ELSEVIER

Food Chemistry 69 (2000) 273–281

Food Chemistry

www.elsevier.com/locate/foodchem

A review of trace element concentrations in edible mushrooms

Pavel Kalač *, Lubomír Svoboda

University of South Bohemia, Faculty of Agriculture, Department of Chemistry, 370 05 České Budějovice, Czech Republic

Received 6 August 1999; accepted 19 October 1999

Abstract

Wild growing mushrooms have been a popular delicacy in many countries. Some species, mainly from genera *Agaricus*, *Macrolepiota*, *Lepista* and *Calocybe* accumulate high levels of cadmium and mercury even in unpolluted and mildly polluted areas. The concentrations of both metals and also of lead increase considerably in the heavily polluted sites, such as in the vicinity of metal smelters. The usual concentrations of the three deleterious metals are presented in tables for 25 species consumed within Europe. A brief overview of 12 other metals in mushrooms is also given. Present knowledge of metal speciation in mushrooms is limited as is knowledge of their bioavailability in man. Thus, consumption of the accumulating species should be restricted. Semimetals selenium, arsenic and antimony do not occur in undesirable levels. The cultivated species, especially the common mushroom (*Agaricus bisporus*) and oyster mushroom (*Pleurotus ostreatus*) contain only low levels of the trace elements. Very scarce information is available on metal losses during preservation and culinary treatment of mushrooms. © 2000 Elsevier Science Ltd. All rights reserved.

---

1. Introduction

Extensive research has been carried out since the 1970's on trace elements (mainly heavy metals) occurrence in mushrooms (higher fungi, macrofungi). The research has had mainly two aims: screening of mushroom fruiting bodies as bioindicators of environmental pollution and searching for edible species accumulating high levels of some trace elements. As detected, many wild growing species accumulate high concentrations, especially of cadmium, mercury, lead and copper, at levels considerably exceeding those in other foods.

Wild growing mushrooms have been a popular delicacy in many countries, mainly in central and east Europe. For instance, collecting mushrooms has become a national hobby in the Czech Republic. By a survey, 72% of families collect mushrooms with a mean yearly level 7 kg per household (Šišák, 1996). However, yearly consumption exceeds 10 kg for some individuals.

Several reviews of heavy metal concentrations in mushrooms have been published (Kalač & Svoboda, 1998; Seeger, 1982; Vetter, 1994). Literature data dealing mainly with toxicological and nutritional aspects of trace elements in edible mushrooms are reviewed in this article. Mycologic terms used in the review are given in Fig. 1.

2. Factors affecting trace elements concentrations in fruiting bodies

Knowledge on roles of trace elements in physiology of higher fungi has been limited. Concentrations of the elements in fruiting bodies are generally species-dependent. Substrate composition is an important factor, but great differences exist in uptake of individual metals (Gast, Jansen, Bierling & Haanstra, 1988; Michelot, Siobud, Dore, Viel & Poirier, 1998; Tyler, 1982). Cadmium, mercury and copper are accumulated in fruiting bodies; levels of zinc and manganese are comparable in the fruiting body and in the relevant substrate, while concentrations of lead and iron are lower in the fruiting body than in the substrate. The reported bioconcentration factors (Gast et al., 1988; Seeger, 1982; Tyler, 1982) are 50–300 and 30–500 for cadmium and mercury, respectively, while they are only 10^{-1}–10^{-2} for lead.

Age of the fruiting body or its size are of less importance. Some authors report higher metal concentrations in younger fruiting bodies. This is explained by the transport of a metal from mycelium to the fruiting body during the start of fructification. During the following increase of the fruiting body mass, the metal concentration decreases. The proportion of metal concentrations from atmospheric depositions seems to be of less importance due to the short lifetime of a fruiting body, which is usually 10–14 days.

---

* Corresponding author.

PII: S0308-8146(99)00264-2

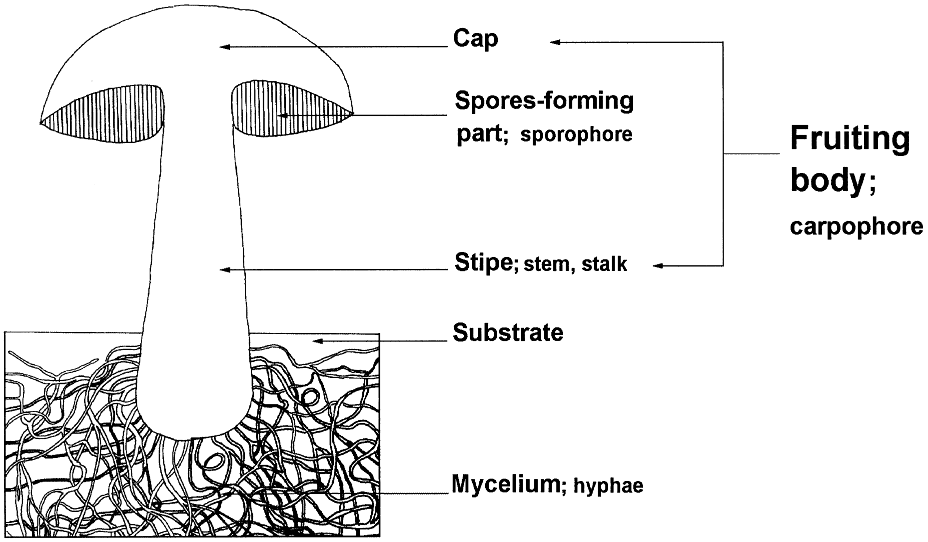

Fig. 1. A sketch of mushroom and used mycologic terms. Fructification is formation of fruiting body.

In our opinion, metal levels in fruiting bodies of wild growing mushrooms are considerably affected by the age of mycelium and by the interval between the fructifications. The highest metal concentrations are observed in the initial harvest wave of cultivated common mushroom (*Agaricus bisporus*). The levels of metals found in wild-growing *A. bisporus* are considerably higher than those in cultivated ones. This may be explained, not only by the differences in substrate composition and contamination, but also by age of mycelium, which may be several years in nature, compared to only several months in a cultivation plant.

All these factors cause very wide variability in the trace element concentrations within a species, commonly to one order of magnitude.

Most of the elements are distributed unevenly within a fruiting body. The highest levels are observed in the sporophore (but not in spores), less in the rest of the cap and the lowest in stipe.

Knowledge of transport mechanisms of metals from mycelium to the fruiting body has been limited. Mercury transport is likely to be affected by sulphydryl group content in a protein carrier, while cadmium transport has another mechanism (Kojo & Lodenius, 1989).

3. Mushrooms as potential bioindicators of environmental pollution with heavy metals

High accumulating ability in several species promoted their screening as bioindicators. Numerous works were reviewed (Wondratschek & Röder, 1993) with a conclusion that no mushroom species can be considered as an exact indicator of environmental pollution with heavy metals but fruiting bodies can be useful for distinguishing between polluted and unpolluted areas. Some species, *Mycena pura* (Dietl, 1987), *Lepista nuda* and *Lycoperdon perlatum*, and also *Coprinus comatus* for lead (García, Alonso, Fernández & Melgar, 1998), seem to have a higher informative value.

High concentrations of heavy metals have been observed in heavily polluted areas, such as in close proximity to highways with heavy traffic (Kuthan, 1979; Sova, Cibulka, Száková, Miholová, Mader & Reisnerová, 1991), landfills of sewage sludge (Zabowski, Zasoski, Littke & Ammirati, 1990) and emission areas (Cibulka, Šišák, Pulkrab, Miholová, Száková, Fučíková, et al., 1996; Lepšová & Mejstřík, 1988) including large cities (Kuusi, Laaksovirta, Liukkonen-Lilja, Lodenius & Piepponen, 1981). Extremely high metal concentrations were determined in mushrooms in the vicinity of metal smelters (Dolischka & Wagner, 1981; Kalač, Burda & Stašková, 1991; Kalač, Nižnanská, Bevilaqua & Stašková, 1996; Liukkonen-Lilja, Kuusi, Laaksovirta, Lodenius & Piepponen, 1986).

Interesting results were published in Sweden (Movitz, 1980). No significant differences in cadmium levels were observed between herbarium mushroom samples from the period 1890–1926 and samples collected from the same sites at the end of the 1970s.

4. Toxicologically important metals

Results from over 150 original papers, dealing with heavy metals in edible mushrooms show that cadmium, mercury and to a lesser extent lead are the metals of toxicological importance. However, their assessment has been difficult due to limited knowledge about their chemical forms and bioavailability in man.

The following data will deal preferably with wild-growing mushroom species commonly collected and consumed throughout Europe. Concentrations have usually been expressed as mg kg^{-1} dry matter. There exists a consensus that dry matter content of mushrooms is 10%.

Some countries have established statutory limits for the metals in edible mushrooms. The limits 5.0, 2.0 and 10.0 mg kg^{-1} dry matter have been valid in the Czech Republic since 1999 for mercury, cadmium and lead, respectively, in wild-growing mushrooms, while 1.0, 1.0 and 10.0 mg kg^{-1} dry matter are established for cultivated ones. For calculations, usually 300 g of fresh mushrooms per meal, is assumed.

4.1. Cadmium

Usual cadmium concentrations in 25 wild-growing common species are given in Table 1. The genus *Agaricus* seems to be highly accumulating, mainly species yellowing after mechanical tissue damage (*flavescentes*). Cadmium concentrations in *Agaricus* spp. may be as high as 100–300 mg kg^{-1} dry matter (Schmitt & Meisch, 1985; Seeger, 1982). Considerably increased cadmium levels were also observed in mushrooms in the vicinity of a lead smelter (Kalač et al., 1991) and mercury and copper smelters (Kalač et al., 1996).

Table 1
Usual cadmium concentrations (mg kg^{-1} dry matter) in mushroom fruiting bodies

No.	Family/species	< 0.5	0.5–1	1–2	2–5	5–10	10–20	20–50	> 50	References
	Boletaceae									
1	*Boletus aestivalis*			●	●					(Cibulka et al., 1996; Falandysz, J., Danisiewicz, D. & Bona, H., 1994; Kalač et al., 1989b)
2	*Boletus edulis*			●						(Falandysz et al., 1994; Jorhem & Sundström, 1995; Kalač et al., 1989b; Vetter, 1994)
3	*Xerocomus badius*		●	●						(Falandysz et al., 1994; Kalač et al., 1989b, Sova et al., 1991)
4	*Xerocomus chyrysenteron*			●						(Falandysz et al., 1994; Kalač et al., 1989b; Sova et al., 1991; Vetter, 1994)
5	*Xerocomus subtomentosus*		●	●						(Falandysz et al., 1994; Kalač et al., 1989b)
6	*Suillus variegatus*		●							(Kalač et al., 1989b)
7	*Suillus luteus*		●							(Falandysz et al., 1994; Jorhem & Sundström, 1995)
8	*Suillus grevillei*			●						(Falandysz & Kryszewski, 1996; Sova et al., 1991)
9	*Leccinum scabrum*				●					(Cibulka et al., 1996; Falandysz et al., 1994)
	Cantharellaceae									
10	*Cantharellus cibarius*	●	●							(Falandysz et al., 1994; Jorhem & Sundström, 1995; Kalač et al., 1989b)
	Agaricaceae									
11	*Agaricus campestris*				●	●	●	●		(Andersen, Lykke, Lange & Bech, 1982; Kalač et al., 1989b; Kalač & Stašková, 1994; Sova et al., 1991; Zurera-Cosano, Rincón-Leon & Pozo Lora, 1987)
12	*Agaricus arvensis*					●	●			(Kalač & Stašková, 1994; Sova et al., 1991, Vetter, 1994; Wilcke, 1989)
13	*Agaricus silvaticus*					●	●	●		(Andersen et al., 1982; Kalač & Stašková, 1994; Vetter, 1994; Wilcke, 1989)
14	*Agaricus silvicola*						●	●	●	(Kalač & Stašková, 1994; Sova et al., 1991)
15	*Macrolepiota*		●	●						(Andersen et al., 1982; Kalač et al., 1989b; Vetter, 1994)
16	*Macrolepiota procera*			●						(Cibulka et al., 1996; Jorhem & Sundström, 1995; Kalač et al., 1989b; Sova et al., 1991; Vetter, 1994)
	Amanitaceae									
17	*Amanita rubescens*			●						(Cibulka et al., 1996; Kalač et al., 1989b; Sova et al., 1991; Vetter, 1994)
	Tricholomataceae									
18	*Lepista nuda*		●	●						(Andersen et al., 1982; Kalač et al., 1989b; Sova et al., 1991; Vetter, 1994)
19	*Calocybe gambosa*				●					(Kalač et al., 1989b)
20	*Armillariella mellea*				●					(Cibulka et al., 1996; Falandysz, Sicińska, Bona & Kohnke, 1992; Kalač et al., 1989b; Vetter, 1994; Wilcke, 1989)
	Russulaceae									
21	*Russula aeruginea*		●							(Falandysz et al., 1994; Kalač et al., 1989b)
22	*Russula cyanoxantha*			●	●					(Kalač et al., 1989b; Sova et al., 1991; Vetter, 1994)
23	*Lactarius deliciosus*									No data
24	*Lactarius volemus*		●							(Kalač et al., 1989b)
	Lycoperdaceae									
25	*Lycoperdon perlatum*		●							(Cibulka et al., 1996; Jorhem & Sundström, 1995; Sova et al., 1991)

The information on chemical forms of cadmium in mushrooms has been very limited. From *Agaricus macrosporus* cadmium-mycophosphatin was isolated, phosphoglycoprotein of molecular weight 12, 000 Da lacking sulphur, with a high proportion of acidic amino acids, glucose and galactose. Moreover, four low-molecular glycoproteins containing sulphur and binding cadmium were isolated (Meisch & Schmitt, 1986). No metallothioneines were found in fruiting bodies of cultivated *Agaricus bisporus* (Esser & Brunnert, 1986).

While the initial information (Diehl & Schlemmer, 1984; Schellmann, Hilz & Opitz, 1980) on bioavailability of cadmium from mushrooms reported only of low proportion, up to 10%, the latest works observed comparable and higher absorbtion from mushrooms than from inorganic cadmium salts (Lind, Wicklund Glynn, Engman & Jorhem, 1995; Mitra, Purkayastha, Chatterjee & Bhattacharyya, 1995; Seeger, Schiefelbein, Seuffert & Zant, 1986). Cadmium is accumulated mainly in kidneys, spleen and liver and its level in blood serum increases considerably following mushroom consumption.

4.2. Mercury

Common mercury concentrations in fruiting bodies are given in Table 2. Heavily accumulating species are *Calocybe gambosa*, *Lepista nuda* and *Agaricus arvensis*. High levels are characteristic for genera *Agaricus*, *Macrolepiota* and *Boletus*. Extremely high concentrations, one order of magnitude higher than background levels in Table 2, were observed in an area polluted from both historical and present mercury smelters (Kalač, et al., 1996).

Table 2
Usual mercury concentrations (mg kg^{-1} dry matter) in mushroom fruiting bodies

No.	Species	<0.5	0.5–1	1–2	2–5	5–10	10–20	References
1	*Boletus aestivalis*			●	●			(Falandysz & Kryszewski, 1996; Kalač et al., 1989b; Kalač & Šlapetová, 1997)
2	*B. edulis*				●			(Falandysz & Kryszewski, 1996; Kalač et al., 1989b; Kalač & Šlapetová, 1997)
3	*Xerocomus badius*	●	●					(Bargagli & Baldi, 1984; Falandysz, Marcinowicz & Chwir, 1996; Falandysz, Marcinowicz, Danisiewicz & Galecka, 1997; Kalač et al., 1989b; Kalač & Šlapetová, 1997; Sova et al., 1991)
4	*X. chrysenteron*	●	●					(Falandysz & Kryszewski, 1996; Falandysz et al., 1997; Kalač et al., 1989b; Kalač & Šlapetová, 1997)
5	*X. subtomentosus*	●	●					(Falandysz et al, 1996; Kalač et al., 1989b; Kalač & Šlapetová, 1997)
6	*Suillus variegatus*	●						(Kalač et al., 1989b; Kalač & Šlapetová, 1997)
7	*S. luteus*							No data.
8	*S. grevillei*	●						(Kalač et al., 1989b; Sova et al., 1991)
9	*Leccinum scabrum*	●						(Cibulka et al., 1996; Falandysz & Kryszewski, 1996; Falandysz et al., 1997; Kalač & Šlapetová, 1997)
10	*Cantharellus cibarius*	●						(Kalač et al., 1989b)
11	*Agaricus campestris*			●	●	●		(Andersen et al., 1982; Kalač et al., 1989b; Kalač & Stašková, 1994; Kalač & Šlapetová, 1997; Sova et al., 1991; Zurera, Rincón, Arcos & Pozo-Lora, 1986)
12	*A. arvensis*				●	●	●	(Kalač & Stašková, 1994; Kalač & Šlapetová, 1997; Sova et al., 1991; Wilcke, 1989)
13	*A. silvaticus*				●			(Andersen et al., 1982; Kalač & Stašková, 1994; Wilcke, 1989)
14	*A. silvicola*				●			(Kalač & Stašková, 1994; Sova et al., 1991)
15	*Macrolepiota rhacodes*				●	●		(Andersen et al., 1982; Kalač et al, 1989b; Kalač & Šlapetová, 1997; Vetter & Berta, 1997)
16	*M. procera*			●	●	●		(Cibulka et al., 1996; Falandysz & Kryszewski, 1996; Falandysz et al., 1996; Kalač et al., 1989b; Kalač & Šlapetová, 1997; Vetter & Berta, 1997; Zurera et al., 1986)
17	*Amanita rubescans*		●	●				(Cibulka et al., 1996; Falandysz & Kryszewski, 1996; Kalač et al., 1989b; Kalač & Šlapetová, 1997; Sova et al., 1991)
18	*Lepista nuda*				●	●	●	(Andersen et al., 1982; Kalač et al., 1989b; Kalač & Šlapetová, 1997; Sova et al., 1991; Vetter & Berta, 1997; Zurera et al., 1986)
19	*Calocybe gambosa*					●	●	(Kalač et al., 1989b; Kalač & Šlapetová, 1997)
20	*Armillariella mellea*	●						(Cibulka et al., 1996; Falandysz et al., 1996; Kalač et al., 1989b; Vetter & Berta, 1997; Wilcke, 1989)
21	*Russula aeruginea*	●						(Falandysz & Kryszewski, 1996; Kalač et al., 1989b)
22	*R. cyanoxantha*		●					(Kalač et al., 1989b; Sova et al., 1991)
23	*Lactarius deliciosus*	●	●					(Falandysz et al., 1996; Falandysz et al., 1997; Vetter & Berta, 1997; Zurera et al., 1986)
24	*L. volemus*			●				(Kalač et al., 1989b)
25	*Lycoperdon perlatum*			●	●			(Cibulka et al., 1996; Falandysz et al., 1996, 1997; Sova et al., 1991; Vetter & Berta, 1997)

Mercury is bound in cultivated *Agaricus bisporus*, preferably in high-molecular weight proteins, while in one fraction (17,000–45,000 Da) is only a small amount. An inverse situation was observed in cultivated *Pleurotus ostreatus* (Lasota & Florczak, 1991).

Limited information is also available on the proportion of highly toxic methylmercury. This is reported to be usually only a few per cent, rarely up to 16% of total mercury concentrations, in *Agaricus* spp. (Kojo & Lodenius, 1989; Stijve & Besson, 1976), *Collybia* spp. (Minagawa, Sasaki, Takizawa, Tamura & Oshina, 1980) and in several species given in Table 2 (Bargagli and Baldi, 1984). 0.7–1.3% was found in widely-consumed species (*Xerocomus badius* and *Leccinum scabrum* (Fischer, Rapsomanikis, Andreae & Baldi, 1995). Mushrooms accumulate methylmercury from substrate with a bioconcentration factor of about 20 and/or methylate mercuric salts (Fischer et al., 1995).

4.3. Lead

Data on lead concentrations in mushrooms are given in Table 3. *Lycoperdon perlatum*, *Macrolepiota rhacodes* and *Lepista nuda* are highly accumulating species. Extremely high lead levels (100–300 mg kg^{-1} dry matter) were observed in many species in the close vicinity of lead smelters (Dolischka & Wagner, 1981; Kalač et al., 1991; Lepšová & Král, 1988; Liukkonen-Lilja et al., 1986), usually together with increased concentrations of other deleterious heavy metals. The increased lead levels were also found in the close vicinity of highways (Kuthan, 1979; Sova et al., 1991).

4.4. Other metals

Normal concentrations of 12 metals in mushrooms and accumulating genera and species, often considerably exceeding common levels, are given in Table 4. Comparison of metal accumulations from all the tables shows that many species may accumulate selectively. Copper levels in mushrooms are higher than those in plants, while for the other metals the concentrations are comparable.

Copper concentrations in the accumulating species are usually 100–300 mg kg^{-1} dry matter, which is not considered a health risk. An acidic peptide was identified in *Grifola frondosa*, which increases the proportion of soluble copper absorbtion from the intestine (Shimaoka, Kodama, Nishino & Itokawa, 1993). Extremely increased nickel concentrations were found in mushrooms from an emission area of a nickel smelter (Barcan, Kovnatsky & Smetannikova, 1998).

Table 3
Usual lead concentrations (mg kg^{-1} dry matter) in mushroom fruiting bodies

No.	Species	0.5–1	1–2	2–5	5–10	10–20	References
1	*Boletus aestivalis*		●	●			(Cibulka et al., 1996; Falandysz et al., 1994; Kalač et al., 1989b)
2	*B. edulis*		●	●			(Cibulka et al., 1996; Falandysz et al., 1994; Kalač et al., 1989b)
3	*Xerocomus badius*		●	●			(Falandysz et al., 1994; Kalač et al., 1989b; Sova et al., 1991)
4	*X. chrysenteron*		●				(Falandysz et al., 1994; Kalač et al., 1989b; Sova et al., 1991)
5	*X. subtomentosus*	●					(Falandysz et al., 1994; Kalač et al., 1989b)
6	*Suillus variegatus*	●					(Kalač et al., 1989b)
7	*S. luteus*		●				(Falandysz et al., 1994; Jorhem & Sundström, 1995)
8	*S. grevillei*		●				(Kalač et al., 1989b; Sova et al., 1991)
9	*Leccinum scabrum*		●	●			(Cibulka et al., 1996; Falandysz et al., 1994)
10	*Cantharellus cibarius*		●				(Falandysz et al., 1994; Jorhem & Sundström, 1995; Kalač et al., 1989b)
11	*Agaricus campestris*			●	●		(Andersen et al., 1982; Kalač et al., 1989b; Kalač & Stašková, 1994; Sova et al., 1991; Zurera-Cosano, et al., 1987)
12	*A. arvensis*			●	●		(Kalač & Stašková, 1994; Sova et al., 1991; Wilcke, 1989)
13	*A. silvaticus*			●	●		(Andersen et al., 1982; Kalač & Stašková, 1994; Wilcke, 1989)
14	*A. silvicola*			●			(Kalač & Stašková, 1994; Sova et al., 1991)
15	*Macrolepiota rhacodes*				●	●	(Andersen et al., 1982; Kalač et al., 1989b)
16	*M. procera*			●	●		(Cibulka et al., 1996; Jorhem & Sundström, 1995; Kalač et al., 1989b; Sova et al., 1991)
17	*Amanita rubescans*		●	●			(Cibulka et al., 1996; Kalač et al., 1989b; Sova et al., 1991)
18	*Lepista nuda*				●		(Andersen et al., 1982; Kalač et al., 1989b; Sova et al., 1991)
19	*Calocybe gambosa*		●				(Kalač et al., 1989b)
20	*Armillariella mellea*		●				(Cibulka et al., 1996; Falandysz et al., 1992; Kalač et al., 1989b; Wilcke, 1989)
21	*Russula aeruginea*			●	●		(Falandysz et al., 1994; Kalač et al., 1989b)
22	*R. cyanoxantha*		●				(Kalač et al., 1989b; Sova et al., 1991)
23	*Lactarius deliciosus*						No data.
24	*L. volemus*	●					(Kalač et al., 1989b)
25	*Lycoperdon perlatum*				●	●	(Cibulka et al., 1996; Jorhem & Sundström, 1995; Sova et al., 1991)

Table 4
Usual concentrations of 12 metals in fruiting bodies and accumulating genera and species

Metal	Concentrations (mg kg^{-1} dry matter)	Accumulators	References
Beryllium	<0.05–0.5		(Seeger, Schleicher & Schweinshaut, 1984)
Caesium	3–12		(Seeger & Schweinshaut, 1981)
Chromium	0.1–2	*Agaricus* spp., *Macrolepiota procera*, *Lactarius deliciosus*	(Jorhem & Sundström, 1995; Kalač, Willingerová & Stašková, 1989a; Kalač & Stašková, 1994; Vetter, 1997)
Cobalt	<0.1–3	*Agaricus arvensis*	(Jorhem & Sundström, 1995; Kalač et al., 1989a; Kalač & Stašková, 1994)
Copper	10–70	*Agaricus* spp., *Macrolepiota procera*, *M. rhacodes*	Andersen et al., 1982; Falandysz & Bona, 1992; Falandysz et al., 1994; Jorhem & Sundström, 1995; Kalač et al., 1989a; Kalač & Stašková, 1994; Vetter, 1994)
Iron	30–150	*Suillus variegatus*, *Suillus luteus*	(Falandysz & Bona, 1992; Falandysz et al., 1994; Kalač et al., 1989a; Kalač & Stašková, 1991)
Manganese	5–60	*Agaricus* spp.	(Falandysz & Bona, 1992; Falandysz et al., 1994; Jorhem & Sundström, 1995; Kalač et al., 1989a; Kalač & Stašková, 1994; Vetter, 1994)
Nickel	0.4–2	*Laccaria amethystina*, *Leccinum* spp.	(Andersen et al., 1982; Barcan et al., 1998; Jorhem & Sundström, 1995; Kalač et al., 1989a; Kalač & Stašková, 1994)
Silver	0.2–3	*Agaricus* spp., *Boletus edulis*, *Lycoperdon perlatum*	(Byrne, Dermelj & Vakselj, 1979; Falandysz, Bona & Danisiewicz, 1994)
Strontium	5–10		(Seeger, Orth & Schweinshaut, 1982)
Thallium	0.25		(Seeger & Gross, 1981)
Zinc	30–150	*Suillus variegatus*, *Suillus luteus*, *Lycoperdon perlatum*	(Andersen et al., 1982; Falandysz & Bona, 1992; Falandysz et al., 1994; Jorhem & Sundström, 1995; Kalač et al., 1989a; Kalač & Stašková, 1994; Vetter, 1989; Vetter, 1994; Vetter, Siller & Horváth, 1997; Wilcke, 1989)

Levels of any metal given in Table 4 are not considered to be of a health risk.

5. Semimetals selenium, arsenic and antimony

Selenium occurrence in fruiting bodies has been assessed, preferably from the nutritional point of view as a potential source of this deficient element. High selenium levels, from 10 to 20 mg kg^{-1} dry matter, were observed in some widely consumed species, such are *Boletus edulis*, *B. pinicola*, *B. aestivalis* and *Xerocomus badius*. Usual values in many species are about 1–5 mg kg^{-1} dry matter (Lasota & Kalinowski, 1985; Piepponen, Liukkonen-Lilja & Kuusi, 1983; Quinche, 1983; Stijve, 1977). Toxicologically interesting level of 367 mg kg^{-1} dry matter was found in the rarely-consumed *Albatrellus pes-caprae* (Stijve, Noorloos, Byrne, Šlejkovec & Goessler, 1998). However, bioavailability of selenium from *B. edulis* was found to be fairly low (Mutanen, 1986).

High accumulation of arsenic with mean concentrations of about 100 mg kg^{-1} dry matter was reported in *Laccaria amethystina* and *L. fraterna* (Byrne & Tušek-Žnidarič, 1983; Stijve, Vellinga & Herrmann, 1990). Mildly accumulating species with mean levels about 5 mg kg^{-1} dry matter are some *Agaricus* spp., *Laccaria laccata*, *Lepista nuda* and *Lycoperdon perlatum*. Values up to 1 mg kg^{-1} dry matter are common in most of the species (Slekovec & Irgolic, 1996; Stijve & Bourqui, 1991; Vetter, 1994).

The main arsenocompound detected in many mushroom species was arsenobetaine. Dimethylarsinic acid was the main metabolite in *Laccaria laccata* and *Volvariella volvacea* (Šlejkovec, Byrne, Stijve, Goessler & Irgolic, 1997).

As for arsenic, *Laccaria amethystina* was found to accumulate antimony (about 300 mg kg^{-1} dry matter) followed by *Amanita rubescens* and *Lepista nuda* (150 mg kg^{-1} dry matter). A negative correlation was observed between antimony and Cd, Pb, As, Ni, Hg and Ag concentrations (Parisis & van den Heede, 1992).

6. Metals in cultivated mushrooms

Levels of the main undesirable metals are considerably lower in the cultivated mushrooms than in those in the same or taxonomically-related wild-growing species (Haldimann, Bajo, Haller, Venner & Zimmerli, 1995; Strmisková, Dubravický & Bánhegyiová, 1990). As was mentioned above, this has been explained both by low concentrations of the metals in substrates, and by a short lifetime of cultivated mycelium. The highest metal levels have been observed in the first harvest wave.

Agaricus bisporus has been very susceptible to increasing content of mercury and to a lesser extent of cadmium in substrate, while the yield of *Pleurotus ostreatus* (oyster mushroom) is not too affected under these conditions (Rácz, Papp & Fodor, 1995; Sanglimsuwan, Yoshida, Morinaga & Murooka, 1993). *A. bisporus* uptakes metals from substrate and casing material in the decreasing order: Hg > Zn > Cd and Pb, while *P. ostreatus* is in the order Cd > Hg and Zn. Lead is accumulated at minimal levels (Lasota, Florczak & Karmanska, 1990). *P. ostreatus* bioconcentration factors for cadmium decrease as its concentrations in substrate increase. Thus, oyster mushroom has probably a regulative mechanism for cadmium intake (Favero, Bressa & Costa, 1990).

Approximately ten times higher cadmium concentrations were determined in cultivated *P. ostreatus* than in *A. bisporus* (Haldimann, et al., 1995).

7. Losses of metals during preservation and cooking

Surprisingly, data on changes in trace element concentrations during preservation processes such as drying, freezing or sterilization, and with different culinary treatments are almost absent. Washing and peeling of *A. bisporus* decreased concentrations of cadmium, lead, copper and zinc by 30–40% (Zródlowski, 1995). During bleaching of *A. bisporus* at 95–100°C for 15 min, losses of 45, 36, 23 and 4% were observed for manganese, iron, zinc and copper, respectively (Coskuner & Özdemir, 1997). Unfortunately, detrimental heavy metals were not determined in this work.

References

Andersen, A., Lykke, S.-E., Lange, M., & Bech, K. (1982). Trace elements in edible mushrooms. *Publ. 68, Stat. Levnedsmiddelinst., Denmark*, 29 pp (in Danish).

Barcan, V.Sh., Kovnatsky, E. F., & Smetannikova, M. S. (1998). Absorption of heavy metals in wild berries and edible mushrooms in an area affected by smelter emissions. *Water, Air and Soil Pollution, 103*, 173–195.

Bargagli, R., & Baldi, F. (1984). Mercury and methyl mercury in higher fungi and their relation with the substrata in a cinnabar mining area. *Chemosphere, 13*, 1059–1071.

Byrne, A. R., Dermelj, M., & Vakselj, A. (1979). Silver accumulation by fungi. *Chemosphere, 10*, 815–821.

Byrne, A. R., & Tušek-Žnidarič, M. (1983). Arsenic accumulation in the mushroom *Laccaria amethystina*. *Chemosphere, 12*, 1113–1117.

Cibulka, J., Šišák, L., Pulkrab, K., Miholová, D., Száková, J., & Fučíková, A., et al. (1996). Cadmium, lead, mercury and caesium levels in wild mushrooms and forest berries from different localities of the Czech Republic. *Scientia Agriculturae Bohemica, 27*, 113–129.

Coskuner, Y., & Özdemir, Y. (1997). Effects of canning processes on the elements content of cultivated mushrooms (*Agaricus bisporus*). *Food Chemistry, 60*, 559–562.

Diehl, J. F., & Schlemmer, U. (1984). Bestimmung der Bioverfügbarkeit von Cadmium in der Pilzen durch fütterungsversuche mit Ratten; Relevanz für den Menschen. *Zeitschrift für Ernährungswissenschaft, 23*, 126–135 (in German).

Dietl, G. (1987). Wildpilze als Akkumulationsindikatoren für Schwermetalle in Boden. *VDI-Berichte* Nr. 609, 765–787 (in German).

Dolischka, J., & Wagner, I. (1981). Investigation about lead and cadmium in wild growing edible mushrooms from differently polluted areas. In: *Recent Developments in Food Analysis. Proc. 1st Eur. Conf. Food Chem.* (pp. 486–491). Vienna.

Esser, J., & Brunnert, H. (1986). Isolation and partial purification of cadmium-binding components from fruiting bodies of *Agaricus bisporus*. *Environmental Pollution, A41*, 263–275.

Falandysz, J., & Bona, H. (1992). Metals content in wild growing mushrooms (*Agaricus spp.*) in the city and region of Gdansk. *Bromatologia i Chemia Toksykologiczna, 25*, 251–256 (in Polish).

Falandysz, J., Bona, H., & Danisiewicz, H. (1994). Silver content of wild-grown mushrooms from Northern Poland. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung, 199*, 222–224.

Falandysz, J., Danisiewicz, D., & Bona, H. (1994). Metals content of wild growing mushrooms gathered in the Tucholskie and Kaszuby Forests. *Bromatologia i Chemia Toksykologiczna*, 129–134 (in Polish).

Falandysz, J., & Kryszewski, K. (1996). Total mercury in mushrooms and underlying substrate from the area of Polanowice in county of Gubin, district of Zielona Góra. *Roczniki Państwowego Zakladu Higieny, 47*, 377–388 (in Polish).

Falandysz, J., Marcinowicz, A., & Chwir, A. (1996). Mercury in edible mushrooms from the area of Kościerzyna Forests and the Vistula Penninsula. *Roczniki Państwowego Zakladu Higieny, 47*, 205–210 (in Polish).

Falandysz, J., Marcinowicz, A., Danisiewicz, D., & Galecka, K. (1997). Mercury in mushrooms and underlying substrate from the neighbourhood of Lubiana, district of Kościerzyna. *Bromatologia i Chemia Toksykologiczna, 30*, 63–68 (in Polish).

Falandysz, J., Sicińska, B., Bona, H., & Kohnke, D. (1992). Metals content in *Armillariella mellea*. *Bromatologia i Chemia Toksykologiczna, 25*, 171–176 (in Polish).

Favero, N., Bressa, G., & Costa, P. (1990). Response of *Pleurotus ostreatus* to cadmium exposure. *Ecotoxicology and Environmental Safety, 20*, 1–6.

Fischer, R. G., Rapsomanikis, S., Andreae, M. O., & Baldi, F. (1995). Bioaccumulation of methylmercury and transformation of inorganic mercury by macrofungi. *Environmental Science and Technology, 29*, 993–999.

García, M. A., Alonso, J., Fernández, M. I., & Melgar, M. J. (1998). Lead content in edible wild mushrooms in Northwest Spain as indicator of environmental contamination. *Archives of Environmental Contamination and Toxicology, 34*, 330–335.

Gast, C. H., Jansen, E., Bierling, J., & Haanstra, L. (1988). Heavy metals in mushrooms and their relationship with soil characteristics. *Chemosphere, 17*, 789–799.

Haldimann, M., Bajo, C., Haller, T., Venner, T., & Zimmerli, B. (1995). Vorkommen von Arsen, Blei, Cadmium, Quecksilber und Selen in Zuchtpilzen. *Mitteilungen aus der Gebiete der Lebensmitteluntersuchung und Hygiene, 86*, 463–484 (in German).

Jorhem, L., & Sundström, B. (1995). Levels of some trace elements in edible fungi. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung, 201*, 311–316.

Kalač, P., Burda, J., & Stašková, I. (1991). Concentrations of lead, cadmium, mercury and copper in mushrooms in the vicinity of a lead smelter. *The Science of the Total Environment, 105*, 109–119.

Kalač, P., Nižnanská, M., Bevilaqua, D., & Stašková, I. (1996). Concentrations of mercury, copper, cadmium and lead in fruiting bodies of edible mushrooms in the vicinity of a mercury smelter and a copper smelter. *The Science of the Total Environment, 177*, 251–258.

Kalač, P., & Šlapetová, M. (1997). Mercury contents in fruiting bodies of wild growing edible mushroooms. *Potravinářské Vědy, 15*, 405–410.

Kalač, P., & Stašková, I. (1991). Heavy metals in fruiting bodies of wild growing mushrooms of the genus *Agaricus*. *Potravinářské Vědy, 12*, 185–195 (in Czech).

Kalač, P., & Svoboda, L. (1998). Heavy metals in edible mushrooms. *Czech Journal of Food Sciences, 16*, 110–116 (in Czech).

Kalač, P., Wittingerová, M., & Stašková, I. (1989a). The contents of seven biogenic trace elements in edible mushrooms. *Potravinářské Vědy, 7*, 131–136 (in Czech).

Kalač, P., Wittingerová, M., Stašková, I., Šimák, M., & Bastl, J. (1989b). Contents of mercury, lead and cadmium in mushrooms. *Československá Hygiena*, *34*, 568–576 (in Czech).

Kojo, M. R., & Lodenius, M. (1989). Cadmium and mercury in macrofungi — mechanisms of transport and accumulation. *Angewandte Botanik, 63*, 279–292.

Kuthan, J. (1979). Die Auswertung des Bleigehaltes im Bronze-Röhrling — *Boletus aereus* Bull. ex Fr. — entlang einer der Verkehrsadern in Bulgarien. *Česká Mykologie*, *33*, 58–59 (in German).

Kuusi, T., Laaksovirta, K., Liukkonen-Lilja, H., Lodenius, M., & Piepponen, S. (1981). Lead, cadmium, and mercury contents of fungi in the Helsinki area and in unpolluted control areas. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung, 173*, 261–267.

Lasota, W., Florczak, J., & Karmanska, A. (1990). Effect of growing conditions on accumulation of some toxic substances in mushrooms. I. A study of absorption of Hg, Cd, Pb and Zn by *Agaricus bisporus* Lange and *Pleurotus ostreatus* Jacq. Fr. Kumm. *Bromatologia i Chemia Toksykologiczna*, *23*, 95–99 (in Polish).

Lasota, W., & Florczak, J. (1991). Effects of growing conditions on accumulation of some toxic substances in mushrooms. II. Absorption and binding of ^{203}Hg by *Agaricus bisporus* Lange and *Pleurotus ostreatus* Jacq. Fr. Kumm. *Bromatologia i Chemia Toksykologiczna*, *24*, 7–71 (in Polish).

Lasota, W., & Kalinowski, R. (1985). Selenium content in some mushroom species. *Bromatologia i Chemia Toksykologiczna*, *18*, 7–10 (in Polish).

Lepšová, A., & Král, R. (1988). Lead and cadmium in fruiting bodies of macrofungi in the vicinity of a lead smelter. *The Sciences of the Total Environment, 76*, 129–138.

Lepšová, A., & Mejstřík, V. (1988). Accumulation of trace elements in the fruiting bodies of macrofungi in the Krušné Hory Mountains, Czechoslovakia. *The Science of the Total Environment, 76*, 117–128.

Lind, Y., Wicklund Glynn, A., Engman, J., & Jorhem, L. (1995). Bioavailability of cadmium from crab hepatopancreas and mushroom in relation to inorganic cadmium: a 9-week feeding study in mice. *Food and Chemical Toxicology, 33*, 667–673.

Liukkonen-Lilja, H., Kuusi, T., Laaksovirta, K., Lodenius, M., & Piepponen, S. (1986). The effect of lead processing works on the lead, cadmium and mercury contents of fungi. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung, 176*, 120–123.

Meisch, H.-U., & Schmitt, J. A. (1986). Characterization studies on cadmium-mycophosphatin from the mushroom *Agaricus macrosporus*. *Environmental Health Perspectives*, *65*, 29–32.

Michelot, D., Siobud, E., Dore, J. C., Viel, C., & Poirier, F. (1998). Update of metal content profiles in mushrooms — toxicological implications and tentative approach to the mechanisms of bioaccumulation. *Toxicon, 36*, 1997–2012.

Minagawa, K., Sasaki, T., Takizawa, Y., Tamura, R., & Oshina, T. (1980). Accumulation route and chemical form of mercury in mushroom species. *Bulletin of Environmental Contamination and Toxicology, 25*, 382–388.

Mitra, A. K., Purkayastha, R. P., Chatterjee, N. B., & Bhattacharyya, B. (1995). Uptake and tissue distribution of cadmium in albino rat after oral exposure to cadmium-contaminated edible mushroom and its effect on blood. *Current Science, 68*, 1050–1053.

Movitz, J. (1980). High levels of cadmium in Swedish wild mushrooms. *VarFöda*, *32*, 270–278 (in Swedish).

Mutanen, M. (1986). Bioavailability of selenium in mushrooms, *Boletus edulis*, to young women. *International Journal for Vitamin and Nutrition Research, 56*, 297–301.

Parisis, N. E., & van den Heede, M. A. (1992). Antimony uptake and correlation with other metals in mushroom species. *Toxicological and Environmental Chemistry, 36*, 205–216.

Piepponen, S., Liukkonen-Lilja, H., & Kuusi, T. (1983). The selenium content of edible mushrooms in Finland. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung, 177*, 257–260.

Quinche, J.-P. (1983). Les teneurs en sélénium do 95 especes de champignons supérieurs et de quelques terres. *Schweizerische Landwirtschaftliche Forschung*, *22*, 137–144 (in French).

Rácz, L., Papp, L., & Fodor, P. (1995). Migration analysis of elements from compost and casing material to the fruit bodies in cultivated mushrooms (*Agaricus bisporus*). *Acta Alimentaria, 24*, 161–166.

Sanglimsuwan, S., Yoshida, N., Morinaga, T., & Murooka, Y. (1993). Resistance to and uptake of heavy metals in mushrooms. *Journal of Fermentation and Bioengineering, 75*, 112–114.

Schellmann, B., Hilz, M.-J., & Opitz, O. (1980). Cadmium- und Kupferausscheidung nach Aufnahme von Champignon-Mahlzeiten. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung*, *171*, 189–192 (in German).

Schmitt, J. A., & Meisch, H.-U. (1985). Cadmium in mushrooms — distribution, growth effects and binding. *Trace Elements in Medicine, 2*, 163–166.

Seeger, R. (1982). Toxische Schwermetalle in Pilzen. *Deutsche Apotheker Zeitung*, *122*, 1835–1844 (in German).

Seeger, R., & Gross, M. (1981). Thallium in höheren Pilzen. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung*, *173*, 9–15 (in German).

Seeger, R., Orth, H., & Schweinshaut, P. (1982). Strontiumvorkommen in Pilzen. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung*, *174*, 381–389 (in German).

Seeger, R., Schleicher, G., & Schweinshaut, P. (1984). Untersuchungen zum Berylliumvorkommen in Pilzen. *Deutsche Lebensmittel-Rundschau*, *80*, 178–186 (in German).

Seeger, R., Schiefelbein, F., Seuffert, R., & Zant, W. (1986). Absorption of cadmium ingested with mushrooms. *Naunyn-Schmiedeberg's Archives of Pharmacology*, *332*(Suppl. 110).

Seeger, R., & Schweinshaut, P. (1981). Vorkommen von Caesium in höheren Pilzen. *The Science of the Total Environment, 19*, 253–276 (in German).

Shimaoka, I., Kodama, J., Nishino, K., & Itokawa, Y. (1993). Purification of a copper binding peptide from the mushroom *Grifola frondosa* and its effect on copper absorption. *Journal of Nutritional Biochemistry, 4*, 33–38.

Slekovec, M., & Irgolic, K. J. (1996). Uptake of arsenic by mushrooms from soil. *Chemical Speciation and Bioavailability*, *8*(3/4), 67–73.

Sova, Z., Cibulka, J., Száková, J., Miholová, D., Mader, P., & Reisnerová, H. (1991). Contents of cadmium, mercury and lead in mushrooms from two areas in Bohemia. *Sborník Agronomické fakulty v Č. Budějovicích, ř. zootech.*, *8*(1), 13–29 (in Czech).

Stijve, T. (1977). Selenium content of mushrooms. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung, 164*, 201–203.

Stijve, T., & Besson, R. (1976). Mercury, cadmium, lead and selenium content of mushroom species belonging to the genus *Agaricus*. *Chemosphere, 5*, 151–158.

Stijve, T., & Bourqui, B. (1991). Arsenic in edible mushrooms. *Deutsche Lebensmittel-Rundschau, 87*, 307–310.

Stijve, T., Noorloos, T., Byrne, A. R., Šlejkovec, Z., & Goessler, W. (1998). High selenium levels in edible *Albatrellus* mushrooms. *Deutsche Lebensmittel-Rundschau, 94*, 275–279.

Stijve, T., Vellinga, E. C., & Herrmann, A. (1990). Arsenic accumulation in some higher fungi. *Persoonia, 14*, 161–166.

Strmisková, G., Dubravický, J., & Bánhegyiová, E. (1990). Mineral composition of oyster mushroom. *Potravinářské Vědy*, *8*, 149–155 (in Slovak).

Šišák, L. (1996). The importance of forests as a source of mushrooms and berries in the Czech Republic. *Mykologický Sborník*, *73*, 98–101 (in Czech).

Šlejkovec, Z., Byrne, A. R., Stijve, T., Goessler, W., & Irgolic, K. J. (1997). Arsenic compounds in higher fungi. *Applied Organometallic Chemistry, 11*, 673–682.

Tyler, G. (1982). Accumulation and exclusion of metals in *Collybia peronata* and *Amanita rubescens*. *Transactions of the British Mycological Society, 79*, 239–245.

Vetter, J. (1989). Vergleichende Untersuchung des Mineralstoffgehaltes der Gattungen *Agaricus* (Champignon) und *Pleurotus* (Austerseitling). *Zeitschrift für Lebensmittel-Untersuchung und -Forschung*, *189*, 346–350 (in German).

Vetter, J. (1994). Data on arsenic and cadmium contents of some common mushrooms. *Toxicon*, *32*, 11–15.

Vetter, J. Die Kupfer-, Mangan- und Zink-Gehalte einiger essbarer Grosspilzarten. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung*, *198*, 469–472 (in German).

Vetter, J. (1997). Chromium and nickel contents of some common edible mushroom species. *Acta Alimentaria, 26*, 163–170.

Vetter, J., & Berta, E. (1997). Mercury content of some wild edible mushrooms. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung A, 205*, 316–320.

Vetter, J., Siller, I., & Horváth, Zs. (1997). Zinc content of sporocarps of basidiomycetous fungi. *Mycologia, 89*, 481–483.

Wilcke, C. (1989). Artspezifische Schwermetallaufnahme von Wildpilzen und Zuchtchampignons. In: *Proc. 6th Int. Trace Elements Symp*. Vol. 5, pp. 1545–1552. Leipzig (in German).

Wondratschek, I., & Röder, U. (1993). Monitoring of heavy metals in soils by higher fungi. In B. Markert, *Plants as biomonitors. Indicators for heavy metals in the terrestrial environment* (pp. 345–363). Weinheim: VCH.

Zabowski, D., Zasoski, R. J., Littke, W., & Ammirati, J. (1990). Metal content of fungal sporocarps from urban, rural, and sludge-treated sites. *Journal of Environmental Quality, 19*, 372–377.

Zródlowski, Z. (1995). The influence of washing and peeling of mushrooms *Agaricus bisporus* on the level of heavy metals contamination. *Polish Journal of Food and Nutrition Science, 45*, 26–33.

Zurera, G., Rincón, F., Arcos, F., & Pozo-Lora, R. (1986). Mercury content in mushroom species in the Cordova Area. *Bulletin of Environmental Contamination and Toxicology, 36*, 662–667.

Zurera-Cosano, G., Rincón-Leon, F., & Pozo-Lora, R. (1987). Lead and cadmium content of some edible mushrooms. *Journal of Food Quality, 10*, 311–317.