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Original Research

Content of Pb, Hg, Zn, Mn, Cu, and Fe in Macrofungi Collected from Wkrzanska Forest in Northwestern Poland

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Abstract

The concentrations of 6 metallic elements (Pb, Hg, Zn, Mn, Cu, and Fe) were determined in fruiting bodies of 8 mushrooms species and underlying soil samples from Wkrzanska Forest in northwestern Poland. The study included the following species: *Russula rosea*, *Paxillus involutus*, *Amanita citrina*, *Boletus badius*, *Amanita excelsa*, *Amanita phalloides*, *Pluteus cervinus*, and *Hygrophoropsis aurantiaca*. The total content of Hg was determined using an AMA 254 Mercury Analyzer. The total content of other elements was determined using an F-AAS iCE 3000 atomic absorption spectrometer. The highest level of bioaccumulation in analyzed species was observed for Zn and Cu, especially in *Boletus badius* (170.7; 77.81 $mg \cdot kg^{-1}$ dry weight). *Amanita citrina* accumulated Pb at the highest level (5.48±3.43 $mg \cdot kg^{-1}$ dw. in caps). The maximum value of Hg was observed in *Boletus badius* caps (0.46 $mg \cdot kg^{-1}$ dw.). Bioaccumulation factors revealed bio-exclusion of Mn, Pb, and Fe (BCFs<1.0). A few positive and statistically significant ($p \leq 0.05$) Spearman correlation coefficients of metal-to-metal bioaccumulation in studied caps of macrofungi were observed.

Keywords: heavy metals, bioaccumulation, mushrooms, trace elements

Introduction

Heavy metals constitute one of the most important environmental problems. They can be transported in an environment in various forms: emitted into the atmosphere they are carried over long distances, accumulate in soil, sediments and organisms by bioaccumulation, and the biomagnification processes in the trophic chain [1]. Deposition of trace elements and heavy metals in vegetables [2] and mushrooms [3-6] to a large extent already has been proven, especially in areas potentially contaminated or located in the zone of pollutants, such as power plants, waste dumpsites, metal smelters, and chemical plants [7].

Due to the fact that overgrowing topsoil long-lived mycelium can retrieve with water significant amounts of trace elements and pass them to the fruiting bodies of macrofungi [8], there is a risk of bioaccumulation of detrimental elements in organisms of potential consumers – wild forest animals, such as roe deer, red deer, wild boars [9], as well as people. The international surveys revealed that macrofungi are able to accumulate in their fruiting bodies a large amounts of cadmium, lead, mercury, zinc, copper, manganese, iron, chromium, silver, and nickel absorbed from contaminated soil [3-6, 10-12].

The purpose of this study was to determine the level of heavy metals (Pb and Hg) and trace element (Zn, Mn, Cu, and Fe) concentrations in fruiting bodies of 8 species of macrofungi, and to indicate the bioaccumulation factors of elements from soil substrate to fruiting bodies.

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Materials and Methods

Mushroom and soil samples were collected in October 2010 from Wkrzanska Forest adjacent to Nowe Warpno in the West-Pomeranian voivodeship of north-western Poland (Fig. 1). The main branch of industry in the sampling area is fisheries, thus the forest environment is potentially unpolluted. Macrofungi and soil substrate samples were collected from dry coniferous forest, characteristic for this region. The forest was a monoculture of *Pinus sylvestris* with a few other species occurring only in undergrowth, like juniper and maple.

Generally, 25 samples (each comprising 2-5 fruiting bodies) of eight mushroom species with underneath fruiting bodies soil samples were collected. The examined species were edible *Boletus badius* (Fr.) Fr. (5 samples) and seven-species inedible for humans: *Russula rosea* Pers. (2 samples), *Paxillus involutus* (Batsch) Fr. (5 samples), *Amanita citrina* (Schaeff.) Pers. (9 samples) and 1 sample of each – *Amanita excelsa* (Fr.) P. Kumm., *Amanita phalloides* (Vaill. ex Fr.) Link, *Pluteus cervinus* P. Kumm., and *Hygrophoropsis aurantiaca* (Wulfen) Maire. 100 g of each soil sample was collected from a depth of 0-10 cm of the surface layer. The main soil type was typical podsol.

The fruiting bodies were cleaned from any debris, divided into cap and stalk, and then dried in a laboratory oven with a temperature up to 40ºC. Dried samples were homogenized using a laboratory mill. Simultaneously, soil samples were air-dried for several days, sieved with 1 mm pore sieve, and then pulverized using a mortar.

Digestion of mushroom samples (0.5 g) was performed with a cold oxi-acidic mixture of 65% HNO_3 and perhydrol (4 and 1 mL, respectively) for at least 12 hours and then put in a MilestoneTM microwave oven. Digestion of soil samples (0.5 g) was conducted using 6 mL of a 5:1 concentrated HNO_3:$HClO_4$ (65:60%) mixture and 1 mL of perhydrol and also mineralized in the microwave oven. Mineralized samples were eventually diluted to 25 mL with deionized water. The purity of utilized acids was as follows (mg·kg^{-1}): Zn ≤ 0.02, Mn ≤ 0.01 Ni ≤ 0.02, Cu ≤ 0.01, Pb ≤ 0.01, Fe ≤ 0.1 for HNO_3, and Zn ≤ 0.1, Mn ≤ 0.02, Ni ≤ 0.1, Cu ≤ 0.1, Pb ≤ 0.1, and Fe ≤ 1.0 for $HClO_4$.

The Zn, Mn, Ni, Cu, Pb, and Fe concentrations in dry weight (dw.) of mushrooms and soil samples was determined using F-AAS iCE 3000 series atomic absorption spectrometer. The process was validated using certified reference materials: tea leaves (INCT-TL-1) produced by the Institute of Nuclear Chemistry and Technology Warsaw, Poland, and loamy sand (CRM 036-050) produced by Resource Technology Corporation (USA and UK). The limits of detection for determined elements were (mg·kg^{-1}): Zn – 0.003, Mn – 0.002, Ni – 0.008, Cu – 0.005, Pb – 0.013, and Fe – 0.004. The sensitivities of the element determination method were as follows (mg·kg^{-1}): Zn – 0.01, Mn – 0.02, Ni – 0.05, Cu – 0.033, Pb – 0.073, and Fe – 0.052.

Hg content was determined in dried and pulverized mushrooms and soil samples using an AMA 254 Mercury Analyzer. The limit of detection for mercury was 1 ng·kg^{-1}.

Obtained results were statistically analyzed with Statistica software (v. 10.0 Statsoft Inc. MR1). The data

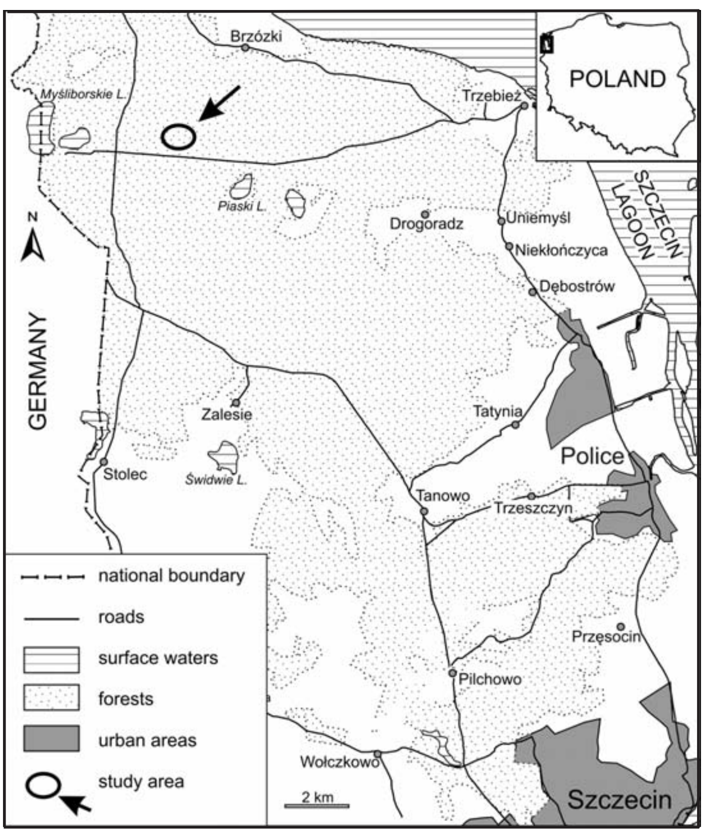

Fig. 1. Location of the sampling area.

were investigated to determine the distribution using Shapiro-Wilks' W-test. Then the element contents in fruiting bodies of analyzing species were compared with Kruskal-Wallis test ($p \leq 0.05$). Spearman's correlation coefficients ($p \leq 0.05$) between element concentrations in caps/stalks and soil were also determined.

Results and Discussion

The data of analyzed elements in dry weight of mushrooms and soil samples are given in Table 1. The contents of elements were characterized by arithmetical means value (AM), standard deviations (SD), minimum (Min), and maximum (Max) values. The bioaccumulation factors ($BCF_{caps/soil}$) of determined elements are presented in Table 2.

Maximum average concentration of Zn was observed in *Paxillus involutus* (205.2 $mg \cdot kg^{-1}$ dw.). Nevertheless, the high level of this element was also determined in *Amanita excelsa* and *Boletus badius* caps, amounting to 176.0 and 170.7 $mg \cdot kg^{-1}$ dw., respectively. *Boletus badius* caps accumulated also a large amount of Cu (77.81 $mg \cdot kg^{-1}$ dw.). From all of the analyzed species, *Amanita citrina* distinguished by very high concentration of Pb amounting to 5.48 $mg \cdot kg^{-1}$ dw. in caps and 3.58 $mg \cdot kg^{-1}$ dw. in stalks, whereas the range of arithmetical mean in other species was 0.24-2.80 $mg \cdot kg^{-1}$ dw.

There is currently no law about permissible maximum concentrations of heavy metals or trace elements in wild growing edible mushrooms. The European Union Regulation [13] concerns only cultivated mushrooms, as champignons or oyster mushrooms and it recommends the maximum content of Pb (0.30 $mg \cdot kg^{-1}$ fresh weight = 2.7 $mg \cdot kg^{-1}$ dry weight) and Cd (0.20 $mg \cdot kg^{-1}$ fresh weight = 1.8 $mg \cdot kg^{-1}$ dry weight). Nevertheless, currently ineffective Polish law Regulations [14, 15] used to dictate safe and permissible concentrations of Zn – 150.0 $mg \cdot kg^{-1}$ dw. and Hg – 0.5 $mg \cdot kg^{-1}$ dw. in wild growing edible mushrooms.

According to the presented limits, the average mean of Zn in caps of edible *Boletus badius* (170.7±26.9) was exceeded. The limit of 150.0 $mg \cdot kg^{-1}$ dw. was also exceeded in caps of inedible species: *Paxillus involutus* (205.2±39.59 $mg \cdot kg^{-1}$ dw.), *Amanita citrina* (190.3±28.81 $mg \cdot kg^{-1}$ dw.), *Hygrophoropsis aurantiaca* (150.0 $mg \cdot kg^{-1}$ dw.), and *Amanita excelsa* (176.0 $mg \cdot kg^{-1}$ dw.). The excess of Hg limit wasn't observed in any of the examined macrofungi species. However, permissible concentrations of Pb were exceeded in some *Boletus badius* stalks (average mean = 1.76±2.27 $mg \cdot kg^{-1}$ dw.; maximum = 5.11 $mg \cdot kg^{-1}$ dw.).

There are also some WHO/FAO limits – PTWI (provisonal tolerable weekly intake) for lead and mercury consumption, which equal 25 $\mu g \cdot kg^{-1}$ body weight and 4 $\mu g \cdot kg^{-1}$ body weight, respectively [16, 17]. Let's assume that mushroom moisture is approximately 90% and exemplar human weight is 65 kg, then a permissible amount of the analyzed *Boletus badius* consumed per week would be: 25 kg of caps and 9.0 kg of stalks for Pb limit and 18 kg of caps and 29 kg of stalks for Hg limit. Preceding calculations lead to the conclusion that there is no significant risk of excessive intake of lead and mercury from collected *Boletus badius* fruiting bodies.

Bioaccumulation factor (BCF) between elements concentration in fruiting bodies (in this case – caps) and in soil substrate indicates the level of species ability to accumulat element. The highest average BCF of Zn (≈25.0) was observed in *Paxillus involutus*, *Boletus badius*, *Amanita citrine*, and *Amanita excelsa*. Mercury was accumulated in the highest level by *Pluteus cervinus* (BCF≈13.0). *Boletus badius* absorbed Cu the most (BCF≈60.0). Moreover, Pb, Mn, and Fe were excluded from bioaccumulation (BCF<1.0) in all of the examined species.

According to Bellion et al. [18], ectomycorrhizal fungi can exudate organic acids, which play a pivotal role in soil acidification. This species-dependent phenomenon is relevant to mobility of heavy metals and their bioavailability. Furthermore, some macrofungi are able to produce metals binding and neutralizing substances, which allows them to accumulate a significant amount of elements, even toxic ones.

Only one statistically significant difference ($p \leq 0.05$) in determined elements bioaccumulation by studied species of macrofungi was observed. Namely, between Hg concentration in *Paxillus involutus* caps (0.04±0.06 $mg \cdot kg^{-1}$ dw.) and *Amanita citrina* caps (0.19±0.04 $mg \cdot kg^{-1}$ dw.). Furthermore, a few positive and statistically significant ($p \leq 0.05$) Spearman correlation coefficients (r) of metal-to-metal bioaccumulation in studied caps of macrofungi were observed:

- *Paxillus involutus* Mn-Cu (r = 0.9)
- *Amanita citrina* Zn-Fe (r = 0.8) and Mn-Cu (r = 0.7)
- *Boletus badius* Hg-Fe (r = 0.9)

Presented above correlations conclude some elements that can assimilate and accumulate in fruiting bodies in a similar way.

Unfortunately, no statistically significant correlation ($p \leq 0.05$) between metal in fruiting bodies and soil samples was discovered, therefore the conclusion of using the mushrooms in soil pollution is impossible.

The concentration of Cu (22.7±0.76 $mg \cdot kg^{-1}$ dw.), Fe (41.34±0.02 $mg \cdot kg^{-1}$ dw.), Mn (13.41±2.26 $mg \cdot kg^{-1}$ dw.), and Zn (56.25±7.73 $mg \cdot kg^{-1}$ dw.) in *Russula rosea* caps in this study was lower than those obtained by Ayaz et al. [3] in mushrooms from the eastern Black Sea region of Turkey (39.40±0.17; 212.0±31.0; 62.2±2.0; 101.0±1.3 $mg \cdot kg^{-1}$ dw., respectively). Borovička and Řanda [19] had investigated *Paxillus involutus* fruiting bodies collected from unpolluted sites of Czech and Slovak republics, and what is interesting, their findings of Fe (73.1-88.0 $mg \cdot kg^{-1}$ dw.) and Zn (155.0-240.0 $mg \cdot kg^{-1}$ dw.) concentrations in caps of mushrooms from the Slovak Republic were very similar to those obtained in this study (54.82-89.02; 156.1-246.1 $mg \cdot kg^{-1}$ dw., respectively). The content of Hg in *Paxillus involutus* caps and stalks is generally very low, which was confirmed by the results of this (caps: 0.01-0.14 $mg \cdot kg^{-1}$ dw.; stalks: 0.01-0.08 $mg \cdot kg^{-1}$ dw.) and Falandysz and Brzostowski [20] research (0.01-0.11 $mg \cdot kg^{-1}$ dw. in both – caps and stalks). Moreover, the Brzostowski et al. [21] results of bioaccumu-

Table 1. The contents of heavy metals and trace elements in macrofungi and topsoil samples ($mg \cdot kg^{-1}$ dry weight).

Species		Zn			Mn			Cu			Pb			Hg			Fe		
		Cap	Stalk	Soil	Cap	Stalk	Soil	Cap	Stalk	Soil	Cap	Stalk	Soil	Cap	Stalk	Soil	Cap	Stalk	Soil
Russula rosea Pers.	AM	56.25	47.55	10.84	13.41	14.14	29.74	22.70	13.35	2.86	0.24	0.36	6.14	0.07	0.06	0.02	41.34	60.90	2117.1
	SD	7.73	8.66	2.06	2.26	2.24	16.94	0.76	1.40	1.61	0.04	0.45	4.50	0.01	0.01	0.01	0.02	20.90	162.8
	Min	50.78	41.42	9.38	11.81	12.55	17.76	22.16	12.36	1.72	0.21	0.04	2.95	0.06	0.05	0.01	41.32	46.12	2002.1
	Max	61.71	53.67	12.29	15.00	15.72	41.72	23.24	14.34	4.00	0.27	0.67	9.32	0.08	0.07	0.03	41.35	75.68	2232.2
Paxillus involutus (Batsch) Fr.	AM	205.2	181.8	8.13	19.13	46.02	32.39	58.10	59.64	1.65	0.69	0.78	8.47	0.04*	0.03	0.03	69.88	45.19	1747.1
	SD	39.59	52.89	1.57	16.36	33.24	22.42	16.86	38.43	0.24	0.87	0.63	3.78	0.06	0.03	0.01	13.24	18.23	331.6
	Min	156.1	109.4	5.91	4.48	13.18	18.47	35.03	10.97	1.28	0.08	0.20	4.88	0.01	0.01	0.02	54.82	20.89	1175.9
	Max	246.1	233.7	10.31	44.66	89.02	72.22	79.74	109.0	1.89	1.97	1.59	13.70	0.14	0.08	0.03	89.02	71.80	1967.5
Amanita citrina (Schaeff.) Pers.	AM	190.3	123.5	8.38	17.14	23.02	19.61	44.42	14.75	2.54	5.48	3.58	10.49	0.19*	0.11	0.03	110.1	115.1	1741.6
	SD	28.81	30.98	2.72	7.42	7.96	5.27	12.33	5.28	1.01	3.43	2.11	2.18	0.04	0.02	0.01	44.28	32.10	304.4
	Min	156.1	89.12	5.11	6.65	9.80	14.57	32.92	10.01	1.27	1.73	0.37	8.27	0.11	0.07	0.02	60.66	70.59	1110.9
	Max	231.9	184.7	13.43	31.73	34.72	31.92	67.88	27.39	4.06	12.9	7.15	13.75	0.23	0.14	0.05	195.1	154.7	2110.4
Boletus badius (Fr.) Fr.	AM	170.7	111.2	6.85	11.99	12.73	26.23	77.81	29.01	1.29	0.64	1.76	7.93	0.14	0.09	0.02	61.44	90.63	1596.6
	SD	26.90	20.13	1.56	10.96	6.98	9.67	17.27	17.01	0.04	0.93	2.27	3.24	0.04	0.02	0.00	12.49	48.73	273.5
	Min	150.6	83.79	5.11	5.99	6.10	15.10	52.39	16.01	1.27	0.05	0.12	4.88	0.08	0.06	0.02	52.06	30.59	1110.9
	Max	205.3	137.3	8.38	31.47	24.37	41.72	92.78	54.02	1.37	2.02	5.11	11.31	0.19	0.11	0.02	81.16	147.2	1738.6
Hygrophoropsis aurantiaca (Wulfen) Maire		150.0	93.98	7.81	37.25	52.91	25.40	12.23	3.46	1.66	<0.013			0.12	0.10	0.03	54.09	89.99	1914.5
Pluteus cervinus P. Kumm.		66.46	42.88	4.80	6.84	15.34	19.34	21.95	14.78	2.05	0.55	1.30	5.71	0.38	0.27	0.03	108.3	85.69	2073.8
Amanita phalloides (Vaill. ex Fr.) Link		50.75	15.93	19.64	8.10	20.65	67.48	51.48	31.62	12.21	0.30	1.25	4.10	0.46	0.25	0.07	159.8	94.28	195.8
Amanita excelsa (Fr.) P. Kumm.		176.0	115.5	7.18	7.80	13.71	18.50	54.97	28.34	3.43	2.80	4.26	8.01	0.18	0.13	0.02	213.0	193.7	2270.0

AM – arithmetical mean, SD – standard deviation, Min – minimum value, Max – maximum value,
*statistically significant difference ($p \le 0.05$)

Table 2. The caps/soil bioaccumulation factors (BCF) of heavy metals and trace elements in macrofungi.

Species		$BCF_{Caps/Soil}$					
		Zn	Mn	Cu	Pb	Hg	Fe
Russula rosea Pers.	AM	5.19	0.45	7.94	0.04	3.50	0.02
	SD	3.76	0.13	0.47	0.01	1.00	0.00
	Min	5.41	0.66	12.88	0.07	6.00	0.02
	Max	5.02	0.36	5.81	0.03	2.67	0.02
Paxillus involutus (Batsch) Fr.	AM	25.24	0.59	35.30	0.08	1.54	0.04
	SD	25.22	0.73	69.02	0.23	10.25	0.04
	Min	26.41	0.24	27.37	0.02	0.50	0.05
	Max	23.87	0.62	42.19	0.14	4.67	0.05
Amanita citrina (Schaeff.) Pers.	AM	22.71	0.87	17.46	0.52	6.11	0.06
	SD	10.60	1.41	12.16	1.57	4.19	0.15
	Min	30.55	0.46	25.92	0.21	5.50	0.05
	Max	17.27	0.99	16.72	0.93	4.60	0.09
Boletus badius (Fr.) Fr.	AM	24.91	0.46	60.13	0.08	6.80	0.04
	SD	17.27	1.13	40.81	0.29	0.00	0.05
	Min	29.47	0.40	41.25	0.01	4.00	0.05
	Max	24.50	0.75	67.72	0.18	9.50	0.05
Hygrophoropsis aurantiaca (Wulfen) Maire		19.20	1.47	7.37	n. d.	4.00	0.03
Pluteus cervinus P. Kumm.		13.85	0.35	10.71	0.10	12.67	0.05
Amanita phalloides (Vaill. ex Fr.) Link		2.58	0.12	4.22	0.07	6.57	0.82
Amanita excelsa (Fr.) P. Kumm.		24.51	0.42	16.03	0.35	9.00	0.09

AM – arithmetical mean, SD – standard deviation, Min – minimum value, Max – maximum value, n. d. – no data

lation factors of some metallic elements in *Paxillus involutus* confirmed that Fe, Mn, and Pb are excluded from bioaccumulation by this species (BCF < 1.0).

The range of average mean of Pb content in *Boletus badius* (0.42-3.70 mg·kg^{-1} dw. in caps) from different sites of Poland [4] is slightly higher than that obtained in this study (0.5-2.02 mg·kg^{-1} dw.). However, the findings of Sembratowicz and Rusinek-Prystupa [22] in *Boletus badius* from Ożarów and Malastowska Magura (0.64 and 0.81 mg·kg^{-1} dw. in caps) were comparable to our study (0.64±0.93 mg·kg^{-1} dw.). The obtained results of Pb, Mn, and Fe bioaccumulation factors (Pb – 0.08, Mn – 0.46, Fe – 0.04) and Malinowska et al. [4] study (0.13, 0.23, 0.02, respectively) affirmed bio-exclusion of these elements by *Boletus badius*.

Conclusions

Analyzed macrofungi bioaccumulate large amounts of trace elements and heavy metals in their fruiting bodies, which may have a negative influence on potential consumers. However, several elements, i.e. Mn, Pb, and Fe are excluded from bioaccumulation, despite their quite high concentration in soil. Usually, the concentration of bioaccumulated elements is higher in caps than in stalks of macrofungi. There are some differences in the bioaccumulation of some elements among individual species. The bioaccumulation of some metals in the macrofungi caps is significantly interrelated.

References

1. KABATA-PENDIAS A., MUKHERJEE A. B. Trace Elements from Soil to Human, Springer-Verlag: Berlin Heidelberg, **2007**.
2. OSMA E., SERIN M., LEBLEBICI Z., AKSOY A. Assessment of heavy metal accumulations (Cd, Cr, Cu, Ni, Pb and Zn) in vegetables and soils. Pol. J. Environ. Stud. **22**, (5), 1449, **2013**.
3. AYAZ F. A., TORUN H., COLAK A., SESLI E., MILLSON M., GLEW R. H. Macro- and microelement contents of fruiting bodies of wild-edible mushrooms growing in the East Black Sea Region of Turkey. Food and Nutrition Sciences. **2**, (2), 53, **2011**.

4. MALINOWSKA E., SZEFER P., FALANDYSZ J. Metals bioaccumulation by bay bolete, *Xerocomus badius*, from selected sites in Poland. Food Chem. **84**, (3), 405, **2004**.
5. FALANDYSZ J., BOROVIČKA J. Macro and trace mineral constituents and radionuclides in mushrooms: health benefits and risks. Appl. Microbiol. Biotechnol. **97**, (2), 477, **2013**.
6. SVOBODA L., HAVLÍČKOVÁ B., KALAČ P. Contents of cadmium, mercury and lead in edible mushrooms growing in a historical silver-mining area. Food Chem. **96**, (4), 580, **2006**.
7. OLAFISOYE O. B., ADEFIOYE T., OSIBOTE O. A. Heavy metals contamination of water, soil and plants around an electronic waste dumpsite. Pol. J. Environ. Stud. **22**, (5), 1431, **2013**.
8. FALANDYSZ J., FRANKOWSKA A. Bioaccumulation of elements and radionuclides by macrofungi. Review for the territory of Poland. Roczn. PZH. **51**, (4), 321, **2000** [In Polish].
9. DŁUGASZEK M., KOPCZYŃSKI K. Elemental composition of muscle tissue of wild animals from central region of Poland. Int. J. Environ. Res. **7**, (4), 973, **2013**.
10. KOJTA A.K., JARZYŃSKA G., FALANDYSZ J. Mineral composition and heavy metal accumulation capacity of Bay Bolete (*Xerocomus badius*) fruiting bodies collected near a former gold and copper mining area. J. Geochem. Explor., **121**, 76, **2012**.
11. MELGAR M. J., ALONSO J., GARCÍA M. A. Mercury in edible mushrooms and underlying soil: Bioconcentration factors and toxicological risk Sci. Total Environ. **407**, (20), 5328, **2009**.
12. GARCÍA M. A., ALONSO J., MELGAR M. J. Bioconcentration of chromium in edible mushrooms: Influence of environmental and genetic factors. Food Chem. Toxicol. **58**, 249, **2013**.
13. COMMISSION REGULATION (EC) No. 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs, Official Journal of the European Union, **364**, (5), **2006**.
14. REGULATION OF THE MINISTER OF HEALTH of 27 December 2000 on the list of acceptable amounts of additives and other xenobiotic substances added to foods or stimulants, and contaminants that may be present in food or stimulants, Journal of Laws of the Republic of Poland, **9**, (72), **2001** [In Polish].
15. REGULATION OF THE MINISTER OF HEALTH of 13 January 2003 on the maximum levels of chemical and biological contaminants that may be present in food, food ingredients, permitted additional substances, substances or processing aids on food, Journal of Laws of the Republic of Poland, **37**, (326), **2003** [In Polish].
16. SUMMARY REPORT of the seventy-second meeting of JECFA, Joint FAO/WHO expert committee on food additives, Rome, 16-25 February 2010, Issued 16th March 2010, JECFA, **72**, SC, **2010**.
17. SUMMARY REPORT of the seventy-third meeting of JECFA, Joint FAO/WHO expert committee on food additives, Geneva 8-17 June 2010, Issued 24th June 2010, JECFA, 73, SC, **2010**.
18. BELLION M., COURBOT M., JACOB C., BLAUDEZ D., CHALOT M. Extracellular and cellular mechanism sustaining metal tolerance in ectomycorrhizal fungi. FEMS Microbiol. Lett. **254**, 173, **2006**.
19. BOROVIČKA J., ŘANDA Z. Distribution of iron, cobalt, zinc and selenium in macrofungi. Mycol. Progress. **6**, (4), 249, **2007**.
20. FALANDYSZ J., BRZOSTOWSKI A. Mercury and its bioconcentration factors in Poison Pax (*Paxillus involutus*) from various sites in Poland. J. Environ. Sci. Health. A Tox. Hazard. Subst. Environ. Eng. **42**, (8), 1095, **2007**.
21. BRZOSTOWSKI A., FALANDYSZ J., JARZYŃSKA G., ZHANG D. Bioconcentration potential of metallic elements by Poison Pax (*Paxillus involutus*) mushroom. J. Environ. Sci. Health. A Tox. Hazard. Subst. Environ. Eng. **46**, (4), 378, **2011**.
22. 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**.