[b]
K, mg/kg	20.31 ± 0.69[a]	22.85 ± 3.11[ab]	24.80 ± 1.12[b]
Mg, mg/kg	0.64 ± 0.06[a]	0.89 ± 0.13[b]	0.94 ± 0.11[b]
	Microelements		
Zn, mg/kg	0.05 ± 0.01[a]	0.06 ± 0.02[a]	0.04 ± 0.01[a]
Fe, µg/kg	15.08 ± 1.39[a]	22.61 ± 2.88[b]	30.24 ± 3.69[c]
Mn, µg/kg	2.12 ± 0.49[a]	2.69 ± 0.46[ab]	3.24 ± 0.23[b]
Cu, µg/kg	2.14 ± 0.33[a]	2.62 ± 0.22[a]	3.25 ± 0.40[b]
Mo, µg/kg	0.42 ± 0.08[a]	0.44 ± 0.07[a]	0.43 ± 0.11[a]
Co, µg/kg	0.029 ± 0.007[a]	0.031 ± 0.009[ab]	0.042 ± 0.004[b]
Se, µg/kg	< 1.00	< 1.00	< 1.00

Note: see Table 1.

According to concentration, the macro- and microelements in Chevre cheese can be arranged in the following order: Na > P > K > Ca > Mg > Zn > Fe > Mn = Cu > Mo > Co > Se.

Analysis of heavy metal content in Chevre cheese showed that the levels of lead, nickel, chromium, and cadmium did not undergo significant changes, unlike aluminum and mercury, whose levels increased by 25.5% and 38.5%, respectively, compared with one-day-old cheese (Table 4). The content of arsenic and antimony in Chevre cheese, similar to Feta cheese, remained below the detection limit throughout the entire ripening period. Thus, in Chevre cheese, the heavy metals can be ranked according to their content as follows: Al > Pb > Ni > Cr > Cd > Hg > As = Sb.

Table 4
Content (µg/kg) of heavy metals in Chevre goat cheese depending on the ripening period (x ± SD, n = 5)

Parameter	Ripening period of cheese, days		
	1	20	40
Al	21.80 ± 2.18[a]	23.73 ± 0.81[ab]	27.35 ± 1.63[b]
Pb	2.59 ± 0.54[a]	2.66 ± 0.12[a]	2.65 ± 0.09[a]
Ni	1.79 ± 0.34[a]	1.62 ± 0.23[a]	1.66 ± 0.17[a]
Cr	0.97 ± 0.18[a]	0.96 ± 0.08[a]	0.91 ± 0.12[a]
Cd	0.19 ± 0.06[a]	0.21 ± 0.02[a]	0.18 ± 0.01[a]
Hg	0.052 ± 0.004[a]	0.069 ± 0.009[b]	0.072 ± 0.006[b]
As	< 1.00	< 1.00	< 1.00
Sb	< 1.00	< 1.00	< 1.00

Note: see Table 1.

Discussion

Analysis of the mineral composition of Feta and Chevre cheeses showed that their baseline macro- and microelement contents were almost identical. This similarity is attributable to their production from the same milk source, using proper equipment and starter cultures of adequate quality and safety. However, during ripening, the dynamics of mineral composition in brined Feta cheese differed from that in Chevre cheese, which is associated with the specific characteristics of their respective ripening processes. Comparing the ripening dynamics of Feta cheese made from unpasteurized goat milk with similar cheeses is challenging due to a lack of such studies. Most analyses of mineral composition have been performed on commercially available cheeses, which do not allow assessment of changes during the ripening process (Capcarova et al., 2024).

A notable feature of white brined cheeses like Feta is their characteristic sour and salty taste due to the high concentration of table salt in the brine. Ripening Feta cheese in an 8–10% salt solution allows it to be preserved for up to one year, and it can contain up to 7% NaCl, which explains the highest sodium content among all macroelements throughout the storage period (Lisak Jakopović et al., 2023). The data obtained in this study regarding sodium content in Feta cheese made from unpasteurized goat milk are consistent with this observation.

Results from the analysis of the Wagashi Gassirè soft cheese sold in southern Benin show that it contained all major minerals, including sodium, magnesium, phosphorus, potassium, calcium, iron, manganese, copper, zinc, selenium, and molybdenum, although selenium was detected in only one of 15 samples. Sodium content in this cheese ranged from 35–81 mg/kg, magnesium 48–131 mg/kg, phosphorus 1601–2381 mg/kg, potassium 17–129 mg/kg, calcium 1526–3092 mg/kg, iron 4.3–5.4 mg/kg, manganese 0.3–0.7 mg/kg, copper 0.7 mg/kg, zinc 19–20 mg/kg, selenium 0.1 mg/kg, and molybdenum 0.020–0.022 mg/kg (Dossou et al., 2024). In comparison, Feta and Chevre cheeses in this study had lower content of calcium, phosphorus, zinc, iron, manganese, and selenium but higher contents of sodium, copper, and molybdenum. The low calcium and phosphorus concentrations in Feta and Chevre cheeses confirm that no calcium or phosphorus additives were included in their recipes to improve texture.

The accumulation of heavy metals in cheeses is related to production technology, milk quality, packaging of the finished product, and the chemical composition of feed and water for dairy animals (Mostafa et al., 2020). Heavy metals, including lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg), can enter dairy products through industrial emissions, contaminated equipment, or poor sanitary conditions during milk production (Ullah et al., 2022). Analyses of soft Egyptian cheeses (Domiati, Feta, Karish, Mish, and Rumi) showed significant differences in lead content. Mish cheese had the highest lead content, followed by Karish, Rumi, Domiati, and Feta, with average contents of 0.25, 0.14, 0.13, 0.07, and 0.02 mg/kg, respectively. Cadmium levels in Mish, Karish, Rumi, Domiati, and Feta ranged from 0.01–0.08 mg/kg. All cheeses contained arsenic, with Mish reaching 0.34 mg/kg, Karish, Rumi, and Domiati ranging 0.11–0.16 mg/kg, and Feta at 0.01 mg/kg. Mercury was not detected in Feta and Rumi cheeses but was found in most samples of Domiati, Karish, and Mish cheeses at 0.002–0.03 mg/kg. Zinc concentrations ranged from 1.55–3.35 mg/kg and copper from 0.04–0.09 mg/kg. These mineral concentrations did not exceed permissible levels for food products, indicating their safety for consumers (Dai et al., 2023).

The Feta and Chevre cheeses in this study had considerably lower content of these mineral components compared with the Egyptian cheeses, reflecting much lower contamination of feed, water, soil, and pasture grasses used for goat grazing, and consequently lower transfer of these elements into the milk (Zhao et al., 2025).

Milk is considered the primary source of mineral components in cheeses. Analysis of the mineral composition of milk used to produce several Georgian cheeses showed that zinc content ranged from 2.22–4.29 mg/L, iron from 0.5–6.15 mg/L, and copper from 0.12–0.59 mg/L. In Imeruli cheese, the zinc content was 75.86 mg/kg, the iron content was 69.09 mg/kg, and the copper content 1.261 mg/kg, whereas in Sulguni cheese, zinc reached 124.8 mg/kg, iron 101.1 mg/kg, and copper 2.46 mg/kg. In raw cow's milk, chromium content ranged from 0.001–0.004 mg/L, manganese from 0.023–0.079 mg/L, cobalt from 0.001–0.007 mg/L, nickel from 0.001–0.017 mg/L, selenium from 0.004–0.042 mg/L, and molybdenum from 0.004–0.047 mg/L. Imeruli cheese made from this milk contained 0.035 mg/kg chromium, 0.886 mg/kg manganese, 0.013 mg/kg cobalt, 0.011 mg/kg nickel, 1.003 mg/kg selenium, and 0.289 mg/kg molybdenum, while Sulguni cheese differed significantly in microelement content, with chromium reaching 0.079 mg/kg, manganese 2.35 mg/kg, cobalt 0.03 mg/kg, nickel 0.026 mg/kg, selenium 3.06 mg/kg, and molybdenum 0.401 mg/kg (Al Sidawi et al., 2021).

Another study conducted by Egyptian researchers showed that the average mercury concentrations in raw milk, powdered milk, fresh cheese, and processed cheese were 0.001 mg/kg, 0.02 mg/kg, 0.04 mg/kg, and 0.002 mg/kg, respectively. The content of other heavy metals differed in raw materials and finished cheeses: arsenic ranged from 0.01–0.1 mg/kg, lead from 0.1–0.3 mg/kg, and cadmium from 0.06–0.1 mg/kg (Elafify et al., 2023). These studies indicate that the technology and recipe of cheeses made from the same milk significantly influence the ability of the cheese matrix to retain and bind mineral components.

Additionally, a key factor in cheese ripening is the autochthonous microflora, which determines the direction and intensity of the ripening process, the synthesis of organic acids (Silva et al., 2023), and the participation of mineral elements as enzyme cofactors (Sadvari et al., 2024a; Davydovych et al., 2025a). These findings are consistent with the results of mineral composition studies in Feta and Chevre cheeses during ripening.

The relationship between mineral content in milk, cheese, and whey is also supported by studies analyzing 60 raw milk samples, 84 cheese samples, 84 whey samples, 12 Oaxaca cheeses, and 12 Ranchero cheeses (Castro-González et al., 2018). Arsenic concentrations in raw milk, fresh cheese, whey, and the two cheese types were 0.12 mg/kg, 0.07 mg/kg, 0.52 mg/kg, 0.17 mg/kg (Oaxaca), and 0.16 mg/kg (Ranchero), respectively, while lead content was 0.03 mg/kg, 0.02 mg/kg, 0.07 mg/kg, 0.05 mg/kg (Oaxaca), and 0.11 mg/kg (Ranchero). Lead levels exceeded the regulatory limit, particularly in Ranchero cheese (Souto et al., 2025).

Analysis of sheep dairy products showed that the mineral composition of milk, cheese, and whey differed, with the following decreasing order: Zn > Fe > Sr > Al > As > Ba > Se > Cu > Ni > Sb > Mn = Li > Pb > Mo > Cr = Co in milk; Fe > Zn > As > Se > Sr = Ni > Al > Cu > Cr = Li > Pb > Mn = Co > Ba > Sb > Mo in whey; and Zn > Fe > Sr > Al > Ba > As > Ni > Se > Mn > Cu > Sb > Pb > Li > Mo > Cr > Co in cheese (Almášiová et al., 2024). This clearly indicates that a significant portion of mineral elements exists in dissolved form and transfers to the whey during cheese production. This may explain the reduction of phosphorus, sodium, potassium, magnesium, manganese, and molybdenum observed during the ripening of brined Feta cheese in our study.

It is believed that pH affects salt absorption and diffusion, enzyme activity during ripening, growth of cheese microflora, and calcium distribution between micellar and whey phases, all of which determine the chemical composition (Bansal & Mishra, 2020). Salt absorption rate increases as pH decreases for brined cheeses. Mineral content in cheese largely depends on pH during whey drainage. Loss of calcium and phosphate from casein micelles affects micelle integrity, which in turn significantly influences cheese structure and texture (Bansal & Veena, 2024).

However, in our study, we did not observe an increase in sodium content in brined Feta cheese; rather, a slight decrease occurred alongside minimal phosphorus loss. Another study reported no significant changes in Ca, Mg, K, and Na concentrations during 180 days of ripening in brined cheeses (Massouras et al., 2023). Such differences in the dynamics of mineral composition among brined cheeses may be related to the type of table salt used for salting (Bae et al., 2020) and the origin of rennet used for milk coagulation (Ben Amira et al., 2021).

Considering the ripening process of soft Chevre cheese, a positive trend in the majority of mineral components is observed as the ripening period increases. This is associated with moisture loss and an increase in the content of dry matter, which in turn raises the amount of crude ash during ripening in cheese heads (Sadvari et al., 2024b; Davydovych et al., 2025c). In contrast, Feta cheese does not exhibit this phenomenon because it ripens in brine, and the ripening period does not affect its dry matter content (Davydovych et al., 2025b).

An important safety criterion is the accumulation of toxic elements in cheese, particularly heavy metals (Abdelmontaleb et al., 2025). The content of heavy metals in cheese is influenced not only by cheesemaking processes but also by other factors. Heavy metals can enter milk and cheese from multiple sources, including processing equipment, packaging, and handling (Altınsoy et al., 2025). Nickel contamination mainly occurs through contact with metallic utensils and equipment used in milk production and cheese processing. The primary route of heavy metal entry into cheeses is through the consumption of contaminated feed and water by dairy animals (Su et al., 2021).

Other studies have shown that vehicle emissions can increase environmental concentrations of Cd, Pb, and Cu, thus forming a significant source of Pb in animal milk, especially on farms located near major roads (Oliveira Filho et al., 2023). Despite the eco-farm producing Feta and Chevre cheeses being in a relatively developed agricultural region, no heavy metal contamination was observed in the cheeses.

Regional factors also influence heavy metal accumulation in cheese depending on meteorological and seasonal conditions (Mara et al., 2024). Analysis of 79 cheese samples from small farms in Croatia showed that Cd, Cr, Mn, Ni, and Pb levels ranged as follows: <0.005–0.012 mg/kg, <0.02–0.84 mg/kg, 0.031–1.128 mg/kg, <0.03–0.67 mg/kg, and <0.01–0.12 mg/kg, respectively. All samples complied with EU regulations and did not pose a direct risk to consumer health (Krivohlavek et al., 2024).

Based on these data, the levels of both essential and toxic minerals in Feta and Chevre cheeses can also serve as indicators of regional authenticity and reflect the ecological state of the surrounding environment, which aligns with other studies (Almeida et al., 2025). Although no official tolerable daily intake (TDI) exists for some heavy metals, EFSA provides reference values for potential human risk (Milanković et al., 2024). For example, the recommended limits are: cadmium – 1.0 µg/kg body weight/day, chromium – 0.3 µg/kg bw/day, nickel – 13 µg/kg bw/day (Schrenk et al., 2020), and lead – 3.6 µg/kg bw/day. The EFSA also specifies acceptable daily intake for Al, Ni, Co, Cd, and Hg as 286, 13, 8.6, 1, and 0.57 µg/kg bw/day, respectively.

Considering that the cheeses in our study had heavy metal contents well below these thresholds, they can be considered safe for consumers (Wong et al., 2022). Calculations of heavy metal intake from consuming 100 g of Feta or Chevre cheese by a 70 kg individual show the following exposure per kg body weight/day: aluminum – 0.03 µg, lead – 0.004 µg, nickel – 0.003 µg, cadmium – 0.0002 µg, and mercury – 0.00003 µg, which is several orders of magnitude below the established safe limits.

Conclusions

During the ripening of brined Feta cheese up to 30 months, no changes were observed in the content of calcium, zinc, and iron. However, decreases were noted in phosphorus (–11.0%), sodium (–23.5%), potassium (–13.5%), magnesium (–36.5%), lead (–21.4%), manganese (2.32-fold), and molybdenum (1.95-fold). Copper and cobalt content increased 2.04- and 1.54-fold, respectively, while selenium, arsenic, and antimony remained below detection limits. The essential mineral elements in Feta were arranged in the following order throughout the ripening period: Na > Ca = P > K > Mg > Zn > Fe > Mn = Cu > Mo > Co > Se. Accumulation of heavy metals in Feta, including aluminum, nickel, chromium, cadmium, and mercury, was independent of ripening time and remained below the permissible limits. The heavy metal content in Feta followed this order: Al > Pb = Ni > Cr > Cd > Hg > As = Sb.

In contrast, most mineral components in Chevre cheese showed a direct dependence on the ripening period, except for phosphorus, zinc, and molybdenum, which remained stable. By the 40th day of ripening, calcium had increased 1.57-fold, sodium by 9.4%, potassium by 22.1%, magnesium by 1.47-fold, iron by 2.00-fold, manganese by 1.53-fold, copper by 1.52-fold, and cobalt by 1.45-fold. Essential minerals in Chevre were arranged in the following order: Na > P > K > Ca > Mg > Zn > Fe > Mn = Cu > Mo > Co > Se. The content of lead, nickel, chromium, and cadmium remained unchanged, while aluminum and mercury increased by 25.5% and 38.5%, respectively. Selenium, arsenic, and antimony were below detection limits. Heavy metals in Chevre followed this order: Al > Pb > Ni > Cr > Cd > Hg > As = Sb.

These results highlight the unique mineral composition of artisanal soft Feta and Chevre cheeses made from raw goat milk, confirming their biological value as sources of essential elements and their safety regarding heavy metal content. Consequently, the mineral profile of artisanal goat cheeses can serve as a criterion for regional authenticity and environmental quality.

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

References

Abd Elnabi, M. K., Elkaliny, N. E., Elyazied, M. M., Azab, S. H., Elkhalifa, S. A., Elmasry, S., Mouhamed, M. S., Shalamesh, E. M., Alhorieny, N. A., Abd Elaty, A. E., Elgendy, I. M., Etman, A. E., Saad, K. E., Tsigkou, K., Ali, S. S., Kornaros, M., & Mahmoud, Y. A.-G. (2023). Toxicity of heavy metals and recent advances in their removal: A review. Toxics, 11(7), 580.

Abdelmontaleb, H. S., Abdelmeged, D. A., Hamdy, S. M., & Ebid, W. M. A. (2025). Trace metal contamination and health risk assessment in traditional Egyptian soft cheeses: A food safety perspective. Food Safety and Health, 3(4), 693–712.

Al Sidawi, R., Ghambashidze, G., Urushadze, T., & Ploeger, A. (2021). Heavy metal levels in milk and cheese produced in the Kvemo Kartli Region, Georgia. Foods, 10(9), 2234.

Almášiová, S., Toman, R., Pšenková, M., Tančin, V., & Jančo, I. (2024). Toxic elements in sheep milk, whey, and cheese from the environmentally burdened area in Eastern Slovakia and health risk assessment with different scenarios of their consumption. Toxics, 12(7), 467.

Almeida, A. C. O., Rodrigues, P. A., Costa, M. P. D., & Conte-Junior, C. A. (2025). Risk assessment of toxic and potentially toxic metals in raw goat milk: A systematic review of global data and environmental factors. Comprehensive Reviews in Food Science and Food Safety, 24(5), e70268.

Altınsoy, C., Taban, G., Tajdar-Oranj, B., Sadighara, P., & Basaran, B. (2025). Occurrence of potentially toxic metals in Turkish cheese with dietary intake and health risk assessment. Scientific Reports, 15, 33416.

Bae, H. C., Nam, J. H., Renchinkhand, G., Choi, S.-H., & Nam, M. S. (2020). Physicochemical changes during 4 weeks ripening of Camembert cheeses salted with four types of salts. Applied Biological Chemistry, 63, 66.

Bansal, V., & Mishra, S. K. (2020). Reduced-sodium cheeses: Implications of reducing sodium chloride on cheese quality and safety. Comprehensive Reviews in Food Science and Food Safety, 19(2), 733–758.

Bansal, V., & Veena, N. (2024). Understanding the role of pH in cheese manufacturing: General aspects of cheese quality and safety. Journal of Food Science and Technology, 61(1), 16–26.

Basaran, B. (2025). Occurrence of potentially toxic metals detected in milk and dairy products in Türkiye: An assessment in terms of human exposure and health risks. Foods, 14(15), 2561.

Ben Amira, A., Arias, A. A., Fickers, P., Hassouna, M., & Attia, H. (2021). Effect of brine concentration on physico-chemical characteristics, texture, rheological properties and proteolysis level of cheeses produced by an optimized wild cardoon rennet. Journal of Food Science and Technology, 58, 1331–1340.

Capcarova, M., Frigenti, M., Arvay, J., Janco, I., Harangozo, L., Bandlerova, A., Sartoni, M., Guidi, A., Stawarz, R., Formicki, G., Argente, M. J., & Massanyi, P. (2024). Levels of essential and trace elements in Mozzarella available on the Slovak market with the estimation of consumer exposure. Biological Trace Element Research, 202(5), 2357–2366.

Carmona, A., Roudeau, S., & Ortega, R. (2021). Molecular mechanisms of environmental metal neurotoxicity: A focus on the interactions of metals with synapse structure and function. Toxics, 9(9), 198.

Castro-González, N. P., Calderón-Sánchez, F., Castro de Jesús, J., Moreno-Rojas, R., Tamariz-Flores, J. V., Pérez-Sato, M., & Soní-Guillermo, E. (2018). Heavy metals in cow's milk and cheese produced in areas irrigated with waste water in Puebla, Mexico. Food Additives and Contaminants, Part B, Surveillance, 11(1), 33–36.

Chwastowska-Siwiecka, I., Kaca, A., & Miciński, J. (2025a). A comparison of the physicochemical properties and sensory attributes of Ricotta cheeses purchased from retail outlets in Poland. Foods, 14(8), 1413.

Chwastowska-Siwiecka, I., Sikorski, S., Paszczyk, B., & Miciński, J. (2025b). The effect of packaging method and storage time on the physicochemical properties and sensory attributes of goat cheese. Applied Sciences, 15(8), 4458.

Dai, Y.-J., Alsayeqh, A. F., Ali, E. W. E. E., Abdelaziz, A. S., Khalifa, H. A., Mohamed, A. S. M., & Alnakip, M. E. (2023). Heavy metals content in cheese: A study of their dietary intake and health risk assessment. Slovenian Veterinary Research, 60(S25), 397–404.

Davydovych, V., Shevchenko, L., Brovenko, T., Nesterenko, N., Altanova, A., Umanets, R., Rudyk, Y., & Kovalenko, N. (2025a). Microbiological changes in craft hard cheeses from raw goat milk during ripening with the use of mites *Acarus siro*. Scifood, 19(1), 176–191.

Davydovych, V., Shevchenko, L., Shulyak, S., Nedashkivskyi, V., Semenko, O., Tyshchenko, L., Nikolaienko, M., Altanova, A., & Marchyshyna, Y. (2025b). Influence of aging time on the physicochemical characteristics of craft soft cheeses made from unpasteurized goat's milk. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 73(4–5), 243–252.

Davydovych, V., Shevchenko, L., Shulyak, S., Slobodyanyuk, N., Nedashkivskyi, V., Tomchuk, V. Slyva, Y., Nesterenko, N., Sydorenko, O., & Ivaniuta, A. (2025c). The influence of ripening time on the physicochemical characteristics of craft hard goat cheeses. Online Journal of Animal and Feed Research, 15(5), 264–273.

de Oliveira Filho, E. F., Miranda, M., Ferreiro, T., Herrero-Latorre, C., Castro Soares, P., & López-Alonso, M. (2022). Concentrations of essential trace and toxic elements associated with production and manufacturing processes in Galician cheese. Molecules, 27(15), 4938.

Dossou, A. W., Seko Orou, B. M. T., Komagbe, G., Sessou, P., Youssao, A. K. I., Farougou, S., Hounhouigan, J. D., Mahillon, J., Mongbo, R., Poncelet, M., Boutaleb, S., Gobert, S., Madode, Y. E., Azokpota, P., Clinquart, A., Scippo, M.-L., & Douny, C. (2024). Nutritional composition and chemical safety of Wagashi Gassirè cheese sold in the southern Benin markets. Dairy, 5(2), 271–286.

Elafify, M., El-Tahan, M., Sallam, K. I., Hassanien, R., & El-Dien, M. N. (2023). Heavy metal residues in milk and some dairy products with insight into their health risk assessment and the role of *Lactobacillus rhamnosus* in reducing the lead and cadmium load in cheese. Food Chemistry Advances, 2, 100261.

Grassi, G., & Perna, A. M. (2025). Effect of heavy metal contamination on Caciotta cheese made from buffalo milk. Applied Sciences, 15(22), 11881.

Herrera, T., Pérez-Baltar, A., Ortiz, L., Letón, P., & Miguel, E. (2025). Physicochemical, microbiological and sensory characteristics of Cabra del Guadarrama cheese and other cheeses from different Spanish autochthonous goat breeds. Foods, 14(13), 2368.

Iakubchak, O., Martynenko, O., Taran, T., Pylypchuk, O., Naumenko, T., Tverezovska, N., Menchynska, A., Stetsyuk, I. (2024). Analysis of the hard rennet cheese microbiota at different stages of the technological process. Potravinarstvo Slovak Journal of Food Sciences, 18, 899–918.

Kaczyński, Ł. K. (2024). Analysis of water activity and gloss of stored goat cheeses according to consumer preferences and tastes. Foods, 13(23), 3789.

Krivohlavek, A., Palac Bešlić, I., Jurak, G., Gavran, M., Mandić Andačić, I., Ivešić, M., Šikić, S., Vitale, K., Štefančić, M., Žuntar, I., Oštarić, F., & Mikulec, N. (2024). Heavy metals and pesticide residues in small farm cheese production in Croatia–Challenge between quality and quantity. Sustainability, 16(4), 1356.

Lisak Jakopović, K., Barukčić Jurina, I., Marušić Radovčić, N., Božanić, R., & Jurinjak Tušek, A. (2023). Reduced sodium in white brined cheese production: Artificial neural network modeling for the prediction of specific properties of brine and cheese during storage. Fermentation, 9(9), 783.
Mara, A., Caredda, M., Addis, M., Sanna, F., Deroma, M., Georgiou, C. A., Langasco, I., Pilo, M. I., Spano, N., & Sanna, G. (2024). Elemental fingerprinting of Pecorino Romano and Pecorino Sardo PDO: Characterization, authentication and nutritional value. Molecules, 29(4), 869.
Martínez-Vérez, A., & Lucini Baquero, C. (2025). Promoting the sale of locally sourced products: Km 0 as a sustainable model for local agriculture and CO_2 reduction. Agriculture, 15(15), 1568.
Maruszewska, A., Żwierełło, W., Skórka-Majewicz, M., Baranowska-Bosiacka, I., Wszołek, A., Janda, K., Kulis, D., Kapczuk, P., Chlubek, D., & Gutowska, I. (2021). Modified baby milk-bioelements composition and toxic elements contamination. Molecules, 26(14), 4184.
Massouras, T., Zoidou, E., Baradaki, Z., & Karela, M. (2023). Physicochemical, microbiological and sensory characteristics of white brined cheese ripened and preserved in large-capacity stainless steel tanks. Foods, 12(12), 2332.
Milanković, V., Tasić, T., Leskovac, A., Petrović, S., Mitić, M., Lazarević-Pašti, T., Novković, M., & Potkonjak, N. (2024). Metals on the menu-analyzing the presence, importance, and consequences. Foods, 13(12), 1890.
Moon, N., Heo, S. J., Park, S., Im, H., & Kim, J. H. (2025). The association between maternal dietary intake and the risk of heavy metals in human breast milk in Korea. Toxics, 13(5), 381.
Mostafa, M. A., Halawa, S. M., Abdel Hamid, R. M., & Abdel-Hameid, N. F. (2020). Contamination and health risks of certain heavy metals and trace elements in milk and milk products consumed in province of Monufia, Egypt. Annals of Agricultural Science, Moshtohor, 58(3), 673–682.
Motas, M., Jiménez, S., Oliva, J., Cámara, M. Á., & Pérez-Cárceles, M. D. (2021). Heavy metals and trace elements in human breast milk from industrial/mining and agricultural zones of southeastern Spain. International Journal of Environmental Research and Public Health, 18(17), 9289.
Oliveira Filho, E. F. d., López-Alonso, M., Vieira Marcolino, G., Castro Soares, P., Herrero-Latorre, C., Lopes de Mendonça, C., de Azevedo Costa, N., & Miranda, M. (2023). Factors affecting toxic and essential trace element concentrations in cow's milk produced in the state of Pernambuco, Brazil. Animals, 13(15), 2465.
Sadvari, V. Y., Shevchenko, L. V., Slobodyanyuk, N. M., Furman, S. V., Lisohurska, D. V., & Lisohurska, O. V. (2024a). Chemical composition of craft hard cheeses from raw goat milk during the ripening process. Regulatory Mechanisms in Biosystems, 15(4), 666–673.
Sadvari, V. Y., Shevchenko, L. V., Slobodyanyuk, N. M., Tupitska, O. M., Gruntkovskyi, M. S., & Furman, S. V. (2024b). Microbiome of artisanal hard cheeses from raw goat's milk during ripening. Regulatory Mechanisms in Biosystems, 15(3), 483–489.
Santarcangelo, C., Baldi, A., Ciampaglia, R., Dacrema, M., Di Minno, A., Pizzamiglio, V., Tenore, G. C., & Daglia, M. (2022). Long-aged Parmigiano Reggiano PDO: Trace element determination targeted to health. Foods, 11(2), 172.
Savchenko, O., Grek, O., Skuibida, V., Onopriichuk, O., Pshenychna, T. (2024). Optimisation of parameters for obtaining milk-plant concentrates. Animal Science and Food Technology, 16(1), 126–140.
Schrenk, D., Bignami, M., Bodin, L., Chipman, J. K., del Mazo, J., Grasl-Kraupp, B., Hogstrand, C., Hoogenboom, L., Leblanc, J., Nebbia, C. S., Nielsen, E., Ntzani, E., Petersen, A., Sand, S., Vleminckx, C., Wallace, H., Alexander, J., Benford, D., & Younes, M. (2020). Update of the risk assessment of nickel in food and drinking water. EFSA Journal, 18(6), e06268.
Shkembi, B., & Huppertz, T. (2021). Calcium absorption from food products: Food matrix effects. Nutrients, 14(1), 180.
Silva, L. F., Sunakozawa, T. N., Monteiro, D. A., Casella, T., Conti, A. C., Todorov, S. D., & Barretto Penna, A. L. (2023). Potential of cheese-associated lactic acid bacteria to metabolize citrate and produce organic acids and acetoin. Metabolites, 13(11), 1134.
Souto, M. R. S., Pimenta, A. M., Catarino, R. I. L., Leal, M. F. C., & Simões, E. T. R. (2025). Heavy metals in milk and dairy products: safety and analysis. Pollutants, 5(3), 29.
Su, C., Gao, Y., Qu, X., Zhou, X., Yang, X., Huang, S., Han, L., Zheng, N., & Wang, J. (2021). The occurrence, pathways, and risk assessment of heavy metals in raw milk from industrial areas in China. Toxics, 9(12), 320.
Thodis, P., Kosma, I. S., Nesseris, K., Badeka, A. V., & Kontominas, M. G. (2023). Evaluation of a new bulk packaging container for the ripening of Feta cheese. Foods, 12(11), 2176.
Ullah, N., Ur Rehman, M., Ahmad, B., Ali, I., Younas, M., Aslam, M. S., Rahman, A. U., Taheri, E., Fatehizadeh, A., & Rezakazemi, M. (2022). Assessment of heavy metals accumulation in agricultural soil, vegetables and associated health risks. PLoS One, 17(6), e0267719.
Wong, C., Roberts, S. M., & Saab, I. N. (2022). Review of regulatory reference values and background levels for heavy metals in the human diet. Regulatory Toxicology and Pharmacology, 130, 105122.
Zhao, Y., Ren, Y., & Wang, F. (2025). Distribution, sources, and risks of heavy metal contamination in farmland soils surrounding typical industrial areas of South Shanxi Province, China. Toxics, 13(11), 984.