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Macro- and microelement contents in fruiting bodies of wild mushrooms from the Notecka forest in west-central Poland

Maria Rudawska *, Tomasz Leski

Institute of Dendrology, Polish Academy of Sciences, 5 Parkowa Str., 62-035 Kórnik, Poland

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Abstract

Fruiting bodies of wild mushrooms and forest soil samples were collected and analyzed for macro- (N, P, K, S, Ca, Mg) and microelement (Al, Zn, Fe, Mn, Cd, Pb) contents in pine stands of the Notecka Forest in west-central Poland. Elements were determined by atomic absorption spectrometry in 160 samples of 8 fungal species and 15 underlying soil samples. Macro- and microelement contents in soil were low and characteristic of the poor and acidic sandy soils of the Polish lowlands not influenced by industrial pollution. In fruiting bodies, the highest mean concentration of macroelements (dry mass basis) was found for N (40.0 g kg^{-1}), followed by K (33.0 g kg^{-1}), P (5.4 g kg^{-1}), S (2.2 g kg^{-1}), Ca (1.0 g kg^{-1}) and Mg (0.7 g kg^{-1}). All macroelements (except for Ca) were concentrated in considerably higher levels in the fruiting bodies than in the forest soil. Nitrogen, P, K, S and Mg were preferably translocated into the cap rather than the stipes. Calcium, however, was often found in higher concentration in stipes than in caps. The mean microelement concentrations, across all tested fungi, were in the following order: Al > Zn > Fe > Mn > Pb > Cd. Microelements showed different distributions, depending on the part of the fruiting body. Some were more concentrated in the caps and some in stipes and distributions varied among species. *Xerocomus badius* is the most often harvested edible mushroom in the Notecka Forest. Pb and Cd distributions in fruiting bodies of this mushroom were evaluated in order to assess health risks to consumers. The estimated dietary exposures to Pb and Cd for consumers of this mushroom were in excess of guidelines on safe exposures.

Keywords: Essential elements; Trace metals; Ectomycorrhizal fungi; Edible mushrooms

1. Introduction

Fungi are important organisms in nature and are present almost everywhere. There are numerous species of wild mushrooms and many are edible. Mushrooms do not constitute a significant portion of the human diet; however, the consumption of wild and cultivated mushrooms continues to increase in many countries (e.g., Alonso, Garcia, Pérez-López, & Melgar, 2003; Demirbaş, 2000; Falandysz et al., 2001; Kalač & Svoboda, 2000; Latiff, Daran, & Mohamed, 1996; Longvah & Deosthale, 1998; Manzi, Aguzzi, & Pizzoferrato, 2001; Sanmee, Dell, Lumyong, Izumori, & Lumyong, 2003). Many common mushrooms, for example, *Amanita*, *Suillus*, *Xerocomus*, *Lactarius*, *Russula*, *Leccinum* and *Paxillus*, are ectomycorrhizal (ECM). External mycelia of ECM fungi (vegetative phase) spread below-ground around trees, acquiring water and minerals from the soil to benefit trees in symbiotic associations (Smith & Read, 1997). Fungal fruiting bodies are also connected to host roots through mycelia which transport carbohydrates necessary for their development. During rainy seasons, the fruiting bodies of ECM fungi can be seen in forests. They represent a visible by-product of ECM mycelia and function as reproductive structures. The chemical composition and nutritional quality of different wild

* Corresponding author. Tel.: +48 61 8170033/8170166; fax: +48 61 8170166.

E-mail address: mariarud@man.poznan.pl (M. Rudawska).

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and cultivated mushroom species have been studied (Aletor, 1985; Alofe, Odeyemi, & Oke, 1996; Díez & Alvarez, 2001; Kreula, Saarivirta, & Karanko, 1976; Longvah & Deosthale, 1998; Manzi et al., 2001; Manzi, Gambelli, Marconi, Vivanti, & Pizzoferrato, 1999; Senatore, Dini, & Marino, 1988; Tshinyangu, 1996). Besides water (85–95% f.w.), carbohydrates (39.9% d.w.), proteins (17.5% d.w.) and low contents of lipids (2.9% d.w.) (Latiff et al., 1996), the wide variety and abundance of minerals are the most characteristic features of ECM fruiting bodies. Macro- and microelements present in the environment are to different extents accumulated by ECM vegetative mycelia and in the ECM fruiting bodies (Harmon, Sexton, Caldwell, & Carpenter, 1994; Kreula et al., 1976; Sanmee et al., 2003; Vogt & Edmonds, 1980). Several studies have been carried out on the trace element contents in fruiting bodies of the wild-growing edible mushrooms in Poland. The major publications consider levels of heavy metals in groups of mushrooms comprised of various species and collected in highly polluted or control sites (Falandysz, Danisiewicz, & Bona, 1994; Grzybek & Janczy, 1990; Malinowska, Szafer, & Falandysz, 2004; Turnau, 1991). Data on the general patterns of macro- and microelement accumulations in fruiting bodies of wild, ECM fungi in Poland are scarce and limited to a few sites in the Pomorskie Voivodeship in northern Poland (Falandysz et al., 2001; Malinowska et al., 2004). Poland is the largest producer of wild mushrooms in Europe and the largest European exporter of edible mushrooms. Commercial harvesting of mushrooms in Poland has a long tradition. A total of 1.71, 3.28, and 2.38 million kg of mushrooms were purchased by the food industry in 2000, 2001 and 2002, respectively (Statistical Yearbook – Forestry, 2003). Of this total, around half (depending on the year) originated from the Notecka Forest situated in west-central Poland. This study was initiated to (1) evaluate macro- and microelement contents in fruiting bodies of wild grown, mostly edible ectomycorrhizal fungi collected in the Notecka Forest region, and (2) determine which toxic metals were accumulated in higher concentrations in fruiting bodies of a frequently harvested and eaten mushroom, *X. badius*, in order to assess the health risks to consumers.

2. Materials and methods

2.1. Study site

The survey was conducted between June 1999 and October 2000 in the Notecka Forest (lowlands of west-central Poland). The Notecka Forest is the second largest forested area in Poland (1350 sq. km), 100 km long and 20 km in width, nestled between the Warta and Noteć rivers (Fig. 1). The study sites are physiographically homogeneous, both with regard to landscape formation and forest vegetation. Soils of this area are influenced mostly by planting haplic podzol and inland dunes with Scots pine (*Pinus sylvestris*) as the dominant tree species (95%). The Notecka Forest is situated far away from the acute sources of industrial pollution and is considered to be one of the most important centres for commercial harvesting of mushrooms in Poland.

2.2. Mushrooms and soil sampling

The fruiting bodies of eight mushrooms species, namely *Amanita rubescens*, *Lactarius deliciosus*, *L. rufus*, *Leccinum scabrum*, *Paxillus involutus*, *Suillus luteus*, *Xerocomus badius*, and *X. chrysenteron*, were selected for this study. All these mushrooms have been consumed; however, the edibility of *P. involutus* and *L. rufus* is problematic (see Section 3).

Fruiting bodies (2–4 fruiting bodies of each species per site) collected in five different areas of the Notecka Forest were divided into the cap and stipe, rinsed in deionized water to remove adhering particles, dried at 60 °C for 48 h, and ground in an automatic mortar; 160 samples of fleshy fruiting bodies (80 caps and 80 stipes) were analyzed.

In addition to the mushroom collection, 15 soil samples of the upper forest soil horizon (0–10 cm, after removing the surface layer of organic detritus) were also collected at appropriate sampling places.

2.3. Chemical analysis

Soil samples and milled fruiting bodies, of approximately 2.5 g d.w. each, were digested in a mixture of spectrally pure concentrated acids: HNO_3 and $HClO_4$ in a proportion of 4:1 (v:v) and diluted with bi-distilled water to make 25 ml. Nitrogen was analyzed by the micro-Kjeldahl method. The rest of the macroelements, aluminium, and heavy metals (Mn, Fe, Zn, Cd and Pb), were measured by atomic absorption spectroscopy (Varian 220 FS) with atomization in an air-acetylene flame. The accuracy of the analyses was checked against standard reference material, namely pine needles SRM 1575 and tomato leaves SRM 1573a (National Institute of Standards and Technology). Detection limit values of microelements, in microgrammes per litre were found to be 1.3 for Al, 0.05 for Mn, 0.11 for Fe, 0.02 for Zn, 0.02 for Cd, and 0.45 for Pb.

2.4. Statistical analysis

Analysis of variance (ANOVA) for a one-way randomized factor design was used to test whether or not mushroom species or part of the fruiting body (cap or stipe) influenced element concentrations of tested fungi. The statistical software package, Statistica 5.1, was used.

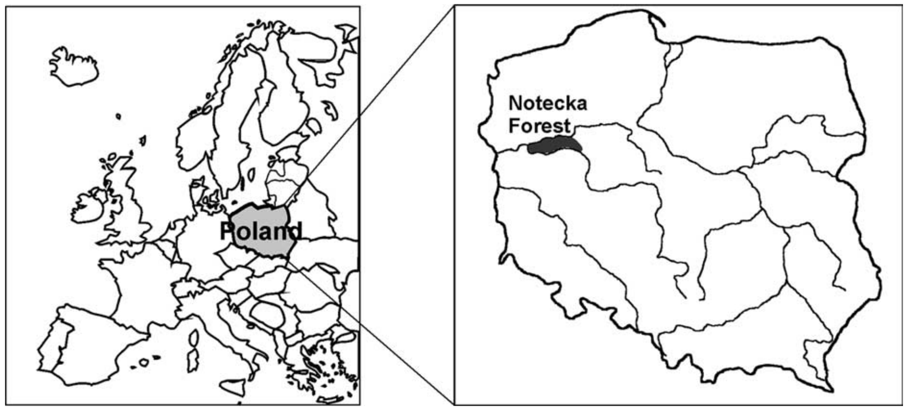

Fig. 1. Location of the sampling area.

3. Results and discussion

The ranges of macro- and microelement concentrations in the topsoil of sites where fruiting bodies were sampled are presented in Table 1. The pH_{salt} of the soil in the Notecka Forest is acidic (3.15–4.03). Macroelement contents, especially N, P and K, were very low and characteristic for the poor sandy soils of the lowlands where the Notecka Forest is situated (Uggla & Uggla, 1979). Low levels of toxic metals indicate that this region is free of direct environmental pollution. Only aluminium content was approximately two times higher than more neutral soils in other studies (Reich, Oleksyn, & Tjoelker, 1994; Rudawska, Kieliszewska-Rokicka, Leski, & Oleksyn, 1995) and was closely connected with soil acidity. The amounts of other extractable metals were also very low and did not reach the levels considered "normal" for the light, sandy soils in Poland (Mn: 80–710 mg kg^{-1}; Zn: 10–200 mg kg^{-1}, Cd: 0.08–1.6 mg kg^{-1}, Pb: 5–25 mg kg^{-1}; Kabata-Pendias & Pendias, 1999).

Table 1
pH and macro- and micro-element contents in the soil from the Notecka Forest in west-central Poland (g kg^{-1} and mg kg^{-1}, respectively)

Soil properties	
pH H_2O	3.56–4.20
pH_{KCl}	3.15–4.03
Macroelements (g kg^{-1})	
N	0.3–0.6
P	0.2–0.4
K	0.6–1.0
Ca	0.7–1.2
Mg	0.1–0.3
S	0.07–0.15
Microelements (mg kg^{-1})	
Al	91–119
Mn	16.7–21.2
Fe	47.5–65.3
Zn	1.32–1.98
Cd	0.05–0.10
Pb	2.1–3.6

The mean concentrations for each analyzed macroelement in the whole fruiting body, together with details for each individual species in cap and stipes, are shown in Table 2. The highest mean of concentration, on a dry mass basis, was found for N (40.5 g kg^{-1}), followed by K (32.8 g kg^{-1}), P (5.3 g kg^{-1}), S (2.2 g kg^{-1}), Ca (1.0 g kg^{-1}), and Mg (0.7 g kg^{-1}). There was a consistent pattern of increased levels of N accumulation occurring in conjunction with elevated P levels in the fruiting bodies of some species. *Xerocomus chrysenteron*, *Amanita rubescens*, and *X. badius* had the highest concentrations of N (68.7, 52.1, and 49.5 g kg^{-1}, respectively) and fruiting bodies of these same species (*A. rubescens*, *X. chrysenteron* and *X. badius*) also had the highest phosphorus contents (8.2, 7.7, and 5.7 g kg^{-1}, respectively). The lowest contents of N and P were found in *Leccinum scabrum* (22.1 and 1.4 g kg^{-1}, respectively). The fruiting bodies of the tested mushrooms were rich in K (mean 32.8 g kg^{-1}). The highest K concentration was measured in *A. rubescens* (49.3 g kg^{-1}). *Lactarius deliciosus* and *L. scabrum* had average K contents that were slightly lower than the material as a whole. A low concentration of Ca (mean 1.0 g kg^{-1}) was a common feature of all tested fruiting bodies. Comparatively high Ca concentrations (3.6 g kg^{-1}) were measured in *L. deliciosus*. A low (mean 0.7 g kg^{-1}) and remarkably constant level was noted in Mg. Sulfur concentration varied significantly among fungal species and ranged from 0.9 in *A. rubescens* to 4.4 g kg^{-1} in *X. chrysenteron*. As revealed by ANOVA analysis, in the fruiting bodies of the tested ectomycorrhizal fungi, only the contents of N and S are species-dependent and the concentrations of P, K, Ca, and Mg did not differ significantly among these species.

The range of macroelement concentrations in the fruiting bodies of mushrooms from our study concurs with literature values for wild and cultivated fungi, irrespective of their geographical origin or how the fungi

Table 2
Macronutrient concentrations (g kg^{-1} d.w.) in the fruiting bodies (F – whole fruiting body, C – cap, S – stipe) of eight fungal species from the Notecka Forest in west-central Poland

Species		Macronutrients (g kg^{-1})					
		N	P	K	Ca	Mg	S
Amanita rubescens	F	52.1 ± 18.2	8.2 ± 2.1	49.3 ± 4.0	0.6 ± 0.2	0.8 ± 0.2	0.9 ± 0.1
	C	58.1 ± 12.5	10.5 ± 3.5	55.1 ± 5.5	0.4 ± 0.1	1.1 ± 0.5	0.8 ± 0.1
	S	45.3 ± 15.4	5.9 ± 2.1	43.5 ± 4.6	0.7 ± 0.3	0.6 ± 0.1	0.9 ± 0.1
Lactarius deliciosus	F	42.4 ± 11.1	4.4 ± 1.1	21.2 ± 0.9	3.6 ± 0.6	0.8 ± 0.3	2.0 ± 0.4
	C	45.5 ± 10.2	6.6 ± 1.1	29.3 ± 1.6	1.9 ± 0.5	1.1 ± 0.5	2.0 ± 0.5
	S	38.3 ± 10.2	2.3 ± 0.6	12.1 ± 0.6	5.3 ± 0.6.	0.6 ± 0.1	1.9 ± 0.5
Lactarius rufus	F	29.4 ± 9.0	4.2 ± 1.2	29.4 ± 10.0	0.6 ± 0.2	0.6 ± 0.1	1.5 ± 0.6
	C	36.0 ± 12.1	5.1 ± 1.0	31.2 ± 11.2	0.4 ± 0.1	0.8 ± 0.4	1.9 ± 0.6
	S	23.8 ± 10.1	3.3 ± 1.3	28.6 ± 10.4	0.8 ± 0.3	0.4 ± 0.1	1.0 ± 0.5
Leccinum scabrum	F	22.1 ± 6.3	1.4 ± 0.6	21.3 ± 11.2	0.9 ± 0.2	0.4 ± 0.1	1.5 ± 0.3
	C	17.1 ± 5.5	1.2 ± 0.4	10.3 ± 9.2	0.8 ± 0.1	0.3 ± 0.1	1.4 ± 0.1
	S	27.1 ± 8.4	1.6 ± 0.6	31.3 ± 12.4	1.0 ± 0.6	0.4 ± 0.1	1.6 ± 0.3
Paxillus involutus	F	28.5 ± 9.3	4.9 ± 1.0	41.4 ± 6.3	0.9 ± 0.1	0.9 ± 0.3	2.0 ± 0.5
	C	32.0 ± 10.6	7.9 ± 2.1	43.8 ± 8.5	1.2 ± 0.3	1.1 ± 0.4	1.9 ± 0.7
	S	25.0 ± 12.5	2.0 ± 0.7	39.0 ± 7.2	0.6 ± 0.2	0.7 ± 0.3	0.2 ± 0.1
Suillus luteus	F	31.2 ± 8.1	6.1 ± 1.4	29.7 ± 2.1	0.7 ± 0.1	0.8 ± 0.2	2.1 ± 0.6
	C	35.3 ± 9.3	7.6 ± 1.9	34.1 ± 0.6	0.5 ± 0.2	1.1 ± 0.1	2.7 ± 0.8
	S	27.1 ± 5.2	4.5 ± 0.5	25.3 ± 4.5	0.8 ± 0.1	0.6 ± 0.2	1.6 ± 0.5
Xerocomus badius	F	49.5 ± 9.5	5.7 ± 0.9	34.9 ± 2.,9	0.7 ± 0.2	0.9 ± 0.2	3.4 ± 0.9
	C	55.0 ± 9.1	6.6 ± 0.9	36.5 ± 4.6	0.6 ± 0.2	1.2 ± 0.3	3.7 ± 0.9
	S	44.0 ± 9.9	4.7 ± 1.5	33.3 ± 2.8	0.9 ± 0.2	0.7 ± 0.1	3.1 ± 0.5
Xerocomus chrysenteron	F	68.7 ± 14.1	7.7 ± 1.2	35.6 ± 0.3	0.3 ± 0.1	0.7 ± 0.1	4.4 ± 0.8
	C	73.1 ± 11.5	8.8 ± 1.6	38.9 ± 0.6	0.2 ± 0.1	0.9 ± 0.1	4.5 ± 0.5
	S	64.4 ± 15.2	6.7 ± 1.1	32.2 ± 0.9	0.4 ± 0.1	0.6 ± 0.1	4.2 ± 0.6
Mean	F	40.5 ± 15.6	5.3 ± 2.1	32.8 ± 9.6	1.0 ± 1.1	0.7 ± 0.2	2.2 ± 1.1
	C	44.0 ± 17.6	6.8 ± 2.8	34.9 ± 12.8	0.75 ± 0.5	0.95 ± 0.3	2.4 ± 1.2
	S	36.8 ± 14.1	3.9 ± 1.9	30.7 ± 9.4	1.3 ± 1.6	0.58 ± 01	2.0 ± 1.1
$p > F$[a]							
Species		**	ns	ns	ns	ns	***
Part of fruiting body		*	**	ns	ns	**	ns

ns, not significant; $p > 0.05$.
*, **, and *** indicate $p < 0.05$, 0.01 and 0.001, respectively.
[a] Based on ANOVA of species or part of fruiting body.

acquire nutrients (saprotrophs, necrotrophs or biotrophs) (Fogel, 1976; Harmon et al., 1994; Kreula et al., 1976; Longvah & Deosthale, 1998; Malinowska et al., 2004; Manzi et al., 1999; Sanmee et al., 2003; Tyler, 1980; Vogt & Edmonds, 1980). Even forest fertilization did not significantly change the nitrogen level in the fruiting bodies of *L. rufus* and *Suillus variegatus* (Ohtonen, 1986). This is in agreement with Vogt & Edmonds (1980) who found that individual species have the same nutrient levels in different forest ecosystems.

A clear tendency toward higher macronutrient accumulations in caps than in stipes was also found. However, differences were statistically significant only for N, K, and Mg. Calcium seems to be preferably accumulated in stipes rather than in caps (Table 2). Similar trends were found in fruiting bodies of *X. badius* by Malinowska et al. (2004).

All macroelements (N, P, K, Ca, Mg and S) were accumulated in much higher concentrations in fruiting bodies of the tested mushrooms than were present in the forest soil where samples of fruiting bodies were collected (Tables 1 and 2). Nitrogen, P, and K concentrations (to a lesser extent Ca, Mg, and S) were also higher in fruiting bodies than in the foliage of *Pinus sylvestris* (Oleksyn, Reich, Karolewski, Tjoelker, & Chalupka, 1999; Oleksyn, Reich, Zytkowiak, Karolewski, & Tjoelker, 2002), an ectomycorrhizal host plant of most analyzed mushrooms. This implies that fungi have a specialized mechanism to accumulate nutrients in their fruiting bodies. Fruiting bodies were especially effective in nitrogen and potassium accumulation, despite a very low content of these elements in the soil substrate (Table 1). Extramatrical mycelia of ECM mushrooms play a key role in the uptake of nutrients from soil, proliferating in nutrient-rich sites and presumably competing effectively with other soil microorganisms (Smith & Read, 1997). ECM mycelia absorb, not only inorganic nutrients, but also mobilize organic

Table 3
Macronutrient concentrations (mg kg^{-1} d.w.) in the fruiting bodies (F – whole fruiting body, C – cap, S – stipe) of eight fungal species from the Notecka Forest in west-central Poland

Species		Micronutrients (mg kg^{-1})					
		Al	Mn	Fe	Zn	Cd	Pb
Amanita rubescens	F	293 ± 73.3	30.5 ± 4.5	65.4 ± 15.6	165 ± 19.6	2.8 ± 0.6	0.10 ± 0.03
	C	75.0 ± 21.2	29.7 ± 12.1	69.7 ± 11.5	176 ± 26.2	3.3 ± 0.3	0.10 ± 0.02
	S	512 ± 95.1	31.2 ± 2.4	61.2 ± 15.4	154 ± 31.1	2.4 ± 0.5	0.10 ± 0.05
Lactarius deliciosus	F	199 ± 53.2	18.3 ± 3.2	28.7 ± 7.3	179 ± 21.3	1.7 ± 0.3	5.2 ± 1.6
	C	312 ± 112	17.5 ± 1.2	33.2 ± 2.5	213 ± 25.2	1.3 ± 0.1	0.85 ± 0.5
	S	85.0 ± 25.2	19.2 ± 4.1	24.3 ± 9.2	146 ± 20.9	2.1 ± 0.3	9.5 ± 1.9
Lactarius rufus	F	118 ± 22.1	31.7 ± 9.8	130 ± 36.5	73.6 ± 18.7	1.1 ± 0.3	8.1 ± 2.4
	C	125 ± 25.2	28.2 ± 5.2	142 ± 36.9	83.5 ± 15.8	1.0 ± 0.2	6.7 ± 1.6
	S	111 ± 38.2	35.1 ± 7.5	118 ± 34.2	63.8 ± 14.5	1.2 ± 0.2	9.5 ± 2.5
Leccinum scabrum	F	365 ± 62.5	9.9 ± 2.5	16.3 ± 3.3	28.6 ± 3.5	0.89 ± 0.3	0.10 ± 0.02
	C	368 ± 58.9	8.2 ± 1.2	7.5 ± 2.1	21.5 ± 1.6	0.85 ± 0.1	0.10 ± 0.02
	S	332 ± 67.2	11.7 ± 2.5	25.2 ± 6.2	35.7 ± 5.2	0.92 ± 0.4	0.10 ± 0.02
Paxillus involutus	F	43.4 ± 6.3	17.1 ± 3.5	57.6 ± 16.5	134 ± 21.2	0.88 ± 0.2	5.3 ± 1.6
	C	66.3 ± 10.1	9.9 ± 1.2	70.5 ± 15.2	128 ± 20.5	0.83 ± 0.2	4.1 ± 1.1
	S	20.5 ± 4.2	24.4 ± 5.8	44.8 ± 11.2	139 ± 25.2	0.93 ± 0.2	6.4 ± 1.6
Suillus luteus	F	8.5 ± 1.2	13.4 ± 2.3	38.3 ± 6.3	52.7 ± 10.1	1.1 ± 0.4	1.4 ± 2.2
	C	12.0 ± 2.4.	10.7 ± 4.2	42.8 ± 6.3	73.1 ± 21.2	0.78 ± 0.5	1.1 ± 0.8
	S	5.0 ± 1.1.	16.1 ± 1.6	33.8 ± 4.5	32.3 ± 9.6	1.4 ± 0.4	1.6 ± 4.2
Xerocomus badius	F	129 ± 26.7	14.6 ± 1.6	85.6 ± 14.1	147 ± 30.1	1.9 ± 1.6	5.4 ± 5.2
	C	198 ± 59.4	14.4 ± 1.2	122 ± 12.2	157 ± 11.2	2.3 ± 1.7	6.1 ± 3.5
	S	59.7 ± 15.2	14.9 ± 3.2	48.9 ± 5.6	136 ± 32.2	1.5 ± 1.7	4.6 ± 7.2
Xerocomus chrysenteron	F	243 ± 32.6	21.9 ± 4.5	53.6 ± 10.3	128 ± 23.5	2.9 ± 1.0	3.2 ± 1.2
	C	8.5 ± 3.2	17.1 ± 3.2	59.7 ± 10.0	164 ± 25.5	5.1 ± 1.5	3.9 ± 3.1
	S	476 ± 112	26.8 ± 11.1	47.5 ± 12.2	91.6 ± 19.4	0.72 ± 0.2	2.4 ± 1.2
Mean	F	175 ± 123	19.8 ± 7.9	59.5 ± 35.9	113 ± 55.0	1.6 ± 0.8	3.6 ± 2.9
	C	146 ± 135	16.9 ± 8.1	68.5 ± 44.7	127 ± 63.1	1.9 ± 1.5	2.9 ± 2.8
	S	200 ± 208	22.4 ± 8.3	50.5 ± 30.1	99.8 ± 50.6	1.4 ± 0.6	4.3 ± 3.8
$p > F$[a]							
Species		ns	ns	*	*	ns	ns
Part of fruit body		ns	ns	ns	ns	ns	ns

ns, not significant; $p > 0.05$.
*, Indicates $p < 0.05$.
[a] Based on ANOVA of species or part of fruiting body.

sources of N and P (Abuzinadah & Read, 1986, 1989a, 1989b; Perez-Moreno & Read, 2000). This temporary concentration of biologically important elements in fruiting bodies may play an important role in decomposition of organic matter and concomitant nutrient cycling in forest ecosystems (Gadd, 1993).

The mean concentrations of microelements in the entire fruiting body, together with details for caps and stipes of each individual species, are shown in Table 3.The mean microelement concentrations, across all tested fungi, were in order: Al > Zn > Fe > Mn > Pb > Cd.

There was a 34-fold difference in Al concentration between *A. rubescens* and *S. luteus*. Though in the individual species the concentrations of Al and Mn varied to some extent, statistical analysis did not reveal significant interspecific differences (Table 3).

The Zn and Fe concentrations are species–specific ($p < 0.05$). Zn concentration ranged from 28.6 in *L. scabrum* to 179 mg kg^{-1} in *L. deliciosus*. An 8-fold difference in Fe concentration was found between *L. rufus* and *L. scabrum*. Cadmium and Pb contents in the tested mushrooms were comparatively low (mean: 1.6 and 3.6 mg kg^{-1} for Cd and Pb, respectively). The highest Cd level was 2.9 mg kg^{-1} for *X. chrysenteron* and the lowest level was 0.88 mg kg^{-1} for *P. involutus*. Cadmium was preferably taken up by fungal fruiting bodies, irrespective of the low concentration in the soil (Table 1). The ability to accumulate Cd is a characteristic of mushrooms (Aruguete, Aldstadt, & Mueller, 1998; Gast, Jansen, Bierling, & Haanstra, 1988; Malinowska et al., 2004; Rühling & Söderström, 1990; Tyler, 1980) and is closely correlated with the presence of a binding compound, which is a genetically coded feature (Schmitt & Meisch, 1985; Vetter, 1993). Interspecies differences were not significant for Cd and Pb. There were no significant differences between cap and stipe for any microelement content ($p > 0.05$).

The chemistry of metal interactions with the soil matrix is central to the uptake of metals by ECM mycelia and further accumulation in ECM fruiting bodies. In general, sorption to soil particles reduces the activity of metals in the system. Thus, the higher the cation-exchange capacity of the soil, the greater are the sorption and immobilization of metals (Babich & Stotzky, 1980; Gadd & Griffiths, 1978). In acidic soils, as in the Notecka Forest, metal desorption from soil binding sites into solution is enhanced due to H^+ competition for binding sites, and appears to be metal specific. Aluminium, Zn, and Cd uptakes in the fruiting bodies of the tested mushrooms were notably influenced by soil acidity, but the remaining metals (Mn, Fe and Pb) showed small pH-dependence.

The occurrence and distribution of different macro- and microelements in fruiting bodies of certain mushrooms is not only an important problem for physiology and ecology of fungi, but also has practical environmental and toxicological aspects. As evident in this and several other studies (Aruguete et al., 1998; Demirbaş, 2000; Falandysz et al., 2002; Malinowska et al., 2004; Rühling & Söderström, 1990), the mycelia of ECM fungi preferably takeup and further accumulate several highly toxic substances (in fruiting bodies), irrespective of the soil concentration. This may be important in areas where mushroom harvesting is a common practice. Poles have long taken an active interest in harvesting edible wild mushrooms from the forest, enjoying the flavour of bolets, chanterelles and other. Some species are particularly popular and are exported to European destinations (e.g. *Boletus edulis*, *Cantharellus cibarius*, *X. badius*) (Statistical Yearbook – Forestry, 2003). Some other edible species are harvested in minor amounts or are collected only for domestic use, because they are not very suitable for long-distance transport (*L. scabrum*, *L. deliciosus*, *S. luteus*). As harvesting of mushrooms in forests, either commercially or recreationally, is increasing, it is important to ensure that mushroom resource is safe and that toxic element contents are kept within limits safe for human health.

All mushroom species analyzed in this paper may be considered as edible. However, the edibility of some of them is problematic. *A. rubescens* and *L. rufus* are edible if cooked, but could cause poisoning when eaten raw. Moreover, *L. rufus* has been classified as an inedible mushroom due to its stinging taste. *P. involutus* is a popular species in some parts of Europe. Some people can eat this widespread mushroom without adverse effects. However, it frequently causes gastric distress and occasionally causes fatal hemolytic symptoms. The literature reports that, although initial consumption is fine, repeated ingestion can be fatal, as toxins from the mushroom build up in the body. Currently this species is considered poisonous and is not collected in Poland. *L. deliciosus* is a highly appreciated edible mushroom, but very rare and thus unimportant in terms of toxicity. *X. chrysenteron* is not very abundant, and is a rarely collected edible mushroom. Fruiting bodies of *S. luteus*, and especially *X. badius*, are commonly collected during the harvest season in Poland. During the past 20–30

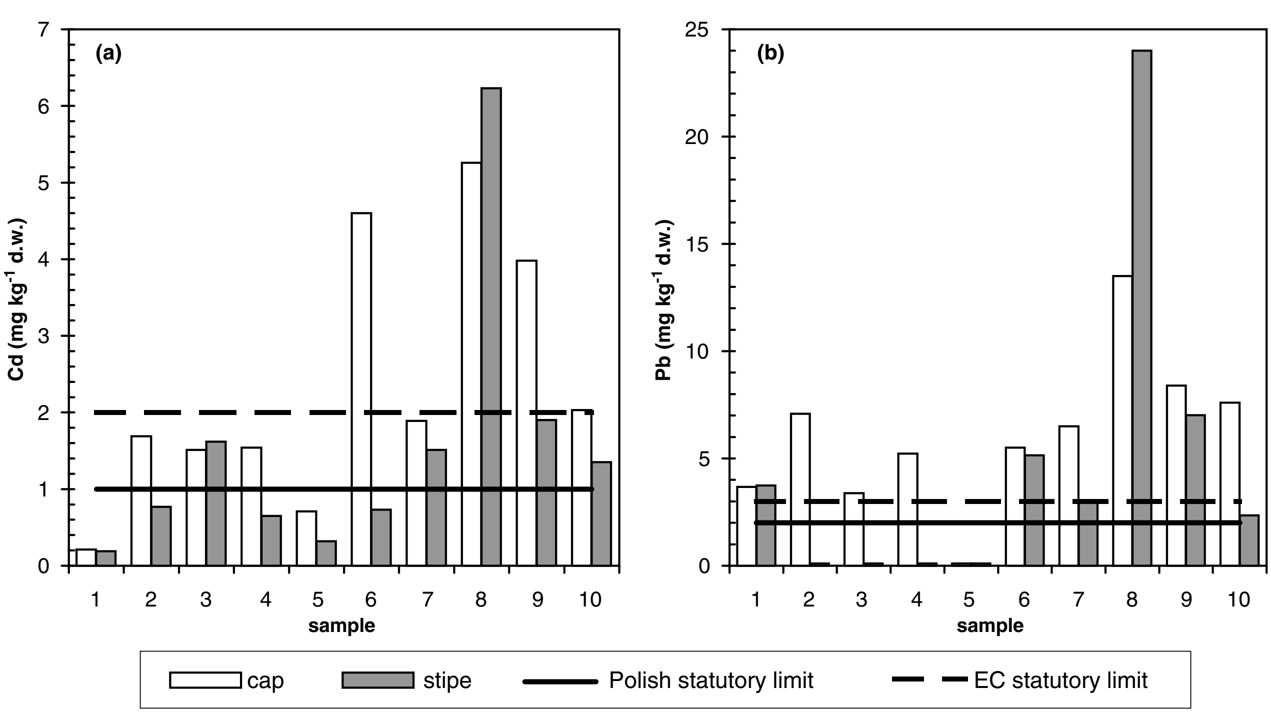

Fig. 2. Cadmium (a) and lead (b) contents in caps and stipes of individual samples ($n = 10$) of *X. badius* collected in different places in the Notecka Forest in west-central Poland. Horizontal lines indicate: Polish (solid line) and European (dashed line) statutory limits for Cd and Pb concentrations in dried mushrooms.

years, significant declines in the availability of certain mushrooms (chanterelles and bolets) in Poland have been observed. At the same time, the crop of *X. badius* increased 4-fold; 408 and 969 tons of *X. badius* was purchased in the years 2001 and 2002, respectively, and nearly half of them originated from the Notecka Forest (Statistical Yearbook – Forestry, 2003).

Certain countries have established statutory limits for metals in edible mushrooms. In the Czech Republic, limits of 2.0 and 10.0 mg kg^{-1} dry matter have been established for Cd and Pb, respectively, in wild-growing mushrooms; whereas 1.0 and 10 mg kg^{-1} dry matter have been established for cultivated mushrooms (Kalač & Svoboda, 2000). In Poland, recommendations concerning the concentrations of Cd and Pb in dried mushrooms are slightly different. The tolerance limits set for Cd and Pb are 1.0 and 2.0 mg kg^{-1} dry weight, respectively (Dziennik Ustaw, No. 9, position 72, 2001).

The maximum level for certain contaminants in foodstuffs established by the Commission of the European Communities (Commission Regulation [EC] No 466/2001) is set at about 0.2 and 0.3 mg kg^{-1} wet weight for Cd and Pb, respectively, in cultivated fungi. Assuming that the dry matter content of mushrooms is 10% (Kalač & Svoboda, 2000), these same limits for dry material will be ten times higher and approach 2.0 and 3.0 mg kg^{-1} dry weight for Cd and Pb, respectively.

In Fig. 2(a) and (b) the range of Cd and Pb contents in caps and stipes of individual samples ($n = 10$) of *X. badius* collected in different places in the Notecka Forest are shown in relation to the statutory limits of Poland and the European Community. The results showed that most samples of *X. badius* from the Notecka Forest had elevated Pb concentrations (mean: 5.4 mg kg^{-1}) and exceeded both the Polish and European tolerance limits set for dried mushrooms (Fig. 2(b)). The cadmium content in most fruiting bodies of *X. badius* was higher than the Polish limits, but below European statutory limits (Fig. 2(a)).

The significance to human health of the element concentrations found in fruiting bodies of edible fungi may also be assessed by comparing estimated exposures with exposures from a normal diet and with the internationally agreed exposure guidelines, where these exist. These guidelines are the Provisional Tolerable Weekly Intakes (PTWIs) or Provisional Maximum Tolerable Daily Intakes (PMTDIs) set by the Joint Expert Committee on Food Additives (JECFA) of the Food and Agriculture Organization of the United Nations and the World Health Organization (FAO/WHO, 1989). Acceptable weekly intakes of Cd and Pb for adults are 0.42–0.49 and 1.5–1.75 mg, respectively. For calculations, usually 300 g of fresh mushrooms per meal is assumed (Kalač & Svoboda, 2000). In relation to FAO/WHO guidelines, the PTWI for Cd is exceeded in the case of *X. chrysenteron* (2.1-fold), *A. rubescens* (2.0-fold), and *X. badius* (1.4-fold) and for lead only in case of *L. rufus* (1.6-fold). Consumption of mushrooms during the harvest season is very often much higher than 300 g of fresh weight/person/week. The estimated dietary exposures to Pb and Cd by consumers of mushrooms from the Notecka Forest may exceed the appropriate guidelines on safe exposures and, therefore, mushrooms should be consumed with caution.

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