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Contents and Health Risk Assessment of Elements in Three Edible Ectomycorrhizal Fungi (*Boletaceae*) from Polymetallic Soils in Yunnan Province, SW China

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Abstract

Ectomycorrhizal fungi (EcMF) can mobilize mineral elements directly from insoluble mineral sources and accumulate various metallic elements and metalloids from soils to their fruiting bodies. Mushrooms from genus *Boletus* and its related genus are one of the most important EcMF which are consumed worldwide as wild edible mushrooms. Yunnan province (China) is a high biodiversity of genus *Boletus* mushrooms but is also an area with potential elevated contents of toxic elements in soil. Total contents of As, Ag, Ba, Cd, Co, Cr, Cs, Cu, Li, Mn, Ni, Pb, Rb, Sb, Sr, Tl, U, V, and Zn in three edible EcMF species collected from five sites of Yunnan were analyzed by inductively coupled plasma mass spectrometer. The highest contents for As, Cd, and Pb were 7.8 mg kg^{-1} dry weight (dw) in the caps of *Butyriboletus roseoflavus*, 3.4 mg kg^{-1} dw in the caps of *B. roseoflavus*, and 6.4 mg kg^{-1} dw in the stipes of *Hemileccinum impolitum*. Health risk assessment of As, Cd, and Pb indicated that the estimated exposure due to intakes of some mushroom samples from the sites were above the limits recommended by the Joint FAO/WHO Expert Committee on Food Additives. Since EcMF were considered as bioexclusors of Cr, higher Cr contents in the mushroom samples, compared with previous studies, indicated high geochemical background value of Cr in the sampling sites. Relatively higher V contents in mushrooms from family *Boletaceae* could also associate with the high V contents in Yunnan soil. Further work is needed to identify the places in Yunnan with geochemical anomalies resulting in high levels of toxic elements in EcMF.

Keywords Environment · Mushroom · Fungi · Food · Metal · Metalloid

Introduction

Ectomycorrhizal fungi (EcMF) that have occurred since the Cretaceous are now associated with the plant species such as families *Betulaceae*, *Fagaceae*, and *Pinaceae* comprising the dominant trees in boreal and temperate forests [1]. They can mobilize mineral elements directly from insoluble mineral sources through excretion of organic acids [2]. Furthermore, many EcMF have variable and specific ability to take up various metallic elements and metalloids from soils and accumulate them in their fruiting bodies [3]. The trace element (such as Co, Cd, Cu, Pb, Mn, Ni, and Zn) contents in mushrooms were found to depend on the natural factors, environmental pollution, microbial communities, and the physiology of the mushroom species (particularly on its trophic pattern) [3–5]. Amongst EcMF, mushrooms from genus *Boletus* are one of the most important groups which are consumed worldwide as wild edible mushrooms [6]. Notably high contents of Ag and Au in *Boletus edulis* indicated its specific ability of taking up the trace elements from the soils with high geochemical background or contaminated by the metal ore smelters [7, 8].

Arsenic is a natural environmental contaminant that can be taken up and accumulated in mushrooms [9, 10]. Mleczek et al. [11] found that the As content was 450 mg/kg dw in

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Imleria badia (previously *Boletus badius*) collected from sludge deposits contaminated with As at level 490 mg/kg dw. Several *Boletus* mushroom species can be considered as an As accumulator, since the bioconcentration factor (the quotient of the As content in mushrooms to the As content in soil, calculated on dry weight basis) was above 1 in those species [12, 13]. Cadmium is one of the most detrimental elements of mushrooms and can be also found at elevated concentrations in wild-grown mushrooms [3, 14]. Lead toxicity is well known [15]. Lead content in edible wild mushrooms can be considered as indicator of environmental contamination [16].

Yunnan province of China has high biodiversity of mushrooms from family *Boletaceae* [17]. These species can be usually foraged from June to September. The toxic element contamination of these species in the region increased concerns due to elevated soil toxic element contents discovered in recent years [18]. For example, the mean soil As content in Yunnan is relatively very high (18–20 mg kg^{-1} dry weight, dw) compared with many other provinces in China [19]. The highest median content (120 mg kg^{-1} dw; 6.7–1500 mg kg^{-1} dw) of V in soils in China was also observed in Yunnan province [20]. Moreover, serious Cr slag contamination accident occurred in Qujing in Yunnan on August 13, 2011 [21]. Previous studies on wild growing mushrooms have shown that variations of elements between caps and stipes of *Boletus* fungi are mainly related to different bedrock soil geochemistry, enrichment capability for various elements as well as mushroom species [22–24]. To get a valid panorama and understand the elemental composition, contents and health risk assessment of elements in edible mushrooms from vast areas with polymetallic soils are sufficiently large database of species and results from different geological regions. Therefore, there is a need to investigate biodiverse mushrooms from polymetallic soils, especially using advanced and fully validated instrumental methodologies and the edible species that are lacking of reliable data on elemental composition.

The aims of this study were to (1) determine the contents of As, Cd, Pb, and other sixteen elements in three edible EcMF from Yunnan, (2) compare our data with those of other studies from Yunnan and European countries, and (3) evaluate the potential health risk of As, Cd, and Pb exposure of the studied mushrooms for the Chinese population.

Materials and Methods

Mushroom Samples

Hemileccinum impolitum (Fr.) Šutara (previously named '*Boletus impolitus*') (20 specimens), *Butyriboletus roseoflavus* (M. Zang & H.B. Li) D. Arora & J.L. Frank (previously named '*Boletus speciosus*') (30 specimens), and *Boletus umbriniporus* Hongo (24 specimens) from family *Boletaceae* were collected from five distantly distributed sites in Yunnan province, China in 2011 and 2012 (Fig. 1). Identification of those specimens was performed by taxonomic keys of Mao [25] and Wang [26] and was further confirmed by professional mycologists. Fungal nomenclature followed the Index Fungorum (www.indexfungorum.org).

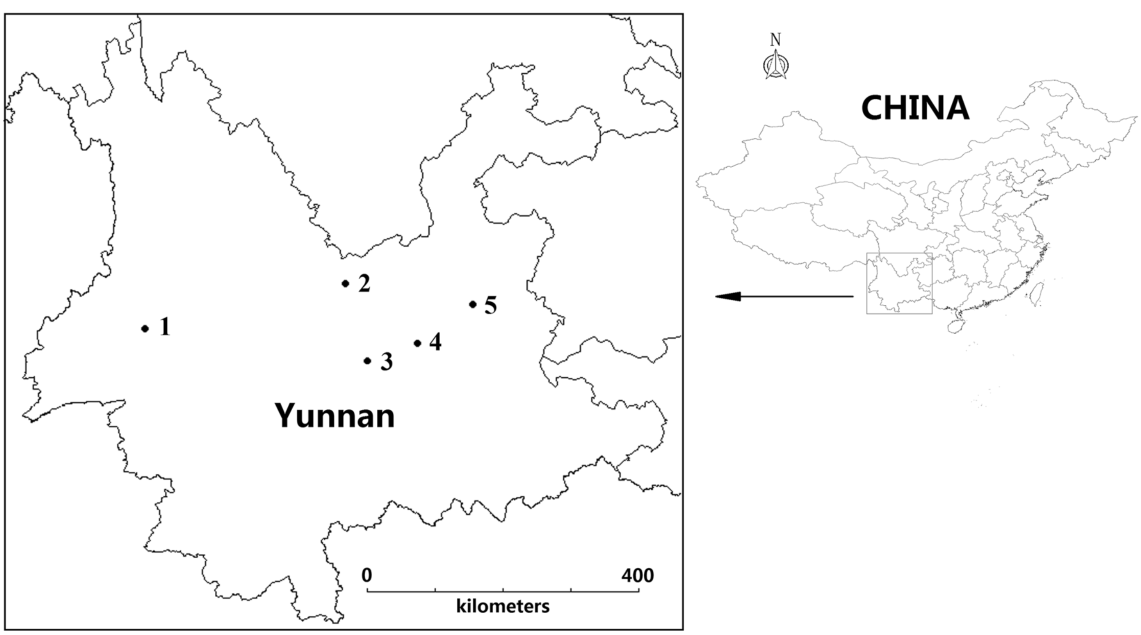

Fig. 1 Sampling sites for the three edible ectomycorrhizal fungi. 1: Longyang, Baoshan; 2: Yuanmou, Chuxiong; 3: Yimen, Yuxi; 4: Wuhua, Kunming; 5: Qilin, Qujing

Fresh mushrooms were cleaned to remove any visible plant and soil debris with a plastic knife, and the bottom part of the stipe was cut off. The fruiting bodies were then separated into caps and stipes and prepared and pooled respectively. Thereafter, the mushroom samples were placed into plastic trays of an electrically heated dehydrator (Ultra FD1000, Ezidri, Australia) and dried at 65 °C to constant mass. Dried mushrooms were pulverized in a porcelain mortar and finally kept in brand new sealed polyethylene bags under dry conditions.

Elemental Analysis

Directly before chemical analysis, the samples were kept at 65 °C for 12 h using an electrically heated laboratory oven before digestion. The subsamples of dried and powdered mushrooms (ca. 0.5 g) were digested with 5 mL of 65% HNO_3 (Suprapure, Merck, Germany) under pressure in a microwave oven (Ethos One, Milestone Srl, Italy) [27]. The heating program was performed in one step: the power of the process was 1500 W, ramp time 20 min, temperature 200 °C, and hold time 30 min. Reagent blank solutions were prepared in the same way. Two blank samples were run for every set of 10 mushroom samples digested. The digest was diluted to 10 mL using deionized water (TKA Smart2Pure, Niederelbert, Germany) [28, 29].

Instrumentation

As, Ag, Ba, Cd, Co, Cr, Cs, Cu, Li, Mn, Ni, Pb, Rb, Sb, Sr, Tl, U, V, and Zn were determined using the ELAN DRC II ICP-MS inductively coupled plasma mass spectrometer (PerkinElmer, SCIEX, Canada). The spectrometer was equipped with a Meinhard concentric nebulizer, cyclonic spray chamber, dynamic reaction cell, Pt cones, and a quadruple mass analyzer. DRC was employed to remove spectral interferences. Typical spectrometer operating conditions for the ICP-MS spectrometer were as follows: RF power, 1100 W; plasma Ar flow rate, 15 L min^{-1}; nebulizer Ar flow rate, 0.87 L min^{-1}; and auxiliary Ar flow rate, 1.2 L min^{-1} and lens voltage, (7.5–9.0) V. The performance of the analytical method applied was under rigorous control using the quality control/quality assurance protocol as was described in detail in previous reports [28, 29]. Certified reference materials SRM NIST 1570a Spinach Leaves (National Institute of Standards and Technology, Department of Commerce, USA), CRM CS-M-4 *Boletus edulis* mushroom powder (Institute of Nuclear Chemistry and Technology, Poland), and CRM CS-M-4 *Leccinum scabrum* mushroom powder (Institute of Nuclear Chemistry and Technology, Poland) were used to verify the element determinations.

Health Risk Assessment of Arsenic, Cadmium, and Lead

In Yunnan, wild edible mushrooms belonging to family *Boletaceae* can be foraged from June to September and eaten by the population for at least one time each week during the mushroom fruiting season. The estimated As, Cd, and Pb intakes were calculated by consumption from a single meal containing 300-g fresh mushrooms (ca. 30-g dry mushrooms) for a 60-kg body weight individual. We compared the estimated As intake with the inorganic arsenic lower limit on the benchmark dose for a 0.5% increased incidence of lung cancer (BMDL0.5), which was 3.0 μg kg^{-1} bw per day [30]. The dietary exposure of Pb corresponding to an increase in systolic blood pressure of 1 mmHg (0.1333 kPa) was estimated to be 1.2 μg/kg bw per day [31]. The corresponding dietary exposure for Cd is 0.8 μg/kg bw per day which would result in a urinary Cd content at the breakpoint of 5.24 μg of Cd per gram creatinine [31].

Results and Discussions

Arsenic

The range of As contents was 0.88–1.2 mg kg^{-1} dw in *H. impolitum*, 0.24–7.8 mg kg^{-1} dw in *Butyriboletus roseoflavus*, and 0.61–1.3 mg kg^{-1} dw in *Boletus umbriniporus* (Table 1). The highest As contents (7.8 mg kg^{-1} dw in the caps and 4.5 mg kg^{-1} dw in the stipes) were found in *Butyriboletus roseoflavus* from Yuanmou County, Yunnan.

In previous studies, the As contents in composite samples for different *Boletus* species from different locations in Yunnan were at the range of 0.090–53 mg kg^{-1} dw [22, 29, 32, 33]. Elevated As contents have been found in other *Boletus* mushrooms, such as *B. edulis* (7.0 mg kg^{-1} dw) and *B. bicolor* (5.6 mg kg^{-1} dw) [34, 35]. However, low As contents can be also found in *B. tomentipes* (0.10–0.24 mg kg^{-1} dw) and *Boletus* sp. (0.26 mg kg^{-1} dw) from Yunnan [32, 36]. Moreover, relatively low As contents were also detected in *Boletus* spp. mushrooms from Italy (0.10–0.41 mg kg^{-1} dw) and Serbia (0.32–1.66 mg kg^{-1} dw) [37, 38]. Considering intense mining activities in Yunnan [39], further work is needed to understand whether the elevated As contents in *Boletus* mushrooms is due to the high As content in soil or the bioaccumulation process.

In this study, the estimated As intakes from most of the samples were below the limit recommended by JECFA (Table 1). The only exception was the caps of *Butyriboletus roseoflavus* from Yuanmou County, in which the estimated As intake was 3.9 μg kg^{-1} bw (Table 1). If the As in *B. roseoflavus* from this site is dominated by the inorganic species, it should not be eaten. Unfortunately, as far as we

Table 1 Arsenic in the mushrooms and the estimated meal intake

Species, place, year, and sample size	As content (mg/kg dw)		Estimated As intake (μg/kg bw)*	
	Cap	Stipe	Cap	Stipe
Hemileccinum impolitum				
Wuhua, Kunming, 2011, (10)	0.88	2.1	0.44	1.1
Yimen, Yuxi, 2012, (10)	1.2	2.6	0.60	1.3
Butyriboletus roseoflavus				
Longyang, Baoshan, 2012, (10)	0.24	0.5	0.12	0.25
Yuanmou, Chuxiong, 2012, (10)	7.8	4.5	3.9	2.3
Qilin, Qujing, 2012, (10)	0.78	0.76	0.39	0.38
Boletus umbriniporus				
Yimen, Yuxi, 2011, (10)	0.61	0.37	0.31	0.19
Longyang, Baoshan, 2011, (7)	1.3	0.74	0.65	0.37
Yimen, Yuxi, 2012, (7)	1.1	0.71	0.55	0.36

*A single meal composed of 300 g of fresh mushrooms for a 60-kg body weight individual

know, few studies have been carried out on As speciation in *Boletaceae* mushrooms [40, 41]. Chen et al. [40] reported that As (V) (0.20 mg kg^{-1} dw) was the dominant As species in a sample named as "yellow bolete," while monomethylarsonic acid (200 mg kg^{-1} dw) was accounted for 94% of the total arsenic in a sample named as "black bolete." Komorowicz et al. [41] recently found in some bolete species from Yunnan the arsenobetaine, dimethylarsenic acid, As(III), monomethylarsenic acid, and As(V) at very broad range of contents. Braeuer et al. [42] found that no inorganic arsenic was detected in *Cyanoboletus pulverulentus* (family *Boletaceae*) mushroom samples from the European countries and the USA, and the arsenic speciation in the samples consisted solely of dimethylarsinic acid which is a probable human carcinogen [43].

Cadmium

Cadmium content was 0.22–3.4 mg kg^{-1} dw in the caps and 0.18–1.4 mg kg^{-1} dw in the stipes (Table 2). In previous studies, nd.− 19 mg kg^{-1} dw in caps and 0.24–12 mg kg^{-1} dw in stipes of *Boletus* spp. from Yunnan [29, 44]. Other studies on the whole fruiting bodies of *Boletus* spp. from Yunnan showed Cd content was 0.16–1.1 mg kg^{-1} dw [32, 45]. In European countries, 0.46–15.6 mg kg^{-1} dw in *Boletus* spp. [37, 38, 46–48]. However, up to 52 mg kg^{-1} dw Cd was detected in the cap of a specimen of *B. edulis* from Poland [49], and 120 ± 65 mg kg^{-1} dw) in specimens ($n = 24$) grew in area impacted by zinc smelter [50]. In this study, the estimated Cd intake was 1.7 μg/kg bw in the caps of *Butyriboletus roseoflavus* from Qilin, 1.1 μg/kg bw in the caps of *Butyriboletus roseoflavus*

Table 2 Cadmium in the mushrooms and the estimated meal intake

Species, place, year, and sample size	Cd content (mg/kg dw)		Estimated Cd intake (μg/kg bw)*	
	Cap	Stipe	Cap	Stipe
Hemileccinum impolitum				
Wuhua, Kunming, 2011, (10)	0.99	0.47	0.50	0.24
Yimen, Yuxi, 2012, (10)	0.22	0.18	0.11	0.090
Butyriboletus roseoflavus				
Longyang, Baoshan, 2012, (10)	1.4	0.48	0.70	0.24
Yuanmou, Chuxiong, 2012, (10)	2.1	0.60	1.1	0.30
Qilin, Qujing, 2012, (10)	3.4	1.4	1.7	0.70
Boletus umbriniporus				
Yimen, Yuxi, 2011, (10)	0.26	0.18	0.13	0.090
Longyang, Baoshan, 2011, (7)	2.0	1.4	1.0	0.70
Yimen, Yuxi, 2012, (7)	0.27	0.10	0.14	0.050

*A single meal composed of 300 g of fresh mushrooms for a 60-kg body weight individual from Yuanmou, and 1.0 μg/kg bw in the caps of *Boletus umbriniporus* from Longyang. These values were above the limit recommended by JECFA.

Lead

When sampling from the same area, EcMF presented lower Pb levels than saprophite species [16]. In this study, Pb content was 0.56–1.5 mg kg^{-1} dw in the caps and 0.78–6.4 mg kg^{-1} dw in the stipes (Table 3). The results were in agreement with previous studies in *Boletus* spp. from Yunnan (0.16–2.9 mg kg^{-1} dw in caps and 0.15–3.2 mg kg^{-1} dw in stipes) [29, 44]. For the whole fruiting bodies of *Boletus* spp. from Yunnan, the reported value was 1.4–6.2 mg kg^{-1} dw [32, 36, 45]. In European countries, Pb content was 0.22–1.5 in fruiting bodies of most studied *Boletus* spp. [37, 38, 48, 51, 52], but 11 mg kg^{-1} Pb was found in one sample of *B. edulis* from Serbia [38]. For *B. edulis* in Poland, the value was 0.18–3.6 mg kg^{-1} dw in caps and 0.35–1.7 mg kg^{-1} dw in stipes [49]. In terms of health risk assessment, our data showed that the stipes of *H. impolitum* from Wuhua (3.2 μg/kg bw) and Yimen (1.9 μg/kg bw) might cause excessive intake of Pb.

Silver

In general, the Ag contents in saprobic fungi are higher than those in EcMF, but *Boletus* mushrooms can be considered as one of the most efficient Ag accumulators [8]. 242 mg kg^{-1} dw Ag has been detected in *B. edulis* in the polluted area in Czech Republic [8]. In *Imleria badia* from smelter-polluted area, Ag content can be up to 385 mg kg^{-1} dw [53]. In pristine area of European continent, Ag contents in *Boletus* spp. were in the range of 0.41–41 mg kg^{-1} dw [38, 49, 51, 54, 55]. In this study, 0.63–5.0 mg kg^{-1} dw in caps and 0.13–1.2 mg kg^{-1} dw in stipes were found in the studied fungal species (Table 4), which were relatively similar to a previous study (1.2–4.7 mg kg^{-1} dw in caps and 0.23–11 mg kg^{-1} dw in stipes) on *Boletus* mushrooms from Yunnan [29].

Barium

Barium content was 0.06–2.9 mg kg^{-1} dw in caps and 0.13–2.1 mg kg^{-1} dw in stipes of *B. edulis* in Poland [49, 56–58], while it was 0.07–0.92 mg kg^{-1} dw in fruiting bodies of *B. edulis* from Croatia [58]. Higher levels of Ba (1.3–32 mg kg^{-1} dw in caps and 1.2–100 mg kg^{-1} dw) in stipes have been identified in *Boletus* spp. from Yunnan [29]. Our Ba data were in the range of those reported from Yunnan (Table 4).

Cobalt

Cobalt content was 0.28–2.5 mg kg^{-1} dw in the caps and 0.58–2.6 mg kg^{-1} dw in the stipes (Table 4). The range of the values was slightly higher than the Co content (1.0–1.7 mg kg^{-1} dw) found in *B. griseus* and *Butyriboletus roseoflavus* from Yunnan [59]. However, 5.2 mg kg^{-1} Co was detected in the stipes of *B. tomentipes* from Panzhihua, Sichuan province [29]. In Europe, Co content was 0.01–2.2 in *Boletus* spp. from different countries [38, 49, 60].

Chromium

Mushrooms were considered as bioexclusors of Cr and Cr content in EcMF usually lower than that in saprophytic fungi [61]. Previous works showed that Cr content was 0.060–0.60 mg kg^{-1} dw in *Boletus* spp. in Europe [38, 49], whereas elevated Cr contents (0.45–15 mg kg^{-1} dw) were detected in

Table 3 Lead in the mushrooms and the estimated meal intake

Species, place, year, and sample size	Pb content (mg/kg dw)		Estimated Pb intake (μg/kg bw)*	
	Cap	Stipe	Cap	Stipe
Hemileccinum impolitum				
Wuhua, Kunming, 2011, (10)	1.0	6.4	0.5	3.2
Yimen, Yuxi, 2012, (10)	1.2	3.8	0.6	1.9
Butyriboletus roseoflavus				
Longyang, Baoshan, 2012, (10)	0.56	1.2	0.28	0.6
Yuanmou, Chuxiong, 2012, (10)	1.5	2.0	0.75	1
Qilin, Qujing, 2012, (10)	1.2	1.6	0.6	0.8
Boletus umbriniporus				
Yimen, Yuxi, 2011, (10)	0.95	0.78	0.475	0.39
Longyang, Baoshan, 2011, (7)	1.2	1.2	0.6	0.6
Yimen, Yuxi, 2012, (7)	0.92	1.3	0.46	0.65

*A single meal composed of 300 g of fresh mushrooms for a 60-kg body weight individual

Table 4 Trace elements content of caps (*C*) and stipes (*S*) of the mushrooms (mg kg^{-1} dry biomass) foraged in Yunnan

Species, place, year, and sample size	Element and part of fruiting body (*C*, caps; *S*, stipes)																															
	Ag		Ba		Co		Cr		Cs		Cu		Li		Mn		Ni		Rb		Sb		Sr		Tl		U		V		Zn	
Hemileccinum impolitum	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*
Wuhua, Kunming, 2011, (10)	4.6	0.48	2.7	7.8	0.28	1.3	5.4	9.3	4.7	2.9	77	21	0.24	1.2	12	24	1.2	5.2	220	95	0.027	0.035	0.69	1.3	0.059	0.30	0.052	0.24	1.1	8.7	230	72
Yimen, Yuxi, 2012, (10)	0.63	0.14	6.1	61	0.67	1.6	3.6	6.7	1.1	0.94	18	9.5	0.29	1.3	13	38	0.88	3.8	390	160	0.068	< 0.001	0.44	1.7	0.020	0.11	0.037	0.19	1.6	7.2	99	57
Mean	2.6	0.31	4.4	34	0.48	1.5	4.5	8.0	2.9	1.9	48	15	0.27	1.3	13	31	1.0	4.5	310	130	0.048	0.018	0.57	1.5	0.040	0.21	0.045	0.22	1.4	8.0	160	65
SD	2.8	0.24	2.4	38	0.28	0.2	1.3	1.8	2.5	1.4	42	8.1	0.04	0.1	1	10	0.2	1.0	120	46	0.029	0.025	0.18	0.3	0.028	0.13	0.011	0.04	0.4	1.1	93	11
Butyriboletus roseoflavus	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*
Longyang, Baoshan, 2012, (10)	1.7	0.47	4.3	13	2.5	2.6	2.5	5.1	6.4	3.4	57	14	0.18	0.72	8.8	11	7.1	1.7	950	430	0.021	0.028	0.54	0.94	0.0092	0.041	0.017	0.051	0.76	1.9	130	58
Yuanmou, Chuxiong, 2012, (10)	4.6	1.0	4.4	9.8	1.2	2.6	24	12	5.4	2.3	62	26	0.29	0.35	14	22	3.1	3.9	430	200	0.033	0.025	0.80	0.96	0.015	0.029	0.046	0.052	1.4	1.5	160	65
Qilin, Qujing, 2012, (10)	1.4	0.35	1.7	2.5	0.30	0.84	1.6	1.7	32	9.5	35	11	0.29	0.32	11	13	1.3	1.3	360	200	0.11	0.11	0.49	0.66	0.063	0.15	0.029	0.040	0.83	0.79	290	120
Mean	2.6	0.61	3.5	8.4	1.3	2.0	9.4	6.3	15	5.1	51	17	0.25	0.46	11	15	3.8	2.3	580	280	0.055	0.054	0.61	0.85	0.029	0.073	0.031	0.048	1.0	1.4	190	81
SD	1.8	0.35	1.5	5.4	1.1	1.0	12.7	5.2	15	3.9	14	8	0.06	0.22	3	6	3.0	1.4	320	130	0.048	0.048	0.17	0.17	0.030	0.067	0.015	0.007	0.4	0.6	85	34
Boletus umbriniporus	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*
Yimen, Yuxi, 2011, (10)	0.66	0.13	5.3	3.1	0.45	0.58	3.9	5.4	0.81	0.46	28	8.3	0.21	0.13	9.3	9.3	1.1	0.86	180	120	0.062	0.040	0.76	0.67	0.020	0.027	0.042	0.023	1.4	0.61	73	43
Longyang, Baoshan, 2011, (7)	5.0	1.2	5.4	3.3	1.1	1.1	3.0	6.1	4.5	2.6	58	24	0.38	0.28	22	23	7.3	3.5	360	210	0.055	0.041	1.6	1.3	0.061	0.12	0.047	0.033	2.5	1.1	180	87
Yimen, Yuxi, 2012, (7)	2.8	0.45	4.3	10	0.35	0.83	6.6	16	1.7	0.50	68	57	0.23	0.64	17	30	0.81	1.8	95	50	0.017	0.016	0.53	1.1	0.030	0.040	0.050	0.040	0.90	2.7	120	45
Mean	2.8	0.59	5.0	5.5	0.63	0.84	4.5	9.2	2.3	1.2	51	30	0.27	0.35	16	21	3.1	2.1	210	130	0.045	0.032	0.96	1.0	0.037	0.062	0.046	0.032	1.6	1.5	120	58
SD	2.2	0.55	0.6	3.9	0.41	0.26	1.9	5.9	1.9	1.2	21	25	0.09	0.26	6.4	11	3.7	1.3	140	80	0.024	0.014	0.56	0.32	0.021	0.050	0.004	0.009	0.8	1.1	54	25

Boletus spp. from Yunnan [29, 32, 59]. In this work, the highest Cr content was 24 mg kg^{-1} dw in the caps of *Butyriboletus roseoflavus* from Yuanmou county in Yunnan and 16 mg kg^{-1} dw in the stipes of *Boletus umbriniporus* from Yimen county in Yunnan (Table 4). It indicated high geochemical background value of Cr in these locations.

Cesium

Cesium content was 0.81–32 mg kg^{-1} dw in the caps and 0.46–9.5 mg kg^{-1} dw in the stipes (Table 4), which was similar or relatively lower than those (0.24–160 mg kg^{-1} dw in caps and 0.29–38 mg kg^{-1} dw in stipes) in previous studies on *Boletus* spp. [29, 49].

Copper

Copper contents in caps of *Boletaceae* species were higher than those in stipes [62]. Copper content was 6.9–110 mg kg^{-1} dw in caps, stipes, or whole fruiting bodies of *Boletus* spp. from Yunnan or Europe [22, 29, 32, 38, 46, 49, 59]. Our results (18–77 mg kg^{-1} dw in the caps and 8.3–57 mg kg^{-1} dw in the stipes) were in the range of the data reported from literature (Table 4).

Lithium

In Hungary, Li content was nd. to 0.61 mg kg^{-1} dw in 38 common, edible wild grown mushrooms [63]. For *Boletus* spp. in Yunnan, Li content was 0.072–8.7 mg kg^{-1} dw in caps and 0.06–4.1 mg kg^{-1} dw in stipes [23, 29]. In this study, relatively low level of Li was found in the caps (0.18–0.38 mg kg^{-1} dw) and in the stipes (0.13–1.3 mg kg^{-1} dw) (Table 4).

Manganese

Manganese content was 2.0–118 in *Boletus* spp. from Europe and China and the stipes accumulated more Mn than the caps [29, 32, 38, 46, 49, 59, 64, 65]. In this study, Mn content was 8.8–22 mg kg^{-1} dw in the caps and 9.3–38 mg kg^{-1} dw in the stipes (Table 4).

Nickel

Nickel content was 0.10–1.2 mg kg^{-1} dw in *Boletus* spp. from Europe [38, 66]. Elevated Ni content was 0.39–10 mg kg^{-1} dw in caps and 0.28–11 mg kg^{-1} dw in stipes in *Boletus* spp. from Yunnan in previous work [29, 32]. In this study, Ni content was 0.81–7.3 mg kg^{-1} dw in the caps and 0.86–5.2 mg kg^{-1} dw in the stipes (Table 4).

Rubidium

Fungal species from family *Boletaceae* are considered as the Rb accumulators [67]. In this study, Rb content was 95–950 mg kg^{-1} dw in the caps and 50–430 mg kg^{-1} dw in the stipes (Table 4). Similar results (65–850 mg kg^{-1} dw in caps and 50–300 mg kg^{-1} dw in stipes) were obtained from other *Boletus* species in Yunnan [29]. In Europe, Rb content was 24–1000 mg kg^{-1} dw in caps, stipes, or whole fruiting bodies of *Boletus* spp. [38, 49].

Antimony

In general, Sb contents in EcMF from clean areas were mostly below 0.1 mg kg^{-1} dw [49, 68]. In this study, Sb content was 0.017–0.11 mg kg^{-1} dw in the caps and < 0.001–0.11 mg kg^{-1} dw in the stipes (Table 4), which indicated that the sampling sites did not contain high level of Sb. However, in another study, Sb content was 0.34 mg kg^{-1} dw in stipes of *B. luridus* from Mindu county in Yunnan [29].

Strontium

Strontium content was 0.44–1.6 mg kg^{-1} dw in the caps and 0.66–1.7 mg kg^{-1} dw in the stipes (Table 4). Higher Sr contents (0.24–5.3 mg kg^{-1} dw in caps and 0.21–26 mg kg^{-1} dw) in stipes were reported from other *Boletus* species from Yunnan [29]. In Europe, Sr content was 0.050–2.1 mg kg^{-1} dw in caps, stipes, or whole fruiting bodies of *Boletus* spp. [38, 49, 57].

Thallium

Thallium content was 0.0092–0.063 mg kg^{-1} dw in the caps and 0.027–0.30 mg kg^{-1} dw in the stipes (Table 4), which was similar to the study by Falandysz et al. (0.010–0.095 mg kg^{-1} dw in caps and 0.0070–0.27 mg kg^{-1} dw in stipes) [29]. Compared with those data from Yunnan, *B. edulis* from European countries had a wider range of Tl content (nd. − 0.74 mg kg^{-1} dw in caps, stipes, or whole fruiting bodies) [49, 56, 69, 70].

Uranium

EcMF can interact with, and transform certain U species [71], but EcMF from unpolluted areas usually did not accumulate high levels of U [51]. In this study, U content was 0.017–0.052 mg kg^{-1} dw in the caps and 0.023–0.24 mg kg^{-1} dw in the stipes (Table 4). Similar results were reported in previous work (0.014–0.29 mg kg^{-1} dw in caps and 0.011–0.21 mg kg^{-1} dw in stipes of *Boletus* spp.) [29, 49].

Vanadium

Vanadium content was 0.76–2.5 mg kg^{-1} dw in the caps and 0.60–8.7 mg kg^{-1} dw in the stipes of the studied mushroom species (Table 4). Similar results (0.18–4.4 mg kg^{-1} dw in caps and 0.24–10 mg kg^{-1} dw in stipes) were obtained by Falandysz et al. [29]. However, much lower V contents (0.004–0.61 mg kg^{-1} dw) have been reported in *Boletus* spp. from Poland and Czech Republic [49, 70].

Zinc

Zinc in *Boletus* spp. was generally accumulated more in the caps than in stipes [3]. Our results confirmed this (99–290 mg kg^{-1} dw in the caps and 43–120 mg kg^{-1} dw in the stipes) (Table 4). In Yunnan, Zn in *Boletus* spp. was found 14–240 in caps and 33–140 in stipes [29, 65]. For whole fruiting bodies of *Boletus* spp., Zn content was 19–97 mg kg^{-1} dw [32, 45, 59]. Slightly higher Zn contents (76–360 mg kg^{-1} dw in caps, 24–210 mg kg^{-1} dw in the stipes, and 65–350 mg kg^{-1} dw in whole fruiting bodies) have been found in *Boletus* spp. from Europe [38, 46, 49, 64].

Conclusion

Three EcMF species, *H. impolitum*, *Butyriboletus roseoflavus*, and *Boletus umbriniporus*, collected from different sites in Yunnan are relatively rich in numerous mineral constituents. The estimated As intake from consuming the sample of *Butyriboletus roseoflavus* from Yuanmou was above the limit recommended by JECFA, if the As in this sample is dominated by the inorganic As species. However, form under which As was present remains unknown. The estimated Cd intakes from some caps of *Butyriboletus roseoflavus* and *Boletus umbriniporus* were above the Cd limit. The stipes of *H. impolitum* might cause excessive intake of Pb. Relatively high contents of Cr and V in some samples indicated high geochemical background levels of the two elements in the sampling sites. The places in Yunnan with geochemical anomalies resulting in high-level toxic elements in mushrooms from family *Boletaceae* need to be further identified.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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