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Assessment of Essential and Toxic Element Intake from Sheep Dairy Products with Different Consumption Scenarios in an Organic Sheep Farm

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Abstract

Monitoring essential and toxic elements in milk and dairy products is important for protecting consumer health. Regular monitoring of these elements helps ensure the quality, safety, and nutritional value of dairy products. This study aimed to determine the concentrations of 8 elements (Ca, Mg, K, Zn, Se, Ni, Sr, and As) in sheep milk, sheep cheese, and traditional Slovak sheep products, including *žinčica* and *bryndza*. A total of 48 samples were collected from an ecologically managed sheep farm located in an undisturbed area of Slovakia. The highest concentrations were recorded for essential elements, particularly in solid sheep milk products such as sheep cheese and *bryndza*. Significant differences ($p < 0.05$) in element concentrations were observed among the analyzed products. Dietary intake assessment was based on 2023 Slovak dairy consumption data and on recommended consumption levels for selected dairy products. Risk assessment of toxic element intake revealed elevated exposure levels in relation to toxicological limits. Ni intake reached 50.77% of the tolerable daily intake (TDI) in *bryndza* and 40.00% in fresh sheep cheese. For As, the preliminary tolerable weekly intake (PTWI) reached 48.00% for *žinčica* and 30.60% for *bryndza*. These findings suggest that long-term excessive consumption of certain sheep products may negatively affect human health. Although sheep milk products are consumed less frequently than cow milk products, their high nutritional value and the detected levels of toxic elements highlight the need for continuous monitoring of element transfer into the food chain and its potential effects on human health.

Keywords: dairy products; dietary risk assessment; essential elements; food safety; toxic elements

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INTRODUCTION

Milk is an important part of human nutrition because of its high nutritional value, availability, and consumer preference (Saribal, 2020; Pompilio et al., 2021). It provides high-quality proteins, essential fatty acids, micronutrients, and bioactive compounds beneficial for physiological functions (Licata et al., 2004; Kapila et al., 2013; Boudebbouz et al., 2022). Milk is a key source of Ca, Mg, and K, especially important for children's growth and development (Oana et al., 2016; Zhou et al., 2017).

Regular consumption has been associated with improved bone health, muscle preservation in older adults, better sleep quality, and reduced risk of cardiovascular diseases, metabolic syndrome, obesity, type 2 diabetes, and certain cancers (Thorning et al., 2016; Aune et al., 2017; Guo et al., 2017; Srbely et al., 2019; Komada

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et al., 2020). Fermented dairy products such as yogurt and cheese may further reduce the risk of type 2 diabetes (Thorning et al., 2016). Dairy products are also valuable in sports nutrition (Beigrezaei et al., 2022). Despite these benefits, milk avoidance is relatively common due to allergies or lactose intolerance (Caffarelli et al., 2010). However, lactose-free dairy products are generally recommended instead of complete exclusion (Harvey et al., 2018). The World Health Organization (WHO, 2006) recommends 2 to 3 servings of dairy products daily for children under 11 years of age.

In recent years, milk from non-bovine species such as goats, sheep, camels, and donkeys has attracted increasing attention because of its nutritional value and health benefits (Ciliberti et al., 2022). Sheep and goat dairy products are becoming more common on local markets, especially from small-scale farms (Kováčová et al., 2021). Compared with cow's milk, sheep's milk contains higher levels of monounsaturated and polyunsaturated fatty acids and more minerals, such as Ca, P, Mg, Zn, and Mn (Park et al., 2007; Balthazar et al., 2017). However, milk composition is influenced by factors such as breed, lactation stage, feeding system, season, and processing methods (García et al., 2006; Wang et al., 2014; Bilandžić et al., 2015; Bakircioglu et al., 2018). Essential minerals support important physiological functions, while both deficiency and excess may contribute to health disorders, such as hypertension, osteoporosis, and cardiovascular diseases (Bilandžić et al., 2015; Bakircioglu et al., 2018).

Although milk and dairy products are generally considered safe and naturally low in heavy metals (Licata et al., 2012), contamination can occur through environmental pollution, animal feed, processing equipment, or packaging materials (Khan et al., 2014; Bansal, 2020; Boudebbouz et al., 2022). Processed milk may contain higher concentrations of heavy metals than raw milk (Koyuncu and Alwazeer, 2019). Long-term exposure to toxic elements, such as Cd and Pb, may lead to metabolic, neurological, developmental, and cardiovascular disorders (Girma et al., 2014; Jaishankar et al., 2014), with children being especially vulnerable (ENHIS, 2007; Rahimi, 2013). Cd and Pb are among the most problematic contaminants in industrialized regions (Zhou et al., 2017; Totan and Filazi, 2020). In contrast, Zn, Cr, Cu, and Fe are essential elements, although excessive intake may also be harmful (Boudebbouz et al., 2022). Therefore, monitoring toxic elements in milk is important for food safety and product quality, and the European Union has established maximum allowable levels of heavy metals in milk (EC No. 1881/2006; González-Montaña et al., 2012).

Despite the increasing interest in sheep dairy products and the growing concern about toxic element contamination, limited information is available on the simultaneous assessment of essential and toxic elements in sheep dairy products originating from organic farms. Moreover, data evaluating potential dietary exposure and health risks under different consumption scenarios, particularly for vulnerable population groups such as children, remain insufficient. Therefore, this study aimed to determine the concentrations of essential and toxic elements in sheep dairy products from an organic sheep farm and to assess dietary intake and potential health risks associated with their consumption under different intake scenarios.

MATERIALS AND METHOD

Sample collection

Forty-eight samples of sheep dairy products, including sheep milk, *žinčica* (fermented milk drink), *bryndza* (fermented sheep milk cheese), and fresh sheep milk cheese, were collected from an organic farm located in northern Slovakia (Central Europe) (Figure 1). This region is characterized by its undisturbed environment. Fresh sheep cheese and *bryndza* samples (200 g each), as well as sheep milk and *žinčica* samples (250 ml each), were collected twice monthly over 6 months. After collection, all samples were put in plastic containers and stored at -18 °C until analysis. A total of 8 chemical elements were analyzed in all dairy product samples, including 5 essential elements (Ca, Zn, Mg, K, and Se) and 3 toxic elements (Ni, Sr, and As).

Sample analysis

The elemental analysis was conducted using inductively coupled plasma–optical emission spectrometry (ICP-OES) equipped with an axial plasma configuration and an SPS-3 autosampler. Before measurement, the samples were mineralized using a high-performance microwave digestion system (Ethos UP, Milestone Srl, Sorisole, BG, Italy). The digestion process employed a mixture consisting of 5 ml of nitric acid (HNO_3, ≥ 69.0%, TraceSELECT®, Honeywell Fluka, Morris Plains, USA), 1 ml of hydrogen peroxide (H_2O_2, ≥ 30%, for trace analysis, Sigma Aldrich, Saint-Louis, Missouri,

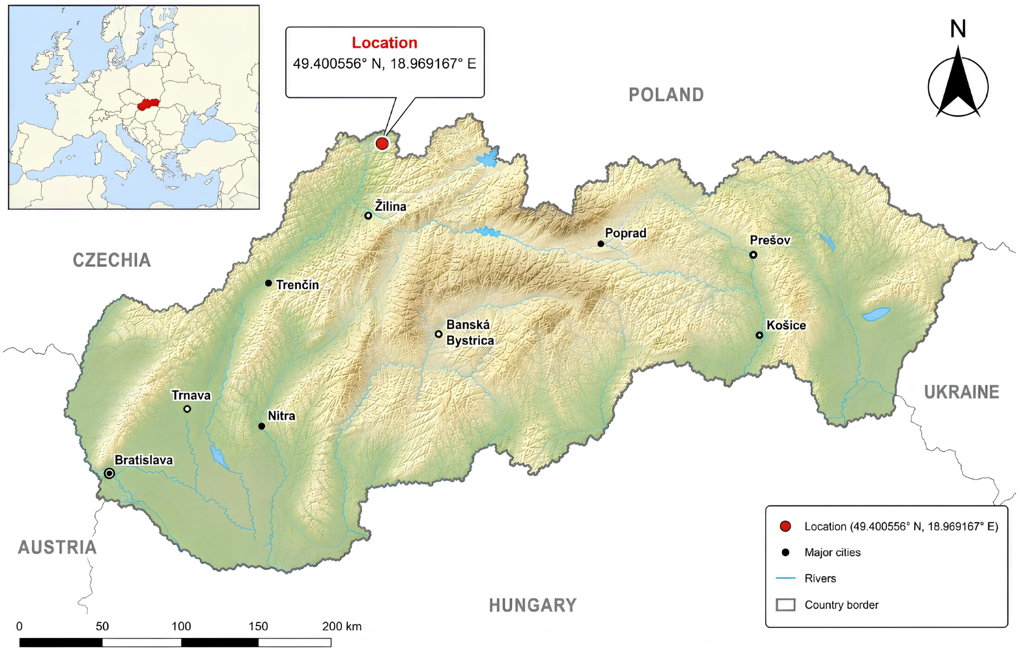

Figure 1. Farm location in the northern part of Slovakia with an undisturbed environment

USA), and 2 ml of ultrapure water (18.2 $M\Omega \cdot cm^{-1}$ at 25 °C, Synergy UV, Merck Millipore, France). The digestion procedure involved controlled heating and cooling stages.

Elemental analysis was then performed using an ICP-OES 720 spectrometer (Agilent Technologies Australia (M) Pty Ltd.) under axial plasma configuration, with automated sampling by the SPS-3 autosampler (Agilent Technologies, Switzerland). The detection limits for the trace elements (in $\mu g\ kg^{-1}$) were as follows: As 1.5; Ca 0.01; K 0.3; Mg 0.01; Ni 0.3; Se 2.0; Sr 0.01; and Zn 0.2. The wavelengths (nm) used for elemental detection were 188.980 for As, 315.887 for Ca, 766.491 for K, 670.783 for Li, 383.829 for Mg, 231.604 for Ni, 196.026 for Se, 407.771 for Sr, and 206.200 for Zn. The reliability and accuracy of the analytical procedure were verified using certified reference material. Detailed instrumental operating parameters are provided in Table 1. The same laboratory equipment, analytical methods, and quality assurance procedures were applied as described in a previous study by Toman et al. (2021).

Estimation of essential element intake through consumption of sheep milk products

The concentrations of essential elements found in sheep dairy products were compared with the recommended nutritional doses for the population of Slovakia (Kajaba et al., 2015). These comparisons were based on the age categories with the highest need for each specific element (Ca and K: breastfeeding women; Mg, Se, and Zn: men with physically demanding work). For each essential element, the contribution of sheep dairy product consumption to the recommended dietary intake was expressed as a percentage.

The percentage intake of individual elements was calculated using the measured element concentrations under 2 consumption scenarios: (1) the actual consumption of sheep dairy products in Slovakia in 2023, and (2) a recommended consumption level of sheep dairy products. In Scenario 1, the daily consumption of sheep dairy products was estimated at 0.02 kg of fresh sheep cheese, 0.01 kg of *bryndza*, 0.006 kg of sheep milk, and 0.04 kg of *žinčica*. In Scenario 2, the daily consumption levels were set at 50 g of fresh sheep cheese, 20 g of *bryndza*, 250 ml of sheep milk, and 250 ml of *žinčica*.

Table 1. The operating parameters for the determination of elements by ICP-OES

Parameter	Value
Radio frequency power (kW)	1.30
Plasma flow (l minute^{-1})	15.0
Auxiliary flow (l minute^{-1})	1.50
Nebulizer flow (l minute^{-1})	0.85
Replicated read time (seconds)	5.00
Instrument stabilization (seconds)	15
Sample uptake delay (seconds)	25
Pump rate [rpm]	15
Rinse time (seconds)	10

Risk assessment analysis

For toxic elements, the estimated daily intake (EDI) was calculated using Equation 1 based on the average concentrations detected in the dairy product samples.

$$\mathrm{EDI} = \frac{\mathrm{C_{metal}} \times \mathrm{W_{milk}}}{\mathrm{BW}} \qquad (1)$$

Where C_{metal} is the concentration of the element in the analyzed sample, W_{milk} is the daily milk consumption, and BW is the average body weight (70 kg).

According to the Statistical Office of Slovakia (2023), the average daily per capita consumption of sheep dairy products was 0.02 kg of fresh sheep cheese, 0.01 kg of soft cheese (*bryndza*), 0.006 kg of sheep milk, and 0.04 kg of fermented milk products.

From the determined values, the estimated weekly intake (EWI) for As was calculated from the EDI using Equation 2.

$$\mathrm{EWI} = \mathrm{EDI} \times 7_{\mathrm{(days)}} \qquad (2)$$

Subsequently, the percentage contribution of Al intake to the provisional tolerable weekly intake (PTWI) established by FAO JECFA (2011) was calculated using Equation 3.

$$\%\mathrm{PTWI} = \frac{\mathrm{EWI}}{\mathrm{PTWI}} \times 100 \qquad (3)$$

For Ni, for which the PTWI value is not determined, the proportion (%) of element intake relative to the tolerable daily intake (TDI) recommended by the WHO (2003) was calculated using Equation 4.

$$\%\mathrm{TDI} = \frac{\mathrm{EDI}}{\mathrm{TDI}} \times 100 \qquad (4)$$

Statistical analysis

Statistical analysis of the data was performed using Statistica Cz version 10 (TIBCO Software, Inc., Palo Alto, CA, USA). The obtained data were tested for normality using the Shapiro–Wilk test. Differences in concentrations of the analyzed chemical elements between farms were compared using ANOVA and Tukey's HSD test. All data were expressed as mean and standard deviation. A *p*-value < 0.05 was considered statistically significant.

RESULTS AND DISCUSSION

Table 2 shows the average concentrations of 8 monitored chemical elements in sheep dairy products from an organic farm in northern Slovakia. Detection, determination, and comparison of essential and toxic elements in milk and dairy products to determine their safety and suitability are of interest worldwide (Ribeiro Sant'Ana et al., 2021). Milk and dairy products are important sources of minerals. Consumption of dairy products is important, especially for preventing osteoporosis and supporting the proper development of bones and teeth. This study showed that sheep dairy products from the monitored farm may serve as good sources of elements, such as Ca, K, and Mg, given the concentrations found.

Significant differences ($p < 0.05$) in Ca concentrations were found among most of the sheep dairy products studied. In contrast, no statistically significant differences were observed between sheep milk and *žinčica* or between *bryndza* and fresh sheep cheese. The Ca concentration ranged from 469.08 to 5,407.39 mg kg^{-1} across the analyzed samples. Ca is one of the most important minerals for maintaining bone health and preventing conditions such as rickets and osteoporosis in the human population (Milikan, 2012). In Slovakia, the highest recommended daily Ca intake is for breastfeeding women, at 1,600 mg day^{-1} (Kajaba et al., 2015).

Table 3 shows that, under Scenario 1, which reflects the current average sheep milk consumption in Slovakia (0.006 kg day^{-1}), breastfeeding women would receive only 1.08% of their recommended daily Ca intake. Under Scenario 2, a daily intake of 250 ml of sheep milk would provide approximately 13.50% of the recommended daily Ca intake for lactating women. While this contribution is noteworthy, direct consumption of sheep milk is relatively uncommon in Slovakia, where it is predominantly used to produce traditional sheep dairy products. Among the products analyzed, *bryndza* and fresh sheep cheese contributed the most to meeting the daily Ca requirement of breastfeeding women (Table 3).

For K, statistically significant differences ($p < 0.05$) were observed among most of the sheep dairy products analyzed, except for *žinčica* and *bryndza*, for which no significant difference was detected. Compared with the concentrations determined in the present study, higher K concentrations were reported by Capcarova et al. (2020) in milk samples from Slovakia and the Czech Republic and by Astolfi et al. (2020) in milk samples from Italy. It is very important to monitor K concentration in the blood of lactating

Table 2. Concentrations of selected essential and toxic elements in sheep dairy products

Product	Elements	Ca	K	Mg	Zn	Se	Ni	Sr	As
Milk	Mean	864.25^{a}	579.43^{a}	89.91^{a}	2.54^{a}	0.18^{a}	0.05^{a}	0.33^{a}	0.19^{a}
	SD	166.57	37.08	12.03	0.52	0.16	0.04	0.13	0.15
	Min	489.89	517.34	66.75	1.21	0.01	0.00	0.07	0.01
	Max	1,099.91	630.04	107.69	3.31	0.54	0.14	0.48	0.55
Milk drink *žinčica*	Mean	469.08^{a}	926.36^{b}	93.38^{a}	0.19^{b}	0.16^{a}	0.04^{a}	0.04^{a}	0.18^{a}
	SD	53.38	71.84	10.01	0.12	0.12	0.03	0.03	0.13
	Min	374.90	829.33	75.81	0.08	0.05	0.01	0.01	0.02
	Max	532.80	1,027.57	106.19	0.39	0.49	0.11	0.10	0.48
*Bryndza**	Mean	5,363.23^{b}	851.18^{b}	303.72^{b}	18.97^{c}	0.67^{b}	0.23^{a}	3.07^{b}	0.23^{a}
	SD	1,039.51	144.42	51.10	4.06	0.38	0.46	0.60	0.20
	Min	3,467.37	592.84	222.83	12.71	0.06	0.00	2.01	0.10
	Max	6,547.28	1,082.71	385.30	24.22	1.30	1.41	3.91	0.53
Sheep cheese	Mean	5,407.39^{b}	692.86^{c}	329.68^{b}	18.44^{c}	0.51^{b}	0.37^{a}	3.34^{b}	0.21^{a}
	SD	550.68	143.43	55.72	2.42	0.31	0.53	0.38	0.17
	Min	4,538.34	490.67	247.97	15.48	0.13	0.02	2.81	0.01
	Max	6,253.84	1,016.74	410.57	22.67	1.09	1.53	3.90	0.64

Note: SD = Standard deviation; Min = Minimum concentrations; Max = Maximum concentrations; different superscripts in the column indicate statistical significance at the level $p < 0.05$; **bryndza* = Traditional Slovak type of sheep fermented cheese

dairy animals, as hypokalemia is a commonly observed electrolyte imbalance in critically ill animals and is associated with depletion of body K stores during significant metabolic acidosis of cows (Trefz et al., 2015). Since it is assumed that K is almost completely absorbed from milk into the human body, and these elements were significantly represented in the analyzed samples of milk and dairy products, it is assumed that the sheep whose milk and dairy products were analyzed did not have metabolic disorders, and this milk may be a significant source of these 2 elements for the population of Slovakia.

For the assessment of K intake, the recommended dietary allowance proposed by Strohm et al. (2017) was used, as K is not included in the Slovak dietary recommendation document. According to Strohm et al. (2017), lactating women have the highest K requirement, with a recommended intake of 4,400 mg day^{-1}, similar to the pattern observed for Ca. Among the analyzed sheep dairy products, the highest contributions to the recommended daily K intake were observed under Scenario 2. Consumption of 250 ml of sheep milk and 250 ml of *žinčica* would provide 3.29% and 5.26% of the recommended daily K intake, respectively (Table 3).

Significant differences ($p < 0.05$) in Mg concentrations were found among most of the sheep dairy products studied. In contrast, no statistically significant differences were observed between sheep milk and *žinčica* or between *bryndza* and fresh sheep cheese. The Mg concentrations ranged from 89.91 to 329.68 mg kg^{-1}, while K concentrations ranged from 579.43 to 926.36 mg kg^{-1} across the analyzed samples. Compared with the findings of Capcarova et al. (2020), who investigated the concentrations of essential and toxic elements in cottage cheese, the sheep dairy products analyzed in the present study, particularly the cheese samples, exhibited substantially higher concentrations of Ca, Mg, and K.

These differences may be attributed to biochemical processes during the cheese-making process, which can lead to the concentration of minerals in the final product. The reduction in water content during the various stages of cheese production is one of the main factors contributing to higher concentrations of trace elements in cheese compared with fresh dairy products that contain a greater proportion of water (Barone et al., 2018). For Mg, the highest recommended intake in Slovakia is for men engaged in physically demanding work, at 420 mg day^{-1}. Among the analyzed sheep dairy products, sheep milk and *žinčica* provided the highest contributions to the recommended daily Mg intake. Consumption of 250 ml of sheep milk and 250 ml of *žinčica* would supply 5.35% and 5.56% of the recommended daily intake, respectively (Table 3).

The remaining essential elements analyzed in this study were Zn and Se. Zn exhibited the highest concentrations, ranging from 0.19 to 18.97 mg kg^{-1} in the analyzed sheep dairy

Table 3. Percentage expression of essential element intake in relation to recommended nutritional doses in 2 different consumption scenarios

RND	Milk		*Žinčica*[a]		*Bryndza*[b]		Sheep cheese	
	S1	S2	S1	S2	S1	S2	S1	S2
Ca (1,600 mg)	1.08%	13.50%	1.17%	7.20%	6.70%	6.70%	3.38%	16.89%
Mg (420 mg)	0.13%	5.35%	0.09%	5.56%	1.47%	1.47%	0.78%	3.92%
Zn (16 mg)	0.09%	3.97%	0.05%	0.29%	2.37%	2.37%	1.15%	5.76%
Se (75 µg)	1.44%	60.00%	8.50%	53.33%	1.79%	1.79%	6.80%	34.00%
K (4,400 mg)	0.08%	3.29%	0.84%	5.26%	0.39%	0.39%	0.02%	0.79%

Note: RND = Recommended nutritional doses; [a]*žinčica* = Fermented milk drink; [b]*bryndza* = Traditional Slovak soft sheep cheese; S1 = consumption scenario 1; S2 = consumption scenario 2

products. No statistically significant differences in Zn concentrations were detected between the 2 cheese types. Higher Zn concentrations (3.7 to 4.8 mg kg^{-1}) in liquid sheep dairy products were reported by Bilandžić et al. (2021) in Croatia than those observed in the liquid sheep dairy products analyzed in the present study. In contrast, the Zn concentrations determined in the present study were higher than those reported by Capcarova et al. (2019), who found Zn concentrations ranging from 11.4 to 13.09 µg ml^{-1}. Zn is an essential trace element involved in a wide range of catalytic, structural, and biochemical functions (Willoughby and Bowen, 2014). Although Zn is beneficial for animal and human health and is generally regarded as relatively non-toxic at low to moderate doses, excessive intake may cause adverse health effects, including impaired immune function, anemia, and neutropenia (Fosmire, 1990).

The last essential element studied in sheep dairy products was Se. The concentration of Se in milk and, consequently, in dairy products varies according to geographical location. Se is present in soil primarily in inorganic salts, which are absorbed by plants and converted into organic forms. In this way, Se enters the food chain through soil properties (Schöne et al., 2013). As shown in Table 1, Se concentrations in these products were very low and ranged from 0.16 to 0.67 mg kg^{-1}. Statistically significant differences ($p < 0.05$) were recorded among all products except between sheep milk and *žinčica* and between *bryndza* and fresh sheep cheese. Significantly lower Se concentrations were determined in the present study than those reported by Rozenská et al. (2011). Similarly, in a previous study (Pšenková et al., 2022), which analyzed Se in sheep milk from a region adjacent to that studied in the present study, lower Se concentrations (0.4 mg kg^{-1}) were recorded compared with those observed in the current study.

Based on the assessment of Zn and Se intake through the consumption of the monitored sheep dairy products, these products may contribute significantly to meeting the daily Se requirement. As shown in Table 3, under Scenario 2, men engaged in physically demanding work and lactating women have the highest requirement for this element. They could achieve a substantial proportion of their daily Se intake by consuming 250 ml of sheep milk or *žinčica*, 20 g of *bryndza*, or 50 g of sheep cheese per day. The highest coverage of the recommended daily Se intake would be provided by sheep milk and *žinčica*, contributing 60.00% and 53.33% of the daily requirement, respectively. Based on 2023 consumption data, *žinčica* and sheep cheese were the best dietary sources of Se, providing 8.50% and 6.80% of the recommended daily Se intake, respectively, for the age groups with the highest requirements.

Milk and dairy products can be a source of toxic elements, especially in areas with industrial contamination. In this study, the presence of 3 toxic elements was monitored in sheep dairy products, and their average concentrations are shown in Table 2. The highest concentrations were recorded for Sr, reaching 3.07 mg kg^{-1} in *bryndza* and 3.34 mg kg^{-1} in fresh sheep cheese. Sr may be important in terms of food contamination because, together with Li, it can affect metabolism. Higher Sr concentrations were reported by Magdas et al. (2019), who found levels ranging from 7.683 to 9.361 mg kg^{-1} in cheese. Coni et al. (1999) reported Sr concentrations of 4.72 to 6.24 µg g^{-1} in sheep milk. In cheese samples, they found Sr concentrations ranging from 2.89 to 6.65 µg g^{-1}, depending on the processing method. These concentrations were significantly lower than those observed in the present study.

Among the monitored toxic elements, the lowest concentrations (0.04 mg kg^{-1}) were recorded for Ni and Sr in *žinčica*. Statistically significant differences ($p < 0.05$) were observed for all toxic elements among the analyzed products, except for Sr, for which no significant difference was detected between sheep milk and *žinčica*.

In the case of long-term exposure to Ni, this condition can lead to neurotoxicity of the organism, as well as damage to the male reproductive system and oxidative stress (Das et al., 2008). Significantly lower Ni concentrations in cow's milk from Slovak and Czech producers compared to those in the present study were reported by Capcarova et al. (2019), who found Ni concentrations ranging from 0.84 to 1.01 μg l^{-1}. In the analyzed milk and *žinčica* samples, Ni concentrations were considerably lower than those reported in the researcher's previous study, in which Ni concentrations in products from the retail network ranged from 0.075 to 0.477 mg kg^{-1} (Pšenková et al., 2022).

The last toxic element monitored in this study was As. It is mainly used in agriculture in herbicide and pesticide formulations, and in many industrial processes. As present in milk may be of natural origin and is excreted in breast milk, or its concentrations partly come from external contamination (Cava-Montesinos et al., 2003). Lower concentrations than those observed in the present study have been reported in the literature, ranging from 0.2 to 50 ng l^{-1} (Simsek et al., 2000), 0.14 ot 0.77 ng ml^{-1} (Cervera et al., 1994), and 0.9 to 27.4 ng l^{-1} (Rosas et al., 1999). An As concentration of 0.64 ng ml^{-1} was also reported in milk used for cheese production (Demirözü-Erdinç and Saldamli, 2000).

An interesting result of the work is the fact that even though the analyzed products came from an organic farm, concentrations of toxic elements were still detected. Table 3 presents an estimated intake of monitored toxic elements through the consumption of monitored sheep dairy products in relation to the toxicological limits of individual toxic elements.

For As, the potential risk may increase with frequent consumption of *bryndza* or *žinčica*, where intake of this element may account for 48.00% of the PTWI through *žinčica* and 30.60% through *bryndza*. As is a common air pollutant and is emitted into the environment as a result of various industrial activities (Toman and Tunegová, 2017). Various industrial environmental contaminations of soil, water, plants, and food with this element cause it to enter the food chain, posing a risk to animal and human health (Bilandžić et al., 2011). Residues of this element are of particular concern when contained in milk, as milk is mainly consumed by children (Chovancová et al., 2014). This element is also considered a potential carcinogen, and its toxic effect is associated with the etiology of many diseases of the cardiovascular system, kidneys, nervous system, blood, and skeletal system (Zhuang et al., 2009).

The lowest risk among the monitored elements was associated with Sr intake through the analyzed products, as %TDI values ranged from 0.18 to 6.75%, substantially lower than those of the other 2 monitored elements. Sr is a relatively understudied toxic element; however, its environmental occurrence is notable in certain regions, and its toxic effects are particularly relevant under long-term intake. It can cause various health problems, such as effects on the nervous system, kidneys, skin, thyroid gland, and lungs. It can have mutagenic and carcinogenic effects (Filatova and Cherpak, 2020; Peana et al., 2021).

Frequent consumption of the dairy drink *žinčica*, sheep cheese *bryndza*, and fresh sheep cheese may represent a potential risk for Ni exposure, as the TDI values for these products were 16.90%, 50.77%, and 40.00%, respectively (Table 4). Ni should be monitored in both animal products and food, particularly due to its potential carcinogenic risk (Liu et al., 2022). In addition, exposure to Ni has various adverse effects on

Table 4. Daily intake of toxic elements in (mg kg^{-1}) and estimation of the risk of their intake according to toxicological limits

Elements	Toxicological limit	Milk	*Žinčica*	*Bryndza*	Sheep cheese
Ni^{1}	EDI	0.00042	0.0022	0.0066	0.0052
	%TDI	3.23%	16.90%	50.77%	40.00%
Sr^{2}	EDI	0.0028	0.23	0.009	0.05
	%TDI	2.15%	0.18%	6.75%	3.68%
As^{3}	EDI	0.0016	0.010%	0.0006	0.0003
	%PTWI	7.60%	48.00%	30.60%	14.00%

Note: ^{1}TDI 13 μg kg^{-1} (EFSA Panel on Contaminants in the Food Chain (CONTAM) et al., 2020); ^{2}TDI 0.13 mg kg^{-1} (WHO, 2010); ^{3}PTWI 15 μg kg^{-1} (FAO JECFA, 2011) human health. An immune reaction to Ni, in the form of dermatitis, is one of the most common allergies worldwide (Torres et al., 2009). In addition, epidemiological studies presented that the probability of lung and nasal cancers is significantly increased in Ni-exposed workers. To date, the exact mechanism of Ni carcinogenicity remains unclear, but DNA damage is considered to play an important role (Guo et al., 2019).

It should be noted that, despite the low consumption of dairy products based on the 2023 consumption report used for estimating toxic element intake, frequent consumption of these products could pose a potential risk, as the percentages of TDI or PTWI were significantly higher. At the same time, the consumption of sheep products is quite popular in Slovakia, as sheep products are also associated with national traditions and folklore. They serve as a tourist attraction and hold an important place in the national cuisine (Horská et al., 2023). However, compared with cow products, sheep products are consumed occasionally.

CONCLUSIONS

The present study confirmed that sheep milk and traditional sheep dairy products from an organic farm in northern Slovakia are valuable sources of essential minerals, particularly Ca, K, Mg, Zn, and Se. Significant differences ($p < 0.05$) in elemental concentrations were observed among the analyzed products, with the highest concentrations generally detected in *bryndza* and fresh sheep cheese. The analyzed products may positively contribute to the dietary intake of important minerals, especially Se and Ca. However, toxic elements such as Ni, Sr, and As were also detected in all products. Although toxicological limits were not exceeded, frequent consumption of some sheep dairy products could increase exposure to As and Ni. Overall, traditional Slovak sheep dairy products can be considered nutritionally beneficial foods, but continuous monitoring of toxic element contamination remains important to ensure food safety and consumer health.

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