

CONTENT OF CHEMICAL ELEMENTS IN "BRYNDZA" (SLOVAK TRADITIONAL SHEEP CHEESE) FROM SUPERMARKET AND HEALTH RISK ASSESSMENT OF ITS CONSUMPTION

Simona Almášiová¹, Róbert Toman^{*1}, Martina Pšenková¹, Vladimír Tančín¹, Ivona Jančo²

Address(es): prof. Ing. Róbert Toman, Dr.

¹ Slovak University of Agriculture in Nitra, Faculty of Agrobiological and Food Resources, Institute of Animal Husbandry, Trieda Andreja Hlinku 2, 949 76 Nitra, Slovak Republic.

² Slovak University of Agriculture in Nitra, AgroBioTech Research Center, Trieda Andreja Hlinku 2, 949 76 Nitra, Slovak Republic.

*Corresponding author: robert.toman@uniag.sk

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ABSTRACT

This study evaluated the content of 21 chemical elements in traditional Slovak bryndza cheese obtained from two producers and assessed potential health risks related to its consumption. The concentrations of essential and toxic elements were determined by ICP-OES. Significant differences ($P < 0.05$) were observed between bryndza samples from the two producers. Bryndza obtained from one producer showed significantly higher concentrations of calcium, magnesium, and zinc, while bryndza from the other producer contained significantly higher levels of potassium. From a nutritional perspective, bryndza represents a valuable dietary source of calcium, magnesium, zinc, and selenium due to their relatively high concentrations in the product and its substantial contribution to recommended dietary intakes, particularly at higher consumption levels. The concentrations of cadmium and molybdenum were below detection limits, while aluminium, barium, chromium, lithium, antimony, strontium, and nickel showed minimal toxicological relevance. However, one sample exceeded the EU limit for lead (0.02 mg/kg), and arsenic levels in several samples indicated potential health risks for children consuming 100 g of bryndza. Overall, bryndza is a nutritionally beneficial traditional food, yet regular monitoring of heavy metals remains essential to ensure its safety.

Keywords: sheep cheese, bryndza, essential elements, heavy metals, health risk assessment, Slovakia

INTRODUCTION

Bryndza is a traditional, white, soft, and spreadable Slovak cheese produced mainly from sheep milk, often referred to as one of the most characteristic and culturally significant products of Slovak gastronomy and Slovak culinary heritage. Since 2008, Slovenská bryndza has been protected under the European Union's Protected Geographical Indication status. The main ingredient in bryndza production is ewe's lump cheese, which undergoes a two-stage ripening process lasting approximately eight to fourteen days. (Koreňovská and Suhaj, 2007; Semjon *et al.*, 2018; Marcinčák *et al.*, 2021; Kunová *et al.*, 2024). It is well known for its distinctive taste, nutritional value, and probiotic potential, and is commonly used as an ingredient in various national dishes. Beyond its sensory and cultural importance, bryndza, as a fermented dairy product, also represents a source of essential minerals necessary for maintaining physiological functions in the human body (Borys *et al.*, 2006; Suhaj *et al.*, 2008; Toman *et al.*, 2023; Bashir *et al.*, 2025). Despite its nutritional benefits, bryndza, like other dairy products, may also contain undesirable or toxic elements that originate from environmental contamination (Rahimi, 2013; Girma and Disassa, 2014; Christophoridis *et al.*, 2019; Zhou *et al.*, 2019). The presence of heavy metals such as lead, cadmium, arsenic, or nickel in milk and cheese can be influenced by feed composition, water quality, soil contamination, or processing conditions (Khan *et al.*, 2014; Bilandžić *et al.*, 2015; Bakircioglu *et al.*, 2018; Bansal, 2020; Boudebouz *et al.*, 2022). Heavy metals such as lead, cadmium, or arsenic are of particular concern because of their cumulative nature and potential toxicity even at low concentrations (Rahimi, 2013). The presence of heavy metals in food is strictly regulated, with maximum residue levels established by European Union legislation to ensure consumer safety (EC No. 1881/2006). Monitoring their presence in commonly consumed traditional foods is therefore essential for ensuring food safety and consumer protection. Most research on bryndza has focused on its microbiological characteristics, microbial diversity, sensory properties, identification of origin, and beneficial health effects (Koreňovská and Suhaj, 2007; Semjon *et al.*, 2018; Štefániková *et al.*, 2020; Hric *et al.*, 2021; Kačániová *et al.*, 2021; Štefániková *et al.*, 2021; Kunová *et al.*, 2024). However, studies addressing the content of chemical elements and their potential variation during processing and fermentation are still lacking. Fermentation alters mineral speciation and bioavailability: The process can convert minerals from less soluble, protein-bound forms to more soluble, absorbable forms, especially for calcium, magnesium, iron, and zinc. This is due to

acidification, enzymatic activity, and breakdown of protein and phytate complexes, which release minerals into more bioavailable states (Ebringer *et al.*, 2008; García-Burgos *et al.*, 2020; Grača *et al.*, 2025). Fermented dairy products may represent a safer alternative from a food safety perspective, as lactic acid bacteria can effectively bind and immobilize toxic heavy metals such as cadmium and lead. This microbial biosorption process reduces the bioavailability of these contaminants, potentially lowering their absorption in the human body (Pakdel *et al.*, 2019). Several studies have analyzed the elemental composition of milk and cheese worldwide (Bilandžić *et al.*, 2015; Castro Gonzales *et al.*, 2017; Christophoridis *et al.*, 2019; Zhou *et al.*, 2019; Boudebouz *et al.*, 2022) and specifically in Slovakia as well (Toman *et al.*, 2021; Pšenková and Toman, 2021; Pšenková *et al.*, 2022; Almášiová *et al.*, 2023; Toman *et al.*, 2023; Almášiová *et al.*, 2024) but limited data are available for Slovak bryndza, especially regarding differences between producers and the associated dietary exposure of consumers. Evaluating both the nutritional contribution and the potential risks from toxic elements is necessary to provide a comprehensive understanding of bryndza's role in the Slovak diet. The objective of this study was to determine the concentrations of selected chemical elements in bryndza cheese from two Slovak producers, evaluate differences in their elemental composition, and assess potential health risks associated with bryndza consumption by adults and preschool children.

MATERIAL AND METHODS

Samples collection and preparation

Samples of traditional Slovak bryndza cheese were collected from two different producers. For each producer, the samples were purchased repeatedly from the same retail chain (supermarket) located in Nitra, Slovakia, to minimize variability related to distribution and storage conditions. Sampling was performed once per month over a period of twelve consecutive months, resulting in a total of 24 samples (12 samples per producer). Each month sample represented a different production batch of bryndza from the same producer. For reasons of commercial confidentiality, the identities of the producers are not disclosed and for the purposes of this study and to ensure clarity and consistency in the interpretation of results, the producers are referred to as Producer 1 and Producer 2 throughout the manuscript. However, both producers represent established manufacturers of traditional Slovak bryndza cheese available on the Slovak retail market. All samples were transported to the laboratory under refrigerated conditions and stored

at -18 °C until analysis. Plastic containers and utensils were used exclusively to avoid possible contamination. Before analysis, each sample was homogenized to ensure representative subsampling, using a Heidolph DIAX 600 (Heidolph Elektro GmbH & Co KG, Germany). Approximately 1.0–2.0 g of each sample was weighed for digestion. Mineralization was performed in a high-performance microwave digestion system Ethos UP (Milestone Srl, Sorisole, BG, Italy) using a mixture of reagents composed of 5 mL of HNO₃ ≥ 69.0 % (TraceSELECT®, Honeywell Fluka, Morris Plains, USA), 1 mL of H₂O₂ ≥ 30 % (for trace analysis, Sigma Aldrich, Saint-Louis, Missouri, USA), and 2 mL of ultrapure water (18.2 MΩ cm⁻¹; 25 °C; Synergy UV, Merck Millipore, France). The digestion program consisted of heating and cooling phases optimized to achieve complete mineralization of the organic matrix.

Elemental analysis

The concentrations of twenty- one chemical elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Zn) were determined by inductively coupled plasma–optical emission spectrometry (ICP-OES 720, Agilent Technologies Australia (M) Pty Ltd.) with axial plasma configuration and an SPS-3 autosampler (Agilent Technologies, Switzerland). Each sample was analyzed in duplicate, and the results represent the mean of two measurements. The instrumental operating parameters were as follows: RF power 1.30 kW, plasma flow 15.0 L/min, auxiliary flow 1.50 L/min, nebulizer flow 0.85 L/min, replicate read time 5.0 s, stabilization time 15 s, sample uptake delay 25 s, pump rate 15 rpm, and rinse time 10 s. The legitimacy of the whole method was verified using the certified reference material (CRM: Yttrium (CAS n.: 1314-36-9), Indium (CAS n.: 7440-74-6), Rhodium (CAS n.: 10049-07-7) ERM: BD 151, BB 184BCR 274). Detections limits (µg/kg) of measured trace elements were followed: Ag 0.3; Al 0.2; As 1.5; Ba 0.03; Ca 0.01; Cd 0.05; Co 0.2; Cr 0.15; Cu 0.3; Fe 0.1; K 0.3; Li 0.06; Mg 0.01; Mn 0.03; Mo 0.5; Na 0.15; Ni 0.3; Pb 0.8; Sb 2.0; Se 2.0; Sr 0.01 and Zn 0.2. and wavelength of determination (nm) follows Ag 328.068; Al 167.019; As 188.980; Ba 455.403; Ca 315.887; Cd 226.502; Co 228.615; Cr 267.716; Cu 324.754; Fe 234.350; K 766.491; Li 670.783; Mg 383.829; Mn 257.610; Mo 204.598; Na 589.592; Ni 231.604; Pb 220.353; Sb 206.834; Se 196.026; Sr 407.771; and Zn 206.200. The methodology was also validated and previously applied within our research group work (Toman et al., 2021; Pšenková et al., 2022; Almášiová et al., 2024).

Statistical analysis

All data were processed using Statistica Cz, version 10 (TIBCO Software, Inc., Palo Alto, CA, USA). Results are presented as mean ± standard deviation, with median values provided separately. Differences in the elemental concentrations between producers were analyzed using one-way ANOVA followed by Scheffé’s post hoc test. Probability levels of *P* < 0.05 were considered statistically significant.

Health risk assessment

To evaluate potential health risks or contribution to recommended dietary intake associated with bryndza consumption, an exposure assessment was performed for adults and preschool children. Adults and preschool children were included in the assessment to cover multiple exposure scenarios, as body weight significantly affects dietary exposure levels. Children are generally considered a more vulnerable group due to their lower body mass and ongoing growth and development (Girma and Disassa, 2014; Rahimi, 2013). Moreover, for essential elements, some population groups—such as lactating or pregnant women and physically active individuals—have higher physiological requirements, which supports the inclusion of different demographic scenarios. The estimated daily intake (EDI) of toxic and potentially toxic elements was calculated according to the formula (Christophoridis et al., 2019; Castro Gonzales et al., 2017; Boudebouz et al., 2021):

$$EDI = \frac{(C \times W)}{BW}$$

where EDI is the estimated daily intake (mg/kg body weight/day), *C* (mg/kg) is the mean concentration of the element in bryndza, *W* is the daily consumption, and *BW* is body weight (70 kg for adults, 22 kg for children (EFSA, 2012)). Two consumption scenarios were applied:

- (1) mean consumption of 20 g per person per day, as reported by the Statistical Office of Slovakia (Sitárová, 2023); and
- (2) a model „worst - case scenario“ assuming 100 g of bryndza consumed daily, since some sources recommend consume 2-4 portions of milk or dairy daily, while 1 portion means 42.5 g of cheese (Hess et al., 2020) or 50-60 g of cheese (Comeford et al, 2021) or specifically for Slovakia by EFSA (2024) 2 portions, where 1 portion means 50 g of cheese.

For toxic elements (Al, As, Ba, Ni, Sb, Sr, Pb, Cd, Cr), health risk was expressed as the percentage of the tolerable daily or provisional tolerable weekly intake (%TDI/%PTWI) or for Li as p-RfD (provisional subchronic and chronic reference dose) using the following formulas (Boudebouz et al., 2021):

$$\%TDI = \frac{EDI}{TDI} \times 100; \%PTWI = \frac{EDI}{PTWI} \times 100; \%p - RfD = \frac{EDI}{p-RfD} \times 100$$

where TDI is tolerable daily intake, EDI is estimated daily intake, PTWI is provisional tolerable intake, p-RfD is provisional subchronic and chronic reference dose. The toxicological reference values used for exposure and risk characterization are summarized in Table 1.

Table 1 Toxicological limits of the tolerable intake for the monitored toxic element

Toxic element	Limit
Al	2 mg/kg PTWI (JECFA 2012)
As	15 µg/kg PTWI (JECFA, 2011)
Ba	0.2 mg/kg TDI (WHO, 1990)
Cd	25 µg/kg ⁻¹ bw/monthly (JECFA, 2023)
Co	The limit was not established
Cr	0.3 mg/kg TDI (EFSA, 2014)
Li	2 µg/kg p-RfD (U.S. EPA, 2008)
Mo	The limit was not established
Ni	13 µg/kg TDI (EFSA, 2020)
Pb	The limit was withdrawn (WHO, 2001)
Sb	6 µg/kg TDI (WHO, 2003)
Sr	0.13 mg/kg TDI (WHO, 2010)

For essential elements (Ca, K, Mg, Na, Fe, Cu, Mn, Mo, Se, Zn, Sr), the contribution to recommended dietary intake was calculated for both preschool children and adults with the highest dietary requirements. The population groups listed in Table 2 represent reference groups with the lowest and highest dietary requirements and were used solely to calculate the relative contribution of bryndza consumption to recommended intakes. However, dietary requirements differ between population groups; therefore, population-specific reference values representing the highest dietary demands were applied in the calculations, since we used for calculations „worst- case scenario“ approach mentioned above. Reference data from the Recommended Nutrient Intakes of the Slovak Republic (Kajaba et al., 2015) were used. Since potassium and manganese are not included in this document, reference values from German-speaking countries (Strohm et al., 2017) and the U.S. Institute of Medicine (2001) were applied, respectively. The evaluation was performed for preschool children (4–6 years) representing the groups with the lowest nutrient requirements, and for the specific subpopulation group of adults with the highest nutrient requirements, respectively. All nutritional and health risk results presented in the manuscript refer exclusively to adults and preschool children (4–6 years), as defined here, in the Materials and Methods section.

Table 2 Reference values for recommended mineral intakes used for the assessment of dietary contribution in preschool children and adults with the highest nutritional requirements

Element	Group with increased requirements	Recommended Intake	Group with lower requirements	Recommended Intake
Ca	Lactating women (Kajaba et al., 2015)	1600 mg	Preschool children (Kajaba et al., 2015)	700 mg
Cu	Physically active men (Kajaba et al., 2015)	1800 µg	Preschool children (Kajaba et al., 2015)	800 µg
Fe	Pregnant women, 2nd trimester (Kajaba et al., 2015)	30 mg	Preschool children (Kajaba et al., 2015)	9 mg
K	Lactating women (Strohm et al., 2017)	4400 mg	Preschool children (Strohm et al., 2017)	1300 mg
Mg	Physically active men (Kajaba et al., 2015)	420 mg	Preschool children (Kajaba et al., 2015)	120 mg
Mn	Lactating women (Institute of Medicine, 2001)	2.6 mg	Children aged 4–8 (Institute of Medicine, 2001)	1.5 mg
Se	Physically active men / Lactating women (Kajaba et al., 2015)	75 µg	Preschool children (Kajaba et al., 2015)	25 µg
Zn	Physically active men (Kajaba et al., 2015)	16 mg	Preschool children (Kajaba et al., 2015)	5 mg

RESULTS AND DISCUSSION

The concentrations of twenty-one chemical elements were determined in bryndza cheese from two Slovak producers. The analysis of bryndza samples revealed noticeable variability in the concentrations of individual elements between samples (Table 3). Statistically significant differences between producers ($P < 0.05$) were observed for calcium, magnesium, potassium, and zinc. Bryndza from Producer 1 contained significantly higher concentrations of calcium, magnesium, and zinc, whereas bryndza from Producer 2 was characterized by a significantly higher potassium content. These differences likely reflect variations in raw milk composition, technological processing, or starter cultures used in production. In particular, differences in salting practices and fermentation conditions may contribute to variations in potassium and sodium content, while calcium, magnesium, and zinc levels may reflect differences in milk composition and curd processing (Khan et al., 2014; Bilandžić et al., 2015; Bakircioglu et al., 2018; Bansal, 2020; Boudebouz et al., 2022). No statistically significant differences were observed for the remaining elements ($P > 0.05$). The concentrations of the most abundant chemical elements were as follows: $Na > Ca > K > Mg > Zn$. The highest concentration was observed for sodium, which is consistent with expectations, as Bryndza is a relatively salty cheese and salting is an integral part of the production process (Štefániková et al., 2020). Bryndza cheese was found to be a rich source of several essential elements. **Macroelements** such as calcium, magnesium, and potassium constitute the dominant part of the mineral profile of bryndza, reflecting its nutritional value and the mineral richness of sheep milk (Park et al., 2007). Sodium and potassium levels were relatively high, which is typical for fermented dairy products (Kravi et al., 2012). In an earlier study analyzing Bryndza cheese samples from various regions of Slovakia, the concentrations of the monitored elements were found within the following ranges: 1.29 - 4.35 mg/kg for Ba, 0.68 - 1.53 mg/kg for Cu, 0.05 - 0.37 mg/kg for Cr, 0.06 - 0.69 mg/kg for Mn, and 0.20 - 0.50 for Ni. These values indicate regional variations in the content of trace elements, which were associated with the origin of the samples, as the study also determined the elemental composition of the soil and found significant correlations between soil and cheese mineral contents (Koreňovská and Suhaj, 2008). In older study Suhaj and Koreňovská (2007) analysed samples of Bryndza cheese from Poland and Romania with following results: 3.65 mg/kg Ba, 0.69 mg/kg Cu, 0.042 mg/kg Cr, 318 mg/kg Mg, 0.13 mg/kg Mn and 0.36 mg/kg Ni in samples from Poland and 3.90 mg/kg Ba, 0.66

mg/kg Cu, 0.06 mg/kg Cr, 179 mg/kg Mg and 0.39 mg/kg Ni in samples from Romania. In the Polish study, the authors reported approximately twice the concentrations of Ca (7.1 g/kg), Mg (0.39 g/kg), K (2 g/kg), Zn (21.22 mg/kg), and Fe (2 mg/kg) in bryndza compared to our samples. Very similar concentrations were also found in cheeses such as Bundz and Feta, which are sometimes compared to bryndza, although bryndza is a highly specific product in terms of its manufacturing process and final characteristics. Bundz contained slightly lower amounts of elements, as it is a less concentrated cheese. Toxic elements such as Pb, Cd, and As were below the limit of detection (Borys et al., 2006). Feta cheese, classified as a soft white brined cheese, shares several compositional and technological features with bryndza. According to Hammam et al. (2022), traditional Feta typically contains 45–60% moisture, 15–20% protein, and 10–20% fat, with a pH ranging between 4.6 and 5.3. Similar to bryndza, it is produced from sheep or mixed milk and undergoes a short fermentation and brining period that supports the development of lactic acid bacteria and contributes to its characteristic slightly acidic flavor and creamy texture. These similarities in moisture content, fermentation process, and microbial profile justify using Feta-type cheese as a technological reference when comparing the mineral composition of bryndza. In a Greek study, three different feta samples were determined to have higher concentrations of Fe (1.67- 4.09 mg/kg) and Zn (9.73 - 21 mg/kg), similar concentrations of Mn (0.1 - 0.5 mg/kg), but lower concentrations of Cu, Cr, Ni, Pb and Se (Christophoridis et al., 2019). Another cheese of global origin compared to bryndza is Italian Stracchino cheese (Toman et al., 2023). Manuelian et al. (2017), analyzing 130 samples of Stracchino cheese, reported concentrations of 3510 mg/kg of Ca, 1570 mg/kg of K, 150 mg/kg of Mg, and 2140 mg/kg of Na. This indicates that the Italian cheese had Ca levels in a similar range to our bryndza, approximately twice the K content compared to bryndza from Producer 1, lower Mg levels, and, surprisingly, two to nearly three times lower Na levels, which was attributed to the strategy of partially substituting NaCl with KCl to reduce sodium content. The Crescenza and Squacquerone cheeses, which belong to the Stracchino-style cheese category and are produced from cow's milk, also showed much lower Na content, higher levels of Ca, Mg, and Zn, but lower concentrations of Fe and Al (Lante et al., 2006). Raynal-Ljutovac (2008) reported that sheep's milk has the highest Fe content among different types of milk, which confirms our results.

Table 3 Content of chemical elements in Bryndza from two different producers (mg/kg)

Element	Producer 1			Producer 2		
	$\bar{x} \pm SD$	Median	Frequency	$\bar{x} \pm SD$	Median	Frequency
Al	1.37 ± 2.71	0	4 (33 %)	1.23 ± 2.04	0	5 (42 %)
As	0.38 ± 0.59	0	4 (33 %)	1.121	-	3 (25 %)
Ba	0.33 ± 0.26	0.42	8 (67 %)	0.36 ± 0.34	0.45	8 (67 %)
Ca	4055.80 ± 573.49*	4037.56	12 (100 %)	3005.70 ± 480.06	3011.89	12 (100 %)
Cd	ND	-	-	ND	-	-
Co	0.071	-	1 (8 %)	0.041	-	2 (17 %)
Cr	0.021	-	1 (8 %)	0.031	-	1 (8 %)
Cu	0.40 ± 0.50	0.08	7 (58 %)	0.32 ± 0.35	0.15	6 (50 %)
Fe	1.43 ± 0.67	1.46	12 (100 %)	1.24 ± 0.58	1.35	12 (100 %)
K	750.07 ± 63.77*	759.67	12 (100 %)	1074.76 ± 360.84	1050.95	12 (100 %)
Li	0.04 ± 0.01	0.03	12 (100 %)	0.04 ± 0.02	0.04	12 (100 %)
Mg	192.70 ± 24.15*	190.07	12 (100 %)	164.10 ± 24.82	157.31	12 (100 %)
Mn	0.10 ± 0.08	0.13	8 (67 %)	0.08 ± 0.07	0.12	7 (58 %)
Mo	ND	-	-	ND	-	-
Na	5779.26 ± 561.81	5628.36	10 (83 %)	5323.15 ± 2244.00	5839.04	7 (58 %)
Ni	0.231	-	1 (8 %)	0.101	-	1 (8 %)
Pb	0.171	-	1 (8 %)	ND	-	-
Sb	0.121	-	2 (17 %)	0.031	-	3 (25 %)
Se	0.51 ± 0.64	0	5 (42 %)	0.50 ± 0.56	0.36	6 (50 %)
Sr	1.47 ± 1.09	2.1	8 (67 %)	1.19 ± 1.01	1.59	8 (67 %)
Zn	14.81 ± 3.44*	15.33	12 (100 %)	8.55 ± 4.44	9.25	12 (100 %)

* $P < 0.05$; ND = not detected; for elements where we determined the presence of the element in less than 3 samples, was not possible to perform statistical operations; Frequency indicates the number (and percentage) of samples in which the concentration of the given element was above the detection limit during the one-year sampling period.

From a nutritional point of view, bryndza proved to be an excellent source of several essential elements. This is primarily due to the relatively high concentrations of calcium, magnesium, zinc, and selenium in the product and their substantial contribution to recommended dietary intakes, as demonstrated by the intake calculations. This finding supports the perception of bryndza not only as a cultural specialty but also as a nutritionally beneficial food. For clarity, all nutritional results discussed below refer to preschool children and adults with the highest dietary requirements, as stated in the Materials and Methods section. Adult population groups with lower dietary requirements, who do not represent risk groups for the respective element, would benefit from bryndza consumption to an even greater extent; however, the present calculations were intentionally based on a „worst-case scenario“ approach, focusing on population groups with the highest dietary requirements. According to the estimated dietary intake calculations (Table 4), bryndza consumption at 100 g per day contributed substantially to the recommended daily intake for these minerals in both adults and preschool children. Even at the lower consumption level (20 g/day), bryndza contributed meaningfully to daily mineral requirements, while at 100 g/day, its nutritional contribution became substantial, especially for selenium. Selenium showed the highest relative contribution to recommended dietary intake, 13-68 % according to consumed amount and producer for adults with the highest requirements, and 40-200 % for children. Selenium plays an essential role in antioxidant defense, thyroid function, and immune regulation (Genchi et al., 2023). Therefore, bryndza may represent an important dietary source of this element, especially in populations where Se

intake is typically low (Stoffaneller and Morse, 2015). Toman et al. (2023) found higher concentrations of Se and Zn in bryndza from an organic farm in comparison with bryndza from a conventional farm. We determined a higher content of Se, while a lower content of Zn in bryndza from the supermarket. In addition to selenium, calcium showed substantial contributions to the fulfilment of dietary requirements. At the model consumption level of 100 g per day, bryndza could provide up to one-quarter of the daily calcium requirement for adults and even more than one-half for children, supporting bone mineralization and proper muscle and nerve function. Calcium is not only present in high concentration but also available in more readily bio-available form in fermented dairy products (Bashir et al., 2025). The contribution of magnesium (3-16 % for children and 1-5 % for adults) and zinc (3-30 % for children and 1-9 % for adults) was also noteworthy especially for children — magnesium being essential for enzymatic and metabolic activity (Fiorentini et al., 2021), while zinc plays a role in immune health, wound healing, and growth (Chasapis et al., 2020). Given that cadmium and molybdenum concentrations were below the detection limits in all samples, their contribution to dietary exposure was considered negligible and they were not further evaluated. This finding represents a very favorable outcome from a food contamination perspective, particularly in the case of cadmium, which is recognized as a highly toxic element of major public health concern.

Table 4 Fullfillment of the recommended daily intake of essential elements by consuming 100 g or 20 g of bryndza for two groups of people* (%)

Element	Group of population*/ Consumed amounts	Sheep cheese „Bryndza“			
		Producer 1		Producer 2	
		100 g	20 g	100 g	20 g
Ca	↑requirements	25.35	5.07	18.79	3.76
	↓requirements	57.94	11.59	42.94	8.59
Cu	↑requirements	2.22	0.44	1.78	0.36
	↓requirements	5.00	1.00	4.00	0.80
Fe	↑requirements	0.48	0.10	0.41	0.08
	↓requirements	1.59	0.32	1.38	0.28
K	↑requirements	1.88	0.38	2.69	0.54
	↓requirements	5.77	1.15	8.27	1.65
Mg	↑requirements	4.59	0.92	3.91	0.78
	↓requirements	16.06	3.21	13.68	2.74
Mn	↑requirements	0.43	0.09	0.35	0.07
	↓requirements	0.67	0.13	0.53	0.11
Se	↑requirements	68.00	13.60	66.67	13.33
	↓requirements	204.00	40.80	200.00	40.00
Zn	↑requirements	9.26	1.85	5.34	1.07
	↓requirements	29.62	5.92	17.10	3.42

*Group „↑requirements“ with the highest requirements vary from element to element. According to national recommendations, it is for Cu and Zn group of men with physically hard work, for Fe pregnant women in the second trimester, for Ca and Se breastfeeding women. For Ca and Mn, according to the RDA, it is a group of adults in general. Group „↓requirements“ with the lowest requirements represents preschool children in all cases.

However, one sample of bryndza from producer 1 contained lead in a concentration exceeding the maximum permissible limit set by the European Union (0.02 mg/kg) (EC No 1881/2006), which highlights the importance of routine control of contaminants even in traditionally produced dairy foods. Lead appears to be the element with the highest potential for bioaccumulation and transfer from soil and feed into milk, indicating its strong ability to move through the food chain (Zhou et al., 2019). Although this finding indicates a potential food safety concern, the actual health risk may be mitigated by the fact that bryndza is a fermented product containing lactic acid bacteria capable of binding heavy metals, thereby reducing their bioavailability (Štefániková et al., 2021). Although our samples were mineralized as whole products, including metals bound to bacterial cells, this did not affect the analytical results. Nonetheless, from a food safety perspective, the biosorption ability of lactic acid bacteria remains important, as it reduces the bioaccessible fraction of toxic metals (Pakdel et al., 2019; Liu et al., 2019; Wahid et al., 2023). In contrast, Amer et al. (2021) reported that fermentation and coagulation processes during cheese manufacture led to elevated concentrations of Cd, Pb, and Al. This increase was attributed to the bioaccumulation of metals within protein matrices, particularly casein fractions, which exhibit strong binding

affinity for metal ions. Furthermore, the reduced water content in the final cheese products was suggested to contribute to an apparent concentration effect, resulting in higher measured metal levels. Concentrations of lead in Kareish cheese from Egypt were $535.51 \pm 85.34 \mu\text{g/kg}$ and $218.38 \pm 19.87 \mu\text{g/kg}$ in Whey Kareish cheese (Amer et al., 2021). Rahimi (2013) compared the content of Pb between various types of milk and found the highest concentration in sheep milk. The health risk assessment based on the estimated daily intake (Table 5) indicated that, under both consumption scenarios (20 g and 100 g per day), the exposure to toxic and potentially toxic elements remained below the applicable health-based guidance values, expressed as percentages of the provisional tolerable daily intake (TDI), provisional tolerable weekly intake (PTWI), or provisional reference dose (p-RfD), depending on the element, with the exception of arsenic. Thus, the values presented in Table 5 represent element-specific risk characterization. Results confirmed that bryndza consumption poses no significant health risk for adults under typical intake conditions. However, the intake of 100 g of bryndza cheese produced by producer 2 by a child corresponds to **237.58%** of the PTWI, which cannot be considered within the safe range of exposure. For adults, this value represents **75% of the PTWI**, while the consumption of 100 g of bryndza from

producer 1 by a child accounts for **80%**, which is also non-negligible considering the weekly exposure limit. Although the intake scenarios are expressed as daily consumption (20 g/day and 100 g/day), the risk characterization for arsenic is based on the provisional tolerable weekly intake (PTWI). A daily consumption of 100 g of bryndza alone is sufficient to exceed the weekly exposure limit for arsenic in children. Moreover, repeated consumption of smaller portions (e.g., 20 g) several times per week may also substantially contribute to weekly arsenic exposure. This concern is further amplified by the fact that bryndza is unlikely to be the sole dietary source of arsenic, and cumulative exposure from other foods may increase the overall health risk. Arsenic was detected only in four samples from Producer 1 (0.38 mg/kg) and three samples from Producer 2 (1.21 mg/kg), and its occurrence may represent a potential concern for vulnerable population groups such as children and deserves further attention as well (Tian et al., 2025). It is also worth mentioning the detected aluminium content (1.37 and 1.23 mg/kg), which is not alarming, yet should not be overlooked, as it may contribute to the overall exposure, particularly in sensitive population groups. However, the high

standard deviations indicate greater variability in the occurrence of this element throughout the year. Much higher concentration of Al was found in samples of bryndza from conventional (8.24 mg/kg) and organic farms (14.7 mg/kg) in Slovakia. The origin of this element could be related to the technology of curd processing and the use of aluminium containers (Toman et al., 2023). For individuals not occupationally exposed to aluminum, diet is the main source of exposure. Its presence in food has increased due to packaging materials and certain additives. Excessive or chronic aluminum exposure is linked to a higher risk of neurodegenerative diseases such as Alzheimer’s, Parkinson’s, and amyotrophic lateral sclerosis (Filippini et al., 2019). Concerning the remaining elements and the outcomes of the risk assessment, Ni and Sr contributed less than 10% of the established limit across all exposure scenarios, Al less than 5%, and Ba, Cr, Sb, and Li below 1%, indicating minimal toxicological relevance under the assessed conditions.

Table 5 Dietary exposure to toxic and potentially toxic elements from bryndza consumption expressed as % of the applicable health-based guidance value (HBGV): PTWI, TDI, or p-RfD (depending on the element), for adults and preschool children under two consumption scenarios (20 g/day and 100 g/day)

Element	Group of population*	Producer 1		Producer 2	
		100 g	20 g	100 g	20 g
Al (PTWI)	adults	0.69	0.14	0.62	0.12
	children	2.18	0.44	1.96	0.39
As (PTWI)	adults	25.33	5.07	74.67	14.93
	children	80.61	16.12	237.58	47.52
Ba (TDI)	adults	0.24	0.05	0.26	0.05
	children	0.75	0.15	0.82	0.16
Cr (TDI)	adults	0.01	0.002	0.01	0.003
	children	0.03	0.01	0.05	0.01
Li (p-RfD)	adults	0.29	0.06	0.29	0.06
	children	0.91	0.18	0.91	0.18
Ni (TDI)	adults	2.53	0.51	1.10	0.22
	children	8.04	1.61	3.50	0.70
Sb (TDI)	adults	0.29	0.06	0.07	0.01
	children	0.91	0.18	0.23	0.05
Sr (TDI)	adults	1.62	0.32	1.31	0.26
	children	5.14	1.03	4.16	0.83

* Calculations were performed for adults with an average body weight of 70 kg, and the population group referred to as “children” in the table corresponds to preschool children aged 4–6 years with an average body weight of 22 kg.

CONCLUSION

The study assessed the content of twenty-one chemical elements in Slovak traditional bryndza cheese from two producers and provides new insights into the elemental composition and potential health risks associated with the consumption of Slovak traditional bryndza cheese. Significant differences were found between producers in the concentrations of several essential minerals, with higher levels of calcium, magnesium, and zinc detected in bryndza from producer 1, and higher potassium levels in bryndza from producer 2. From the nutritional point of view, bryndza represents a valuable source of essential elements, particularly selenium, calcium, zinc, and magnesium, which substantially contribute to daily mineral intake. The concentrations of Cd and Mo were below detection limits, and according to the results of health- risk assesment indicating minimal contamination by Al, Ba, Cr, Li, Sb, Sr, and Ni. However, the presence of Pb in one sample from producer 1 exceeded the maximum permissible limit set by the European Union (0.02 mg/kg) (EC No 1881/2006), highlighting the need for continuous monitoring of heavy metals in dairy products. Nevertheless, the detected presence of arsenic—mainly in samples from producer 2—may pose a potential health risk for sensitive groups, such as preschool children. Overall, the study emphasizes that while bryndza cheese can contribute positively to the intake of important minerals, ensuring its safety through regular quality control remains essential for protecting public health and should be maintained continuously.

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