BIOACCUMULATION OF TOXIC HEAVY METALS IN MUSHROOMS - A REVIEW

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Abstract. An overview of the accumulation potential of four heavy metals in fungal sporophores is given. Heavy metals with toxic effects on humans as Lead (Pb) Cadmium (Cd) Nickel (Ni) and Mercury (Hg) were chose. The literature from 2000 to present was reviewed. A number of 207 species were recorded in our database. All the considered samples were wild mushrooms. The highest found concentrations were: 895 µg/g Pb in *Amanita citrina*, 117 mg/kg Cd in *Agaricus arvensis*, 145 mg/kg Ni in *Pleurotus ostreatus* and 120 mg/kg Hg in *Lycoperdon utriforme* (in one sporofore). Species from the genera: *Russula, Agaricus* and *Amanita* were found to contain high concentrations of heavy metals. The following species can accumulate two metals in very high quantities: *Macrolepiota procera* (Pb and Hg); *Agaricus bisporus, Lepista nuda, Lycoperdon perlatum,* and *Lycoperdon utriforme* (Pb and Ni); *Agaricus arvensis* (Cd and Hg); *Amanita muscaria, Agaricus sylvicola,* and *Laccaria laccata* (Cd and Ni).

Keywords: fungi, heavy metals, bioaccumulation.

Rezumat. Bioacumularea metalelor grele toxice în macromicete – un comentariu. Lucrarea prezintă potențialul de acumulare a patru metale grele în macromicete. Au fost alese următoarele metale grele: plumb (Pb) cadmiu (Cd) nichel (Ni) şi mercur (Hg) deoarece acestea au efecte toxice asupra sănătății umane. A fost revizuită literatura de specialitate din anul 2000 până în prezent. Un număr de 207 specii ce acumulează metale grele au fost înregistrate în baza noastră de date. Au fost luate în considerare doar probele colectate din teren. Cele mai mari concentrații găsite în sporofori au fost: 895 µg/g Pb în *Amanita citrina* , 117 mg/kg Cd în *Agaricus arvensis,* 145 mg/kg Ni în *Pleurotus ostreatus* și 120 mg/kg Hg (într-un singur sporofor) în *Lycoperdon utriforme*. Speciile din genurile *Russula, Agaricus* și *Amanita* pot acumula cantități mari de metale grele. Următoarele specii pot acumula două metale grele în cantități foarte mari: *Macrolepiota procera* (Pb și Hg); *Agaricus bisporus, Lepista nuda, Lycoperdon perlatum* şi *Lycoperdon utriforme* (Pb si Ni); *Agaricus arvensis* (Cd și Hg); *Amanita muscaria, Agaricus sylvicola* şi *Laccaria laccata* (Cd și Ni).

Cuvinte cheie: fungi, metale grele, bioacumulare.

INTRODUCTION

The importance of fungi for ecosystem functions makes them frequent subjects for the scientific study worldwide. Fungi have three main roles in the ecosystem: energy cycling within, and between, ecosystems as they are the main decomposers of organic matter; support of partner plants in case of mycorrhizal fungi, rising the resistance and resilience of plants to dryness, heavy metals, and pathogen attach; food source for insects, small mammals and humans.

For the conservation point of view, it is necessary to know much more about the command factors that affect fungal development. One of the factors that can influence fungal growth is heavy metals. The literature on the occurrence of heavy metals in mushrooms has increased in the last period. A great interest is accorded to heavy metal content in edible mushroom. Around 4,000 species are edible and they are used by people in many cuisines because of their delicacy (MLECZEK et al., 2013). Wild mushrooms are appreciated for their unique taste, low calorie content, high contents in vitamins, proteins and minerals (RACZ et al., 1996; KULA et al., 2011). There are many species of fungi that can accumulate metals and therefore caution must be taken in wild mushroom consumption. Cooking and preservation might decrease metal levels. An extensive leaching was observed for cadmium after boiling the mushroom slices that had been previously frozen (SVOBOTA et al., 2002).

It was found that the heavy metals content in sporophores increases in polluted areas such as in the vicinity of metal smelters, within cities or along highways (KALAČ & SVOBODA, 2000). In mushroom fruiting bodies, there are accumulated also trace elements with geological origins (NIKKARINEN & MERTANEN, 2004) not only from anthropogenic polluting activities There are some very interesting exceptions. Some species collected from polluted areas have low concentration. This might be due to extracellular sequestration of metals (ANAHID et al., 2011) or in some cases to non-homogenous soil composition over the whole area or preference of some fungi for a specific soil horizons that can contain low heavy metal concentration (LESKI et al., 1995).

There is a wide variability of trace element concentration in and within fungal species. This might be due to different factors. Accumulation of heavy metals in sporophores has been found to be affected by fungal factors such as: species (KALAC & SVOBODA, 2000), appurtenance of a species to a trophic group (LAAKSOVIRTA & ALAKUIJALA, 1978), age of mycelium (KALAC & SVOBODA, 2000) development stage of sporophores, interval between fructification (DAS, 2005) and by environmental factors such as : pH soil, heavy metal concentration in soil, availability of metal in soil, non-homogenous soil composition over the whole area, or over soil horizons.

Regarding the concentration of metals in different parts of the sporophores, it was found out that the cap contain higher metal concentration than the stalk in most of the cases (TYLER, 1980; ŠIRIĆ et al., 2016) and the highest metal concentration is in hymenium, but not in spores (KALAC & SVOBODA, 2000). The mechanism involved in reducing metal concentration in spores is important to be investigate in detail as we believe that it reduces the influence of metals on spore germination and first stage of the colony development.

Reviewing the literature, we found that the non-homogenous methodology used by researchers for the preparation of sporophores for metal analysis might introduce also some difference. There are differences in: the clinging procedure of the sporophores - removing the adhering substrata and/or washing with distilled water or demineralised water; the drying process by lyophilisation or, in most of the cases, by oven at different temperature and different periods of time; the storing procedure of samples from drying to metal analyze.

The bioconcentration factor presented in many papers is calculated after the following equation: BCF=metal concentration in mushroom /metal content of substrate x100. From our point of view, it must be taken into consideration that the substrate it is possible to contain mycelia that also accumulate heavy metals. This will depend on the mycelia density and the species it belongs to.

We believe that the capacity of a species to accumulate metals should take into consideration not only the concentration in the sporophores but also in the mycelium from the substratum. The metal concentration in sporophores can be different from the one in mycelium as LESKI et al. (1995) pointed out in their studies on *Suillus luteus* (L.) Roussel. It is difficult to estimate the metal concentration in mycelium from the substratum in natural ecosystems. There are some studies made in laboratory conditions.

MATERIAL AND METODS

The literature from 2000 to present was reviewed. In the analysis, it was introduced one paper from 1996 because the author found extremely higher concentration of metals in sporophores. His samples were collected near a mercury smelter and a copper smelter. A number of 207 species were recorded in our database. All the considerate samples were wild mushrooms. The metal concentrations (dry matter) presented in tables were only for species that were analyzed by at least three different authors. The concentration intervals were chose after KALAC & SVOBODA (2000) with small modifications. We use Index Fungorum for fungal nomenclature.

RESULTS AND DISCUSSION

The high Pb concentrations were found by KRUPA & KOZDROJ (2004) in sporophores collected from industrial desert surrounding the zinc and lead works of Miasteczko Slaskie. They found the following concentrations: 895 µg/g in *Amanita citrina* Pers.; 850 µg/g in *Suillus grevillei* (Klotzsch) Singer; 840 µg/g in *Suillus luteus* (L.) Roussel; 820 µg/g in *Paxillus involutus* (Batsch) Fr.; 800 µg/g in *Russula aeruginea* Lindblad ex Fr.; 780 µg/g in *Imleria badia* (Fr.) Vizzini; 690 µg/g in *Scleroderma citrinum* Pers.; 680 µg/g in *Lactarius helvus* (Fr.) Fr. and *Laccaria laccata* (Scop.) Cooke; 661 µg/g in *Lepista nuda* (Bull.) Cooke and 650 µg/g in *Russula cyanoxantha* (Schaeff.) Fr.

Other species (Table 1) that accumulate Pb are: *Laetiporus sulphureus* (Bull.) Murrill - 33 mg/kg (YILMAZ et al., 2003); *Macrolepiota procera* (Scop.) Singer -26.4 mg/kg (KALAČ et al., 1996); *Lycoperdon perlatum* Pers -15.36 mg/kg (SARIKURKCU et al., 2015); *Lepista nuda* (Bull.) Cooke -15.3 mg/kg (KALAČ et al., 1996); *Agaricus bisporus* (J. E. Lange) Imbach -13.88 mg/kg (CHAUHAN, 2014); and *Lentinula edodes* (Berk.) Pegler -10.12 mg/kg (CHAUHAN, 2014).

Table 1. Pb concentrations in fungal species (mg/kg).

Species	**Concentration intervals**							**Reference**
	<0.49	0.5-0.99	1-4.99	5-9.99	10-19.99	20-99.99	>100	
Agaricus arvensis Schaeff.			x					SARIKURKCU et al., 2011; PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006.
Agaricus bisporus (J.E. Lange) Imbach		x	x		x			CHAUHAN, 2014; COCCHI et al., 2006; DEMIRBAS, 2001; ISILDAK et al., 2007; ITA et al., 2008; DANIEL-UMERI et al., 2015.
Agaricus campestris L.		x	x					PETKOVŠEK & POKORNY, 2013; CAMPOS & TEJERA, 2011; COCCHI et al., 2006; SEVEROGLU et al., 2013.
Agaricus sylvicola (Vittad.) Peck		x	x					PETKOVŠEK & POKORNY, 2013; CAMPOS & TEJERA 2011; COCCHI et al., 2006; DEMIRBAS, 2001.
Amanita muscaria (L.) Lam.		x	x				x	PETKOVŠEK & POKORNY, 2013; DEMIRBAS, 2001; KRUPA & KOZDROJ, 2004.
Amanita rubescens Pers.	x	x	x					PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; CAMPOS & TEJERA, 2011; COCCHI et al., 2006; DEMIRBAS, 2001.
Boletus edulis Bull.		x	x					PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; NOVÁČKOVÁ et al., 2007; KALAČ et al., 1996.
Coprinus comatus (O.F. Müll.) Pers.		x	x					PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; SEVEROGLU et al., 2013.
Hydnum repandum L.	x	x	x					PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; DEMIRBAS, 2001; SEVEROGLU et al., 2013.
Imleria badia (Fr.) Vizzini		x		x			x	NOVÁČKOVÁ et al., 2007; KRUPA & KOZDROJ, 2004; SVOBODA et al., 2002.
Lactarius deliciosus deliciosus (L.) Gray	x	x	x					PETKOVŠEK & POKORNY, 2013; ALOUPI et al., 2012; CAMPOS & TEJERA, 2011; SEVEROGLU et al., 2013; YILMAZ et al., 2003.
Lepista nuda (Bull.) Cooke			x	x	x		x	PETKOVŠEK & POKORNY, 2013; CAMPOS & TEJERA, 2011; COCCHI et al.,

								2006; IBRAHIM et al., 2004; ISILDAK et al., 2007; KALAČ et al., 1996 ; KRUPA & KOZDROJ, 2004.
Lycoperdon perlatum Pers.			x	x	x			PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; COCCHI et al., 2006; MLECZEK et al., 2013; SARIKURKCU et al., 2015; YILMAZ et al., 2003.
Macrolepiota procera (Scop.) Singer			x			x		PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; CAMPOS & TEJERA, 2011; COCCHI et al., 2006; KALAČ et al.,1996 ; SARIKURKCU et al., 2015; SEVEROGLU et al., 2013; SIRIC et al. 2016.
Marasmius oreades (Bolton) Fr.			x	x				CAMPOS & TEJERA, 2011; COCCHI et al., 2006; YILMAZ et al., 2003.
Picipes badius (Pers.) Zmitr. & Kovalenko	x		x					PETKOVŠEK & POKORNY, 2013; ISILDAK et al., 2007; KALAČ et al., 1996.
Pleurotus ostreatus (Jacq.) P. Kumm.		x	x	x				DEMIRBAS, 2001; ITA et al., 2008; SEVEROGLU et al., 2013.
Russula cyanoxantha (Schaeff.) Fr.		x	x	x			x	PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; COCCHI et al., 2006; DEMIRBAS, 2001; KALAČ et al., 1996; KRUPA & KOZDROJ, 2004.
Russula delica Fr.	x		x					ALOUPI et al., 2012; DEMIRBAS, 2001; ISILDAK et al., 2007; YILMAZ et al., 2003.
Suillus luteus (L.) Roussel		x	x				x	PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; KALAČ et al., 1996; KRUPA & KOZDROJ, 2004.
Tricholoma terreum (Schaeff.) P. Kumm.			x	x				DEMIRBAS, 2001; ISILDAK et al., 2007; SEVEROGLU et al., 2013; YILMAZ et al., 2003.
Xerocomellus chrysenteron (Bull.) Šutara	x	x	x		x			PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; COCCHI et al., 2006; OUZOUNI et al., 2007; KALAČ et al., 1996; MOGÎLDEA, 2008.

From the literature review we found the following species (Table 2) as Cd accumulators: *Agaricus arvensis* Schaeff. - 117 mg/kg (PETKOVŠEK. & POKORNY, 2013); *Agaricus urinascens* (Jul. Schäff. & F.H. Møller) Singer- 101 mg/kg (COCCHI et al., 2006); *Laccaria laccata* (Scop.) Cooke - 93.3 µg/g (KRPATA et al., 2009); *Amanita muscaria* (L.) Lam. – 80 µg/g (KRUPA & KOZDROJ, 2004) and *Agaricus sylvicola* (Vittad.) Peck - 67.9 mg/kg (PETKOVŠEK & POKORNY, 2013).

Table 2. Cd concentrations in fungal species (mg/kg).

Species	Concentration intervals							Reference
	<0.49	0.5-0.99	1-4.99	5-9.99	10-19.99	20-99.99	>100	
Agaricus arvensis Schaeff.						x	x	PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; RANDA & KUCERA, 2004; SARIKURKCU et al., 2011.
Agaricus bisporus (J.E. Lange) Imbach		x	x					COCCHI et al., 2006; DEMIRBAS, 2001; ISILDAK et al., 2007; ITA et al., 2008; DANIEL-UMERI et al., 2015.
Agaricus campestris L.	x		x					PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; SEVEROGLU et al., 2013; SIRIC et al. 2016.
Agaricus sylvicola (Vittad.) Peck			x			x		PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; DEMIRBAS, 2001.
Amanita muscaria (L.) Lam.			x		x	x		PETKOVŠEK & POKORNY, 2013; DEMIRBAS, 2001; KRUPA & KOZDROJ, 2004; RANDA & KUCERA, 2004.
Amanita rubescens Pers.		x	x	x				PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; COCCHI et al., 2006; DEMIRBAS, 2001.
Amanita vaginata (Bull.) Lam.		x	x		x	x		COCCHI et al., 2006; DEMIRBAS, 2001; KRPATA et al., 2009.
Boletus edulis Bull.			x	x				PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; NOVÁČKOVÁ et al., 2007; KALAČ et al., 1996.
Cantharellus cibarius Fr.	x	x	x					PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; DANIEL-UMERI et al., 2015; OUZOUNI et al., 2007.
Coprinus comatus (O.F. Müll.) Pers.	x		x	x				PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; SEVEROGLU et al., 2013.
Hydnum repandum L.	x	x						PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; DEMIRBAS, 2001; OUZOUNI et al., 2007; SEVEROGLU et al., 2013.
Hypholoma fasciculare (Huds.) P. Kumm.		x	x					DEMIRBAS, 2001; TĂNASE et al., 2008; YILMAZ et al., 2003.
Imleria badia (Fr.) Vizzini			x		x	x		NOVÁČKOVÁ et al., 2007; KRUPA & KOZDROJ, 2004; SVOBODA et al., 2002.
Laccaria laccata (Scop.) Cooke		x	x		x	x		DEMIRBAS, 2001; KRPATA et al., 2009; YILMAZ et al., 2003; KRUPA & KOZDROJ, 2004.
Lactarius deliciosus deliciosus (L.) Gray	x	x	x					PETKOVŠEK & POKORNY, 2013; ALOUPI et al., 2012; KALAČ et al., 1996; SEVEROGLU et al., 2013; YILMAZ et al., 2003
Lepista nuda (Bull.) Cooke		x	x			x		PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; IBRAHIM et al., 2004; ISILDAK et al., 2007; KALAČ et al.,1996 ; KRUPA & KOZDROJ, 2004; ŞEN et al., 2012.
Lycoperdon perlatum Pers.	x	x	x					PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; COCCHI et al., 2006; SARIKURKCU et al., 2015; ŞEN et al., 2012; YILMAZ et al., 2003; STIHI et al., 2009.
Macrolepiota procera (Scop.) Singer	x	x	x	x				PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; COCCHI et al., 2006; KALAČ et al., 1996 ; SARIKURKCU et al., 2015; SEVEROGLU et al., 2013.
Picipes badius (Pers.) Zmitr. & Kovalenko	x	x	x					PETKOVŠEK & POKORNY, 2013; ISILDAK et al., 2007; KALAČ et al., 1996.

Pleurotus ostreatus (Jacq.) P. Kumm.	x		x					DEMIRBAS, 2001; ITA et al., 2008; SEVEROGLU et al., 2013.
Russula cyanoxantha (Schaeff.) Fr.	x		x			x		PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; COCCHI et al., 2006; DEMIRBAS, 2001; KALAČ et al.,1996 ; KRUPA & KOZDROJ, 2004; ŞEN et al., 2012.
Russula delica Fr.	x	x	x					ALOUPI et al., 2012; DEMIRBAS, 2001; ISILDAK et al., 2007; YILMAZ et al., 2003.
Suillus collinitus (Fr.) Kuntze	x	x						COCCHI et al., 2006; SARIKURKCU et al., 2011; ŞEN et al., 2012.
Suillus luteus (L.) Roussel		x				x		PETKOVŠEK & POKORNY, 2013; COCCHI et al., 2006; KALAČ et al., 1996; KRUPA & KOZDROJ, 2004.
Tricholoma terreum (Schaeff.) P. Kumm.	x	x	x					DEMIRBAS, 2001; ISILDAK et al., 2007; ŞEN et al., 2012; SEVEROGLU et al., 2013.
Xerocomellus chrysenteron (Bull.) Šutara	x		x	x				PETKOVŠEK & POKORNY, 2013; NOVÁČKOVÁ et al., 2007; COCCHI et al., 2006; MLECZEK et al., 2013; OUZOUNI et al., 2007; SARIKURKCU et al., 2011; KALAČ et al., 1996; MOGÎLDEA, 2008 .

Regarding species that accumulate Ni (Table 3), in his study, DEMIRBAS (2001) found species with high Ni accumulation, such as: *Pleurotus ostreatus* (Jacq.) P. Kumm. -145 mg/kg; *Laccaria laccata* (Scop.) Cooke - 127 mg/kg; *Russula delica* Fr. -116 mg/kg; *Lactarius volemus* (Fr.) Fr - 111 mg/kg; *Amanita rubescens* Pers.- 95.8 mg/kg; *Tricholoma terreum* (Schaeff.) P. Kumm. - 94.1 mg/kg; *Russula cyanoxantha* (Schaeff.) Fr. - 92.8 mg/kg; *Amanita vaginata* (Bull.) Lam. - 83.6 mg/kg; *Amanita muscaria* (L.) Lam. - 78.3 mg/kg; *Russula foetens* Pers. - 76.4 mg/kg; *Hypholoma fasciculare* (Huds.) P. Kumm. - 72.4 mg/kg; *Lactarius piperatus* - 68.1 mg/kg; *Hydnum repandum* L. - 58.3 mg/kg; *Agaricus bisporus* (J.E. Lange) Imbach - 56.1 mg/kg; *Agaricus sylvicola* (Vittad.) Peck - 44.6 mg/kg. High concentration in *Lycoperdon perlatum* (55 mg/kg) was found by SARIKURKCU et al. (2015) and lower by TĂNASE et al. (2008) in *Hebeloma subsaponaceum* P. Karst. (23.32 µg/g), *Hypholoma fasciculare* (Huds.) P. Kumm. (12.73 µg/g) and, ISILDAK et al. (2007) in *Verpa conica* (O.F. Müll.) Sw. (15.52 µg/g).

Table 3. Ni concentrations in fungal species (mg/kg).

Species	**Concentration intervals**							**Reference**
	<0.49	0.5-0.99	1-4.99	5-9.99	10-19.99	20-99.99	>100	
Agaricus bisporus (J.E. Lange) Imbach	x		x			x		ITA et al., 2008; DEMIRBAS. 2001; ISILDAK et al., 2007; DANIEL-UMERI et al., 2015
Cantharellus cibarius Fr.	x		x	x				CAMPOS & TEJERA, 2011; OUZOUNI. P. K. et al., 2007; DANIEL-UMERI et al., 2015
Hypholoma fasciculare (Huds.) P. Kumm.			x		x	x		DEMIRBAS, 2001; TĂNASE et al., 2008; YILMAZ et al., 2003.
Lactarius deliciosus deliciosus (L.) Gray	x		x		x			ALOUPI et al., 2012; CAMPOS & TEJERA, 2011; YILMAZ et al., 2003.
Lactarius salmonicolor R. Heim & Leclair			x	x				MLECZEK et al., 2013; OUZOUNI et al., 2007; SARIKURKCU et al., 2011.
Lycoperdon perlatum Pers.			x	x		x		MLECZEK et al., 2013; SARIKURKCU et al., 2015; YILMAZ et al., 2003.
Macrolepiota procera (Scop.) Singer	x		x	x				CAMPOS & TEJERA, 2011; SARIKURKCU et al., 2015; SIRIC et al., 2016
Russula delica Fr.			x				x	ALOUPI et al., 2012; DEMIRBAS, 2001; ISILDAK et al., 2007; YILMAZ et al., 2003.
Tricholoma terreum (Schaeff.) P. Kumm.	x		x	x		x		DEMIRBAS, 2001; ISILDAK et al., 2007; YILMAZ et al., 2003; SIRIC et al., 2016.

Regarding Hg accumulation (Table 4) KALAČ et al. (1996) found out, near a mercury smelter and copper smelter, species with high accumulation capacities, such as: *Lycoperdon utriforme Bull.* - 120 mg/kg (in one sporophore); *Macrolepiota procera* (Scop.) Singer -119 mg/kg; *Russula olivacea* (Schaeff.) Fr.- 112 mg/kg (in one or two sporophore); *Lepista nuda* (Bull.) Cooke - 84.7 mg/kg; *Russula cyanoxantha* (Schaeff.) Fr. - 77 mg/kg (in one sporophore); *Lactarius piperatus* L.(Pers.)71 mg/kg (in one or two samples) and *Hydnum repandum* L. 55 mg/kg (in one or two sporophore)

In recent publications the Hg concentration found in fungi were lower. FALANDYSZ (2015) found 7.4mg /kg Hg concentration in *Coprinus comatus* (O.F. Müll.) Pers.; COCCHI et al. (2006) found 8.05mg /kg Hg concentration in *Agaricus bitorquis* (Quél.) Sacc. and OSTOS et al. (2015) found 9.14mg/kg in *Boletus aereus* Bull.

Table 4. Hg concentrations in fungal species (mg/kg).

Species	Concentration intervals							Reference
	<0.49	0.5-0.99	1-4.99	5-9.99	10-19.99	20-99.99	>100	
Amanita rubescens Pers.	x		x					NOVÁČKOVÁ, 2007; COCCHI et al., 2006; DEMIRBAS, 2001.
Boletus edulis Bull.			x	x		x		COCCHI et al., 2006; NOVÁČKOVÁ, 2007; KALAC et al., 1996.
Macrolepiota procera (Scop.) Singer			x			x	x	COCCHI et al., 2006; KALAČ et al., 1996; OSTOS et al., 2015; RIEDER et al., 2011; SIRIC et al., 2016.
Russula cyanoxantha (Schaeff.) Fr.	x		x	x				COCCHI et al., 2006; DEMIRBAS, 2001; KALAČ et al., 1996; RIEDER et al., 2011.

Most of the species tend to accumulate Cd and Pb in low quantities than 5 mg/kg dry weight. The highest number of species accumulates Cd, Pb and Ni in concentrations between 1 and 4.99 mg/kg. Half of the species from this concentrations interval were registrated for both Cd and Pb.

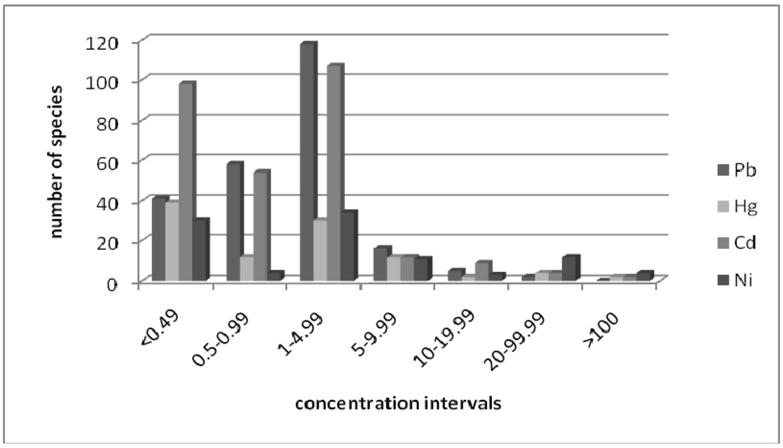

Figure 1. Heavy metal concentration in fungal species.

We found that the following species can accumulate two metals in high quantities: *Macrolepiota procera* (Pb and Hg); *Agaricus bisporus, Lepista nuda, Lycoperdon perlatum, L. utriforme* (Pb and Ni); *Agaricus arvensis* (Cd and Hg); *Amanita muscaria, Agaricus sylvicola*, *Laccaria laccata* (Cd and Ni)

We found out that species from the genera *Russula*, *Agaricus* and *Amanita* tend to accumulate one or more heavy metals. Our findings are in agreement with ŠIRIĆ I et al. (2016) that group the species on heavy metals concentration bases using hierarchical cluster analysis and find out that species from the same genus have a similar ability to accumulate metals from their growing environment.

CONCLUSIONS

The highest Pb concentration was found in the toxic species *Amanita citrina* Pers. (895 µg/g).

The highest Cd concentration was found in the edible species *Agaricus arvensis* Schaeff. (117 mg/kg).

The highest Ni concentration was found in the edible species *Pleurotus ostreatus* (Jacq.) P. Kumm (145 mg/kg).

The highest Hg concentration was found in the edible species *Lycoperdon utriforme* Bull. - 120 mg/kg (in one sporophore).

Species from the genera *Russula*, *Agaricus* and *Amanita* were found to contain high concentrations of one or more heavy metals. Most of the species tend to accumulate Cd and Pb in low quantities than 5 mg/kg dry weight.

The highest number of species accumulates Cd, Pb and Ni in concentrations between 1 and 4.99 mg/kg. Half of the species from this concentrations interval were registrated for both Cd and Pb.

The following species can accumulate two metals in high quantities: *Macrolepiota procera* (Pb and Hg); *Agaricus bisporus, Lepista nuda, Lycoperdon perlatum, L. utriforme* (Pb and Ni); *Agaricus arvensis Cd and Hg*; *Amanita muscaria, Agaricus sylvicola,* and *Laccaria laccata* (Cd and Ni). With the exception of *Amanita muscaria* the rest of this species are edible.

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