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# MERCURY CONTENT IN THE WILD EDIBLE *LECCINUM* MUSHROOMS GROWING IN SLOVAKIA: ENVIRONMENTAL AND HEALTH RISK ASSESSMENT

*Natália Čeryová[1], Ivona Jančo[2], Marek Šnirc*[1], Judita Lidiková[1], Rastislav Sabo[3], Theodorus Wassenaar[4], Alexander Meroro[4], Hilma Amwele[4], Július Árvay[1]*

***Address(es):*** Ing. Marek Šnirc, PhD.
[1] Slovak University of Agriculture in Nitra, Faculty of Biotechnology and Food Sciences, Institute of Food Sciences, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic.
[2] Slovak University of Agriculture in Nitra, AgroBioTech Research Centre, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic.
[3] University of Veterinary Medicine and Pharmacy in Košice, Department of Pharmacology and Toxicology, Komenského 73, 041 81, Košice, Slovak Republic.
[4] Namibia University of Science and Technology, Faculty of Natural Resources and Spatial Sciences, Department of Agriculture and Natural Resources Sciences, 13 Jackson Kaujeua Street, Windhoek, Republic of Namibia.

*Corresponding author: marek.snirc@uniag.sk

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## ABSTRACT

The samples of 4 mushroom species from the genus *Leccinum* ((*Leccinum pseudoscabrum* (Kallenb.) Šutara, *Leccinum scabrum* (Bull.) Gray, *Leccinum duriusculum* (Schulzer ex Kalchbr.) Singer, and *Leccinum albostipitatum* den Bakker & Noordel) were picked from 6 forested areas of Slovakia in 2020 (Čačín – Jelšovec, Hliník and Hronom, Kurima – Taraš, Mníšek nad Popradom, Snina – Štefekovo, Žákylské pleso). Total mercury content in soil and mushroom parts was determined by cold-vapor AAS analyzer AMA 254. Mercury content in monitored soil samples ranged from 0.07 to 0.18 $mg.kg^{-1}$ DM. The limit value for Hg in soil ( 0.50 $mg.kg^{-1}$) was not exceeded. Mercury content in analyzed cap samples ranged from 0.41 to 7.52 $mg.kg^{-1}$ DM. Mercury content in analyzed stem samples ranged from 0.40 to 2.91 $mg.kg^{-1}$ DM. The EU limit value in edible mushrooms for Hg (0.75 mg $kg^{-1}$ FW) was exceeded in caps from Mníšek nad Popradom. Values of the bioconcentration factor indicate that *Leccinum* mushrooms are accumulators of Hg. The PTWI of Hg was not exceeded. The THQ of all samples was lower than 1. This means that the average consumption of mushrooms from this localities should not cause a serious risk to human health. However, the intake of Hg from other sources must also be taken into account.

**Keywords:** *Leccinum*; mushroom; mercury; health risk assessment; environmental risk assessment

## INTRODUCTION

Mushrooms are eaten as a delicacy, mainly for their distinctive texture and aroma. The consumption of edible cultivated and wild mushrooms has become more and more popular in recent years, even though they do not form a substantial part of the human diet. In many countries, edible wild mushrooms are collected for consumption, treatment of various diseases, or for recreational purposes **(Rasalanavho *et al.*, 2020; Money, 2017)**. The request for consumption of mushrooms is linked to various properties, such as attractive taste, the content of nutrients, and accessibility. Mushrooms are a valuable source of nutrients, as they contain proteins,carbohydrates, fiber, minerals, and. They are low in, fat, cholesterol, and calories **(Boonsong *et al.*, 2016; Kozarski *et al.*, 2015)**. Besides their nutritional value, they also exhibit antioxidant, antibacterial, antiviral, antifungal, anticancer, anti-inflammatory, antihypertensive, antiallergic, immunoregulatory, antidiabetic, and cholesterol-reducing properties **(Nowakowski *et al.*, 2021)**.

However, mushrooms can accumulate hazardous elements from the environment, which can represent a considerable risk of harm to the human health. Factors that influence the presence of risk elements in mushrooms are geographical location, environmental conditions, climate, and environmental stress. It is the content of risk elements in mushroom fruiting bodies that helps to indicate the degree of industrial pollution of the environment from various sources and therefore some use mushroom species as bioindicators. Higher concentrations of risk elements in the fruiting bodies of mushrooms are typically caused by soil pollution from anthropogenic sources. The concentration of risk elements in the mushroom is unevenly distributed, the larger part is always found in the cap, lower values are in the spores and the lowest values are recorded in the stems. Mushrooms are known to accumulate mercury, both inorganic and methylmercury, and can also convert inorganic mercury into methylmercury. The mechanisms of mercury absorption by the mycelium and further transfer and accumulation in the mushroom rely on the species, genus, or family of fungi **(Fischer *et al.*, 1995; Falandysz *et al.*, 2017; Ostos *et al.*, 2015; Melgar *et al.*, 2009)**. The soil-plant complex represents a very mobile system for mercury. Mercury enters fungi through the root system and is transported by it to other parts. How much Hg the fungi is able to take in with its system affects the interspecies distribution. Most often, Hg enters during respiration through assimilation organs **(Dias and Edwards, 2003).**

Mercury is a naturally occuring element found in soil, water, and air. Currently, it is one of the ten most dangerous chemicals for public health **(WHO, 2017)**. Mercury has the ability to harm almost all organs of the human body. It can have a toxic effect on the skin, nervous system, cardiovascular system, and also respiratory system. It causes gastrointestinal disturbances and neurological losses. Exposure to high concentrations of mercury damages the immune system and reproductive center. Poisoning is manifested by many symptoms, e.g. weakness, tremors, emotional changes, muscle atrophy, insomnia, and performance deficit. Mercury has proven mutagenic and teratogenic effects, so its content in food is limited. Elemental mercury is mobile, which means that it easily crosses the blood-encephalitic barrier and oxidizes in the skin and tissues **(Kim *et al.*, 2016; Kowalski and Frankowski, 2015)**. Methylmercury is a highly specific, irreversible inhibitor of selenoenzymes which are crucial in preventing and reversing oxidative damage in the body. Because of methylmercury's binding affinities for Se, Se can be considered protective against methylmercury toxicity. Therefore, Se-enriched diets can prevent methylmercury toxicity, and can even reverse some of its most severe symptoms **(Ralston & Raymond, 2010; Ralston & Raymond, 2018)**. Some wild-grown edible species of mushrooms are naturally rich in selenium **(Falandysz, 2008)**. Household treatments, such as short-time boiling, or blanching, have only a limited effect on decreasing mercury content in mushrooms (**Svoboda et al., 2002**; **Falandysz & Drewnowska, 2015).**

*Leccinum* is one of the most economically and ecologically important mushroom species **(Meng *et al.*, 2021)**. Mushroom fruiting bodies of the genus *Leccinum* are particularly popular for picking in Slovakia **(Olah *et al*. 2020)**. *Leccinum* species are easily recognized by their prominent, squamulose stipe ornamentation, brownish, whitish, or yellowish pores, and white context lacking color changes or staining gray, blue, or reddish tints when damaged **(Den Bakker & Noordeloos, 2005; Meng *et al.*, 2021).** *Leccinum spp.* is considered to be highly host-specific, the presence of the tree host partner is essential for most species **(Den Bakker *et al.*, 2004; Olah *et al.*, 2020).** They are commonly spread in the boreal, subarctic, and temperate regions **(Meng *et al.*, 2021).** They are rich in protein, fiber, minerals, such as K, P, and Mg, but also bioactive polyphenols, immunomodulatory and antitumor polysaccharides, and fatty acids, such as linoleic acid. They also showed to biocumulate Ag, Cd, Cu, Hg, Mn, Na, Rb, Zn **(Li *et al*., 2020; Mędyk et al., 2020; Pietrzak-Fiećko et al., 2020; Zheng *et al*., 2020; Falandysz et al., 2021)**. *Leccinum* species can be characterized by the presence of caffeic and gallic acid and absence of the pulvinic acids **(Binder & Besl, 2000).**

Taking into consideration the position of mushrooms in the human food chain, it is needed to monitor the content of risk elements in order to protect and preserve human health **(Borui and Qing, 2015)**. Therefore, the objective of our study was to determine mercury content in soil and *Leccinum* mushrooms from various localities of Slovakia and evaluate environmental and health risks.

## MATERIAL AND METHODS

### Sample preparation

The samples of 4 mushroom species from the genus *Leccinum* ((*Leccinum pseudoscabrum* (Kallenb.) Šutara, *Leccinum scabrum* (Bull.) Gray, *Leccinum duriusculum* (Schulzer ex Kalchbr.) Singer, and *Leccinum albostipitatum* den Bakker & Noordel), and topsoil samples (0 – 10 cm) were collected from 6 forested areas of Slovakia in 2020 (Hliník nad Hronom n = 21, Kurima – Taraš n = 25, Mníšek nad Popradom n = 28, Snina – Štefekovo = 19, Čačín – Jelšovec n = 18, Žákylské pleso n = 22).

All the samples were authenticated according to their microscopic and macroscopic characteristics by prof. Vladimír Kunca. Immediately after the picking, all mushrooms were cleaned up from any inorganic and organic debris and the bottom part of the stem was cut off. In laboratory, they were split into cap and stem, and cut into small fragments using a ceramic knife. Samples were then dried for 22 h to a constant weight at 45 °C in a Memmert laboratory dry heat oven with forced air circulation (Memmert GmbH & Co. KG, Schwabach, Germany). The dried samples were homogenized in the IKA A 10 basic mill (Werke GmbH & Co. KG, Staufen, Germany) and stored in polyethylene bags prior to further analysis.

### Mercury analysis

Total mercury content was determined by AMA 254 cold-vapor atomic absorption spectroscopy analyzer (Al-tec, Prague, Czech Republic). The limit of detection (LOD) for Hg was set at $1.5 \times 10^{-6}$ mg.kg$^{-1}$ DM and the limit of quantification (LOQ) at $4.45 \times 10^{-6}$ mg.kg$^{-1}$ DM. To check the accuracy and precision of the analytical method, two Certified Reference Materials (CRM) from the Institute for Reference Materials and Measurements were used. The recovery value for the loam soil (ERM-CC141), varied between 89.6 - 91.1 %, and for the Mussel tissue (ERM-CE278k), it varied between 92.2 - 93.3 %.

### Bioconcentration factor (BCF)

The bioconcentration factor (BCF) is used to determine the ability of organisms to uptake chemical element from the substrate to their body. BCF was expressed as the ratio of the Hg content in mushrooms and the Hg content in the soil. The BCF could be divided into three categories: BCF < 1 suggests excluder species, BCF = 1 suggests indicator species, and BCF > 1 suggests accumulator species **(Demková *et al*., 2021)**.

### Environmental risk assessment

*Contamination factor ($C_f^i$)*

The contamination factor is expressed as a ratio of the total heavy metal content in the soil and its reference value ($C_{RefS}$) **(Hakanson, 1980)**.

$$C_f^i = \frac{C_s^i}{C_{RefS}}$$

$C_s^i$ is the concentration of Hg in the soil and

$C_{RefS}$ is a reference value (0.08 mg.kg$^{-1}$) from the Soil Monitoring of the Slovak Republic according to **Linkeš (1997)**.

Based on the value of $C_f^i$, the level of soil contamination can be categorized as follows **(Hakanson, 1980)**:

$C_f^i \leq 1$: low contamination

$1 < C_f^i \leq 3$: moderate contamination

$3 < C_f^i \leq 6$: high contamination

$C_f^i \geq 6$: very high contamination

*Geoaccumulation index ($I_{geo}$)*

The Geoaccumulation index is used to quantify the degree of soil contamination **(Muller, 1969)**. $I_{geo}$ was calculated as follows:

$$I_{geo} = \log_2\left(\frac{C_s^i}{1.5 \times C_{RefS}}\right)$$

$C_s^i$ is the concentration of Hg in the soil and

$C_{RefS}$ is a reference value (0.08 mg.kg$^{-1}$) from the Soil Monitoring of the Slovak Republic according to **Linkeš (1997)**.

1.5 is a constant that is used due to potential variations in the underlying data (characteristics of the depositional feature, rock geology, and other influences).

Soil contamination determined based on the geoaccumulation index can be categorized as follows **(Muller, 1969)**:

$I_{geo} \leq 0$: uncontaminated,

$0 \leq I_{geo} \leq 1$: uncontaminated to moderately contaminated,

$1 \leq I_{geo} \leq 2$: moderately contaminated,

$2 \leq I_{geo} \leq 3$: moderately to highly contaminated,

$3 \leq I_{geo} \leq 4$: highly contaminated,

$4 \leq I_{geo} \leq 5$: highly to very highly contaminated,

$I_{geo} \leq 5$: very highly contaminated.

*Potential ecological risk factor ($E_r^i$)*

The potential ecological risk factor is used to assess the toxicity of monitored soils **(Hakanson, 1980)**. $E_r^i$ was calculated as follows:

$$E_r^i = T_r^i \times C_f^i$$

$C_f^i$ is the contamination factor

$T_r^i$ is the biological toxic factor of Hg (40).

The toxic factor should mainly provide information on the dangers for humans and possible ways of transporting toxic substances to humans.

Based on the $E_r^i$ value, soil can be categorized as follows **(Hakanson, 1980)**:

$E_r^i < 40$: low risk

$40 < E_r^i < 80$: moderate risk

$80 < E_r^i < 160$: high risk

$160 < E_r^i < 320$: very high risk

$E_r^i > 320$: extremely high risk

### Health risk assessment

*Provisional tolerable weekly intake (PTWI)*

Percentage of the provisional tolerable weekly intake (PTWI) was used to consider the potential risk of long-term consumption of edible mushrooms. The tolerable weekly intake for Hg per adult person weighing 70 kg was established at 0.28 mg per person per week **(JECFA, 2012)**. According to the Statistical Organization of the Slovak Republic (2021), the average consumption of mushrooms in Slovakia was 0.18 kg FW per person per week. Based on this data, the percentage of PTWI was calculated as follows:

$$\text{PTWI (\%)} = \frac{BS_{Hg} \times 0.18}{0.28} \times 100$$

$BS_{Hg}$ is the determined content of Hg in the sample (mg kg$^{-1}$ of fresh weight – 10 % of dry weight in mushrooms).

If the detected value was greater than 100%, the consumption of mushroom samples from the area is potentially hazardous.

*Target hazard quotient (THQ)*

The target hazard quotient (THQ) was used to evaluate the comprehensive dangers of long-term consumption of edible mushrooms. THQ is expressed as the ratio of toxic element exposure and the highest reference dose at which no adverse effects on human health are expected **(Demková *et al*, 2021)**. *THQ* was calculated as follows:

$$\text{THQ} = \frac{\text{Efr} \times \text{ED} \times \text{ADC} \times C_E}{\text{RfDo} \times \text{BW} \times \text{ATn}} \times 10^{-3}$$

*Efr* is the frequency of exposure (365 days)

*ED* is exposure duration (70 years)
*ADC* is an average daily consumption of fresh mushrooms (25.7 g/day)
$C_E$ is average Hg concentration in mushroom samples (mg kg$^{-1}$ of fresh weight – 10 % of dry weight in mushrooms)
*RfDo* is the oral reference dose for mercury (0.0003 mg/kg/day) **(Kalač, 2016)**
*BW* is the average body weight (70 kg)
*ATn* is the average exposure time (365 days ∗ 70 years = 25 550 days)
$10^{-3}$ is a factor considering the unit's conversion

If the THQ is lower than 1, non-carcinogenic health effects are not expected; if the THQ is bigger than 1, there is a serious possibility that adverse health effects can be experienced.

### Statistical analysis

Statistical analysis was performed using Jamovi software version 2.3.**9 (The jamovi project, 2021; R Core Team, 2021; Patil, 2018; Brunson, 2019; Koneswarakantha, 2019; Wickham *et al.*, 2018).** The normality of distribution verified, using the Shapiro–Wilk test, showed no normal distribution of the analyzed quantitative variables, therefore, the non-parametric ANOVA test (Kruskal-Wallis) and Dunn pairwise test with Holm correction were used for comparison of mercury content between the tested variables. Spearman correlation was used to determine the relationships between the fruiting body parts of the tested mushrooms and soil.

## RESULTS AND DISCUSSION

### Mercury content in the soil

The Hg contents in analyzed soil samples are presented in Table 1.

**Table 1** Mercury content (mg.kg$^{-1}$ DM) in the soils from the studied localities

| Locality | Median | SD | Min | Max | $C_f^i$ | $I_{geo}$ | $E_r^i$ |
|---|---|---|---|---|---|---|---|
| Hliník nad Hronom | 0.17 | 0.04 | 0.09 | 0.18 | 2.13 | 0.50 | 85.2 |
| Kurima - Taraš | 0.12 | 0.05 | 0.07 | 0.21 | 1.50 | 0.00 | 60.0 |
| Mníšek nad Popradom | 0.17 | 0.03 | 0.12 | 0.21 | 2.13 | 0.50 | 85.2 |
| Snina - Štefkovo | 0.07 | 0.01 | 0.05 | 0.08 | 0.88 | -0.78 | 35.2 |
| Čačín - Jelšovec | 0.18 | 0.01 | 0.16 | 0.21 | 2.25 | 0.58 | 90.0 |
| Žakýlske pleso | 0.08 | 0.01 | 0.06 | 0.10 | 1.00 | -0.58 | 40.0 |

SD – standard deviation, $C_f^i$ – contamination factor, $I_{geo}$ – geoaccumulation index, $E_r^i$ – potential ecological risk factor

Mercury content in analyzed soil samples ranged from 0.07 to 0.18 mg.kg$^{-1}$ DM. The Highest Hg content was determined in the samples from Čačín - Jelšovec, while the lowest Hg content was determined in the samples from the locality Snina - Štefkovo. The limit value of mercury for soils in Slovakia is set to 0.50 mg.kg$^{-1}$ DM. This limit was not exceeded in any soil. As shown in Figure 1., significant differences were observed between locality Mníšek nad Popradom and Snina – Štefkovo (p= 0.031), Snina – Štefkovo and Čašín – Jelšovec (p= 0.000413) and Čačín – Jelšovec and Žakýlske pleso (p= 0.001). The contamination factor of analyzed soil samples ranged from 0.88 to 2.25, which means that soils were contaminated low (Snina – Štefkovo) and moderate (Hliník nad Hronom, Kurima – Taraš, Mníšek nad Popradom, Čačín – Jelšovec, Žakýlske pleso).

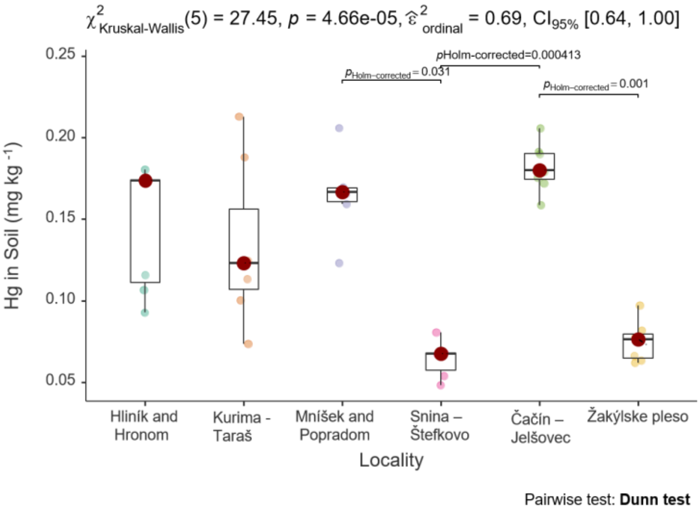


**Figure 1** Significant differences in soil mercury concentrations in mg kg$^{-1}$ DM, concerning localities. Note: The lowest data point presents a minimum value; the largest data point presents a maximum value; the middle value of the dataset presents the median, and the dots out of the box are outliers.

The Geoaccumulation index of analyzed soil samples ranged from -0.78 to 0.58, which means that soils were uncontaminated (Kurima - Taraš, Snina – Štefkovo, Žakýlske pleso) and uncontaminated do moderately contaminated (Hliník nad Hronom, Mníšek nad Popradom, Čačín – Jelšovec). Potential ecological risk factor of analyzed soil samples ranged from 35.2 to 90, which means that soils were low risk (Snina – Štefkovo), moderate risk (Kurima – Taraš, Žakýlske pleso), and high risk (Hliník nad Hronom, Mníšek nad Popradom, Čačín – Jelšovec). The composition and pollution of soils in Slovakia are largely affected by geochemical differences, wasteful exploitation of natural resources, several mining areas, and environmental loads **(Demková *et al.*, 2021)**. Soils in some studied regions are loaded by air pollution deposits **(Kunca *et al*. 2003)**.

### Mercury content in mushrooms

The Hg contents in analyzed mushroom samples are presented in Table 2. No significant differences were observed between individual species.

**Table 2** Mercury content (mg.kg$^{-1}$ DM) in the fruiting parts of mushrooms from the studied localities

| Part | Locality | Median | SD | Min | Max | $Q_{C/S}$ | BCF |
|---|---|---|---|---|---|---|---|
| Cap | Hliník nad Hronom | 0.69 | 0.86 | 0.39 | 0.86 | 1.21 | 4.97 |
| | Kurima - Taraš | 0.90 | 2.06 | 0.29 | 2.06 | 1.48 | 7.04 |
| | Mníšek nad Popradom | 7.52 | 7.95 | 5.49 | 7.95 | 2.58 | 45.04 |
| | Snina - Štefkovo | 0.42 | 0.96 | 0.25 | 0.96 | 1.05 | 7.42 |
| | Čačín - Jelšovec | 0.54 | 1.12 | 0.43 | 1.12 | 1.32 | 3.00 |
| | Žakýlske pleso | 0.41 | 0.71 | 0.22 | 0.71 | 1.17 | 5.17 |
| Stem | Hliník nad Hronom | 0.57 | 0.69 | 0.51 | 0.69 | 1.21 | 3.96 |
| | Kurima - Taraš | 0.61 | 1.15 | 0.07 | 1.15 | 1.48 | 4.98 |
| | Mníšek nad Popradom | 2.91 | 4.65 | 2.44 | 4.65 | 2.58 | 19.77 |
| | Snina - Štefkovo | 0.40 | 0.50 | 0.09 | 0.50 | 1.05 | 5.75 |
| | Čačín - Jelšovec | 0.41 | 0.95 | 0.25 | 0.95 | 1.32 | 2.12 |
| | Žakýlske pleso | 0.35 | 0.64 | 0.12 | 0.64 | 1.17 | 4.57 |

SD – standard deviation, $Q_{C/S}$ – translocation quotient, BCF – bioconcentration factor

Mercury content in analyzed *Leccinum* cap samples ranged from 0.41 to 7.52 mg.kg$^{-1}$ DM. The Highest Hg content was determined in the samples from the Mníšek nad Popradom, while the lowest Hg content was determined in the samples from the Žakýlske pleso. Mercury content in analyzed *Leccinum* stem samples ranged from 0.40 to 2.91 mg.kg$^{-1}$ DM. The Highest Hg content was determined in the samples from the Mníšek nad Popradom, while the lowest Hg content was determined in the samples from locality Žakýlske pleso.

The EU limit value in edible mushrooms (both cap and stem) for Hg is 0.75 mg kg$^{-1}$ FW. This limit was exceeded in caps from Mníšek nad Popradom. The translocation quotient ($Q_{C/S}$) ranged from 1.05 to 2.58. This means that higher Hg content was determined in the caps. This is in the agreement with other studies **(Falandysz *et al.*, 2007; Falandysz *et al.*, 2012; Krasińska and Falandysz, 2015; Falandysz, 2018; Mędyk *et al.*, 2018)**. The bioconcentration factor was bigger than 1 in all samples, which means that analyzed samples are accumulators of Hg. This is in agreement with other authors (**Jarzyńska & Falandysz, 2012; Falandysz *et al.*, 2012; Falandysz & Drewnowska, 2015; Mędyk *et al.*, 2018; Falandysz, 2018; Demková *et al.*, 2020)**. The higher content of Hg in mushrooms from Mníšek and Popradom could be caused by the later maturity of samples, or by air pollution. Windborn transport of air pollution and its serious consequences on environmental quality, even in localities without direct pollution sources have been confirmed **(Li *et al.*, 2017)**.

**Demková *et al.* (2020)** reported 5.77 mg Hg.kg$^{-1}$ DM, with a BCF value of 1.33, in *Leccinum pseudoscabrum* from the former mining area Nižná Slaná (Slovakia).

**Falandysz *et al*. (2015)** determined that the Hg content in *Leccinum* caps and stems from China ranged from 0.54 to 4.8 mg.kg$^{-1}$ DM and 0.32 to 2.8 mg.kg$^{-1}$ DM respectively, and in *Leccinum* caps and stems from Poland ranged from 0.18 to 1.5 mg.kg$^{-1}$ DM and from 0.036 to 0.65 mg.kg$^{-1}$ DM respectively. BCF in *Leccinum* caps and stems from China ranged from 2.3 to 35, and from 1.3 to 10 respectively, and in *Leccinum* caps and stems from Poland ranged from 3.0 to 54.0, and from 0.59 to 60.0 respectively.

**Falandysz *et al*. (2012)** analyzed *Leccinum aurantiacum* collected in sites across Poland, and reported 0.27 to 1.3 mg Hg.kg$^{-1}$ DM in caps, with BCF in the range from 9 to 130, and 0.19 to 0.58 mg Hg.kg$^{-1}$ DM in stems, with BCF in the range from 5 to 64. **Falandysz *et al*. (2007)** reported Hg content in the *Leccinum scabrum* collected in Poland in the range from 0.25 to 0.48 mg.kg$^{-1}$ DM. **Yang *et al*., (2016)**

reported Hg content in the caps and stems of *Leccinum* mushrooms collected in Yunnan Province (China) in the range of 0.54 – 4.80 mg.kg$^{-1}$ DM and 0.32-2.80 mg.kg$^{-1}$ DM, respectively. The values of the cap and stem total Hg content ratio ($Q_{C/S}$) of the samples from the same area were greater than 1 in all samples. **Krasińska and Falandysz, 2015** reported the Hg content in caps of *Leccinum griseum* collected in sites across Poland ranged from 0.12 to 2.7 mg kg$^{-1}$ DM, with BCF in the range from 4.6 to 24, and in stems ranged from 0.056 to 0.99, with BCF in the range from 3.2 to 11. **Falandysz and Bielawski (2001)** reported Hg content in the *Leccinum* caps collected near the Augustow (Poland) in the range from 0.12 to 2.4 mg.kg$^{-1}$ DM, and in stems in the range from 0.061 to 1.8 mg.kg$^{-1}$ DM. **Mędyk *et al* (2018)** determined Hg content in the caps and stems of *Leccinum scabrum* from the Augustow Primeval Forest (Poland) in the range 0.12 – 1.5 mg.kg$^{-1}$ DM, and 0.061 – 0.77 mg.kg$^{-1}$ DM respectively, with BCF in the range 4.3–27, and 2.4–17 respectively. **Falandysz (2018)** reported Hg content in the caps of *Leccinum scabrum* from lowland locations in central Europe in the range from 0.42 to 0.54 mg.kg$^{-1}$ DM, with BCF in the range from 14 to 19, and in the stems 0.17 to 0.34 mg.kg$^{-1}$ DM with BCF in the range from 6 to 9.3.

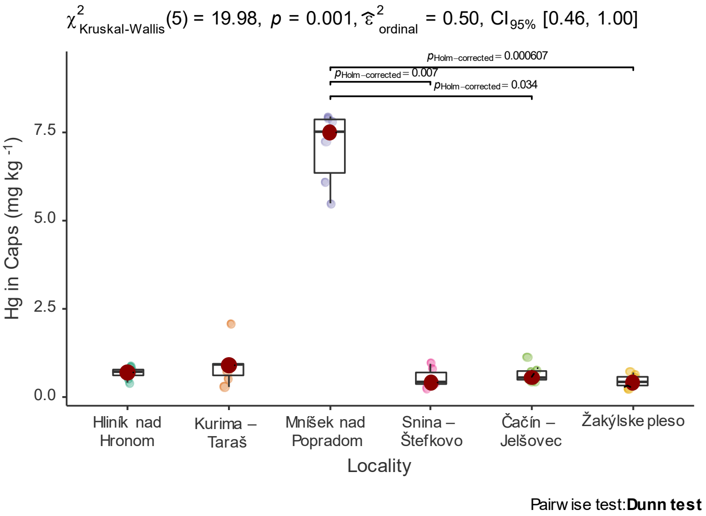


**Figure 2** Significant differences in cap mercury concentrations in mg kg$^{-1}$ DW, concerning localities. Note: The lowest data point presents a minimum value; the largest data point presents a maximum value; the middle value of the dataset presents the median, and the dots out of the box are outliers.

As shown in Figure 2., significant differences were observed between cap samples from locality Mníšek nad Popradom and Snina – Štefkovo (p= 0.007), Čačín – Jelšovec (p= 0.034) and Žakýlske pleso (p= 0.000607).

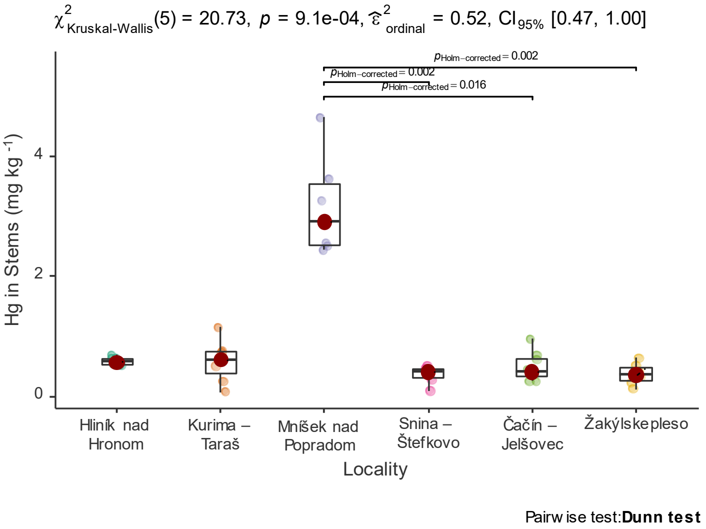
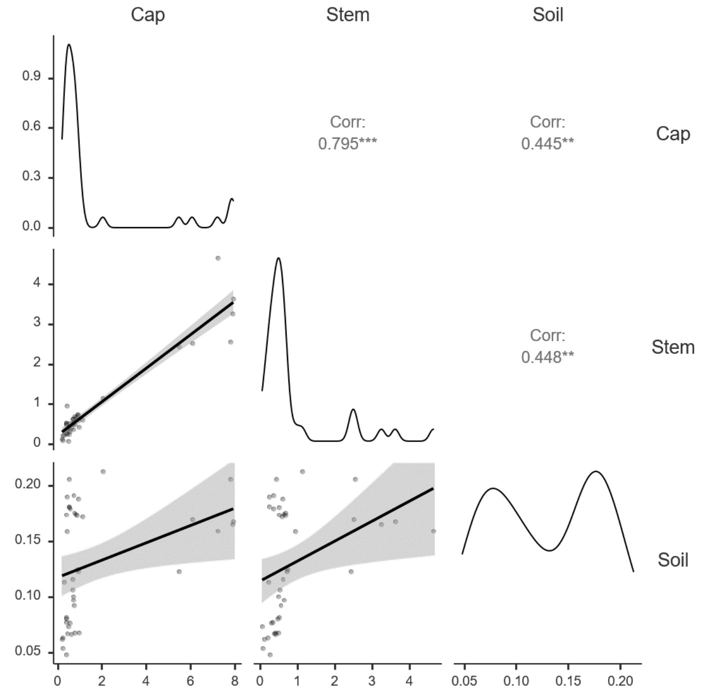


**Figure 3** Significant differences in stem mercury concentrations in mg kg$^{-1}$ DW, concerning localities.

Note: The lowest data point presents a minimum value; the largest data point presents a maximum value; the middle value of the dataset presents the median, and the dots out of the box are outliers.

As shown in Figure 3., significant differences were observed between cap samples from locality Mníšek nad Popradom and Snina – Štefkovo (p= 0.002), Čačín – Jelšovec (p= 0.016) and Žakýlske pleso (p= 0.002).



** p <0.01; *** p < 0.001

**Figure 4.** Correlations between analyzed samples

As shown in Figure 4., a high positive correlation (p < 0.001) was determined between mercury content in cap and mercury content in stems. Positive correlations (p <0.01) were also determined between mercury content in soil and mercury content in mushrooms.

**Health risk assessment**

**Table 3** Health risks assessments

| **Locality** | **% PTWI Cap** | **% PTWI Stem** | **THQ Cap** | **THQ Stem** |
|---|---|---|---|---|
| Hliník nad Hronom | 4.46 | 3.64 | 0.085 | 0.069 |
| Kurima - Taraš | 5.75 | 3.90 | 0.110 | 0.074 |
| Mníšek nad Popradom | 48.3 | 18.7 | 0.920 | 0.356 |
| Snina - Štefkovo | 2.71 | 2.59 | 0.052 | 0.049 |
| Čačín - Jelšovec | 3.50 | 2.62 | 0.067 | 0.050 |
| Žakýlske pleso | 2.64 | 2.28 | 0.050 | 0.043 |

The percentage of provisional tolerable weekly intake of Hg, assuming consumption of 180 g of fresh mushrooms per week, for caps ranged from 2.64 % to 48.3 %, and for stems from 2.28 % to 18.7 %. Based on the results obtained, there is not a serious threat to humans if the mushrooms from the studied localities were consumed. The target hazard quotient (THQ) for caps ranged from 0.050 to 0.920, and for stems from 0.043 to 0.356. The THQ was lower than 1 in all samples. This could mean that no serious possibility of adverse health effects should be expected. However, consumption of the caps from the locality Mníšek nad Popradom should be limited.

## CONCLUSION

Based on the results, *Leccinum* mushrooms have the potential to accumulate mercury in their fruiting bodies, more in the caps. Therefore, it is important to collect mushrooms from low-risk localities. Average consumption of mushrooms from monitored localities should not pose a risk to adult consumers, however, the intake of Hg from other sources must also be considered. Further research on lowering mercury content by technological procedures is needed.

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