Long-term study on cadmium concentrations in the tissues of kids and goats in the Czech Republic (Central Europe)

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Abstract

This study focused on evaluating the cadmium (Cd) concentration in edible parts of goats and kids using data from the monitoring conducted by the State Veterinary Administration in the Czech Republic in 1993–2023. Over a thirty-year period, a total of 26 goats and 4 kids were analysed for Cd in kidney, liver, and muscle tissues. In goats, a higher mean Cd content was found in kidneys (0.358 ± 0.091 mg/kg) and liver (0.100 ± 0.022 mg/kg) compared to muscles (0.005 ± 0.001 mg/kg) (P = 0.006 and P = 0.002, respectively). In kids, the Cd content was 0.009 ± 0.002 mg/kg, 0.012 ± 0.003 mg/kg, 0.005 ± 0.001 mg/kg in the liver, kidneys, and muscle, respectively. The Cd content in both the liver and kidneys differed significantly between kids and goats, being higher in goats (P = 0.004 and P = 0.007, respectively). Regulation 2023/915 does not set a maximum limit for Cd content in goat liver, kidneys, and muscle for human consumption, but the State Veterinary Administration compares the results with the 'action limits' which are the same as for sheep, according to the aforementioned regulation. Although Cd was detected in all examined samples, the 'action limit' for human consumption in kids was not exceeded in any sample. In goats, it was exceeded in four of the 26 kidney samples (15% of samples). It is concluded that the consumption of goat meat is not potentially risky to human health but active surveillance is necessary to protect public health.

Caprine, heavy metals, kidney, liver

Cadmium (Cd) is a cumulative toxic metal with important health implications for both humans and animals (Abd Elnabi et al. 2023). General population is exposed to Cd by consumption of contaminated food and water as well as by inhalation of fumes or smoke (Andrée et al. 2010). Cadmium can enter the diet of goats through various environmental and agricultural pathways (Li et al. 2019). The primary routes by which Cd can contaminate goat feed include soil contamination, water contamination, feed contamination and atmospheric deposition. Cadmium is mainly accumulated in leaves and shoots, then in inflorescences of different plant species (Bosiacki 2008). Since goats are herbivores, their main source of Cd intake is through plant consumption. Cadmium can be found in various parts of the plants, including leaves, stems, and fruits, which are consumed by goats as part of their diet. Goats as grazing animals can thus be good indicators of general environmental pollution, according to Okoye and Ugwu (2010).

Cadmium accumulates in animal tissues. After absorption, Cd is transported by blood to the liver where it forms a complex with metallothionein. In the kidneys, the cadmium-metallothionein complex is filtered in the glomeruli and thereafter reabsorbed in the renal tubules (Järup et al. 1998). Therefore, Cd accumulates mainly in the liver and kidneys.

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The uptake of Cd represents a potential threat to human health. In the kidneys, Cd can cause renal dysfunction upon reaching certain concentrations. Charkiewicz et al. (2023) stated that Cd interferes with the metabolism of calcium, magnesium, iron, zinc and copper in cells. Several studies have shown an increased risk of osteoporosis even at low-level Cd exposure (Kazantzis 2004). Some studies show interference with the parathyroid hormone or kidney enzymes which are involved in the activation of vitamin D (Akesson et al. 2006). The parathyroid hormone has an important role in calcium homeostasis, as it stimulates vitamin D activation in the kidneys, increases renal calcium reabsorption in the distal tubules and affects bone cells such as osteoblasts, osteoclasts and stromal cells (Potts 2005).

The aim of this study was to evaluate the content of Cd in the tissues of goats using data from the monitoring conducted by the State Veterinary Administration between 1993 and 2023 in the Czech Republic (Central Europe) and compared with other animals and other countries.

Materials and Methods

Samples

Data taken from the monitoring of foreign substance concentrations conducted by the State Veterinary Administration of the Czech Republic were used for this study. The monitoring is carried out in accordance with the Council Directive 96/23/EC and from January 2023 also in accordance with the Regulation (EU) 2017/625 of the European Parliament and of the Council and Commission delegated regulation (EU) 2022/931 and Commission implementing regulation (EU) 2022/932. Samples of liver (25 goats and 4 kids), kidney (26 goats and 4 kids), and muscle (26 goats and 3 kids) were analysed for Cd content. The goats were 2 to 4 years old and the kids were about 2 months old.

The analyses were conducted in the laboratories of the State Veterinary Institutes in the Czech Republic, which are accredited according to ČSN EN ISO/IEC 17025:2018. All methods are validated and laboratories regularly participate in control tests in laboratory proficiency testing programs (State Veterinary Administration 2024).

A detailed description of the Cd measurement method can be found in the study by Svoboda et al. (2020). In the case of Cd value below the detection limit, half of the detection limit was used for the calculation.

Statistical analysis

The differences in the Cd content between liver, kidney, and muscle and between kids and goats were analysed using repeated measures ANOVA followed by multiple *t*-tests with Bonferroni correction to identify differences between sample groups. $P < 0.05$ was considered significant in all tests. Data manipulation and statistical analysis were performed using Statistica, version 14 (TIBCO Software Inc.).

Results

The content of Cd in goat tissues was examined as part of the monitoring performed by the State Veterinary Administration of the Czech Republic in the last 30 years. The highest number of samples was taken in 1996 (5 samples for all tissues), 2 pieces were taken in 1994, 2003, and 2005, and in other years, there was 0 or 1 sample for Cd analysis.

The Cd content varied from 0.002 to 0.018 mg/kg in kids and ranged from 0.002 to 1.612 mg/kg in goats. The highest mean content of Cd for goats was found in the kidney, followed by the liver, and the lowest mean was found in the muscle (Table 1). In the case of kids, the highest mean was also found in the kidney, followed by the liver, with the lowest content found in the muscle (Table 1).

The Cd concentration was significantly affected by the tissue (repeated measures ANOVA: the effect of tissue: $F[2,52] = 10.638$; $P < 0.001$), the effect of age category (kids/goats) was not confirmed in the complex model (repeated measures ANOVA: the effect of age category: $F[1,26] = 2.255$; $P = 0.145$). A more detailed comparison of sample groups revealed significant differences between tissues as well as between kids and goats. In goats, significant differences in Cd concentration were found between liver and muscle ($P = 0.002$) and between kidney and muscle ($P = 0.006$). No difference in Cd content was

found between liver and kidney (P = 0.103). In kids, differences between tissues were not significant (P > 0.05) (Table 1). The Cd content in both the liver and kidney differed significantly between kids and goats, being higher in goats (P = 0.004 and P = 0.007; Table 1).

Table 1. The cadmium content in the liver, kidney, and muscle tissues of kids and goats.

Animals	Tissue	N	Median (mg/kg)	Mean ± SEM (mg/kg)
Kids	Liver	4	0.009	$0.009 \pm 0.002^{A,a}$
	Kidney	4	0.013	$0.012 \pm 0.003^{A,a}$
	Muscle	3	0.005	$0.005 \pm 0.001^{A,a}$
Goats	Liver	25	0.054	$0.100 \pm 0.022^{A,b}$
	Kidney	26	0.175	$0.358 \pm 0.091^{A,b}$
	Muscle	26	0.005	$0.005 \pm 0.001^{B,a}$

SEM : standard error of the mean

[A,B] The cadmium concentration in different tissues followed by the same uppercase superscript did not differ significantly (shown separately for kids and goats).

[a,b] The cadmium concentration in kids and goats followed by the same lowercase superscript did not differ significantly (shown separately for liver, kidney, and muscle).

Discussion

Cadmium contamination affects various animal species, including livestock, and its accumulation in tissues can pose significant health risks. To ensure an effective protection of public health, food containing contaminants exceeding the maximum concentrations should not be used for human consumption.

Thus, a maximum level for Cd content in tissues has been set for bovines, pigs, poultry, horses and fishes, but not for goats (Regulation 2023/915). Although there is a limit set for Cd content in sheep, no such limit exists for goats. Where limits have not yet been set for some substances, the State Veterinary Administration uses ‘action limits’. Where concentrations exceed this limit, it is desirable to search for the source of contamination and take measures to reduce or eliminate it. An action limit for Cd in goats is the same as for Cd in sheep and is based on Commission Regulation (EU) 2023/915 which states 0.05 mg/kg for muscle, 0.5 mg/kg for liver and 1.0 mg/kg for kidneys.

Although Cd was detected in all examined samples, the action limit for human consumption in kids was not exceeded in any sample; however, in goats, it was exceeded in four out of 26 kidney samples, i.e. in 15% of samples. These individual animals also had elevated liver Cd concentrations, but they did not exceed the action limit for liver.

Comparison with other animals

In the Czech Republic, previous studies of Cd content were focused on pigs (Svoboda et al. 2020), cattle (Drapal et al. 2021), and sheep (Svobodova et al. 2024). These studies demonstrated that the Cd content is different in animals of different species. The lowest Cd content in kidneys was found in calves (0.06 mg/kg) and lambs (0.061 ± 0.013 mg/kg), followed by pigs (0.124 ± 0.005 mg/kg) and young cattle (0.24 mg/kg). Higher values in kidneys were found for goats (0.655 ± 0.091 mg/kg, our results), sows (0.361 ± 0.032 mg/kg) and cows (0.64 mg/kg). The highest values of Cd were detected in sheep (1.255 ± 0.204 mg/kg).

Obeid et al. (2016) focused on the Cd concentrations in internal organs of lambs, cattle, and goats from Lebanon. The authors concluded that cattle tissues in general showed the lowest concentration of Cd in comparison to goats and sheep. They have pointed out the fact

that cows are often raised indoors whereas goats and lambs are raised outdoors in pastures. This could mean that goats and lambs are more at risk of higher exposure to toxic metals.

The different size of animals can also play a role in Cd accumulation. Our results showed that Cd concentrations, both in the liver and kidneys, differ significantly between kids and goats, being higher in goats. Cadmium is a cumulative substance that builds in the body over time. Adult goats are exposed to environmental sources of Cd for a longer period than kids, leading to higher accumulation in their tissues. Goats consume more food and spend more time grazing compared to kids, which subsequently increases their intake of potentially contaminated soil, plants, and water.

Age seems to be an important factor also for cattle. Drapal et al. (2021) reported a significantly higher mean Cd concentration in the kidneys and liver of bovines over two years of age compared to the mean Cd concentration in the kidneys and liver of young bovines under two years of age. Also, a significant positive correlation between the Cd concentration in kidneys and the age of cattle was found (Drapal et al. 2021).

Cadmium in the kidneys

Kidneys are the main storage organ of Cd both in animals and humans (Chan et al. 2004; Oing et al. 2021). This knowledge is in line with our results, where the mean Cd concentration in goats was the highest in the kidneys, followed by the liver, and the lowest in the muscle. In kids, the difference between the liver and kidney Cd contents was not significant.

An experiment conducted by Haneef et al. (1998) showed that the level of Cd in the blood increased after oral ingestion of Cd and that the highest Cd concentration was found in the kidneys compared to the liver. Tomovic et al. (2015) from Serbia published a lower value of Cd concentration in male goats compared to our study (kidneys 0.114 ± 0.013 mg/kg), and Njoga et al. (2021) also reported a lower Cd concentration of 0.06 ± 0.36 mg/kg in the kidneys of goats from Enugu State, Nigeria; their results were × 6 lower than our data. In contrast, Okoye and Ugwu (2010) reported a mean Cd content of 0.83±0.73 mg/kg in goat kidneys from Nigeria which has a higher value than our data. Furthermore, Obeid et al. (2016) presented × 2 higher mean Cd values (0.635 mg/kg) in the kidney of goats from Lebanon. This points to a difference in the environmental load across regions. Thus, the Cd content could be influenced by the environment where the animals live.

Cadmium in the liver

Our results showed that the second highest concentration of Cd was found in the liver. This is in agreement with Tomovic et al. (2015) who reported that the second highest Cd content was found in the nine edible liver samples taken from male goat kids in Serbia. Our results are also similar to the Cd content in the study by Obeid et al. (2016), where the mean Cd concentration goats was 0.133 mg/kg. While Njoga et al. (2021) published a very low Cd concentration (0.02 ± 0.00 mg/kg) in goat carcasses processed for human consumption in South-Eastern Nigeria, Okoye and Ugwu (2010) reported a higher Cd content in the liver of goats from Nigeria (0.35 ± 0.36 mg/kg). High Cd accumulation in the liver is also found to be directly related to its function as an excretory organ.

Cadmium in the muscle

The lowest mean Cd content was found in the muscle of both goats and kids, which is consistent with the findings of Njoga et al. (2021) (0.02 ± 0.00 mg/kg), Obeid et al. (2016), and Nkansah and Ansah (2014) (0.018 ± 0.002 mg/kg in chevon from Ghana). In light of our results in combination with the results from previous studies, it is apparent that the consumption of goat meat is the least risky in terms of Cd content compared to the consumption of goat kidneys or liver. From the point of view of Cd accumulation, goat meat is not potentially risky to human health.

Cadmium content in the tissues of goats is mostly found in the kidneys, followed by the liver, and the least amount of Cd is found in the muscle. The results available for the period from 1993 to 2023 show that there was more Cd in goats compared to kids, due to the accumulation of Cd over time. Only 15% exceeded the action limit. Active surveillance is necessary to protect public health. These findings highlight the need to monitor and control Cd concentrations in the environment to prevent food chain contamination and to safeguard both animal and human health.

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