Available online at www.sciencedirect.com

SCIENCE DIRECT®

Food Chemistry 98 (2006) 277–284

Food Chemistry

www.elsevier.com/locate/foodchem

Heavy metals in edible mushrooms in Italy

Luigi Cocchi [a,b], Luciano Vescovi [a,c], Liliane E. Petrini [d], Orlando Petrini [d,*]

[a] *Gruppo Micologico e Naturalistico R. Franchi, Via D. Piani, 6, I-42100 Reggio Emilia, Italy*
[b] *Comitato Scientifico Nazionale dell'Associazione Micologica Bresadola, Via A.Volta, 46, I-38100 Trento, Italy*
[c] *Azienda Gas Acqua Consorziale (A.G.A.C.), I-42100 Reggio Emilia, Italy*
[d] *Società Micologica di Lugano, Casella Postale 6367, CH-6901 Lugano, Switzerland*

Received 28 March 2005; received in revised form 25 May 2005; accepted 25 May 2005

Abstract

The distribution of arsenic, cadmium, lead, mercury, and selenium was investigated in 1194 samples of 60 species of common, edible mushrooms collected mainly in the province of Reggio Emilia, Italy. The quantitative determination of heavy metals (mg/kg dry weight) was carried out by spectrophotometry, with the exception of Hg, which was determined by atomic absorption spectroscopy.

The amount of arsenic accumulated in the samples studied was in general modest. *Sarcosphaera eximia*, on the other hand, may contain arsenic concentrations reaching 1000 mg/kg dry weight. Within the *Agaricus* Subgenus *Flavoagaricus*, only *Agaricus nivescens* contains amounts of cadmium inferior to the allowed maximum level. The Cd levels in samples of *Amanita caesarea*, *Boletus edulis* and *Boletus pinophilus* exceeded the maximum amount allowed. The content of cadmium in *Agaricus macrosporus* is roughly 50 times the maximum weekly dose recommended by the WHO. The average amount of lead present in all samples, was in general, below the the maximum allowed concentration. *Agaricus bitorquis*, *Agaricus arvensis*, *Agaricus essettei*, *Agaricus albertii*, *B. pinophilus*, *Clitocybe geotropa*, and *Macrolepiota rachodes* had high contents of Hg that were within the range 5–10 mg/kg dry weight. Mushrooms in general, but species in the *B. edulis* group, in particular, were rich in selenium. Accumulation of specific heavy metals could be species-specific and thus assume a taxonomic role but it has proved in our study to be unreliable as an ecological indicator.

Keywords: Fungi; Edible mushrooms; Heavy metals; Ecology

1. Introduction

Mushrooms have been long known to accumulate high levels of heavy metals (e.g., Allen & Steinnes, 1978; Cocchi & Vescovi, 1996, 1997, 1997– 2005; Cocchi et al., 2002; Dojmi Di Delupis & Dojmi Di Delupis, 1996; Kalac & Svoboda, 2000; Mornand, 1990; Schmitt, 1987; Seeger, 1976a, 1976b Stegnar et al., Stegnar, Kosta, Byrne, & Ravnik, 1973; Stijve & Besson, 1976). For instance, radioactive heavy metals in fruit bodies of edible mushrooms were already reported in the 1960s (Grüter, 1964). Several factors may affect the accumulation and concentration of trace elements and heavy metals in mushrooms. Concentrations of the elements are generally assumed to be species-dependent, but substrate composition is also considered to be an important factor (Cocchi & Vescovi, 1997; Kalac & Svoboda, 2000; Stijve, Goessler, & Dupuy, 2004).

Intensive research has been carried out to detect and explain the presence and distribution of several heavy metals in edible mushrooms, in particular arsenic, cadmium, caesium, copper, iron, lead, manganese, mercury, selenium, rubidium, and zinc (Alonso, Salgado, Garcia, & Melgar, 2000; Blanusa, Kucak, Varnai, & Saric, 2001; Borella, Quaglio, Fabio, & Caselgrandi, 1992; Bressa, Cima, & Costa, 1988; Falandysz, Gucia, Frankowska,

* Corresponding author. Present address: Téra d' Sott 5, CH-6949 Comano, Switzerland. Fax: +41 91 941 3833.
E-mail address: opetrini@swissonline.ch (O. Petrini).

0308-8146/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2005.05.068

Kawano, & Skwarzec, 2001, 2002a, 2002b, 2002c, 2003, 2004; Ismail, 1994; Jorhem & Engman, 2000; Jorhem & Sundstrom, 1995; Kalac, Burda, & Staskova, 1991; Kalac & Svoboda, 2000; Stijve, 2001; Stijve, Vellinga, & Hermann, 1990; Svoboda & Kalac, 2003; Vetter, 1994).

This study was started, on the one hand, to evaluate the possibility of using mushrooms as bioindicators of environmental contamination and, on the other, to assess the impact of the presence of heavy metals in mushrooms on public health. We report here on the distribution of arsenic, cadmium, lead, mercury, and selenium in a group of common, edible mushrooms collected mainly in the province of Reggio Emilia, Italy.

2. Materials and methods

2.1. Material examined

A list of all species studied is presented in Table 1. Most samples were collected in the region of Reggio Emilia, although some samples of *Agaricus* and *Boletus* (*edulis* group) from other geographic origins were also included. Samples were collected directly by two authors (LC and LV) or were provided for analysis by corresponding members of the Mycological Society, Bresadola. Chemical analyses were then carried out in the chemical laboratory of the Azienda Gas Acqua Consorziale (AGAC).

2.2. Chemical methods

Fruit bodes were first cleaned manually with soft brushes from soil and substrate and exsiccated in a ventilated oven on a plastic tray at 40–60 °C over at least 24 h. The dry material was then stored, either intact or milled. Probes of the samples (0.5–0.7g) were then put in Teflon containers, mixed with 10 ml HNO_3 and incubated for 30 min in a microwave oven (Perkin–Elmer Multiwave® microwave oven) at ≈180 °C at 30 bar pressure. The material obtained from this mineralisation was diluted with deionised H_2O to yield a sample of 50 ml. The quantitative determination of heavy metals (mg/kg dry weight) was carried out using a ICP-OES Perkin–Elmer Optima 3000 XL spectrophotometer, with the exception of Hg, which was determined by atomic absorption spectroscopy using a cold-vapour Perkin–Elmer FIMS 100 (Markert, 1992; Tsaler & Zaprianov, 1985).

2.3. Statistical analysis

All values reported refer to the amount of heavy metals related to the dry weight, which is approximately one tenth of the fresh weight.

Table 1
Species of fungi studied

Subdivision Basidiomycotina
Class Homobasidiomycetes
Subclass Agaricomycetideae Bon
Order Agaricales Clements (sensu stricto)
Genus *Agaricus* L.: Fr.
Subgenus *Agaricus* (L.: Fr.) Heinem.
A. bisporus (J. Lange) Imbach (17 wild; 14 cultivated)
A. bitorquis (Quél.) Sacc. (20)
A. campestris L.: Fr. (30)
Subgenus *Flavoagaricus* Wasser
A. arvensis Schäff.: Fr. (23)
A. essettei Bon (16)
A. macrosporus (Møller and Schäff.) Pilát (16)
A. nivescens Møller: Møller (17)
A. sylvicola (Vitt.) Sacc. (10)
Macrolepiota procera (Scop.: Fr.) Singer (15)
Macrolepiota rachodes (Vitt.) Singer (10)
Coprinus comatus (Müll.: Fr.) S. F. Gray (11)
Order Amanitales Jülich
Amanita caesarea (Scop.: Fr.) Pers. (7)
Amanita ovoidea (Bull.: Fr.) Link (12)
Amanita rubescens Pers.: Fr.(23)
Amanita vaginata (Bull.: Fr.) Vitt. (15)
Order Russulales (Roze) Kreisel
Russula cyanoxantha (Schäff.) Fr. (29)
Russula olivacea (Schäff.) Pers. (12)
Russula vesca Fr. (25)
Order Cortinariales Locquin ex Jülich
Agrocybe aegerita (Briganti) Fayod (41)
Cortinarius praestans (Cordier) Gillet (12)
Rozites caperatus (Pers.: Fr.) P. Karsten (16)
Order Entolomatales Locquin ex Jülich
Clitopilus prunulus (Scop.: Fr.) Kümmer (14)
Entoloma saundersii (Fries) Sacc. (23)
Order Tricholomatales Kühner
Armillariella mellea (Vahl: Fr.) Kümmer (14)
Clitocybe geotropa (Bull.) Quél. (19)
Clitocybe gibba (Pers.: Fr.) Kümmer (12)
Clitocybe nebularis (Batsch.: Fr.) Kümmer (28)
Hygrophorus penarius Fr. (15)
Hygrophorus russula (Schäff.: Fr.) Quélet (11)
Calocybe gambosa (Fr.: Fr.) Donk (18)
Laccaria affinis (Sing.) Bon (17)
Lepista nuda (Bull.: Fr.) Cooke (13)
Lyophyllum decastes (Fr.: Fr.) Sing. (22)
Marasmius oreades (Bolt.: Fr.) Fr.
Order Boletales Gilbert
Boletus aereus Bull.: Fr. (19)
Boletus aestivalis (Paulet) Fries (24)
Boletus edulis Bull.: Fr. (41)
Boletus pinophilus Pilát and Dermek (31)
Boletus edulis group (24 commercial samples)
Boletus appendiculatus Schäff. (12)
Boletus erythropus Pers. (10)
Boletus luridus Schäff. (26)
Suillus collinitus (Fr.) Kuntze (14)
Suillus granulatus (L.: Fr.) Rouss. (17)
Suillus luteus (L.: Fr.) Rouss. (17)
Xerocomus chrysenteron (Bull.) Quél. (10)
Xerocomus dryophilus (Thiers) Sing. (12)

Table 1 (*continued*)

Subdivision Basidiomycotina
Xerocomus ferrugineus (Schäff.) Bon (14)
Xerocomus rubellus Quél. (45)
Xerocomus subtomentosus (L.: Fr.) Quél. (27)
Subclass Gasteromycetideae E. Fisch.
Order Lycoperdales Clements
Lycoperdon perlatum Pers.: Pers. (13)
Calvatia utriformis (Bull.: Pers.) Jaap (24)
Subclass Aphyllophoromycetideae (Rea) Bon
Order Cantharellales Gaüm.
Cantharellus cibarius (Fr.: Fr.) Fr. (27)
Calvatia utriformis (Bull.: Pers.) Jaap (24)
Hydnum repandum L.: Fr. (18)
Class Phragmobasidiomycetes
Order Auriculariales Schroeter
Hirneola auricula-judae (L.: Fr.) Berkeley (11)
Subdivision Ascomycotina
Class Hymenoascomycetes
Subclass Pezizomycetideae (Fr.) Locq.
Order Pezizales Rehm
Helvella crispa (Scop.: Fr.) Fr. (16)
Morchella esculenta (L.) Pers. (10)
Morchella semilibera De Cand.: Fr. (16)
Ptychoverpa bohemica (Kromb.) J. Schroeter (19)

The numbers in parentheses indicate the number of samples investigated.

For each fungal species, descriptive statistics (minimum, mean, median, maximum, and standard deviation) were computed for the concentrations of arsenic, cadmium, lead, mercury and selenium. For graphical displays, boxplots, a graphical analogue of analysis of variance (Tukey, 1977) were used. All statistical analyses were performed using Systat 11 (SPSS Inc., Chicago, IL, USA) on a PC running Windows XP.

3. Results and discussion

Out of approximately 7000 mushroom samples investigated during the whole period of the study, we chose 1194 samples in 60 mushroom species, for which at least 10 probes were available, in order to obtain representative statistical data.

Table 2 shows that the amount of arsenic accumulated in the samples studied is in general modest. Noteworthy, however, are *Sarcosphaera eximia*, with arsenic concentrations reaching 1000 mg/kg dry weight and *Laccaria amethystina*, two species for which we were able to examine only five samples each and which are accordingly not discussed in detail in this paper. The values we recorded, however, are in good agreement with the findings of Stijve et al. (1990).

The amounts of cadmium recorded for species of the genus *Agaricus* [Subgenus *Flavoagaricus* Wasser (=*Flavescentes* Møller and Schäff.)], *Amanita* spp., and species in the *Boletus edulis* group are displayed in Fig. 1. The straight line drawn in all graphs represents the maximum concentration of cadmium (0.2 mg/kg fresh weight) allowed in cultivated mushrooms by the EU guideline 466/2001. Within the *Agaricus* Subgenus *Flavoagaricus*, only *Agaricus nivescens* contains amounts of cadmium inferior to the allowed upper level. *Amanita caesarea* exceeds, by approx. 4 times, the maximum amount allowed, and the values of cadmium present in both *B. edulis* and *B. pinophilus* are clearly above the upper allowed levels. The content of cadmium in *Agaricus macrosporus* (Møller and Schäff.) Pilát (=*Agaricus alberti* Bon), a common edible species, is noteworthy, as it is roughly 50 times the maximum weekly dose recommended by the WHO (0.5 mg) (Anon., 1996; WHO, 1996). Table 3 lists values measured for Cd (mg/kg dry weight) in vegetables commonly consumed in Italy. The concentration of Cd in species of *Agaricus* Subgenus *Flavoagaricus* is approximately 60 times higher than that contained in soybeans, the crop containing the highest Cd concentration. As approximately half of the maximum recommended Cd intake is provided by the normal alimentation, a weekly consumption of 50 g of fresh material of *A. macrosporus*, *A. arvensis*, *Agaricus essettei*, or *Agaricus sylvicola* would thus provide, at least theoretically, as mushrooms are not usually consumed daily, an amount of Cd already in excess of the maximum recommended weekly dose. It is also noteworthy that the average amount of cadmium contained in all samples studied is significantly higher than the maximum concentration allowed by the EU guideline 466/2001 (Fig. 1, Table 2).

A similar picture can be seen for lead (Fig. 2, Table 2), although the average amount of lead contained in all samples is lower than the maximum allowed concentration. In particular, *Calvatia utriformis* contains high amounts of lead that are clearly above the maximum level allowed. Of all species included in Table 1, only *Agaricus bisporus* (cultivated), *Agaricus campestris*, *Armillariella mellea*, the commercial *Boletus edulis* group (*B. edulis*, *B. pinophilus*, *Boletus aereus*, *Boletus aestivalis*), *Boletus appendiculatus*, *Boletus erythropus*, *Boletus luridus*, *Cantharellus cibarius*, *Hydnum repandum*, *Clitocybe geotropa*, *Cantharellus gibba*, *Cantharellus nebularis*, *Clitopilus prunulus*, *Coprinus comatus*, *Entoloma saundersii*, *Hygrophorus penarius*, *Lyophyllum decastes*, *Marasmius oreades*, *Mitrophora hybrida*, *Morchella esculenta*, *Russula cyanoxantha*, *Russula olivacea*, *Suillus collinitus*, *Suillus granulatus*, *Suillus luteus*, *Xerocomus dryophilus* and *Xerocomus ferrugineus* comply with the EU directive 466/2001 with regard to their lead content (3 mg/kg dry weight). All

Table 2
Mean arsenic, cadmium, mercury, lead and selenium contents (mg/kg fresh weight) and 95% confidence intervals (C.I.) in the fungi studied

Taxon	As		Cd		Hg		Pb		Se	
	Mean	C.I.	Mean	C.I.	Mean	C.I.	Mean	C.I.	Mean	C.I.
Agaricus arvensis	1.06	0.63–1.50	27.7	14.4–41.0	4.19	3.15–5.22	1.78	1.19–2.37	3.75	3.12–4.38
Agaricus bisporus	0.21	0.07–0.35	1.00	0.49–1.52	3.94	−1.32 to 9.21	1.25	0.06–2.44	3.40	2.59–4.21
Agaricus bitorquis	0.29	0.02–0.56	2.38	1.56–3.20	8.05	5.25–10.9	5.90	3.15–8.65	12.9	9.35–16.47
Agaricus campestris	0.22	0.02–0.42	1.74	0.40–3.08	2.49	1.87–3.12	1.64	1.03–2.25	4.27	3.31–5.23
Agaricus essettei	1.98	0.87–3.09	37.8	27.7–47.8	4.40	3.09–5.70	4.22	2.68–5.76	2.90	2.35–3.45
Agaricus macrosporus	1.79	0.82–2.76	101	77.0–124	6.56	4.72–8.41	1.25	0.81–1.69	3.93	3.15–4.71
Agaricus nivescens	5.00	5.00–5.00	4.99	4.99–4.99	5.35	5.35–5.35	1.70	1.70–1.70	3.00	3.00–3.00
Agaricus sylvicola	1.52	0.55–2.49	39.6	25.8–53.5	3.69	2.53–4.85	3.08	1.99–4.16	2.90	2.35–3.45
Agrocybe aegerita	0.14	0.06–0.22	2.78	2.15–3.42	0.22	0.17–0.27	0.82	0.41–1.23	1.44	1.14–1.75
Amanita caesarea	0.10	0.10–0.10	7.05	5.74–8.37	2.47	2.03–2.92	1.12	0.61–1.62	3.30	2.55–4.06
Amanita ovoidea	0.25	−0.07 to 0.56	0.99	0.58–1.40	0.65	0.39–0.91	0.57	0.32–0.82	1.82	1.07–2.56
Amanita rubescens	0.10	0.10–0.10	4.24	4.24–4.24	3.77	3.77–3.77	0.70	0.70–0.70	0.20	0.20–0.20
Amanita vaginata	0.10	0.10–0.10	3.96	−1.25 to 9.17	0.53	−1.38 to 2.44	1.25	−1.93 to 4.43	2.00	2.00–2.00
Armillariella mellea	0.10	0.10–0.10	1.76	1.18–2.33	0.19	0.08–0.31	1.15	0.16–2.13	0.79	0.35–1.23
Boletus aereus	0.39	−0.03 to 0.81	2.06	0.87–3.24	3.29	2.16–4.41	1.19	0.23–2.15	24.6	16.3–32.8
Boletus aestivalis	0.10	0.10–0.10	1.89	1.41–2.36	2.68	1.52–3.85	0.74	0.34–1.15	21	17.0–25.03
Boletus appendiculatus	0.10	0.10–0.10	0.55	0.37–0.74	1.05	0.71–1.39	0.64	0.30–0.98	7.27	5.46–9.07
Boletus edulis	0.10	0.10–0.10	3.97	3.05–4.88	2.67	1.02–4.32	1.21	0.37–2.06	30.8	24.1–37.5
Boletus erythropus	0.10	0.10–0.10	0.54	0.22–0.87	0.51	0.31–0.71	0.74	0.23–1.25	7.29	4.97–9.60
Boletus pinophilus	0.41	−0.12 to 0.94	4.39	2.41–6.36	4.96	3.85–6.07	1.14	0.44–1.83	94.4	81.9–107
Calocybe gambosa	0.47	−0.03 to 0.97	2.57	1.99–3.15	4.52	3.01–6.03	0.94	0.70–1.18	6.50	5.39–7.61
Calvatia utriformis	1.51	0.29–2.73	1.54	1.27–1.82	3.55	2.96–4.14	10.6	6.42–14.8	4.97	4.19–5.74
Cantharellus cibarius	0.10	0.10–0.10	0.42	0.34–0.51	0.16	0.07–0.26	1.13	0.94–1.31	1.28	0.96–1.60
Cantharellus lutescens	0.10	0.10–0.10	0.52	0.43–0.61	0.21	0.13–0.28	2.62	2.28–2.95	1.23	0.88–1.57
Clitocybe geotropa	11.59	6.44–16.75	1.48	1.10–1.86	4.93	3.76–6.11	0.68	0.40–0.95	3.79	2.77–4.81
Clitocybe gibba	0.92	0.07–1.77	1.38	0.82–1.93	0.83	0.54–1.12	1.53	0.28–2.78	2.79	2.06–3.51
Clitocybe nebularis	0.19	0.01–0.38	0.89	0.75–1.02	2.25	1.72–2.77	1.57	1.14–2.00	5.41	4.31–6.51
Clitopilus prunulus	0.43	0.09–0.77	1.07	0.63–1.52	1.89	1.50–2.27	1.89	0.29–3.49	6.71	5.55–7.87
Coprinus comatus	0.10	0.10–0.10	1.53	0.30–2.75	0.78	0.42–1.14	0.80	0.43–1.18	2.05	1.16–2.94
Cortinarius praestans	0.44	−0.07 to 0.96	3.55	2.59–4.50	0.36	0.23–0.49	0.70	0.34–1.06	4.00	1.13–6.87
Entoloma saundersii	1.11	0.43–1.79	1.41	0.96–1.86	0.18	0.12–0.23	1.77	1.13–2.41	1.76	1.12–2.41
Helvella crispa	0.10	0.10–0.10	1.97	0.76–3.18	0.35	0.18–0.52	1.42	0.64–2.21	1.72	1.22–2.23
Hirneola auricula-judae	0.10	0.10–0.10	0.16	0.10–0.21	0.18	0.08–0.28	3.13	2.10–4.16	1.62	0.81–2.42
Hydnum repandum	0.37	0.15–0.59	0.23	0.18–0.29	0.69	0.54–0.84	0.82	0.64–1.00	1.34	0.97–1.71
Hygrophorus penarius	0.10	0.10–0.10	0.25	0.18–0.31	0.22	0.14–0.30	0.83	0.42–1.24	1.54	0.95–2.13
Hygrophorus russula	0.10	0.10–0.10	2.88	1.80–3.96	0.77	0.49–1.04	1.14	0.46–1.81	2.02	1.62–2.41
Laccaria affinis	4.12	−1.27 to 9.52	4.21	2.47–5.95	0.12	0.08–0.17	1.45	0.11–2.79	2.26	1.58–2.94
Lepista nuda	1.64	0.07–3.21	0.80	0.41–1.18	6.25	−1.03 to 13.5	4.64	1.80–7.49	3.64	2.54–4.74
Lycoperdon perlatum	0.10	0.10–0.10	0.75	0.53–0.97	1.92	1.21–2.64	4.48	2.78–6.18	3.44	2.55–4.33
Lyophyllum decastes	0.13	0.06–0.20	2.39	0.70–4.09	1.74	0.51–2.98	2.34	0.24–4.43	3.19	1.99–4.39
Macrolepiota procera	0.22	−0.03 to 0.47	1.33	0.77–1.89	2.37	1.47–3.27	3.45	2.19–4.71	3.45	2.64–4.26
Macrolepiota rachodes	1.55	0.45–2.65	0.71	0.48–0.93	5.26	3.02–7.49	4.44	0.38–8.51	8.50	6.10–10.9
Marasmius oreades	0.20	−0.01 to 0.41	0.58	0.43–0.73	1.78	1.50–2.06	1.49	0.61–2.37	2.74	2.47–3.01
Mitrophora hybrida	0.10	0.10–0.10	0.96	0.78–1.14	0.08	0.05–0.11	2.37	0.76–3.97	1.46	0.99–1.92
Morchella esculenta	0.34	−0.19 to 0.87	0.55	0.32–0.78	0.09	0.05–0.12	0.74	0.07–1.41	1.33	0.67–1.99
Ptychoverpa bohemica	0.10	0.10–0.10	1.97	1.30–2.64	0.12	0.09–0.14	1.19	0.74–1.64	2.22	1.58–2.86
Rozites caperatus	0.10	0.10–0.10	24.2	18.4–29.9	1.07	0.89–1.25	0.84	0.54–1.13	1.88	1.58–2.18
Russula cyanoxantha	0.10	0.10–0.10	1.34	1.01–1.67	1.31	0.99–1.63	1.34	0.89–1.79	2.18	1.88–2.48
Russula olivacea	0.26	−0.09 to 0.61	1.34	0.85–1.83	0.82	0.23–1.40	1.23	0.53–1.92	1.40	0.84–1.96
Russula vesca	0.16	0.04–0.29	11.6	9.25–13.9	0.39	0.25–0.52	2.20	1.65–2.75	1.72	1.38–2.07
Suillus collinitus	0.10	0.10–0.10	0.22	0.07–0.37	0.18	0.08–0.28	1.15	0.57–1.73	2.95	2.23–3.68
Suillus granulatus	0.10	0.10–0.10	0.51	0.36–0.66	0.29	0.19–0.38	1.32	0.39–2.25	3.42	2.39–4.45
Suillus luteus	0.32	0.05–0.59	0.54	0.23–0.84	0.28	0.19–0.37	1.23	0.72–1.75	3.27	2.22–4.31
Xerocomus chrysenteron	0.10	0.10–0.10	3.85	0.84–6.87	0.23	0.16–0.30	0.54	0.28–0.80	1.63	1.05–2.21
Xerocomus dryophilus	0.47	0.04–0.91	0.26	0.07–0.46	0.18	0.05–0.30	0.69	0.27–1.11	1.86	1.53–2.18
Xerocomus ferrugineus	0.26	0.01–0.50	0.43	0.31–0.55	0.25	0.16–0.34	0.94	0.48–1.40	1.77	1.27–2.26
Xerocomus rubellus	0.44	−0.11 to 0.99	2.46	1.98–2.94	0.70	0.43–0.98	1.60	0.86–2.33	1.76	1.50–2.01
All samples	23.4	16.9–29.8	4.00	3.69–4.31	1.15	1.05–1.25	1.70	1.61–1.79	4.43	4.11–4.76

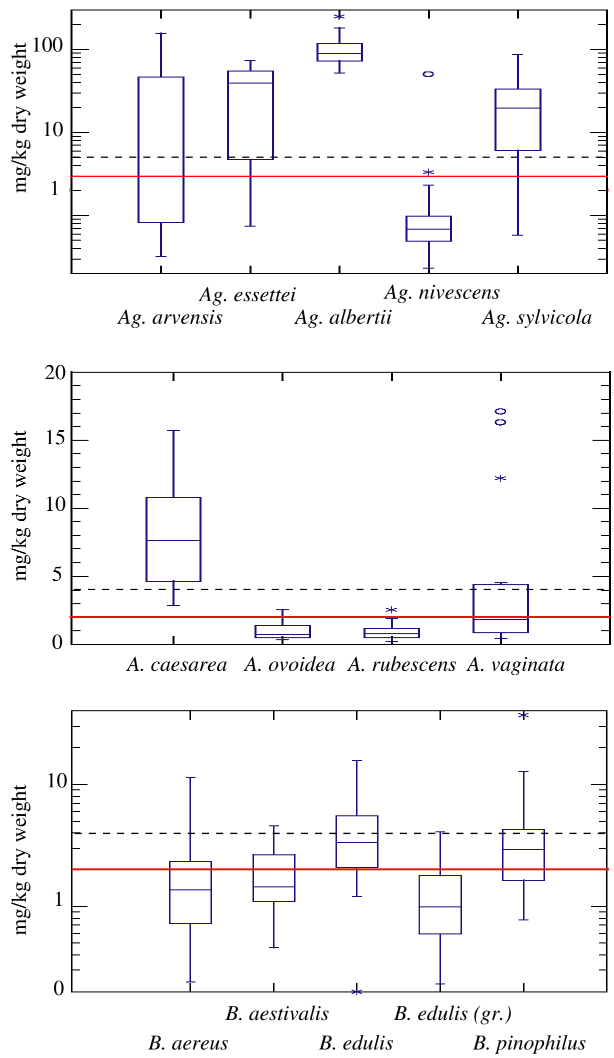

Fig. 1. Boxplot displays of the content of cadmium in selected mushroom species of the genera *Agaricus*, *Amanita*, and *Boletus*. The straight line represents the maximum amount allowed by the EU directive 466/2001 (0.2 mg/kg dry weight, corresponding to approx. 2 mg/kg fresh weight). The dashed line shows the mean value of all samples studied.

Table 3
Cadmium concentration (mg/kg fresh weight) in vegetables

	Mean	Range
Wheat	0.068	0.018–0.136
Rice	0.11	0.001–0.310
Soy	0.17	0.05–0.48
Spinach	0.045	0.019–0.070
Lettuce	0.054	0.031–0.147
Cabbage	0.031	0.022–0.094
Peas	0.004	0.003–0.005
Beans	0.042	0.019–0.075
Potatoes	0.016	0.005–0.055
Onions	0.04	0.01–0.09
Peppers	0.029	0.015–0.043
Tomatoes	0.02	0.01–0.08
Apples	0.01	0.005–0.027
Pears	0.011	0.010–0.013
Oranges	0.002	0.001–0.007
Lemons	0.01	0.01–0.04

[AGAC, Internal report].

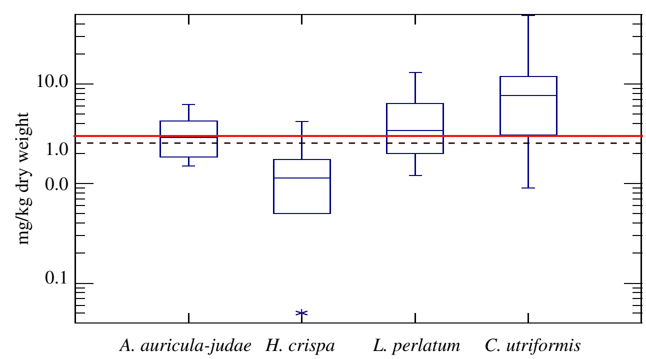

Fig. 2. Boxplot displays of the contents of lead in *Auricularia auricula-judae*, *Helvella crispa*, *Lycoperdum perlatum*, and *Calvatia utriformis*. The straight line represents the maximum amount allowed by the EU directive 466/2001 (0.3 mg/kg dry weight, corresponding to approx. 3 mg/kg fresh weight). The dashed line shows the mean value of all samples studied.

others appear to contain lead levels that are either borderline (wild *A. bisporus*, *A. bitorquis*, *Agrocybe aegerita*, *Amanita ovoidea*, *B. aereus*, *B. aestivalis*, *Calocybe gambosa*, *Cantharellus lutescens*, *Helvella crispa*, *Hirneola auricula-judae*, *Hygrophorus russula*, *Lepista nuda*, *Lycoperdon perlatum*, *Macrolepiota procera*, *M. rachodes*, *Ptycoverpa bohemica*, *Xerocomus chrysenteron*, *X. rubellus*, *X. subtomentosus*) or clearly above the limits allowed (*A. essettei*, *A. albertii*, *A. macrosporus*, *A. sylvicola*, *A. caesarea*, *A. rubescens*, *A. vaginata*, *Boletus edulis*, *B. pinophilus*, *C. utriformis*, *Cortinarius praestans*, *Laccaria affinis*, *Rozites caperatus*, and *Russula vesca*). The case of *C. utriformis* is noteworthy, as all samples examined were collected, with no exceptions, in mountain meadows unlikely to be polluted. This raises some doubts about the use of mushrooms as bioindicators, but this question will be addressed elsewhere.

The maximum acceptable content of mercury in mushrooms has so far not been established. The WHO recommends the maximum weekly intake of mercury not to exceed 0.3 mg (0.2 mg methyl mercury, respectively). Inspection of Table 2 reveals that *A. bitorquis*, *A. arvensis*, *A. essettei*, *A. albertii*, *B. pinophilus*, *C. geotropa*, and *M. rachodes* all have high contents of Hg that are within a range of 5–10 mg/kg dry weight. Fig. 3 also shows that, in general, all mushroom species contain very high amounts of Hg, species in the genus *Boletus*, and in particular *B. pinophilus* being those with the highest values. Our data closely match reports by other authors, in particular those of Alonso et al. (2000), Bargagli (1992), Falandysz et al. (2003), and Stijve and Besson (1976).

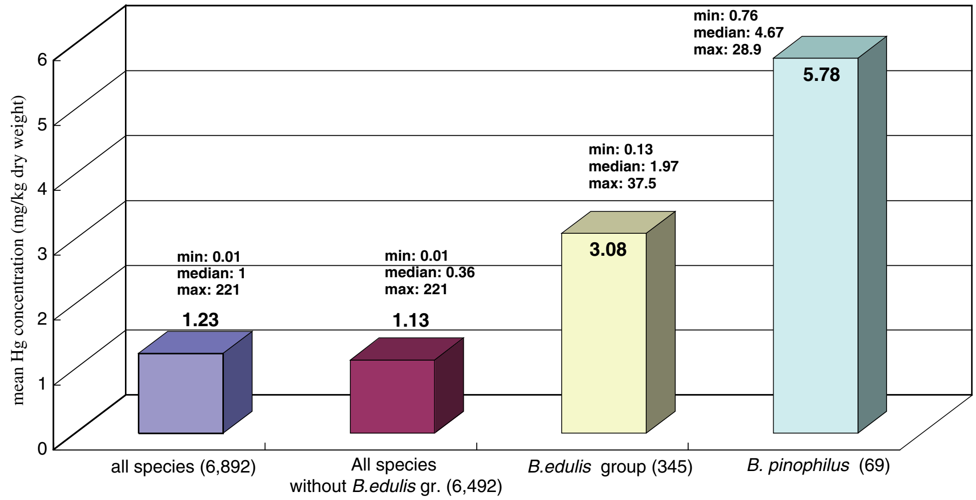

Fig. 3. Bar chart comparing the content of mercury in groups of mushroom species investigated.

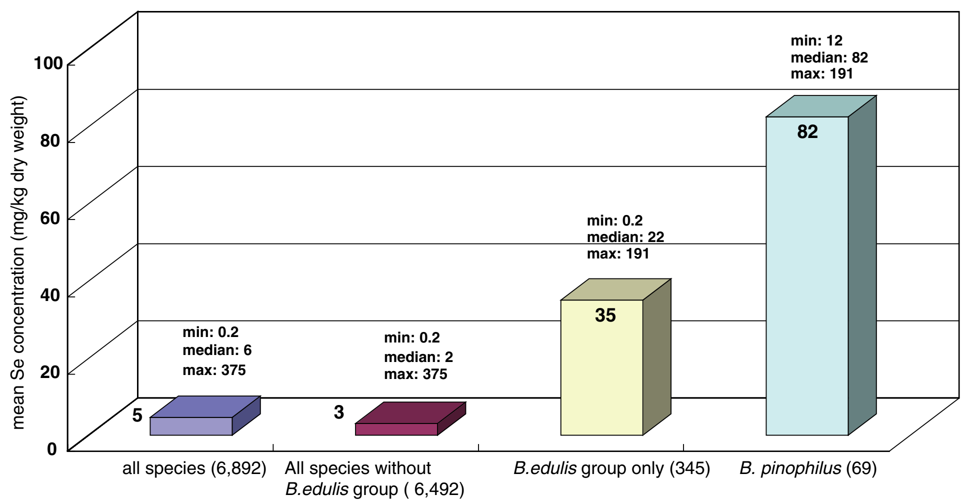

Fig. 4. Bar chart comparing the content of selenium in groups of mushroom species investigated.

Selenium is an element which plays an important role in human nutrition and metabolism: according to the European Scientific Committee on Foods (SCF) the Dietary Reference Intake is 55 μg; the total intake should, in no case, exceed 100 μg daily. Table 2 and Fig. 4 reveal that mushrooms, in general, but species in the *B. edulis* group, in particular, are rich in selenium. For *B. pinophilus*, the ingestion of 10 g of fresh mushroom would already provide the body an amount of selenium above to the maximum recommended daily dose.

Overall, our study has shown that mushrooms, and among them some excellent edible species such as *A. caesarea* or the *B. edulis* group, can accumulate high amounts of heavy metals.

Our data on heavy metals confirm reports by Blanusa et al. (2001), Falandysz et al. (2001, 2002a, 2002b, 2003, 2004), Jorhem and Engman (2000) and Stijve and Besson (1976) for mercury and cadmium, and by Kalac et al. (1991) for lead, cadmium and mercury that suggest mushrooms are able to accumulate heavy metals in amounts that, after chronic consumption, could be harmful to humans. Several authors (e.g. Bargagli, 1988; Cocchi & Vescovi, 2000; Gremigni, 1986; Kalac & Svoboda, 2000) have suggested that mushrooms could be potential bioindicators of environmental pollution with heavy metals. Our data, as exemplified by *C. utriformis* and *A. albertii*, do not support this hypothesis. Additional analyses of the complete dataset examined (data not shown) do not indicate any bioindicator role of any of the fungi we studied. On the other hand, it appears that accumulation of specific heavy metals could be species-specific and thus assume a taxonomic role. Species-dependent concentrations of specific elements in the fruiting bodies have already been observed (Kalac & Svoboda, 2000). Additional investigations, currently ongoing with our samples, will provide further information on this potentially useful taxonomic tool.

References

Anon. (1996). Gli oligoelementi nella nutrizione e nella salute dell'uomo. *Schede Informative n. 3-4/96. World Health Organization Geneva and Istituto Scotti Bassani per la Ricerca e l'Informazione Scientifica e Nutrizionale Milano*.

Allen, R. O., & Steinnes, E. (1978). Concentrations of some potentially toxic metals and other trace elements in wild mushrooms from Norway. *Chemosphere, 4*, 371–378.

Alonso, J., Salgado, M. J., Garcia, M. A., & Melgar, M. J. (2000). Accumulation of mercury in edible macrofungi: influence of some factors. *Archives of Environmental Contamination and Toxicology, 38*(2), 158–162.

Bargagli, R. (1988). Fungi and higher plants as biomonitors of trace elements in soil. In *Trace elements in terrestrial plants: An ecophysiological approach to biomonitoring and biorecovery* (pp. 153–177). Berlin Heidelberg and Georgetown, TX, USA: Springer-Verlag and R.G. Landes Company.

Bargagli, R. (1992) Possibili implicazioni igienico sanitarie nel consumo dei funghi eduli, efficaci accumulatori di metalli pesanti. In *Atti 2° Convegno Nazionale sugli Avvelenamenti da Funghi. Rovereto (TN)*, *Supp. Ann. Mus. Civ. Rovereto 8*, 79–96.

Blanusa, M., Kucak, A., Varnai, V. A., & Saric, M. M. (2001). Uptake of cadmium, copper, iron, manganese, and zinc in mushrooms (Boletaceae) from Croatian forest soil. *Journal of AOAC International, 84*(6), 1964–1971.

Borella, P., Quaglio, G., Fabio, G., & Caselgrandi, E. (1992). Metalli tossici nei funghi: rischio per la salute o problema di inquinamento ambientale. *Bollettino Chimici Igienisti, 43*, 209–215.

Bressa, G., Cima, L., & Costa, P. (1988). Bioaccumulation of Hg in the mushroom *Pleurotus ostreatus*. *Ecotoxicology and Environmental Safety, 16*(2), 85–89.

Cocchi, L., & Vescovi, L. (1996). Considerazioni sulle concentrazioni di elementi chimici in funghi dell'Ordine Boletales. *Il Fungo, Associazione Micologica Bresadola*, (pp. 42–60).

Cocchi, L., & Vescovi, L. (1997). Considerazioni sul contenuto di elementi chimici nei funghi. Argento, cadmio, mercurio e piombo nel genere Agaricus. *Riv Micol, 1*, 53–72.

Cocchi, L., & Vescovi, L. (2000). I funghi come bioindicatori di inquinamento. In *Proceedings of the symposium on micologia e ambiente, Viterbo, Italy*.

Cocchi, L., Petrini, O., & Vescovi L. (2002). Metalli pesanti e isotopi radioattivi nei funghi: aspetti igienico – sanitari. In *Proceedings of the 2nd international meeting of mycotoxicology. Pagine di micologia 17* (pp. 73–91).

Cocchi, L., & Vescovi, L. (1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005). Schede della rubrica Funghi - Metalli - Radioattività. Il Fungo, Associazione Micologica Bresadola.

Dojmi Di Delupis, G., & Dojmi Di Delupis, F. (1996). *Contaminazione di funghi commestibili con mercurio, cadmio e piombo*. Rapporto ISTISAN 96/36 Istituto Superiore di Sanità, Roma.

Falandysz, J., Gucia, M., Frankowska, A., Kawano, M., & Skwarzec, B. (2001). Total mercury in wild mushrooms and underlying soil substrate from the city of Umeå and its surroundings, Sweden. *Bulletin of Environmental Contamination and Toxicology, 67*(5), 763–770.

Falandysz, J., Gucia, M., Skwarzec, B., Frankowska, A., & Klawikowska, K. (2002a). Total mercury in mushrooms and underlying soil substrate from the Borecka Forest, Northeastern Poland. *Archives of Environmental Contamination and Toxicology, 42*(2), 145–154.

Falandysz, J., Lipka, K., Gucia, M., Kawano, M., Strumnik, K., & Kannan, K. (2002b). Accumulation factors of mercury in mushrooms from Zaborski Landscape Park, Poland. *Environmental International, 28*(5), 421–427.

Falandysz, J. (2002c). Mercury in mushrooms and soil of the Tarnobrzeska Plain, south-eastern Poland. *Journal of Environmental Science and Health Part A, 37*(3), 343–352.

Falandysz, J., Gucia, M., Brzostowski, A., Kawano, M., Bielawski, L., Frankowska, A., et al. (2003). Content and bioconcentration of mercury in mushrooms from northern Poland. *Food Additives and Contamination, 20*(3), 247–253.

Falandysz, J., Jedrusiak, A., Lipka, K., Kannan, K., Kawano, M., Gucia, M., et al. (2004). Mercury in wild mushrooms and underlying soil substrate from Koszalin, North-central Poland. *Chemosphere, 54*(4), 461–466.

Gremigni, G. (1986). *Tricholoma album*: un indicatore biologico della contaminazione da fallout. *Quaderni di Storia Naturale di Livorno*, (p. 81).

Grüter, H. (1964). Selective accumulation of the fission product ^{137}Cs in fungi. *Naturwissenschaften, 51*, 161–162 (in German).

Ismail, S. S. (1994). Distribution of Na, K, Rb, Cs, and ^{137}Cs in some Austrian higher fungi. *Biological Trace Elements Research, 43–45*, 707–714.

Jorhem, L., & Engman, J. (2000). Determination of lead, cadmium, zinc, copper, and iron in foods by atomic absorption spectrometry after microwave digestion: NMKL Collaborative Study. *Journal of AOAC International, 83*(5), 1189–1203.

Jorhem, L., & Sundstrom, B. (1995). Levels of some trace elements in edible fungi. *Zeitschrift fur Lebensmittel-Unterschung und -Forschung, 201*(4), 311–316.

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

Kalac, P., & Svoboda, L. (2000). A review of trace elements concentrations in edible mushrooms. *Food Chemistry, 69*, 273–281.

Markert, B. (1992). Multi-element analysis in plant materials (pp. 401–428). *Analytical tools and biological questions. Biogeochemistry of Trace metals*. Lewis Publishers: Boca Raton, FL.

Mornand, J. (1990). Présence de métaux lourds dans les champignons. *Bulletin de la Société Mycologique de France, 106*(1), 31–46.

Schmitt, J. A. (1987). Fungi and heavy metals – Fungi atque loci natura. *Atti IV Convegno Internazionale di Micologia - Borgo Val di Taro (PR)*, (pp. 105–146).

Seeger, R. (1976a). Distribution of mercury in the fruit-bodies of *Boletus edulis* and *Agaricus* species. *Zeitschrift fur Lebensmittel-Unterschung und -Forschung, 161*(2), 115–117 (in German).

Seeger, R. (1976b). Mercury content of mushrooms (in German). *Zeitschrift fur Lebensmittel-Unterschung und -Forschung, 160*(3), 303–312.

Stegnar, P., Kosta, L., Byrne, A. R., & Ravnik, V. (1973). The accumulation of mercury by, and the occurrence of methyl mercury in some fungi. *Chemosphere, 2*, 57–63.

Stijve, T. (2001). La pollution des champignons: le point sur l'arsenic. *Bulletin de la Fédération Mycologique Dauphiné–Savoie, 160*, 39–47.

Stijve, T., & Besson, R. (1976). Mercury, cadmium, lead and selenium content of mushroom species belonging to the Genus *Agaricus*. *Chemosphere, 2*, 151–158.

Stijve, T., Vellinga, E. C., & Hermann, A. (1990). Arsenic accumulation in some higher fungi. *Persoonia, 14*(2), 161–166.

Stijve, T., Goessler, W., & Dupuy, G. (2004). Influence of soil particles on concentrations of aluminium, iron, calcium and other metals in mushrooms. *Deutsche Lebensmittel-Rundschau, 100*(1), 10–13.

Svoboda, L., & Kalac, P. (2003). Contamination of two edible *Agaricus* spp. mushrooms growing in a town with cadmium, lead, and mercury. *Bulletin of Environmental Contamination and Toxicology, 71*(1), 123–130.

Tsaler, D. L., & Zaprianov, Z. K. (1985). *AAS in occupational and environmental health practice*. Boca Raton, FL: CRC Press.

Tukey, J. W. (1977). *Exploratory data analysis*. Reading, MA: Addison-Wesley Publishing Co.

Vetter, J. (1994). Data on arsenic and cadmium contents of some common mushrooms. *Toxicon, 32*(1), 11–15.

World Health Organization. (1996). *Trace elements in human nutrition and health*. Geneva.