ACTA VET. BRNO 2026, 95: 39–44; https://doi.org/10.2754/avb202695010039

Mercury as a contaminant in small ruminants

Kamila Novotná Kružíková[1], Veronika Vlasáková[2], Danka Haruštiaková[3], Zdeňka Svobodová[1], Petr Chloupek[1], Martin Svoboda[4]

[1]University of Veterinary Sciences Brno, Faculty of Veterinary Hygiene and Ecology, Department of Animal Protection and Welfare and Veterinary Public Health, Czech Republic
[2]State Veterinary Administration, Czech Republic
[3]Masaryk University, Faculty of Science, RECETOX, Brno, Czech Republic
[4]University of Veterinary Sciences Brno, Faculty of Veterinary Medicine, Ruminant and Swine Clinic, Czech Republic

Received October 16, 2025
Accepted March 2, 2026

Abstract

This study evaluates the total mercury content in liver, kidneys, and muscle of small ruminants during the monitoring programme in the Czech Republic from 2014 to 2023. Significantly the highest mean (P < 0.05) mercury content in sheep (n = 23) was found in the kidneys (5.0 ± 0.6 µg/kg) and liver (4.8 ± 1.0 µg/kg) in comparison to the muscle (0.5 ± 0.0 µg/kg). In lambs (n = 7), a significantly higher mean (P < 0.05) mercury content was found in the kidneys (6.4 ± 2.8 µg/kg) and liver (4.3 ± 0.9 µg/kg) in comparison to the muscle (0.5 ± 0.1 µg/kg). No significant difference in mercury content was found between the liver and kidneys in either sheep or lambs (P > 0.05). In the case of goats (n = 11), the kidneys (3.5 ± 0.9 µg/kg) exhibited a significantly higher mean mercury concentration than the liver (1.7 ± 0.7 µg/kg) and muscle (0.4 ± 0.1 µg/kg). The difference in mercury concentration between the kidneys and the other two tissues was found to be significant (P < 0.05 in both comparisons); however, the mercury concentration in the liver and muscle did not differ significantly (P > 0.05). The maximum residual limit for human consumption, as set by the Regulation (EC) No 396/2005, was not exceeded in any sheep and goat sample during the period 2014–2023 in the Czech Republic. In analysed samples, the mercury content was 10 times lower than the limit. There was no significant increase in mercury content in sheep and goat tissues during the monitored years.

Heavy metals, sheep, lambs, goats

Mercury is a heavy metal known for its toxic effects on environmental, animal, and human health, as well as for its capacity to bioaccumulate and biomagnify within the food chain. As asserted by Stoev and Lazarova (1998) and Pathak and Bhownik (1998), mercury accumulates predominantly in the liver and kidneys of sheep and goat, resulting in organ damage. Stoev and Lazarova (1998) describe numerous alterations observed in the organisms of sheep following treatment with two concentrations of $HgCl_2$ (3.5 and 7 mg per kg body mass). The effects of mercury on the human body include depression, loss of appetite, anorexia and motor disturbance, together with minor necrosis of kidneys. It is hypothesised that the described damage is the result of the elimination and detoxification of mercury and its compounds via the same organs. Pathak and Bhowmik (1998) studied the chronic toxicity of inorganic mercury by adding mercury to water that was available to the goats *ad libitum* over a period of 90 days. The intensity of cytotoxic changes (gastrointestinal disturbances, renal dysfunction, centrilobular necrosis of the liver) in various organs was found to be proportional to the amount of mercury accumulated.

Due to the fact that mercury is a toxic heavy metal with the potential to accumulate in animal tissues and enter the human food chain, monitoring mercury levels in livestock is crucial for public

Address for correspondence:
Kamila Novotná Kružíková
Department of Animal Protection and Welfare and Veterinary Public Health
Faculty of Veterinary Hygiene and Ecology
University of Veterinary Sciences Brno
Palackého tř. 1946/1, 612 42, Brno, Czech Republic
Phone: +420 541 562 502
E-mail: novotnakruzik@vfu.cz
http://actavet.vfu.cz/

health. It has been well-documented that chronic exposure to mercury through the consumption of meat or dairy products can lead to serious health issues, including neurological and renal deterioration. Regular testing helps prevent contaminated food from reaching consumers and ensure compliance with food safety regulations. The primary regulatory framework governing mercury concentrations in food is the Commission Regulation (EU) 2023/915, which establishes a maximum limit for mercury in fishery products and bivalve molluscs at 0.3 and 0.5 mg/kg, respectively. However, an exception is made for muscle meat of some specific fish species, for which a maximum limit of 1 mg/kg is set. In contrast, no maximum limit is specified for meat of goat or sheep. Notwithstanding the previous utilisation of mercury compounds as pesticides, their current authorisation in the EU has been revoked (EFSA 2012). Nevertheless, the presence of mercury in food can be attributed to environmental contamination. Accordingly, the European Parliament and the Council have established a new maximum residual limit (MRL) for mercury in accordance with the Regulation (EC) of the European Parliament and of the council No 396/2005. For sheep and goat, the MRL for human consumption is set at 0.01 mg/kg for mercury in muscles and 0.02 mg/kg for mercury in liver and kidneys.

The presence of mercury in most regions of the world is primarily attributable to mining activities, the release of metallic mercury into the environment during the extraction of gold by the crude method of amalgamation and the utilisation of mercury in agrochemicals such as herbicides, fungicides, and fertilizers. Mercury can enter animal tissues via contaminated drinking water or dietary substances (WHO 2003).

The aim of this study was to evaluate the total mercury content in liver, kidneys, and muscle of sheep and goats sampled during the monitoring programme in the Czech Republic from 2014 to 2023 and to compare the mercury content found in sheep and goats with that found in other livestock.

Materials and Methods

Samples

From 2014 to 2023, the State Veterinary Administration (SVA) in the Czech Republic (Central Europe) examined a total of 30 sheep (23 adult animals and 7 lambs under 2 months old) and 11 adult goats from a slaughterhouse. The animals came from Czech farms and were intended for human consumption after slaughter in slaughterhouses. This sampling was part of the National Residue Control Plan, which was conducted in accordance with the Council Directive 96/23/EC until 2022. Since 2023 it has been conducted under the new EU rules, specifically, the Commission Delegated Regulation (EU) 2022/931, the Commission Implementing Regulation (EU) 2022/932, and the Regulation of the European Parliament and of the Council (EU) 2017/625. Each year, three sheep and one goat (except for 2022 when 2 individuals were involved) were selected randomly from different regions across the Czech Republic and examined. Risk-based control plan sets out the sampling strategy (numbers) and risk criteria with justification for the application of these criteria. The randomized surveillance plan includes random monitoring of a wide range of substances that are not included in the national risk-based plan. Samples were taken by veterinary inspectors.

The mercury content was measured in the liver, kidneys, and muscle of the examined animals. The analyses were performed in accredited (EN ISO/IEC 10025:2018) laboratories of the State Veterinary Institutes in the Czech Republic using valid methods. The total mercury content (THg) in the tissues (wet weight) of sheep and goats was determined by cold vapour atomic absorption spectrometry on an AMA 254 analyser (Altec Ltd., Dvůr Králové nad Labem, Czech Republic). Analytical quality was ensured through the use of reference, duplicate, and blank samples. The certificate reference material (CRM) NIST 1566b Oyster Tissue was used (National Institute of Standards and Technology, Gaithersburg, MD, USA). The certified THg is 37.1 ± 1.3 μg/kg. This CRM is regularly analysed together with the measured samples. The recovery rate is observed to range between 90% and 101%. The required level of quantification (LOQ) in the tissues for the methods used was 1.0 or 0.4 μg/kg, depending on the laboratory where the sample was processed. Values below LOQ were replaced by half of this limit, i.e. by the value of 0.5 or 0.2 μg/kg.

Statistical analyses

Year-to-year comparisons of values (separately for goats and sheep, individual tissues and age groups) were performed using Kruskal-Wallis ANOVA and did not show significant differences ($P > 0.05$ in all comparisons). Furthermore, no significant trend of a decrease in the mercury content in tissues was found during the observed time period. Pearson's correlation between the mercury concentration and year was very weak (from −0.558 to −0.031) and therefore, all data were processed together regardless of the year of sampling. The differences in the mercury content between the liver, kidneys and muscle and between the groups of samples were analysed using repeated measures ANOVA with the animal group as a categorical factor and tissue as the repeated measures factor (as the values in the three tissues were always measured in the same individual). Subsequently, Fisher's *post hoc* test was employed to identify differences between sample groups. $P < 0.05$ was considered to be significant in all tests. Data manipulation and statistical analyses were performed using Statistica, version 14 (TIBCO Software Inc.).

Results

Mercury in sheep tissues

The monitoring included the whole of the Czech Republic: Prachatice, Louny, Liberec, Rakovník, Sokolov, Karlovy Vary, Strakonice, Blansko, Písek, Třebíč, Kladno, Plzeň and Zlín regions. The mercury content in different locations of the Czech Republic was similar. The highest mercury values were found in one sample from Liberec from 2016 (20.0 µg/kg in the liver) and one sample from Svitavy from 2022 (17.3 µg/kg in the kidneys). The kidneys (5.4 ± 0.8 µg/kg) and liver (4.7 ± 0.8 µg/kg) exhibited significantly higher mean mercury concentrations compared to the muscle (0.5 ± 0.03 µg/kg). However, the MRL for human consumption was not exceeded in any sample. Mercury concentration was significantly affected by the tissue (repeated measures ANOVA: the effect of tissue: $F(2,56) = 14.850$, $P < 0.001$), but not by age (lambs/sheep) (repeated measures ANOVA: the effect of age category: $F(1,28) = 0.109$, $P = 0.744$). The concentration of mercury was significantly higher in the liver and kidneys than in the muscle, both in lambs and in sheep ($P < 0.05$). No difference in the mercury content was found between the liver and kidneys in either the sheep or lambs ($P > 0.05$; Table 1). The mercury content did not differ significantly between lambs and sheep in any tissue ($P > 0.05$ for all three comparisons; Table 1).

Table 1. Mercury content in lamb and sheep tissues (µg/kg).

Animals	Tissue	Number	Median	Mean ± SEM	Min–max
Sheep	Kidneys	23	4.0	5.0 ± 0.6 ^{A}	1.0–11.9
	Liver	23	3.5	4.8 ± 1.0 ^{A}	0.5–20.0
	Muscle	23	0.5	0.5 ± 0.0 ^{B}	0.2–0.9
Lambs	Kidneys	7	3.0	6.4 ± 2.8 ^{A}	0.5–17.3
	Liver	7	4.9	4.3 ± 0.9 ^{A}	0.7–7.0
	Muscle	7	0.5	0.5 ± 0.1 ^{B}	0.2–0.8

^{A,B} The total mercury content in different tissues followed by the same uppercase superscript did not differ significantly (separately for lambs and sheep). SEM - standard error of the mean.

Mercury in goat tissues

In the case of goat samples (N = 11), the mercury content ranged from 0.2 to 10.0 µg/kg. The mercury concentration was significantly affected by the tissue (repeated measures ANOVA: the effect of tissue: $F(2,20) = 10.098$, $P = 0.001$). The highest mercury concentration was found in the kidneys (3.5 ± 0.9 µg/kg), followed by the liver (1.7 ± 0.7 µg/kg) and muscle (0.4 ± 0.1 µg/kg). The difference in mercury concentration in the kidneys and the other two tissues was found to be significant ($P < 0.05$ in both comparisons); however, the mercury concentration in the muscle and liver did not differ significantly ($P > 0.05$; Table 2).

Table 2. Mercury content in goat tissues (µg/kg).

Tissue	Number	Median	Mean ± SEM	Min–max
Kidneys	11	2.8	3.5 ± 0.9 ^{B}	0.2–10.0
Liver	11	1.0	1.7 ± 0.7 ^{A}	0.2–8.0
Muscle	11	0.5	0.4 ± 0.1 ^{A}	0.2–0.8

^{A,B} The mercury concentration in different tissues followed by the same uppercase superscript did not differ significantly. SEM - standard error of the mean.

Discussion

In the Czech Republic, intensive monitoring of foreign substances is conducted, particularly in relation to edible parts of livestock bodies, given their long-standing utilisation in public health contexts. The analysis of 123 samples from sheep and goat tissues revealed that none of them exceeded the MRL. The mercury content was found to be more than 10 times lower than the MRL. It is therefore concluded that neither the health nor the welfare of sheep and goats is endangered. It is unlikely that the sheep and goat meat and edible organs would cause any adverse health effects to human consumers and thus, they are suitable for human consumption.

The mercury concentrations measured in our study were significantly below the concentrations associated with mercury-induced renal dysfunction (Simpson et al. 1997; Pathak and Bhowmik 1998). Therefore, environmental mercury contamination is unlikely to pose a health risk to sheep and goats in the Czech Republic.

Mercury in sheep tissues

Mercury concentrations in sheep are low and correspond to the results published by Rudy (2009) (liver of sheep from Poland; range 0–6 µg/kg), MacLachlan et al. (2016) (kidneys of Australian sheep; 6.1 µg/kg) and Bilandžič et al. (2010) (1–3 years old sheep kidneys from Croatia; 11 µg/kg). In contrast, Akoto et al. (2014) reported a tenfold increase in mercury concentrations in kidneys and livers of sheep reared in the Obuasi gold mine area in Ghana. The mean mercury concentrations in these organs were 70 ± 30 µg/kg and 30 ± 20 µg/kg, respectively. Elevated mercury concentrations were reported by Darwish et al. (2017) for the liver (77 µg/kg) and kidneys (64 µg/kg) of sheep from Egypt. It is therefore evident that environmental loads directly affect the mercury content in animal tissues. Our study has demonstrated that mercury accumulates to a greater extent in the kidneys and liver (the primary organs responsible for the elimination and detoxification of metals) in both lambs and sheep when compared to muscle tissue. This is in accordance with the study by Darwish et al. (2017), which reported significantly higher concentrations of mercury in the liver and kidneys compared to the lung, tongue, and masseter muscle. This observation is further corroborated by the findings of MacLachlan et al. (2016), who observed that the mean mercury content in the kidneys (6.1 µg/kg) was twice that found in the liver (3.4 µg/kg) and three times higher than that observed in muscle (2.5 µg/kg).

In our study, mercury concentrations did not exhibit significant differences between lambs and sheep across all examined tissues, which also supports the conclusions of Rudy (2009). This author conducted a comparative analysis of three distinct groups of sheep: the first group comprised lambs (0 to 8 months of age), the second group consisted of sheep between 8 months and 1.5 years of age, and the third group comprised sheep between 1.5 and 2.5 years of age. Similarly, MacLachlan et al. (2016) conducted a comparative analysis of lambs, young sheep, and mature sheep, and they too found no significant differences between the observed age groups of sheep.

Mercury in goat tissues

As Pathak and Bhowmik (1998) have reported that mercury accumulates the most in the kidneys, followed by the liver and spleen. In addition, the data presented here demonstrate that the kidneys contain a greater amount of mercury compared to the liver and muscle.

There is a lack of data for mercury content in the tissues of goats. However, the results of the study conducted by Mustaq et al. (2024) indicated that the mercury content in the livers and kidneys of goats from a slaughterhouse in Pakistan was lower than the results of our study. In comparison to our results, mercury concentrations in tissue samples from goats in gold-mining areas such as Obuasi in Ghana revealed contents > 20 times higher (goat kidneys 70 ± 20 µg/kg; goat liver 10 ± 10 µg/kg) (Akoto et al. 2014) than in the Czech Republic.

Mercury in the food chain

A comparison of the published results of mercury content in livestock tissues reveals that sheep and goats are at the bottom of the descending series of mercury content. The mercury content in livestock decreases as follows: predatory fish > omnivorous fish > wild boar > hare > pig > fattening cattle > sheep > goats > poultry (Maršálek et al. 2006; Kenšová et al. 2012; Demirbaş and Erduran 2017; Nawrocka et al. 2020; Svoboda et al. 2021; Novotna Kruzikova et al. 2022; Novotná Kružíková et al. 2023; Svoboda et al. 2025; Mushtaq et al. 2024). As demonstrated by Hu et al. (2013), the conversion of the inorganic form of mercury in bottom sediments to its organic form results in the entry of organic mercury into bacteria, zoobentos and zooplankton organisms. Accumulation and magnification of mercury occurs with the food chain, with mostly mercury being found in unpolluted locations in predatory fish (approximately 1 000 µg/kg). In omnivorous or non-predatory fish, however, mercury concentrations decrease to values of up to 500 µg/kg. Available results of monitoring mercury content in animals outside the aquatic environment kept on pastures in the wild show lower mercury values compared to fish, approximately 50 µg/kg. The lifespan of sheep and goats is comparatively shorter than that of cattle and pigs; on the other hand, they exhibit elevated concentrations of mercury compared to poultry as the fattening time of poultry is shorter than that of sheep and goats, which seems to affect the mercury content in livestock.

Among other papers describing mercury contamination of the food chain in the Czech Republic we can find studies of mercury content in livestock in the Czech Republic based on the monitoring in pigs during the years 2015–2019 (Svoboda et al. 2021) and in cattle during the years 2014 and 2023 (Svoboda et al. 2025). Compared to our current study conducted on sheep where no exceedance of MRL in tissues was found in any sample, in the aforementioned studies the limits were exceeded. In the study of pigs, the MRL for human consumption was exceeded in 14 kidney samples. In the study of cattle, the MRL for human consumption was exceeded in 10 kidney samples (3 calves, 6 cows, 1 fattening cattle) and 1 liver sample (calf).

In conclusion, the necessity for the biomonitoring of mercury content in livestock remains a crucial aspect of public health. It is obvious that biomagnification of mercury in animals is indicative of the food chain and the load from the breeding area. From this point of view, consumption of goat and sheep meat or edible organs (with the exception of those from mining areas) is not likely to be a significant concern for human exposure.

Acknowledgements

This work was financially supported by the grant 2024ITA26 VETUNI. The authors would like to express their gratitude to the State Veterinary Administration for providing their data.

References

Akoto O, Bortey-Sam N, Nakayama SMM, Ikenaka Y, Baidoo E, Yohannes YB, Mizukawa H, Ishizuka M 2014: Distribution of heavy metals in organs of sheep and goat reared in Obuasi: A gold mining town in Ghana. Int J Environ Sci Toxic **2**: 81-89

Bilandžič N, Dokič M, Sedak M 2010: Survey of arsenic, cadmium, copper, mercury and lead in kidney of cattle, horse, sheep and pigs from rural areas in Croatia. Food Addit Contam B **3**: 172-177

Council of the European Union 1996: Council Directive 96/23/EC of 29 April 1996 on measures to monitor certain substances and residues thereof in live animals and animal products and repealing Directives 85/358/EEC and 86/469/EEC and Decisions 89/187/EEC and 91/664/EEC. Off J EU **L125**: 10-32

Darwish WS, Gad TM, Imam TS 2017: Lead, cadmium and mercury residues in the edible offal of sheep and goat with a special reference to their public health implications. Int J Adv Res **5**: 189-199

Demirbaş X, Erduran N 2017: Concentration of selected heavy metals in brown hare (*Lepus europaeus*) and wild boar (*Sus scrofa*) from central Turkey. Balkan J Wild Res **4**: 26-33
European Food and Safety Authority 2012: Scientific opinion on the risk for public health related to the presence of mercury and methylmercury in food. EFSA Journal **10**: 2985
European Commission 2022: Commission delegated regulation (EU) 2022/931 of 23 March 2022 supplementing Regulation (EU) 2017/625 of the European Parliament and of the Council by laying down rules for the performance of official controls as regards contaminants in food. Off J EU **L162**: 7-12
European Commission 2022: Commission implementing regulation (EU) 2022/932 of 9 June 2022 on uniform practical arrangements for the performance of official controls as regards contaminants in food, on specific additional content of multi-annual national control plans and specific additional arrangements for their preparation. Off J EU **L162**: 13-22
European Commission 2023: Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006. Off J EU **L119**: 103-157
European Parliament and the Council of the European Union 2017: Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products, amending Regulations (EC) No 999/2001, (EC) No 396/2005, (EC) No 1069/2009, (EC) No 1107/2009, (EU) No 1151/2012, (EU) No 652/2014, (EU) 2016/429 and (EU) 2016/2031 of the European Parliament and of the Council, Council Regulations (EC) No 1/2005 and (EC) No 1099/2009 and Council Directives 98/58/EC, 1999/74/EC, 2007/43/EC, 2008/119/EC and 2008/120/EC, and repealing Regulations (EC) No 854/2004 and (EC) No 882/2004 of the European Parliament and of the Council, Council Directives 89/608/EEC, 89/662/EEC, 90/425/EEC, 91/496/EEC, 96/23/EC, 96/93/EC and 97/78/ EC and Council Decision 92/438/EEC (Official Controls Regulation). Off J EU **L95**: 1-142
European Parliament and the Council of the European Union 2005: Regulation (EC) No 396/2005 of the European parliament and of the Council of 23 February 2005 on maximum residue levels of pesticide in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC. Off J EU **L70**: 1-4021
Hu H, Lin H, Zheng W, Tomanicek SJ, Johs A, Feng X, Eliasm DA Liang L, Gu B 2013: Oxidation and methylation of dissolved elemental mercury by anaerobic bacteria. Nat Geosci **6**: 751-754
Kenšová R, Kružíková K, Svobodová Z 2012: Mercury speciation and safety of fish from important fishing location in the Czech Republic. Czech J Food Sci **30**: 276-284
MacLachlan DJ, Budd K, Connolly J, Derric J, Penrose L, Tobin T 2016: Arsenic, cadmium, cobalt, copper, lead, mercury, molybdenum, selenium and zinc concentrations in liver, kidney and muscle in Australian sheep. J Food Compos Anal **50**: 97-107
Maršálek P, Svobodová Z, Randák T 2006: Total mercury and methylmercury contamination in fish from sites along the Elbe River. Acta Vet Brno **75**: 579-585
Mustaq A, Sajjad A, Ismail T, Ali O 2024: Heavy metals accumulation in the meat, kidney and liver of cattle, broilers and goats sold in Quetta, northwestern city of Balochistan, Pakistan. Brit Poultry Sci **65**: 740-750
Nawrocka A, Durkalec M, Szkoda J, Filipek A, Kmiecik M, Żmudzki J, Posyniak A 2020: Total mercury levels in the muscle and liver of livestock and game animals in Poland 2009-2018. Chemosphere **258**: 127311
Novotná Kružíková K, Široká Z, Jurajda P, Harustiakova D, Smolikova Z, Kubicek M Svobodová Z 2023: Total mercury content in selected tissues of common carp (*Cyprinus carpio*) pond in the Czech Republic. Acta Vet Brno **92**: 419-425
Novotna Kruzikova K, Siroka Z, Jurajda P, Harustiakova D, Smolikova, Z, Kubicek M, Svobodová Z 2022: Mercury content in fish from drinking-water reservoirs in the Morava River Basin (Czech Republic). Environ Sci Pollut Res **29**: 17394-17405
Pathak SK, Bhowmik MK 1998: The chronic toxicity of inorganic mercury in goats: clinical signs, toxicopathological changes and residual concentrations. Vet Res Commun **22**: 131-138
Rudy M 2009: The analysis of correlations between the age and the level of bioaccumulation of heavy metals in tissues and the chemical composition of sheep meat from the region in SE Poland. Food Chem Toxicol **47**: 1117-1122
Simpson VR, Stuart NC, Munro R, Hunt A, Livesey CT 1997: Poisoning of dairy heifers by mercurous chloride. Vet Rec **140**: 549-552
Stoev S, Lazarova S 1998: Morphological investigations in experimental cases of mercuric poisoning in sheep. Vet Arhiv **68**: 163-171
Svoboda M, Vlasakova V, Harustiakova D, Illek J, Staffa A, Vasek J, Novotna Kruzikova K, Cahova J, Svobodova Z 2025: Multi-year study monitoring the mercury content in the tissues of cattle sampled in the Czech Republic between 2014 and 2023. Vet Med Czech **70**: 307-312
Svoboda M, Bureš J, Drápal J, Geboliszová K, Haruštiaková D, Nepejchalová L, Skočovská, M, Svobodová Z, 2021: A survey of mercury content in pig tissues carried out in the Czech Republic during years 2015–2019. Acta Vet Brno **90**: 287-293
World Health Organization 2003: Elemental mercury and inorganic mercury compounds: Human health. Geneva: World Health Organization. Available at: https://iris.who.int/bitstream/handle/10665/42607/9241530502.pdf