Pol. J. Environ. Stud. Vol. 22, No. 6 (2013), 1759-1765

Original Research

Cadmium and Lead in Wild Edible Mushrooms from the Eastern Region of Poland's 'Green Lungs'

Iwona Mirończuk-Chodakowska[1]*, Katarzyna Socha[2], Anna M. Witkowska[1], Małgorzata E. Zujko[1], Maria H. Borawska[2]

[1]Department of Food Commodities Science and Technology, Faculty of Health Sciences, Medical University of Bialystok, Szpitalna 37, 15-295 Białystok, Poland
[2]Department of Bromatology, Faculty of Pharmacy with the Division of Laboratory Medicine, Medical University of Bialystok, Mickiewicza 2D, 15-222 Białystok, Poland

Received: 17 April 2013
Accepted: 19 August 2013

Abstract

The aims of this study were to determine Cd and Pb contents in wild mushrooms from the eastern region of the "Green Lungs" of Poland (GLP), compare them to Cd and Pb contents in some popular species of cultivated mushrooms, and evaluate mushroom contribution to the daily intake of Cd and Pb. Trace elements were determined in 21 species of edible mushrooms: 18 species of wild mushrooms and 3 species of cultivated mushrooms.

The mean Pb contents in wild mushrooms ranged from 0.14 μg/g dry mass (DM) in *Tricholoma portentosum* to 2.61 μg/g DM in *Russula vinosa*, and for Cd from 0.10 μg/g DM in *Russula heterophylla* to 10.20 μg/g DM in *Boletus chrysenteron*. The Pb mean contents in cultivated mushrooms ranged from 0.03 μg/g DM in *Agaricus bisporus* to 0.12 μg/g DM in *Lentinus edodes*, and for Cd – from 0.09 μg/g DM in *Agaricus bisporus* to 1.20 μg/g DM *Pleurotus ostreatus*.

Wild mushrooms from the eastern GLP region is generally safe with regards to Pb intake. In contrast to Pb, the consumption of two species of wild mushrooms (*Rozites caperatus* and *Boletus chrysenteron*) may marginally exceed provisional tolerable monthly intake (PTMI) in temporary high consumers of these fungi, which pose a risk in Cd toxicity.

Keywords: cadmium, lead, wild edible mushrooms, cultivated mushrooms

Introduction

The area of the Green Lungs of Poland, which clusters regions of five provinces, is located in the northeastern territories of Poland. The area takes its name from the fact that it is free from big industry and is characterized by forest lands and low urbanization. The eastern area of GLP encompasses the territory of Podlaskie province.

Wild edible mushrooms are appreciated for their numerous culinary features like taste, aroma, texture, and flavor. Generally, mushrooms are considered a balanced food as they contain considerable amounts of nutrients, such as carbohydrates, proteins (all essential amino acids) and water-soluble vitamins, especially from the B-group, few fatty acids, energy, and lipids [1, 2]. Mushrooms are also good sources of macro- and microelements. But one must be aware that they are able to accumulate considerable amounts of toxic metals such as lead, cadmium, or mercury [3, 4]. Therefore, regular consumers of mushrooms are characterized by higher cadmium dietary exposure than from other foods [5].

*e-mail: iwona.mironczuk-chodakowska@umb.edu.pl

Lead and cadmium are metals with a tendency to cumulate in living organisms. Lead pollution of soils is observed mainly in industrial areas. Exposure to lead is related to a wide range of health effects, including reduced intellectual development in children and increased blood pressure and cardiovascular diseases in adults [6]. Cadmium is a natural constituent of earth crust. As a result of human activity, the amounts of cadmium in the soil increase. The main source of Cd exposure for non-smokers is food (90%), particularly cereals and vegetables. Exceeding cadmium can negatively affect kidney function and cause skeletal and reproductive disorders [6].

Mushrooms are not precise bioindicators of environmental exposure to heavy metals [7, 8]. A high variability of metal concentration was observed in mushrooms collected from the same areas [9]. Generally, mushrooms picked in uncontaminated areas are characterized by lower contents of heavy metals, when compared to mushrooms growing in contaminated soils. Heavy metal contents in mushrooms are largely dependent on their trophic pattern, physiology of mushroom species, area of sample collection, mushroom accumulation of other metals, and the distance from the pollution sources. Moreover, the age of mycelium and lag between fructification seem to be further factors affecting metals content [10]. Some mushroom species like *Boletus edulis* tend to accumulate metals due to the presence of Cd-binding proteins [11, 12].

The aims of this study were to determine Cd and Pb contents in wild mushrooms from the eastern GLP region, compare them to Cd and Pb contents in some popular species of cultivated mushrooms and evaluate mushroom, contribution to the daily intake of Cd and Pb. Trace elements were determined in 21 species of edible mushrooms: 18 species of wild mushrooms and 3 species of cultivated mushrooms.

Experimental Procedures

Twenty-one mushroom species were analyzed, including 3 species of cultivated mushrooms: *Pleurotus ostreatus*, *Agaricus bisporus,* and *Lentinus edodes*, and 18 wild growing mushrooms: *Armillaria mellea*, *Boletus badius*, *Boletus chrysenteron*, *Boletus edulis*, *Boletus subtomentosus*, *Cantharellus cibarius*, *Lactarius deliciosus*, *Leccinum aurantiacum*, *Leccinum scabrum*, *Macrolepiota procera*, *Rozites caperatus*, *Russula heterophylla*, *Russula vinosa*, *Suillus bovinus*, *Suillus grevillei*, *Suillus luteus*, *Tricholoma flavovirens*, and *Tricholoma portentosum*. The wild mushrooms were sampled in three specimens in six communal areas of Podlaskie Province (Fig. 1). Collected in distant places, three specimens of each mushroom species were analyzed. Mushrooms have been picked during the time period 2007-10. The samples were harvested in distant places so as to not originate from one mycelium. The purchased fruiting bodies were fully developed (size typical of each species) and non-verminated. Cultivated mushrooms from Polish cultivations were purchased at local food markets. Wild mushrooms were identified according to The Atlas of Mushrooms [13]. Mushroom fruiting bodies were cleaned and cut to pieces, then dried in an air-dryer to a constant mass, and afterward pulverized in a grinder. Dried samples were stored at room temperature in a desiccator. Approximately 0.300 g dried mushroom samples were taken for analysis. Four milliliters of concentrated nitric acid were added to the sample, which was than mineralized in an automatic microwave digestion system (Speedwave, Berghof, Germany). Lead and cadmium were assayed using inductively coupled plasma mass spectrometry (ICP-MS, NexION 300D Perkin Elmer, USA). The accuracy of the ICP-MS measurements was verified by determining metals in a certified reference material – Corn Flour INCT-CF-3 (Institute of Nuclear Chemistry and Technology INCT – Warsaw, Poland). Detection limits for lead and cadmium were as follows: 0.16 µg/l and 0.017 µg/l. Repeatability expressed as a coefficient of variation for lead (2.6%) and for cadmium (3.5%).

Contents of moisture were calculated for every mushroom sample and were given in percentages. Average Pb and Cd contents were expressed as µg/g dry mass (DM) and fresh mass (FM). Daily intakes of Cd and Pb from mushrooms were expressed as mg/100g FM.

Fig. 1. A map of the study area.

Table 1. Lead and cadmium contents tested in wild edible mushrooms.

No.	Mushrooms	n	Moisture %	Pb		Cd	
				µg/g DM	µg/g FM	µg/g DM	µg/g FM
1.	*Armillaria mellea*	3	86.57-91.76	0.16±0.13	0.02±0.02	4.53±1.20	0.53±0.24
2.	*Boletus badius*	3	89.23-93.55	0.59±0.37	0.05±0.03	0.51±0.24	0.05±0.03
3.	*Boletus chrysenteron*	3	93.44-94.38	0.15±0.05	0.01±0.00	10.20±4.01	0.61±0.22
4.	*Boletus edulis*	3	90.72-92.04	0.47±0.38	0.04±0.03	3.70±1.53	0.31±0.12
5.	*Boletus subtomentosus*	3	88.39-92.62	0.30±0.18	0.03±0.01	0.91±0.27	0.09±0.04
6.	*Cantharellus cibarius*	3	91.50-93.17	0.47±0.15	0.04±0.01	0.41±0.14	0.03±0.01
7.	*Lactarius deliciosus*	3	90.79-92.11	0.34±0.17	0.03±0.02	2.79±0.65	0.24±0.04
8.	*Leccinum aurantiacum*	3	90.50-91.53	0.38±0.20	0.03±0.02	0.44±0.26	0.04±0.03
9.	*Leccinum scabrum*	3	83.91-91.84	0.37±0.22	0.05±0.04	0.79±0.43	0.11±0.05
10.	*Macrolepiota procera*	3	82.00-87.06	2.08±1.80	0.30±0.21	1.76±0.78	0.26±0.09
11.	*Rozites caperatus*	3	91.15-93.26	0.37±0.18	0.04±0.02	9.29±2.93	0.68±0.20
12.	*Russula heterophylla*	3	92.50-94.83	2.03±1.70	0.20±0.23	0.10±0.06	0.004±0.001
13.	*Russula vinosa*	3	86.27-90.36	2.61±2.06	0.18±0.19	0.32±0.12	0.03±0.01
14.	*Suillus bovinus*	3	82.91-85.73	0.27±0.15	0.04±0.02	0.22±0.09	0.03±0.01
15.	*Suillus grevillei*	3	92.38-95.73	0.21±0.09	0.01±0.01	2.28±0.56	0.13±0.01
16.	*Suillus luteus*	3	91.32-94.22	0.33±0.03	0.02±0.00	0.58±0.27	0.04±0.01
17.	*Tricholoma flavovirens*	3	86.30-92.09	1.39±0.62	0.15±0.11	1.11±0.37	0.11±0.03
18.	*Tricholoma portentosum*	3	91.59-93.36	0.14±0.13	0.01±0.01	1.79±0.34	0.13±0.02

To identify the high metal-contaminated mushrooms species, a sum of chemical Pb and Cd equivalents was calculated as follows: a molecular weight of each analyzed metal was divided by its valence, and then the mean content of each metal in mushrooms was divided by its equivalent. Finally, both metals in mushrooms were added up.

Descriptive statistics (minimum, mean, maximum, and standard deviation) were computed for the concentrations of lead and cadmium in fungal species. Microsoft Excel 2010 Software was applied for data computation.

Results and Discussion

The average moisture contents of the studied mushrooms were 90.8% FM, ranging between 82% and 95.7% (Table 1). These percentages were similar to values found in recent reports [14, 15].

Lead and Cadmium Contents in Wild Mushrooms

The average concentrations of lead (Pb) and cadmium (Cd) in wild and commercial mushrooms species expressed as µg/g dry mass (DM) and fresh mass (FM) are given in Table 1.

The highest Pb level was observed in *Russula vinosa* – 2.6 µg/g DM. Lead levels in the remaining wild mushrooms ranged from 0.1 µg/g DM in *Tricholoma portentosum* to 2.1 µg/g DM in *Macrolepiota procera*. Pb values reported earlier in the literature were 0.1-13.4 µg/g DM in Poland [16] and 0.2-1.3 µg/g DM in unpolluted areas of other countries [3], while these from the polluted areas reached hundreds µg/g DM [17, 18]. According to other reports published, lead concentration in mushrooms from unpolluted areas may vary between <0.5 µg/g and 5 µg/g [19] with an exception of a few mushroom species with high bioaccumulation potential, such as *Macrolepiota procera* for instance. As some authors reported [8, 20], this latter species demonstrates relatively high background levels of lead, as evidenced by the high Pb concentration in mushrooms obtained from unpolluted areas. Despite the generally high concentration of lead in *Macrolepiota procera* in our own study, the Pb content is still below the tolerance limit of 3.0 µg/g DM set for cultivated mushrooms in EU [20]. Mean lead content in *Macrolepiota procera* in a Spanish study was similar to our result [21]. In conclusion, *Macrolepiota procera* from Podlaskie Province was characterized by very low contents of Pb, but it should be mentioned that *M. procera* may accumulate other metals, i.e. mercury [3], which was not tested in this study.

Table 2. Pb and Cd contents in the cultivated mushrooms assayed.

No.	Mushrooms	n	Moisture %	Pb		Cd	
				µg/g DM	µg/g FM	µg/g DM	µg/g FM
1.	*Agaricus bisporus* (white)	3	91.48-92.54	0.03±0.01	< 0.01	0.09±0.04	0.01±0.00
2.	*Lentinus edodes*	3	90.94-90.76	0.12±0.05	0.01±0.00	0.42±0.09	0.04±0.01
3.	*Pleurotus ostreatus*	3	90.93-91.91	0.03±0.01	< 0.01	1.20±0.34	0.10±0.03

Among the mushrooms studied, *Russula vinosa* exhibited the highest lead contents (2.6±2.1 µg/g DM). There is a lack of literature data available, however, regarding Pb content in this species for comparison purposes, possibly because *Russula vinosa* is not a popular consumed species.

The lowest Pb values in the present study were found in *Tricholoma portentosum* and *Boletus chrysenteron* (0.1 µg/g DM and 0.2 µg/g DM, respectively). These values for *Tricholoma portentosum* were similar (<0.6 µg/g DM) to other studies [21], but differed for *Boletus chrysenteron* from those reported in the literature, which were lower (0.05 µg/g DM) [22] or higher (2.5 µg/g DM) [16] than our data. As compared to the EU limits for Pb – 0.3 µg/g FM, Pb concentrations in wild edible mushrooms in the present study were generally low [23].

The minimum and maximum levels of the second studied metal (Cd) were between 0.1 µg/g DM in *Russula heterophylla* and 10.2 µg/g DM in *Boletus chrysenteron*. In a French study cadmium concentrations in mushrooms collected from control plots (unpolluted) ranged from 1 to 12 µg/g DM [8]. Some national data show even higher contents of Cd in wild mushrooms – 20 µg/g DM [16]. Higher contents of cadmium in mushrooms from unpolluted areas may possibly be a result of high cumulative properties of some mushroom species, which was evidenced for *Boletus chrysenteron* [7]. In the present study *Boletus chrysenteron* and *Rozites caperatus* cumulated the highest cadmium contents among the mushrooms tested, exceeding 9 µg/g DM. An Italian study [9] showed similar values for *Rozites caperatus*, which was one of the most Cd-polluted species among the studied mushrooms. According to some national reports, *Boletus badius* is another species that accumulates Cd [16, 24, 25]. Our study did not corroborate these findings, but evidenced that Cd content in *Boletus badius* was generally low.

When compared to the literature, the Cd contents in mushrooms in our study were about twelve times lower than those in mushrooms growing in the vicinity of the industrial emission sources like copper, zinc, and mercury smelters [7, 11, 18, 26].

Generally, wild mushroom species in the present study were characterized by low concentrations of Cd as compared to the EU regulation set for mushrooms species other than *Agaricus bisporus*, *Pleurotus ostreatus*, and *Lentinus edodes* (1 µg/g FM) [23]. According to this regulation, all samples of fresh mushrooms do not represent a risk from cadmium exposure.

Cd and Pb Contents in Cultivated Mushrooms

Cd and Pb contents were assayed in the three most popular cultivated mushrooms (Table 2) and expressed on a dry and fresh mass basis. The lowest mean lead content was found in *Agaricus bisporus* (white botton mushroom) – 0.03 µg/g DM (0.002 µg/g FM), while the highest in *Lentinus edodes* – 0.1 µg/g DM (0.010 µg/g FM), while the lowest mean cadmium content was found in *Agaricus bisporus* 0.1 µg/g DM (0.01 µg/g FM), and the highest in *Pleurotus ostreatus* 1.2 µg/g DM (0.10 µg/g FM).

Pb and Cd concentrations were mostly lower in the cultivated than in the wild species, except *Pleurotus ostreatus*, in which cadmium content was 1.2 µg/g DM, and exceeded Cd contents of a few wild mushroom species: *Cantharellus cibarius*, *Leccinum aurantiacum*, *Leccinum scabrum*, *Russula heterophylla*, *Russula vinosa*, *Suillus bovinus*, *Suillus luteus*, *Tricholoma flavovirens*, *Boletus badius,* and *Boletus subtomentosus*. A Mexican study concerning cultivated mushrooms (*Agaricus bisporus* and *Pleurotus ostreatus*) demonstrated much higher contents of Pb than these presented in our own study (in *Pleurotus ostreatus* 29-fold and in *Agaricus bisporus* 14-fold higher) [27].

Cd values determined in the cultivated mushrooms in this study presented similar values to the literature [28, 29, 30]. In a Hungarian study cultivated mushroms demonstrated generally higher concentrations of cadmium than these in our own study, except *Pleurotus ostreatus*, which exhibited similar Cd concentrations [31]. Considerably higher levels of cadmium have been noted in cultivated Chinese mushrooms [32, 33].

Summing up the collected data, the lead contents in the cultivated mushrooms did not exceed the statutory limits of 0.3 µg/g FM established by EU [23]. The cadmium concentrations of assayed mushroom samples were grossly inferior to the tolerable upper limit of 0.2 µg/g FM [23]. High values of standard deviation in most of the species prove that great variation occurs even among individual fruit bodies from the same region [9].

To indicate the most Pb- and Cd-contaminated mushroom species, a sum of chemical equivalents was calculated (Fig. 2). The two most Pb- and Cd-contaminated species were *Rozites caperatus* and *Boletus chrysenteron*. These results are indicative of metal accumulative properties of these two species.

Cd and Pb Dietary Intake from Mushrooms

Lead and cadmium dietary intakes from mushrooms are presented in Table 3. To calculate the possible Pb and Cd intakes from wild and cultivated mushrooms, a 70 kg body mass of average consumer was used for calculations in accordance with the EFSA Scientific Committee for adult weight parameter [34], considering that a dish of mushrooms weighs 100 g FM [35].

The provisional tolerable weekly intake (PTWI), set by the Joint FAO/WHO Expert Committee on Food (JECFA), for Pb is 0.025 mg/kg body weight [36] (equivalent to 0.0036 mg/kg bw per day), resulting in a 1.50 mg Pb intake /week for a person with a body weight of 70 kg. This result recalculated per day gives value of 0.214 mg. With respect to this, neither of the tested mushrooms represented a source of Pb exposure. The calculated daily Pb dietary intakes from wild mushrooms ranged from 0.0009 mg/100g FM in *Boletus chrysenteron* to 0.0295 mg/100g FM in *Macrolepiota procera* and between 0.0002-0.0010 mg/100g FM in the cultivated mushrooms. Summing up, the consumption of studied mushrooms does not represent a risk from lead intoxication, even for the most Pb-contaminated mushroom assayed – *Macrolepiota procera* – 0.0295 mg/100g FM (equivalent to 0.2065 mg/100g per week), because the calculated Pb intake from this mushroom was about seven times lower than the PTWI.

The recommended provisional tolerable monthly intake (PTMI) for Cd is 0.025 mg/kg body weight (bw), which is equivalent to 0.0008 mg/kg bw per day [6]. An estimated provisional daily intake (PDI) calculated for the average consumer (70 kg) is 0.056 mg per day.

The Cd dietary intakes per day for the tested mushrooms ranged from 0.0004 mg/100g FM in *Russula heterophylla* to 0.068 mg/100g FM for *Rozites caperatus* in the wild mushrooms group. The highest cadmium intakes were calculated for *Rozites caperatus* – 0.068 mg/100g FM and *Boletus chrysenteron* – 0.061 mg/100g FM. These Cd lev-

Table 3. Daily Pb and Cd dietary intakes from a 100 g mushroom portion by a 70 kg consumer.

No.	Wild mushrooms	Pb mg/100g FM	Cd mg/100g FM
1.	*Armillaria mellea*	0.0018±0.0016	0.053±0.024
2.	*Boletus badius*	0.0045±0.0033	0.005±0.003
3.	*Boletus chrysenteron*	0.0009±0.0003	**0.061±0.022**
4.	*Boletus edulis*	0.0040±0.0030	0.031±0.012
5.	*Boletus subtomentosus*	0.0027±0.0012	0.009±0.004
6.	*Cantharellus cibarius*	0.0037±0.0013	0.003±0.001
7.	*Lactarius deliciosus*	0.0029±0.0016	0.024±0.004
8.	*Leccinum aurantiacum*	0.0026±0.0020	0.004±0.003
9.	*Leccinum scabrum*	0.0049±0.0042	0.011±0.005
10.	*Macrolepiota procera*	0.0295±0.0213	0.026±0.009
11.	*Rozites caperatus*	0.0036±0.0017	**0.068±0.020**
12.	*Russula heterophylla*	0.0198±0.0231	0.0004±0.0001
13.	*Russula vinosa*	0.0183±0.0190	0.003±0.001
14.	*Suillus bovinus*	0.0042±0.0022	0.003±0.001
15.	*Suillus grevillei*	0.0013±0.0007	0.013±0.001
16.	*Suillus luteus*	0.0023±0.0003	0.004±0.001
17.	*Tricholoma flavovirens*	0.0154±0.0109	0.011±0.003
18.	*Tricholoma portentosum*	0.0010±0.0008	0.013±0.002
No.	Commercial mushrooms	Pb mg/100g FM	Cd mg/100g FM
1.	*Agaricus bisporus* (white)	0.0002±0.0001	0.001±0.0001
2.	*Pleurotus ostreatus*	0.0003±0.0001	0.010±0.003
3.	*Lentinus edodes*	0.0010±0.0004	0.004±0.001

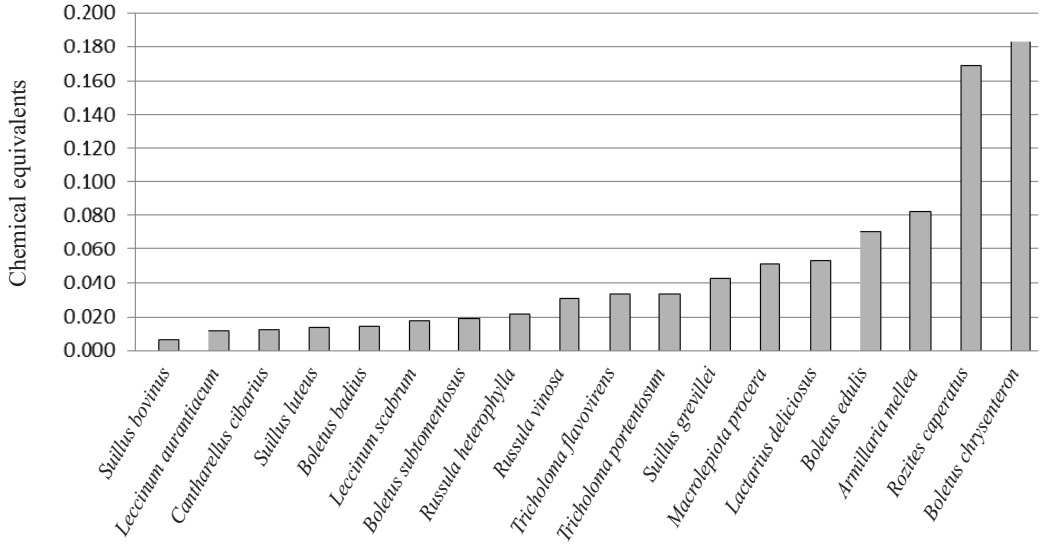

Fig. 2. The sum of chemical Cd and Pb equivalents in the wild mushrooms tested.

els may marginally exceed the PTMI set for Cd. In cultivated mushrooms daily Cd dietary intakes were low – 0.001-0.010 mg/100 g FM.

It can be concluded that the consumption of wild-grown or cultivated mushrooms is safe with regarded to Pb exposure for humans. Two species of wild mushrooms tested, however, may pose a risk with regard to Cd toxicity. Among the mushrooms exceeding limits set by the EU were: *Rozites caperatus* and *Boletus chrysenteron*. In a good mushroom year, large servings of *Rozites caperatus* and *Boletus chrysenteron* may cause short-term (few weeks up to one month) exposure of the wild mushroom fanciers to elevated Cd doses exceeding the PTMI.

Generally, mushrooms are not advised to be eaten raw [37]. Various methods of food-processing may be efficient for cadmium leaching from mushrooms. Boiling or microwaving with water can reduce Cd level in mushrooms to nearly 40% [32, 38].

But it must be kept in mind that the primary sources of toxic elements in the diet (including Cd and Pb) are not mushrooms, but other food products (meat, vegetables, fruits), and also drinks.

Conclusions

In conclusion, it must be emphasized that the concentrations of Pb and Cd found in the wild-growing and cultivated mushrooms tested in this study were much lower than these from areas affected by industrial pollution found in the literature. According to the EC Regulation No. 629/2008 [23], none of the mushroom samples assayed in this study represented a toxicological risk from lead and cadmium exposure. The consumption of two mushroom species – *Rozites caperatus* and *Boletus chrysenteron*, however, may marginally exceed provisional tolerable monthly intake (PTMI) for Cd established by the JOINT FAO/WHO Expert Committee on Food Additives, when temporarily high consumption of mushrooms (100 g/day monthly) is taken under consideration [6].

References

1. KALAČ P. A review of chemical composition and nutritional value of wild-growing and cultivated mushrooms. J. Sci. Food Agric. **93**, 209, **2013**.
2. WITKOWSKA A. M., ZUJKO M. E., MIROŃCZUK-CHODAKOWSKA I. Comparative study of wild edible mushroms as sources of antioxidants. Int. J. Medic. Mushroom. **13**, 335. **2011**.
3. KALAČ P. Trace element contents in European species of wild growing edible mushrooms: A review for the period 2000-2009. Food Chem. **122**, 2, **2010**.
4. PELKONEN R., ALFTHAN G., JÄRVINEN O. Cadmium, lead, arsenic and nickel in wild edible mushrooms. Finnish Environ. **17**, 15, **2006**.
5. EFSA 2009. European Food Safety Authority (2009). Cadmium in food. EFSA J. **980**, pp. 1-139, **2009**.
6. Joint FAO/ WHO Expert Committee on Food Additives, **2010**.
7. SVOBODA L., ZIMMERMANNOVA K., KALAČ P. Concentrations of mercury, cadmium, lead and copper in fruiting bodies of edible mushrooms in an emission area of copper smelter and mercury smelter. Sci. Total Environ. **246**, 61, **2000**.
8. BENBRAHIM M., DENAIX L., THOMAS A. L., BALET J., CARNUS J. M. Metal concentration in edible mushroms following municipal sludge application on forest land. Environ. Pollut. **144**, 847, **2006**.
9. COCCHI L., VESCOVI L., PETRINI L. E., PETRINI O. Heavy metals in edible mushrooms in Italy. Food Chem. **98**, 277, **2006**.
10. ISILDAK O., TUKEKUL I., ELMASTAS M., ABOUL-ENEIN H. Y. Bioaccumulation of heavy metals in some wild-grown edible mushrooms. Anal. Lett. **40**, 1099, **2007**.
11. COLIN-HANSEN C., YTTRI K. E., ANDERSEN R. A., BERTHELSEN B. O., STEINNES E. Mushrooms from two metal-contaminated areas in Norway: Occurrence of metals and metallothionein-like proteins. Geochem.: Explor. Environ., Anal. **2**, 121, **2002**.
12. COLIN-HANSEN C., ANDERSEN R. A., STEINNES E. Isolation and N-terminal sequencing of a novel cadmium-binding protein from *Boletus edulis*. J. Physic. IV France. **107**, 311, **2003**.
13. FLUCK M. Atlas of mushrooms. Identification, collection, using. Warsaw, Delta W-Z, **2001** [In Polish].
14. OUZOUNI P. K., PETRIDIS D., KOLLER W. D., RIGANAKOS K. A. Nutritional value and metal content of wild edible mushrooms collected from West Macedonia and Epirus, Greece. Food Chem. **115**, 1575, **2009**.
15. KALAČ P. Chemical composition and nutritional value of European species of wild growing mushrooms. A review. Food Chem. **113**, 9, **2009**.
16. RUDAWSKA M., LESKI T. Trace elements in fruiting bodies of ecomycorrhizal fungi growing in Scots pine (*Pinus sylvestris* L.) stands in Poland. Sci. Total Environ. **339**, 103, **2005**.
17. KALAČ P., SVOBODA L., HAVLICKOVA B. Contents of detrimental metals mercury, cadmium and lead in wild growing edible mushrooms. A review. Energ. Educ. Sci. Technol. **13**, 31, **2004**.
18. PETKOVŠEK S. A. S., POKORNY B. Lead and cadmium in mushrooms from the vicinity of two large emission sources in Slovenia. Sci. Total Environ. **443**, 944, **2013**.
19. SARIKURKCU C., COPUR M., YILDIZ D., AKATA I. Metal concentration of wild edible mushrooms in Soguksu. National Park in Turkey. Food Chem. **128**, 731, **2011**.
20. FALANDYSZ J., KUNITO T., KUBOTA R., BIELAWSKI L., FRANKOWSKA A., FALANDYSZ J. J., TANABE S. Multivariate characterization of elements accumulated in King Bolete *Boletus edulis* mushroom at lowland and high mountain regions. J. Environ. Sci. Heal. **43A**, 1692, **2008**.
21. GARCÍA M. A., ALONSO J., MELGAR M. J. Lead in edible mushrooms: levels and bioaccumulation factors. J. Hazard. Mater. **167**, 777, **2009**.
22. OUZOUNI P. K., PANAYOTIS G. V., PALEOLOGOS E. K., RIGANAKOS K. A. Determination of metal content on wild edible mushroom species from regions of Greece. J. Food Composition. Analysis **20**, 480, **2007**.
23. Commission regulation (EC) No. 629/2008 of 2 July 2008 amending regulation (EC) No. 1881/2006 setting maximum levels for certain contaminants in foodstuff. Official Journal or the European Union L 173,6.
24. MALINOWSKA E., SZEFER P., FALANDYSZ J. Metals bioaccumulation by bay bolete, *Xerocomus badius*, from selected sites in Poland. Food Chem. **84**, 405, **2004**.

25. SEMBRATOWICZ I., RUSINEK-PRYSTUPA E. Content of cadmium, lead, and oxalic acid in wild edible mushrooms harvested in places with different pollution levels. Pol. J. Environ. Stud. **21**, (6), 1825, **2012**.
26. YAMAÇ M., YILDIZ D., SARIKÜRKCÜ C., ÇELIKKOLLU M., SOLAK M.H. Heavy metals in some edible mushrooms from the Central Anatolia. Turkey. Food Chem. **103**, 263, **2007**.
27. MUÑOZ A. H., CORONA F. G., WROBEL K., SOTO G. M., WROBEL K. Subcellular distribution of aluminum, bismuth, cadmium, chromium, copper, iron, manganese, nickel, and lead in cultivated mushrooms (*Agaricus bisporus* and *Pleurotus ostreatus*). Biol. Trace. Elem. Res. **106**, 265, **2005**.
28. COLAK A., KOLCUOGLU Y., SESLI E., DALMAN Ö. Biochemical composition of some Turkish fungi. Asian J. Chem. **19**, 2193, **2007**.
29. SESLI E., TÜZEN M. Micro- and macroelement contents in fruiting bodies of edible wild growing mushrooms in Artvin province of Turkey. Asian J. Chem. **18**, 1423, **2006**.
30. MATTILA P., KÖNKÖ K., EUROLA M., PIHLAVA J. M., ASTOLA J., VAHTERISTO L., HIETANIEMI V., KUMPULAINEN J., VALTONEN M., PIIRONEN V. Contents of vitamins, mineral elements, and some phenolic compounds in cultivated mushrooms. J. Agric. Food Chem. **49**, 2343, **2001**.
31. VETTER J., HAJDÚ CS., GYŐRFI J., MASZLAVÉR P. Mineral composition of the cultivated mushrooms *Agaricus bisporus*, *Pleurotus ostreatus* and *Lentinus edodes*. Acta Alimentaria. **34**. 441, **2005**.
32. SUN L., LIU G., YANG M., ZHUANG Y. Bioaccessibility of cadmium in fresh and cooked *Agaricus blazei* Murill assessed by *in vitro* biomimetic digestion system. Food Chem. Toxicol. **50**, 1729, **2012**.
33. MAIHARA V. A., da COSTA MOURA P. L., CATHARINO M. G. M., MOREIRA E. G., CASTRO L. P., FIGUEIRA R. C. L. Cadmium determination in *Lentinus edodes* mushroom species. Ciênc. Tecnol. Aliment. **32**, 553, **2012**.
34. Scientific opinion. Guidance on selected default values to be used by the EFSA Scientific Committee, Scientific Panels and Units in the absence of actual measured data. Parma, Italy. EFSA Journal. **10**, 2579, **2012**.
35. WOJCIECHOWSKA-MAZUREK M., MANIA M., STARSKA K., REBENIAK M., KARŁOWSKI K. Noxious elements in edible mushroms in Poland. Bromat. Chem. Toksykol. **2**, 143, **2011** [In Polish].
36. WHO 1993. Evaluation of certain food additives and contaminants, 41st Report of the Joint FAO/WHO Expert Committee on Food Additives. Technical Reports Series No. 837. World Health Organization, Geneva (Switzerland). **1993**.
37. FALANDYSZ J., BOROVIČKA J. Macro and trace mineral constituents and radionuclides in mushrooms: health benefits and risks. Appl. Microbiol. Biot. **97**, 477, **2013**.
38. SVOBODA L., KALAČ P., ŠPIČKA J., JANOUŠKOVÁ D. Leaching of cadmium, lead and mercury from fresh and differently preserved edible mushroom, *Xerocomus badius*, during soaking and boiling. Food Chem. **79**, 41, **2002**.