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ORIGINAL PAPER

Trace metal levels in edible wild fungi

Z. Severoglu · S. Sumer · B. Yalcin · Z. Leblebici · A. Aksoy

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Abstract Metal levels (cadmium, cobalt, chromium, copper, iron, nickel, lead and zinc) of seventeen different edible wild fungi species (*Agaricus campestris, Calocybe gambosa, Coprinus comatus, Hericium coralloides, Hydnum repandum, H. repandum* var. *rufescens*, *Lactarius deliciosus, L. salminocolor, Macrolepiota procera, Pleurotus ostreatus, P. ostreatus* var. *columbinus, Ramaria aurea, R. stricta, Rhizopogon luteolus, Sparassis crispa, Suillus bovinus*, *Tricholoma terreum*) growing in Bolu-Turkey were measured by inductively coupled plasma optical emission spectrocopy. The obtained data were analyzed with "statistical package for the social sciences" statistics program. In addition, relation between metal concentrations in both soil and fungi samples were investigated. The highest metal concentrations in Bolu District, Turkey were measured in *A. campestris* (cadmium 0.270, chromium 2.735 and zinc 7.683), *C. comatus* (iron 160.12), *M. procera* (copper 15.990, cobalt 0.352 and nickel 3.645), *R. luteolus* (Pb 4.756) mg/kg dw (dry weight). As a result of the measurements, it was observed that metal uptake is related with the species of fungi and is also affected by pH and organic contents of the soil.

Keywords Forest · Heavy metals · Mushroom · Soil

Z. Severoglu (✉) · S. Sumer
Department of Biology, Faculty of Science and Arts, Marmara University, Goztepe, 34722 Istanbul, Turkey
e-mail: zseveroglu@marmara.edu.tr

Z. Severoglu
Faculty of Science, Department of Biology, Kyrgyzstan-Turkey Manas University, Bishkek, Kyrgyzstan

B. Yalcin
Department of Chemistry, Faculty of Science and Arts, Marmara University, Goztepe, 34722 Istanbul, Turkey

Z. Leblebici
Department of Biology, Faculty of Science and Arts, Nevsehir University, 50300 Nevsehir, Turkey

A. Aksoy
Department of Biology, Faculty of Science and Arts, Erciyes University, 38039 Kayseri, Turkey

Introduction

Great quantities of metallic (Cu, Fe, Hg, Mn, Ni, Zn) and nonmetallic substances (Br, Cl, N, Na, I, P, S) are often emitted into the atmosphere in different ways; through natural sources (continental dust, volcanic dust and gas, sea spray and biogenic particles) or anthropogenic inputs (industries, agriculture, mining, combustion of fossil fuels, etc.) (Celik et al. 2005; Baslar et al. 2009; Yasar et al. 2010). Some toxic elements (Al, As, Ba, Be, Cd, Pb, Hg, Os, Th, Va) affect soil pH and uptake of the nutrients from the soil, which influence growth and development on terrestrial flora (Vitorello et al. 2005). In addition, dust pollution may affect photosynthesis, respiration, transpiration and allows the penetration of some toxic gaseous pollutants (Kinalioglu et al. 2010). Today, it is obviously known that, some organisms called "biomonitors" have better ability of accumulating certain metals and/or toxic elements and they can be used by scientists for monitoring many trace elements in their environments (Akguc et al. 2008; Yasar and Ozyigit 2009; Yasar et al. 2010). Nylander first reported the usability of biological materials to measure environmental effects of atmospheric deposition in 1886, and then an increasing use of many organisms as biomonitors has been seen in the scientific world (Aksoy and Sahin 1999; Akguc et al. 2010).

It is well known that, all such cultivated fungi show bioaccumulation of metal ions and thus, a considerable

attention has been focused on the bioaccumulation of heavy metals in fruit bodies of fungi in recent years (Abdel-Azeem et al. 2007; Ezzouhri et al. 2009; Amna et al. 2010; Kalpana et al. 2011; Joshi et al. 2011). Today, with its large edible fungi potential, Turkey is becoming an important exporter of wild fungi species. The climate character is especially mild and rainy in the west parts of Black-Sea Region. The seasons are normally wet with moderate temperatures (Akman 1999). These kinds of climate properties are ideal for fungal growth especially in both spring and autumn. Although numerous studies (Isiloglu et al. 2001a, b; Demirbas 2002; Konuk et al. 2007; Kaya and Bag 2010) have also been carried out on heavy-metal contents of fungi in Turkey, some additional researches are required because of rich biodiversity of fungi species in Turkey.

In comparison with the green plants, the fungi can build up large concentrations of certain trace elements. To warn about the hazardous effects of heavy metals such as Cd, Hg and Pb, a great effort has been made to evaluate the possible danger for human health from ingestion of fungi (Brzostowski et al. 2011; Skrbic et al. 2012). This would suggest that fungi possess a very effective mechanism that enables them to uptake some trace elements from the substrate (Falandysz et al. 2008; Jarzynska et al. 2011).

This study is aimed to determine Cd, Co, Cr, Cu, Fe, Ni, Pb and Zn contents of the fruit bodies of 17 fungi species originally found in Bolu Region, Turkey. Fungi samples were collected in 2009 and determination of the heavy-metal concentrations has been performed by inductively coupled plasma optical emission spectroscopy (ICP-OES).

There are some researches about uptake of heavy metals by fungi in urban lands and ruderals in Turkey and other countries (Lepsova and Mejestrik 1988; Kojo and Lodenius 1989; Mandic et al. 1992; Sesli and Tuzen 1999; Svoboda et al. 2000; Isiloglu et al. 2001a, b; Demirbas 2002; Soylak et al. 2005; Tuzen et al. 2003; Konuk et al. 2007; Falandysz et al. 2008; Jarzynska et al. 2011; Skrbic et al. 2012). The samples collected in some of these studies have used ruderals as control group with the assumption that these are unpolluted. This study is important in terms of determining heavy-metal levels in forests, which are considered free of heavy metals and, therefore, can be taken as a reference.

Materials and methods

In this study, 17 fungi species were used to determine Cd, Co, Cr, Cu, Fe, Ni, Pb and Zn levels in their bodies. In addition, soil samples of forest upper soil layer (0–10 cm), after removing superficial layer of organic detritus were also collected at appropriate sampling places. The soil is moderately drained and varies reddish brown podzol (Uyar and Cetin 2006). The fungi species were collected from various locations in Bolu (Aladaglar, Yedigoller, Abant), Turkey in 2009 vegetation period (Fig. 1). In this study, the forested area that fungi samples were collected has primary importance for wooden plant industry of Turkey.

The family and species names, trophic status, habitats and some other properties of studied fungi species include *Agaricus campestris*, *Calocybe gambosa*, *Coprinus comatus*, *Hericium coralloides*, *Hydnum repandum*, *H. repandum* var.

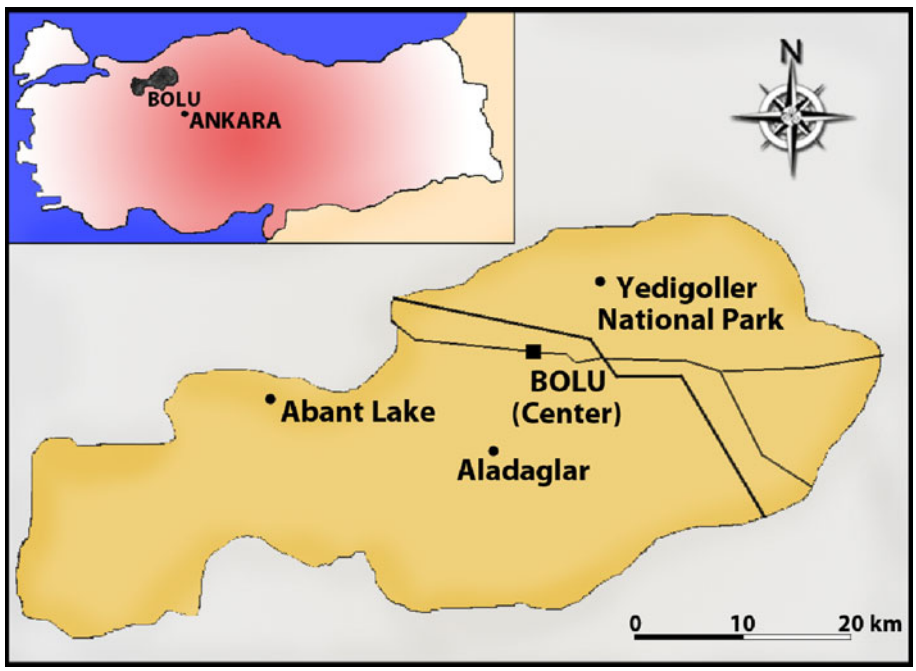

Fig. 1 A map of the study area

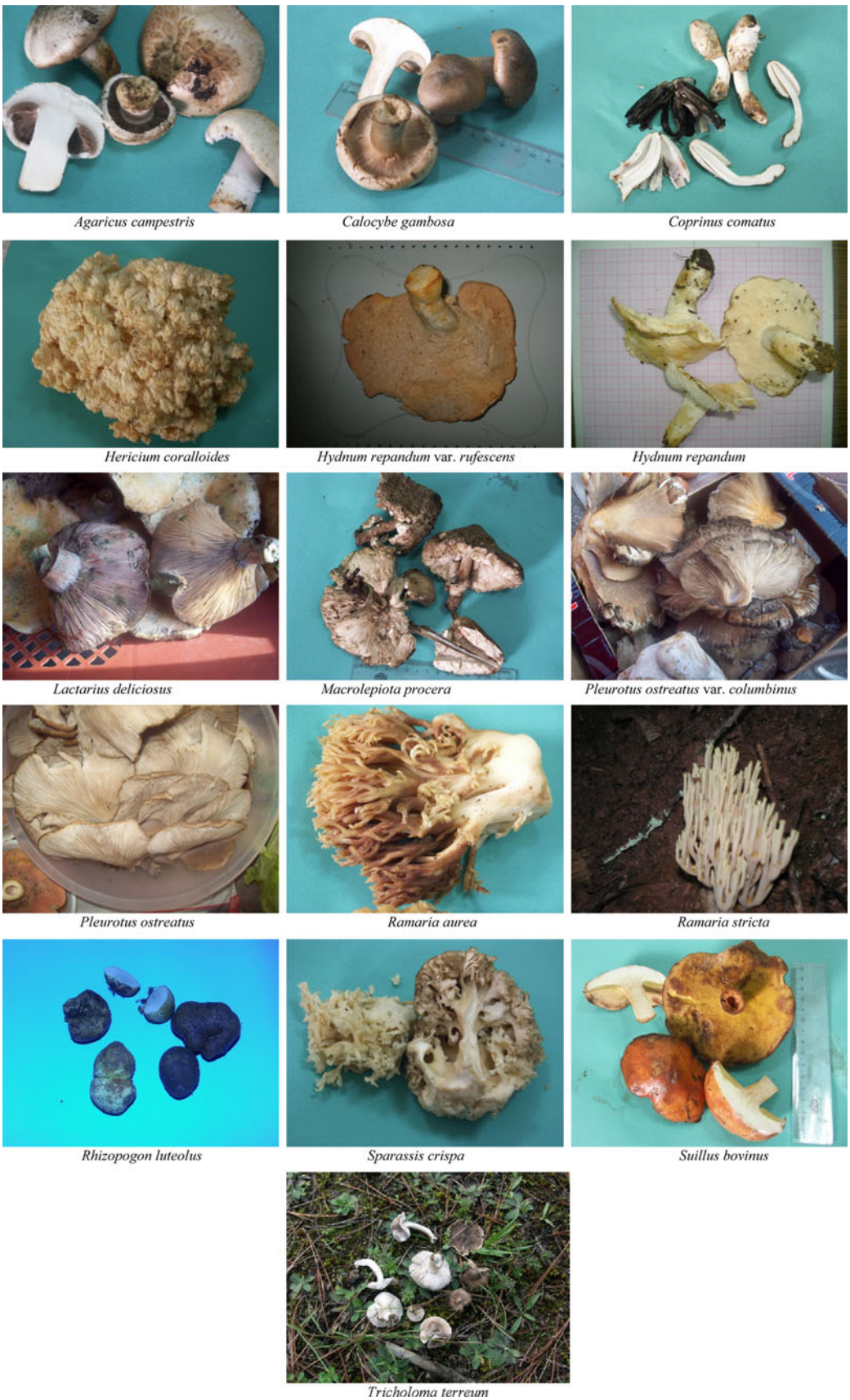

Fig. 2 The studied fungi

Table 1 Some properties of studied fungi

Scientific names	Order	Family	Trophic status	Habitat	Color	Odor	Other features
Hydnum repandum var. *rufescens*	Cantharellales	Hydnaceae	Mycorrhizal	In meadows and coniferous wood	Salmon-pink	Not distinctive	Taste; bitter after a delay, edible
Hydnum repandum	Cantharellales	Hydnaceae	Mycorrhizal	In meadows and coniferous wood	Cream sometimes with yellowish tinge	Not distinctive	Taste: bitter after a delay, edible
Lactarius salminocolor	Russulales	Russulaceae	Mycorrhizal	Soil, under Fir	Wholly ochraceous-orange	Not distinctive	Milk white, edible
Sparassis crispa	Sparassidaceae	Cantharellales	Parasitic	The base of conifers	Cream, pallid ochraceous or buff	Sweetish, pleasant	Taste not distinctive, edible
Ramaria aurea	Gomphales	Ramariaceae	Saprotrophic	Broad-leaf woods	Saffron-yellow	Taste mild	Edible
Agaricus campestris	Agaricales	Agaricales	Saprotrophic	Soil, in pastures	With creamy-white cap ant stem	Not distinctive	Edible
Pleurotus ostreatus	Lamellate	Lentinaceae	Saprotrophic	Leaf trees	Bluish-grey or brown oyster-shaped cap pale gills	Not distinctive	Edible
Pleurotus ostreatus var. *columbinus*	Lamellate	Lentinaceae	Saprotrophic	Leaf trees	Bluish-grey or brown oyster-shaped cap pale gills	Not distinctive	Edible
Macrolepiota procera	Agaricales	Agaricales	Saprotrophic	Grassy woodlands and meadows	Brown- beige	Not distinctive	Edible
Suillus bovinus	Boletales	Strobilomycetaceae	Mycorrhizal	Soil, under conifers	Odor of fruit	Not distinctive	Edible
Coprinus comatus	Agaricales	Coprinaceae	Saprotrophic	Soil, in short grass	Cap white	Slightly acidic	Edible
Rhizopogon luteolus	Boletales	Rhizopogonaceae	Ectomycorrhizal	Sandy soil	Not distinctive	Not distinctive	Edible
Lactarius deliciosus	Russulales	Russulaceae	Mycorrhizal	Under conifers	Pallid buff	Faint of fruit	Taste mild, edible
Tricholoma terreum	Agaricales	Tricholomataceae	Mycorrhizal	Soil, in pastures; soil, conifers and broad-leaf	Not distinctive	Not distinctive	Edible
Calocybe gambosa	Agaricales	Tricholomataceae	Mycorrhizal	Mixed wood and pastures	Cream	Taste of meal	Edible
Hericium coralloides	Hericiales	Hericiaceae	Saprotrophic	Broad-leaf woods	White	Not distinctive	Edible
Ramaria stricta	Gomphales	Ramariaceae	Saprotrophic	Broad-leaf woods	Ochraceous tinged buff	Sweat or earthy	Edible

rufescens, *Lactarius deliciosus*, *L. salminocolor*, *Macrolepiota procera*, *Pleurotus ostreatus*, *P. ostreatus* var. *columbinus, Ramaria aurea*, *R. stricta*, *Rhizopogon luteolus*, *Sparassis crispa*, *Suillus bovinus*, *Tricholoma terreum* were given in Fig. 2 and Table 1. The color, odor and other macroscopical properties of the fungi and their vegetation features were noted in the field, and all fungi species were photographed and archived in Marmara University Biology Department for later identification of samples (Specimens). The fungi were identified microscopically using certain reference books such as *European Flora* (Breitenbach and Kranzlin 1984, 1986, 1991), *How to Identify Fungi to Genus III–IV* (Largent et al. 1977; Stuntz 1977), *Edible Fungi of Turkey* (Sumer 1987), *Key to Agarics and Boleti* (Moser 1983), *Field Guide to the Fungi & Toadstools of Britain and Europe* (Pegler 1990), *Wild Guide Fungi & Toadstools Get to Know the Natural World* (Spooner 1996), *How to Identify Edible Fungi* (Harding et al. 1996). After identification, collected samples were cleaned, cut and dried at 70 °C for 24 h. Dried samples were homogenized in an agate homogenizer and stored in pre-cleaned polyethylene bottles until the analysis time. Deionized water was used to prepare all aqueous solutions and all mineral acids and oxidants (HNO_3 and H_2O_2) used were of highest quality (Merck, Darmstadt, Germany). All the plastic and glassware were cleaned by soaking overnight in a 10 % HNO_3 solution and then rinsed with deionized water. Each sample (0.5 g) was then digested with 10 mL of HNO_3 (65 %) and 1 mL of H_2O_2 (30 %) using a CEM-MARS 5 (CEM Corporation Mathews, NC, USA) microwave digestion system (maximum power 1,200 W, power 100 %, ramp 20.00 min, pressure 180 psi, temperature 210 °C and hold time 10.00 min). After digestion, the volume of each sample was adjusted to 25 ml using double-deionized water (Markert 1993; Aksoy et al. 2005).

Soil pH measurements were also made with the procedure as follows; 25 mL of distilled water were added into 10 g of air-dried soil samples and the mixture was left for 1 h at 25 °C. There after, pH was determined using standard pH meter (Hanna precision pH meter Model pH 212). Soil samples were dried at room temperature for several weeks and then sieved through a pore size of 2 mm. Later, the samples (1 g) were cold treated with a mixture of concentrated HCl and concentrated HNO_3 (3:1) for 24 h, heated up to 105 °C for 90 min and extract is obtained after filtering through Whatman No. 42 filter paper into volumetric flask and was brought to a volume of 50 mL with deionized water (Aksoy et al. 2005). Determinations of Cd, Co, Cr, Cu, Fe, Ni, Pb and Zn in the fruit bodies of 17 fungi species and soil samples were carried out by ICP-OES (Varian-Liberty II, ICP-OES). Peach leaves (NIST, SRM-1547) and CRM 039–050 were used as reference material and also all analytical procedures were performed for reference materials. Samples were analyzed in triplicate.

The experiments were made as randomized block design. Two-way analysis (ANOVA) was performed with all the data to confirm the variability of data and validity of results, and Duncan's multiple range test (DMRT) was done to determine the significant difference between treatments. A linear regression correlation test was performed to investigate correlations between metal concentrations. Statistical Package for the Social Sciences (SPSS) statistical program was used for statistical analysis (Kinnear and Gray 1999).

Results and discussion

In this study, it was determined that heavy-metal contents in fruiting body samples decreased as the distance from settlement regions increased. All metal concentrations were determined on a dry-weight basis and the contents of trace metals in the 17 fungi were found to be within the ranges of 0.034–0.270 (Cd), 1.766–15.980 (Cu), 0.002–2.735 (Cr), 2.642–160.12 (Fe), 2.946–5.374 (Pb), 1.377–7.683 (Zn), 0.379–3.645 (Ni) and 0.051–0.352 (Co). ANOVA test and DMRT were applied for the statistical analyses of the averages and it was found that the results of this study were meaningful in the test according to $p < 0.05$.

The mean Cd, Cr, Co, Cu, Fe, Ni, Pb, Zn, values in fungi samples were given in Table 2. The highest and lowest cadmium concentrations were measured 0.270 mg/kg *A. campestris* and 0.034 mg/kg in *S. crispa*, respectively. Cadmium contents of fungi samples in previous studies have been reported as 0.81–7.50 mg/kg, 0.28–1.6 mg/kg (Mendil et al. 2005), and 0.12–2.60 mg/kg (Malinowska et al. 2004), 0.14–0.95 mg/kg (Soylak et al. 2005). Cadmium level findings in this study were seen to be lower than those reported in the previous studies (Malinowska et al. 2004; Mendil et al. 2005; Soylak et al. 2005).

The minimum and maximum cobalt levels were 0.051 mg/kg in *H. coralloides* and 0.345 mg/kg in *A. campestris*, respectively. According to the previous studies, cobalt values were between 1.72–24.1 mg/kg (Soylak et al. 2005), 0.12–0.62 mg/kg (Sesli and Tuzen 1999) and 0.15–6.03 mg/kg (Isiloglu et al. 2001a, b). Cobalt values found in this study were good agreement with the previous studies realized with different fungi species (Sesli and Tuzen 1999; Isiloglu et al. 2001a, b; Soylak et al. 2005). The lowest chromium content found to be 0.002 mg/kg in *T. terreum* and the highest chromium content was found to be 2.735 mg/kg in *Agaricus campestris.* In previous studies, chromium values in fungi samples were in the range of 0.34–1.10 mg/kg (Soylak et al. 2005), 0.16–4.86 mg/kg

Table 2 Trace metal concentrations (mg/kg, dry-weight basis) in fungi samples

Fungal species	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
Hydnum repandum var. *rufescens*	$0.09^{e} \pm 0.00$	$0.16^{i} \pm 0.01$	$2.23^{b,c} \pm 0.67$	$2.19^{g} \pm 0.28$	$17.76^{j} \pm 2.13$	$3.59^{a} \pm 0.39$	$4.59^{a,b} \pm 1.02$	$2.26^{o} \pm 0.01$
Hydnum repandum	$0.11^{d} \pm 0.01$	$0.12^{k} \pm 0.00$	$0.74^{hi} \pm 0.06$	$2.08^{g} \pm 0.65$	$50.06^{c} \pm 2.40$	$2.45^{d,e} \pm 0.03$	$4.34^{b,c,d} \pm 0.64$	$2.03^{p} \pm 0.00$
Lactarius salminocolor	$0.06^{fg} \pm 0.02$	$0.09^{m} \pm 0.01$	$1.76^{cd} \pm 0.24$	$2.20^{g} \pm 0.08$	$54.95^{b} \pm 4.25$	$1.77^{h} \pm 0.00$	$3.57^{c,d,e,f,g} \pm 0.39$	$5.38^{f} \pm 0.01$
Sparassis crispa	$0.03^{h} \pm 0.01$	$0.23^{f} \pm 0.01$	$0.11^{j} \pm 0.01$	$1.86^{g} \pm 0.08$	$36.62^{e,f} \pm 0.24$	$3.19^{b} \pm 0.10$	$3.64^{c,d,e,f,g} \pm 0.13$	$2.34^{n} \pm 0.02$
Ramaria aurea	0.1412 ± 0.02	$0.07^{n} \pm 0.00$	$1.29^{e,f} \pm 0.16$	$2.02^{g} \pm 0.11$	$20.70^{i} \pm 1.50$	$0.38^{k} \pm 0.01$	$4.26^{b,c,d,e} \pm 0.44$	$3.24^{k} \pm 0.01$
Agaricus campestris	$0.27^{a} \pm 0.02$	$0.35^{b} \pm 0.01$	$2.73^{a} \pm 0.16$	$8.946^{g} \pm 0.38$	$21.74^{i} \pm 1.53$	$2.77^{c} \pm 0.01$	$4.20^{b,c,d,e} \pm 0.33$	$7.68^{a} \pm 0.01$
Pleurotus ostreatus	$0.06^{f,g} \pm 0.01$	$0.22^{f} \pm 0.00$	$1.00^{g,h} \pm 0.32$	$2.17^{g} \pm 0.05$	$8.93^{k} \pm 0.47$	$2.30^{e,f} \pm 0.00$	$3.38^{e,f,g} \pm 0.13$	$3.35^{j} \pm 0.00$
Pleurotus ostreatus var *columbinus*	$0.1212\text{-} \pm 0.01$	$0.17^{h} \pm 0.01$	$0.75^{h,i} \pm 0.16$	$1.93^{g} \pm 0.06$	$2.64^{m} \pm 0.13$	$2.18^{e,f,g} \pm 0.01$	$4.04^{b,c,d,e,f} \pm 0.17$	$3.51^{i} \pm 0.01$
Macrolepiota procera	$0.25^{b} \pm 0.00$	$0.35^{a} \pm 0.01$	$2.16^{b,c} \pm 0.46$	$15.99^{a} \pm 0.76$	$38.76^{e} \pm 1.08$	$3.64^{a} \pm 0.02$	$3.99^{b,c,d,e,f} \pm 0.87$	$7.66^{b} \pm 0.01$
Suillus bovinus	$0.07^{e,f} \pm 0.00$	$0.07^{n} \pm 0.01$	$0.90^{g,h,i} \pm 0.23$	$2.89^{f} \pm 0.36$	$45.89^{d} \pm 1.11$	$0.46^{k} \pm 0.01$	$3.44^{e,f,g} \pm 0.28$	$7.45^{c} \pm 0.00$
Coprinus comatus	$0.08^{e} \pm 0.01$	$0.08^{m} \pm 0.00$	$2.00^{b,c,d} \pm 0.10$	$7.88^{c} \pm 0.01$	$160.12^{a} \pm 0.44$	$2.04^{f,g,h} \pm 0.05$	$5.37^{a} \pm 0.28$	$4.85^{g} \pm 0.00$
Rhizopogon luteolus	$0.01^{i} \pm 0.00$	$0.14^{j} \pm 0.00$	$1.14^{f,g,h} \pm 0.12$	$1.92^{g} \pm 0.03$	$35.54^{f} \pm 0.48$	$1.94^{g,h} \pm 0.03$	$4.76^{a,b} \pm 0.19$	$2.75^{l} \pm 0.00$
Lactarius deliciosus	$0.01^{i} \pm 0.00$	$0.28^{e} \pm 0.01$	$1.00^{g,h} \pm 0.25$	$1.91^{g} \pm 0.01$	$26.91^{h} \pm 0.31$	$0.77^{j} \pm 0.00$	$4.11^{b,c,d,e} \pm 0.59$	$2.49^{m} \pm 0.02$
Tricholoma terreum	$0.05^{g,h} \pm 0.00$	$0.32^{c} \pm 0.01$	$0.01^{j} \pm 0.00$	$3.87^{e} \pm 0.01$	$30.27^{g} \pm 0.62$	$2.69^{c,d} \pm 0.58$	$3.48^{d,e,f,g} \pm 0.45$	$5.89^{e} \pm 0.01$
Calocybe gambosa	$0.09^{e} \pm 0.00$	$0.29^{d} \pm 0.00$	$2.28^{b} \pm 0.32$	$8.32^{c} \pm 0.00$	$49.20^{c} \pm 0.65$	$1.16^{i} \pm 0.00$	$2.95^{g} \pm 0.23$	$6.60^{d} \pm 0.00$
Hericium coralloides	$0.09^{e} \pm 0.01$	$0.05^{o} \pm 0.00$	$1.60^{d,e} \pm 0.06$	$1.77^{g} \pm 0.01$	$30.30^{g} \pm 0.43$	$2.26^{e,f} \pm 0.01$	$3.17^{f,g} \pm 0.01$	$1.38^{r} \pm 0.00$
Ramaria stricta	$0.14^{c} \pm 0.01$	$0.19^{g} \pm 0.00$	$0.45^{i,j} \pm 0.12$	$4.80^{d} \pm 0.02$	$19.21^{k} \pm 0.51$	$1.77^{h} \pm 0.01$	$4.41^{b,c} \pm 0.21$	$4.56^{h} \pm 0.00$

All values are means of triplicates ± SD

ANOVA significance was set at $p \leq 0.01$

Different letters indicate significantly different values at a particular time point (DMRT $p \leq 0.05$). For a given metal, mean concentrations followed by the same letter are not significantly different ($p < 0.05$)

(Malinowska et al. 2004). Minimum and maximum values of copper in *H. coralloides* and *M. procera*, respectively, were found to be 1.766 and 15.980 mg/kg. Copper contents of fungi samples mentioned in the previous studies were between 13.4–50.6 mg/kg (Soylak et al., 2005), 12–181 mg/kg (Tuzen et al., 2003) and 10.3–145 mg/kg. Copper values have been reported to be in the range of 34.5–83.0, 10.0–14.0 and 21.1–42.6 mg/kg varies in the previous studies (Svoboda et al. 2000; Demirbas 2002). In the present study, the copper levels were found to be lower than normal limits reported in the previous studies (Svoboda et al. 2000; Demirbas 2002; Tuzen et al. 2003; Soylak et al. 2005).

The minimum iron concentration was 2.64 mg/kg in *P. ostreatus* var. *columbinus*. The maximum iron concentration was 160.12 mg/kg in *C. comatus.* Iron values in fungi samples have been reported to be in the range of 102–1580 mg/kg (Soylak et al. 2005) 31.3–1190 mg/kg (Sesli and Tuzen 1999), 568–3904 mg/kg (Turkekul et al., 2004) and 56.1–7162 mg/kg (Isiloglu et al. 2001a, b). Iron levels in the study were found to be lower than those reported in the previous studies (Sesli and Tuzen 1999; Isiloglu et al. 2001a, b; Soylak et al. 2005; Turkekul et al., 2004). The lowest and highest nickel concentrations were 0.379 mg/kg in *R. aurea* and 3.645 mg/kg in *M. procera*, respectively. Nickel values have been reported at the ranges of 1.72–24.1 mg/kg (Soylak et al. 2005), and 0.4–15.9 mg/kg (Isildak et al. 2004). Nickel levels in the study were found to be lower than those reported in the previous studies (Isildak et al. 2004; Soylak et al. 2005). The lowest lead content was 3.169 mg/kg in *H. coralloides* while the highest lead content was 4.756 mg/kg in *R. luteolus*. Lead contents in fungi samples in the previous studies were between 0.40–2.80 mg/kg (Svoboda et al. 2000), 0.75–7.77 mg/kg (Tuzen et al. 2003), and 0.14–0.15 mg/kg (Soylak et al. 2005). The fact that toxic metals are present in high concentrations in fungi is particularly important in relation to the FAO/WHO (FAO/WHO Standard 1976) standards for Cd and Pb as toxic metals. For an adult, not more than 3 mg Pb and 0.5 mg Cd should be taken per week; yet the recommended doses are only one-fifth of above-mentioned quantities (FAO/WHO Standard 1976). Lead values in this study were in good agreement with those reported in the literature. The minimum zinc concentration was 1.377 mg/kg in *H. coralloides* while the maximum zinc concentration was 7.683 mg/kg in *A. campestris.* Previous studies indicated that zinc concentrations of fungi samples were in the range of 33.5–89.5 mg/kg (Soylak et al. 2005), and 29.3–158 mg/kg (Isiloglu et al. 2001a, b). Zinc is widespread among living organisms due to its biological significance (Yasar and Ozyigit 2009). Fungi are known as zinc accumulators and sporophore substrate ratio for Zinc ranges from 1 to 10 (24). Zinc level in the study was found to be lower than those reported in the previous studies (Isiloglu et al. 2001a, b; Soylak et al. 2005).

The mean Cd, Cr, Co, Cu, Fe, Ni, Pb, Zn, values in soil samples were given in Table 3. The lowest soil Cd value was measured in soils where *P. ostreatus* samples were collected with 0.02 ± 0.00 mg/kg while the highest Cd was measured where *S. crispa* samples were collected with 0.34 ± 0.01 mg/kg. The lowest and highest soil Co values were found 0.03 ± 0.00 mg/kg (*S. bovinus*) and 0.66 ± 0.01 mg/kg (*Lactarius salminocolor*), respectively. The lowest soil Cr value was 0.02 ± 0.01 mg/kg where *S. crispa* samples were collected and the highest was 1.24 ± 0.21 mg/kg where *S. bovinus* samples were collected. The lowest soil Cu value was 2.23 ± 0.06 mg/kg (*P. ostreatus*) and the highest was 19.18 ± 0.06 mg/kg (*H. coralloides*). The lowest and highest soil Fe values were found 5.02 ± 0.56 mg/kg (*L. deliciosus*) and 104.4 ± 4.20 mg/kg (*Lactarius salminocolor*), respectively. The lowest soil Ni value was measured in soils where *T. terreum* samples were collected with 0.2 ± 0.01 mg/kg while the highest Cd was measured where *Hydnum repandum* samples were collected with 2.57 ± 0.09 mg/kg. The lowest and highest soil Pb values were found 0.56 ± 0.20 mg/kg (*P. ostreatus* var. *columbinus*) and 1.9 ± 0.06 mg/kg (*C. gambosa*), respectively. The lowest soil Zn value was measured in soils where *Ramaria stricta* samples were collected with 3.46 ± 0.01 mg/kg while the highest Zn was measured where *P. ostreatus* var. *columbinus* samples were collected with 13.06 ± 0.02 mg/kg.

In this study, a linear regression correlation test was performed to investigate correlations between metal concentrations. The values of correlation coefficients between metal concentrations are given in Table 4. There are good correlations between chromium and copper, chromium and cadmium, chromium and zinc, zinc and copper, zinc and cadmium, cadmium and copper, copper and cobalt. The other correlations between metals were not significant. There are positive correlations of chromium and iron, chromium and cobalt, iron and zinc, iron and lead, iron and copper, nickel and cadmium, nickel and lead, nickel and copper, nickel and cobalt, zinc and cobalt, cadmium and lead, cadmium and cobalt, lead and copper. Negative correlations were found between chromium and nickel, chromium and lead, iron and nickel, iron and cadmium, iron and cobalt, nickel and zinc, zinc and lead, lead and cobalt.

A linear regression correlation test was performed to investigate correlations between metal concentrations in soil samples. The values of correlation coefficients between metal concentrations are given in Table 5. There are good correlations between cadmium and zinc, copper and zinc, copper and cadmium. The other correlations between metals were not significant. There are positive correlations

Table 3 Trace metal concentrations of soil samples

Soil samples	pH	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
Hydnum repandum var. *rufescens*	6.91	$0.07^{b,c} \pm 0.00$	$0.07^{b,c} \pm 0.01$	$0.31^{c} \pm 0.60$	$10.09^{k} \pm 0.18$	$34.75^{f} \pm 2.03$	$1.16^{f} \pm 0.40$	$1.74^{k} \pm 1.02$	$10.73^{m} \pm 0.02$
Hydnum repandum	6.37	$0.05^{a,b,c} \pm 0.01$	$0.12^{d} \pm 0.02$	$0.97^{i} \pm 0.08$	$2.63^{e} \pm 0.45$	$33.74^{e} \pm 2.04$	$2.57^{n} \pm 0.09$	$1.7^{j} \pm 0.35$	$3.84^{b} \pm 0.00$
Lactarius salminocolor	5.64	$0.04^{a,b,c} \pm 0.00$	$0.66^{h} \pm 0.01$	$0.72^{h} \pm 0.25$	$2.63^{e} \pm 0.04$	$104.4^{p} \pm 4.20$	$0.93^{d} \pm 0.01$	$1.32^{e} \pm 0.15$	$9.15^{l} \pm 0.03$
Sparassis crispa	5.95	$0.34^{f} \pm 0.01$	$0.44^{g} \pm 0.01$	$0.02^{a} \pm 0.01$	$9.36^{j} \pm 0.13$	$56.65^{j} \pm 0.30$	$1.36^{i} \pm 0.20$	$1.5^{h} \pm 0.13$	$6.96^{i} \pm 0.02$
Ramaria aurea	6.21	$0.07^{b,c} \pm 0.00$	$0.41^{g} \pm 0.01$	$0.40^{d} \pm 0.18$	$2.3^{b} \pm 0.48$	$7.94^{b} \pm 1.11$	$0.348^{b} \pm 0.09$	$1.44^{g} \pm 0.56$	$4.74^{d} \pm 0.03$
Agaricus campestris	6.15	$0.04^{a,b,c} \pm 0.00$	$0.07^{b,c} \pm 0.02$	$0.22^{b} \pm 0.18$	$2.81^{f} \pm 0.06$	$11.24^{c} \pm 1.23$	$1.5^{k} \pm 0.01$	$1.14^{c} \pm 0.35$	$5.59^{f} \pm 0.01$
Pleurotus ostreatus	6.07	$0.02^{a} \pm 0.00$	$0.17^{e} \pm 0.00$	$0.05^{a} \pm 0.35$	$2.23^{a} \pm 0.06$	$69.58^{l} \pm 0.45$	$1.68^{l} \pm 0.01$	$1.35^{ef} \pm 0.13$	$3.98^{c} \pm 0.01$
Pleurotus ostreatus var. *columbinus*	5.98	$0.17^{e} \pm 0.02$	$0.27^{f} \pm 0.00$	$0.19^{b} \pm 0.18$	$10.72^{l} \pm 0.66$	$16.98^{d} \pm 0.17$	$0.46^{c} \pm 0.09$	$0.56^{a} \pm 0.20$	$13.06^{o} \pm 0.02$
Macrolepiota procera	5.8	$0.07^{b,c} \pm 0.00$	$0.30^{f} \pm 0.01$	$0.64^{g} \pm 0.40$	$4.27^{h} \pm 0.09$	$73.64^{m} \pm 1.11$	$1.35^{i} \pm 0.01$	$0.82^{b} \pm 0.08$	$8.21^{k} \pm 0.01$
Suillus bovinus	6.42	$0.11^{d} \pm 0.01$	$0.03^{a} \pm 0.00$	$1.24^{j} \pm 0.21$	$7.79^{i} \pm 0.00$	$35.72^{g} \pm 1.11$	$1.24^{g} \pm 0.09$	$1.37^{f} \pm 0.02$	$11.51^{n} \pm 0.03$
Coprinus comatus	5.82	$0.03^{a,b} \pm 0.00$	$0.13^{d} \pm 0.01$	$0.19^{b} \pm 0.11$	$3.56^{g} \pm 0.01$	$67.53^{k} \pm 0.66$	$1.1^{e} \pm 0.03$	$1.89^{l} \pm 0.18$	$8.17^{j} \pm 0.00$
Rhizopogon luteolus	5.5	$0.08^{cd} \pm 0.00$	$0.13^{d} \pm 0.00$	$0.33^{c} \pm 0.09$	$2.32^{b} \pm 0.03$	$45.32^{i} \pm 0.58$	$1.15^{f} \pm 0.00$	$1.5^{h} \pm 0.49$	$5.97^{h} \pm 0.00$
Lactarius deliciosus	5.84	$0.04^{a,b,c} \pm 0.00$	$0.17^{e} \pm 0.00$	$0,44^{e} \pm 0.26$	$2.6^{e} \pm 0.00$	$5.02^{a} \pm 0.56$	$1.21^{g} \pm 0.68$	$1.25^{d} \pm 0.46$	$5.69^{g} \pm 0.01$
Tricholoma terreum	6.01	$0.08^{c,d} \pm 0.20$	$0.06^{a,b} \pm 0.01$	$0.56^{f} \pm 0.18$	$2.42^{c} \pm 0.09$	$39.32^{h} \pm 0.01$	$0.2^{a} \pm 0.01$	$1.58^{i} \pm 0.06$	$5.5^{e} \pm 0.20$
Calocybe gambosa	5.87	$0.03^{a,b} \pm 0.08$	$0.13^{d} \pm 0.02$	$0.19^{b} \pm 0.35$	$3.56^{g} \pm 0.06$	$67.53^{k} \pm 0.09$	$1.1^{e} \pm 0.01$	$1.9^{l} \pm 0.06$	$8.17^{j} \pm 0.01$
Hericium coralloides	5.73	$0.15^{e} \pm 0.09$	$0.27^{f} \pm 0.09$	$0.94^{i} \pm 0.01$	$19.18^{m} \pm 0.06$	$87.18^{n} \pm 0,01$	$1.92^{m} \pm 0.09$	$1.48^{h} \pm 0.20$	$13.03^{o} \pm 0.00$
Ramaria stricta	5.82	$0.07^{b,c} \pm 0.01$	$0.1^{c,d} \pm 0.00$	$0.32^{c} \pm 0.11$	$2.5^{d} \pm 0.01$	$95.11^{o} \pm 0.41$	$1.3^{h} \pm 0.09$	$1.61^{i} \pm 0.31$	$3.46^{a} \pm 0.01$

All values are means of triplicates ± SD

ANOVA significance was set at $p \leq 0.01$

Different letters indicate significantly different values at a particular time point (DMRT $p \leq 0.05$). For a given metal, mean concentrations followed by the same letter are not significantly different ($p < 0.05$)

Table 4 Correlations between metal concentrations in fungi species

	Cr	Fe	Ni	Zn	Cd	Pb	Cu	Co
Cr	1.00							
Fe	0.34	1.00						
Ni	−0.14	−0.07	1.00					
Zn	0.51**	0.17	−0.05	1.00				
Cd	0.52**	−0.12	0.30	0.52**	1.00			
Pb	−0.03	0.42	0.13	−0.18	0.10	1.00		
Cu	0.63**	0.29	0.32	0.72**	0.70**	0.08	1.00	
Co	0.14	−0.29	0.39	0.45	0.35	−0.20	0.56**	1.00

Correlation is significant at the 0.01 level (2-tailed)

Table 5 Correlations between metal concentrations in soil sample

	Cr	Fe	Ni	Zn	Cd	Pb	Cu	Co
Cr	1.00							
Fe	−0.04	1.00						
Ni	0.33	−0.38	1.00					
Zn	0.29	0.14	-0.14	1.00				
Cd	0.31	−0.17	−0.06	0.60**	1.00			
Pb	0.08	0.33	0.06	−0.35	−0.42	1.00		
Cu	0.22	0.13	0.13	0.66**	0.64**	−0.01	1.00	
Co	−0.08	−0.00	0.17	0.17	0.39	−0.43	0.34	1.00

Correlation is significant at the 0.01 level (2-tailed)

of, nickel and chromium, zinc and chromium, zinc and iron, cadmium and chromium, lead and chromium, lead and iron, lead and nickel, copper and chromium, copper and iron, copper and nickel, cobalt and nickel, copper and zinc, copper and cadmium. Negative correlations were found between iron and chromium, nickel and iron, zinc and nickel, cadmium and nickel, lead and zinc, lead and cadmium, copper and lead, cobalt and chromium, cobalt and iron, cobalt and lead.

Conclusion

In this study, it is determined that the fungi samples collected in Bolu (Aladaglar, Yedigoller, Abant), Turkey does not completely lack heavy metals, but they are within acceptable limits for some elements. Cu, Co, Fe and Zn, in soils, generally, these metal levels in fungi species increased with increasing metal concentrations in the underlying soil substrates. As it is known, the sources of heavy metals in forest soils are rocks, deposition, fertilizers and some other anthropogenic sources such as mining, traffic and urbanization near forest areas. In this study, soil heavy-metal amounts were within normal/accepted limits. However, Ni, Cd and Cr and Pb levels in fungi species were higher than soil samples. In general, the fungi bioaccumulated high amounts of Pb, Ni Cr and Cd; any higher concentrations of those metals showed a toxic effect, causing a lower yield. It appears that the fungi take up the heavy metals readily. Metal concentrations heavily depend on the type of species.

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