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Nutritional composition of boletus mushrooms from Southwest China and their antihyperglycemic and antioxidant activities

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ABSTRACT

Thirteen samples representing five species were collected from different provinces of Southwest China, and their chemical composition, antihyperglycemic activity, and antioxidant activity were evaluated. These mushrooms had high crude protein (21.72–30.59 g/100 g dw) and total carbohydrate (49.18–62.58 g/100 g dw) contents, but low crude fat contents (1.96–7.87 g/100 g dw). They also accumulated notable quantities of potassium, zinc, sodium, magnesium and copper from the soil. The potassium content, in particular, was 18.75–39.21 times that found in the soil at the collection site. The natural habitat of these mushrooms, especially the mineral content of the soil, seems to have more influence on the mineral content of these mushrooms than their species. Most of the samples possessed antihyperglycemic and antioxidant activities. *Suillellus luridus* showed the highest antioxidant activity and antihyperglycemic activities, suggesting that *S. luridus* shows potential for development as a dietary nutritional supplement.

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1. Introduction

It has been estimated that there are >20,000 species of ectomycorrhizal mushrooms, among which >1000 species are edible, with some having superb flavors and aromas (Hall & Zambonelli, 2012). These edible mushrooms are both popular delicacies and important nutraceuticals. Recent studies have shown that mushrooms are low in fat and rich in polysaccharides, proteins, and minerals, making them a good food for preventing diabetes and cardiovascular disease (Barros, Cruz, Baptista, Estevinho, & Ferreira, 2008; Lau, Abdullah, & Aminudin, 2013; Ouzouni, Veltsistas, Paleologos, & Riganakos, 2007). Edible mushrooms also possess medicinal properties. The ancient Chinese medical book *Compendium of Materia Medica* records that some mushrooms can enhance immunity and slow aging. Edible mushrooms have also been shown to have antioxidant, antidiabetic, antimicrobial, antitumor, and antiviral properties, as well as immunoregulatory activity (Wang, Fu, & Han, 2013; Xu, Yan, Chen, & Zhang, 2011).

Evaluation of the chemical composition and biological activities of edible mushrooms has recently been an active area of research. Studies of this type enable the discovery of fungal species with high nutritional value and important biological activities. In particular, the mineral content of mushrooms has recently become a universal concern. On the one hand, numerous reports have pointed out that mushrooms are excellent accumulators of minerals, so they can be a good source of minerals for human nutrition. Vetter (2005), for example, demonstrated that *Amanita muscaria* accumulates vanadium. Certain mushrooms are also suitable accumulators of selenium, with concentrations of selenium that are 1000 times higher than those of plants (Dumont, Vanhaecke, & Cornelis, 2006). Many studies have reported that most edible mushrooms contain higher levels of potassium than vegetables or fruits (Liu et al., 2012; Vetter, 2005). Dietary potassium can affect the potassium to sodium (K/Na) ratio, and a high K/Na ratio exerts a positive effect on high blood pressure and cardiovascular disease (Vetter, 2003). On the other hand, they show unique absorption and tolerance to heavy metals, which can be considered a health risk (Hall & Zambonelli, 2012). However, based on numerous reports, the toxic metal (As, Pb, Cd and Hg) content of mushrooms is within an acceptable range in most cases (Lau et al., 2013; Liu et al., 2012, 2015).

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Boletus mushrooms are wild edible mushrooms that are consumed worldwide. They are popular because their flesh is tender and rich in nutrients; for example, chicken stew with boletus mushrooms is popular in China. China's edible mushroom output ranks first in the word. The *Yearbook of China Agricultural Products Processing Industries* (Ministry of Science & Technology of the People's Republic of China, Chinese Academy of Agricultural Mechanization Sciences, & China National Packaging & Food Machinery Corporation, 2007) reported that the output of boletus reached 17,000 tons in 2006. Several species are common in Sichuan and Yunnan Provinces and *Boletus aereus*, *Suillus bovinus*, *Suillellus luridus* (formerly *Boletus luridus*), *Boletus edulis*, and *Boletus violaceofuscus* Chiu are among the most popular in local markets. Although some of these species have been individually studied, comprehensive evaluations of the chemical composition and biological activities of many of these species from Southwest China is still lacking.

In this study, 13 samples of boletus mushroom belonging to *B. aereus*, *S. bovinus*, *S. luridus*, *B. edulis* and *B. violaceofuscus* Chiu were obtained from Yunnan and Sichuan Provinces. There is still a lack of conclusive and comprehensive reports about these mushrooms from Southwest China, perhaps because of geographic and climatic limitations. Therefore, the chemical composition (moisture, ash, crude protein, crude fat, total carbohydrates, amino acids, minerals and heavy metals) and biological activities (antihyperglycemic and antioxidant activities) of these mushrooms were evaluated.

2. Materials and methods

2.1. Sample preparation

Samples of *B. aereus*, *S. bovinus*, *B. luridus*, *B. edulis*, and *B. violaceo-fuscus* Chiu were collected under *Pinus massoniana* and *Picea asperata* in Yunnan and Sichuan Provinces (Southwest China) from August to September 2014 (Table 1). They were collected at the same growth stage (three replicates were taken for each sample) and identified by Prof. Douxi Zhu – a taxonomist from Mianyang Edible Fungi Research Institute in Sichuan. All samples were freeze-dried, powdered finely (40 mesh), and then stored at −80 °C, as previously described, until further analysis (Liu et al., 2012).

Soil samples were simultaneously collected from the habitats where the mushrooms were picked (collection site). Six soil-sampling points were assigned for each mushroom sample and a drill with a 10-cm inner diameter was used to collect soil to a depth of 20 cm. The final sample was a mixture of the soils collected from these six points. Before chemical analysis, the soil samples were freeze-dried, ground, and then sieved to fine powder (40 mesh) (Liu et al., 2015).

2.2. Chemicals and reagents

1,1-Diphenyl-2-picrylhydrazyl (DPPH), 2,6-di-*tert*-butyl-4-methylphenol (BHT), ethylenediaminetetraacetic acid (EDTA), dimethyl sulfoxide, 4-*N*-trophenyl-α-D-glucopyranoside, and amino acid standards were obtained from Sigma–Aldrich (Germany). All other chemicals and solvents were analytical grade and obtained from Sinopharm Chemical Reagent Co. Ltd. (Shanghai, China).

2.3. Chemical composition

2.3.1. Proximate analysis

Proximate analysis of the chemical composition (moisture, ash, crude protein and crude fat) of the mushrooms was conducted in accordance with Association of Official Analytical Chemists (1995) methods. Moisture content was determined by heating the fresh sample at 105 °C overnight until constant weight. Ash content was determined by weighing the residue obtained after incineration at 550 °C for 24 h. Crude protein content (N × 4.38) was determined using the Kjeldahl method. Crude fat content was determined by Soxhlet extraction with petroleum ether as the solvent. Total carbohydrate content was determined using the phenol–sulfuric acid method (Whistler & Wolfrom, 1962). Total energy was calculated using the following equation:

$$\text{Total Energy (kJ)} = 17 \times (\text{g crude protein} + \text{g total carbohydrate}) + 37 \times (\text{g crude fat}).$$

Table 1
Information of samples.

Abbreviation	Species	Information of voucher specimen	Collection site
Bolae.1	*Boletus aereus*	Y. T. Liu. S189. (NL-CFS-SICAU)	Qingchuan, Guangyuan, Sichuan, China
Bolae.2	*Boletus aereus*	D. Chen. Y205. (NL-CFS-SICAU)	Fumin, Kunming, Yunnan, China
Suibo.1	*Suillus bovinus*	Y. T. Liu. S123. (NL-CFS-SICAU)	Qingchuan, Guangyuan, Sichuan, China
Suibo.2	*Suillus bovinus*	D. Chen. Y256. (NL-CFS-SICAU)	Midu, Dali, Yunnan, China
Suilu.1	*Suillellus luridus*	Y. T. Liu. S145. (NL-CFS-SICAU)	Qingchuan, Guangyuan, Sichuan, China
Suilu.2	*Suillellus luridus*	Y. T. Liu. S134. (NL-CFS-SICAU)	Pingwu, Mianyang, Sichuan, China
Suilu.3	*Suillellus luridus*	D. Chen. Y260. (NL-CFS-SICAU)	Simao, Puer, Yunnan, China
Suilu.4	*Suillellus luridus*	D. Chen. Y298. (NL-CFS-SICAU)	Fumin, Kunming, Yunnan, China
Boled.1	*Boletus edulis*	Y. T. Liu. S193. (NL-CFS-SICAU)	Qingchuan, Guangyuan, Sichuan, China
Boled.2	*Boletus edulis*	D. Chen. Y201. (NL-CFS-SICAU)	Nanhua, Chuxiong, Yunnan, China
Boled.3	*Boletus edulis*	Y. T. Liu. S178. (NL-CFS-SICAU)	Pingwu, Mianyang, Sichuan, China
Boled.4	*Boletus edulis*	D. Chen. Y233. (NL-CFS-SICAU)	Luquan, Kunming, Yunnan, China
BolviCh	*Boletus violaceo-fuscus* Chiu	D. Chen. Y286. (NL-CFS-SICAU)	Luquan, Kunming, Yunnan, China

Information of specimen voucher: collector. specimen number. (repository); NL-CFS-SICAU: Nutrition Laboratory, College of Food Science, Sichuan Agricultural University.

2.3.2. Amino acid analysis

Amino acids analyses were performed as described by Liu et al. (2012). The amino acid composition of each sample (aqueous extract) was determined using an Agilent 1100 reverse-phase high-performance liquid chromatography (HPLC) system equipped with a Waters 2478 ultraviolet detector (280 nm and 254 nm) and a Hypersil ODSC18 column (4 mm × 125 mm, Agilent). The column was eluted with a gradient of buffer A (0.8 g of sodium acetate in 500 mL deionized water plus 90 μL of triethylamine and 2.9 mL of tetrahydrofuran, adjusted to pH 7.2 ± 0.05 with acetic acid) and buffer B (0.8 g of sodium acetate in 100 mL deionized water plus 200 mL of acetonitrile and 200 mL of methanol, adjusted to pH 7.2 ± 0.05 with acetic acid) at 40 °C and a flow rate of 1 mL/min. Prior to use, the mobile phases were degassed using membrane filtration (0.45 μm). The gradient began at 100% A,

was ramped to 50% A at 17 min, then to 0% A at 20 min, where it was maintained until 24 min, then ramped back to 100% A at 24.1 min. The quantification of each amino acid in the mushrooms was based on a standard chromatogram derived from standard amino acids. Determinations were carried out in triplicate and the data are presented as the average of these determinations.

2.3.3. Mineral analysis

Mineral analyses were performed as described by Liu et al. (2012). Mushrooms or soil samples (1 g) were placed in a porcelain crucible and ashed in a muffle furnace at 500 °C for 24 h. After cooling, the material was digested in 2 mL of concentrated HNO_3 in a microwave and then diluted with distilled water to 25 mL. This solution was filtered before storage. A blank digest was carried out in the same way. The concentrations of Fe, Zn, K, Na, Ca, Mn, Cu, and Mg were determined via flame atomic absorption spectrometry with a SpectrAA 220Z (Varian, USA) spectrometer. The concentrations of Pb, As, and Cd were determined via graphite furnace atomic absorption spectrometry with SpectrAA 220Z (Varian, USA) spectrometer.

2.4. Preparation of aqueous extract

Aqueous extracts were prepared as described by Wang, Zhang, Zhang, Yao, and Zhang (2010) with minor modifications. Powdered samples (250 g) were decocted with boiling water (2500 mL) for 2 h under agitation. The aqueous extracts were passed through filter paper and then evaporated using a rotary evaporator at 50 °C under reduced pressure. Finally, the extracts were immediately lyophilized. The aqueous extract was re-dissolved in water at a final concentration of 50 mg/mL for subsequent assays.

2.5. Antihyperglycemic activity assays

2.5.1. α-Glucosidase inhibitory activity

The α-glucosidase inhibition activity was assessed as described by Liu et al. (2012). The assay was carried out using an ultraviolet (UV) spectrophotometer (UV-2450, Shimadzu, Japan). α-Glucosidase from *Saccharomyces cerevisiae* was dissolved in 2 mL phosphate buffer (0.1 M, pH 6.8) to a concentration of 0.2 IU/mL and 50 μL of glutathione (1 mg/mL) and 50 μL of 4-*N*-trophenyl-α-D-glucopyranoside (0.1 M) were added. The mixture was incubated at 37 °C for 15 min with and without an aqueous mushroom extract (0.1 mL). The reaction was stopped with 10 mL of 0.1 M sodium carbonate, and the absorbance was measured at 400 nm. Acarbose was used as a positive control, whereas the reaction mixture without the mushroom extract was used as a negative control. The percentage of inhibition was calculated as follows:

$$\%\ \text{inhibition} = \left[(A_{\text{negative}} - A_{\text{sample}})/A_{\text{negative}}\right] \times 100, \quad (1)$$

where A is the absorbance. Inhibitory activity was assessed by plotting the percentage inhibition against a range of extract concentrations (0.01–1 mg/mL). The EC_{50} value represents the concentration of extract producing 50% inhibition.

2.5.2. α-Amylase inhibitory activity

α-Amylase inhibition assayed using a spectrophotometric method. α-Amylase was dissolved to a concentration of 2 IU/mL in 0.5 mL of 20 mM phosphate buffer (pH 6.9) containing various dilutions of extract and incubated at 37 °C for 15 min. Subsequently, 0.5 mL of soluble potato starch solution (1.5%) was added and the mixture was incubated at 37 °C for 5 min. At this point, 1 mL of dinitrosalicylic acid (DNS) solution was added and the mixture was incubated in a water bath at 100 °C for 10 min to detect reducing sugar. The absorbance was measured at 520 nm using a UV-2450 spectrophotometer. Acarbose was used as a positive control. α-Amylase inhibitory activity was assessed by plotting the percent inhibition against a range of extract concentrations. The percentage inhibition and EC_{50} were calculated as described in Section 2.5.1 (Liu et al., 2012).

2.6. Antioxidant activity assays

2.6.1. DPPH radical scavenging activity

The DPPH radical scavenging activities of the mushroom extracts were determined by measuring the reduction of a methanolic solution of DPPH spectrophotometrically. The procedure was performed as described by Blois (1958) with slight modifications. Aqueous mushroom extracts (0.1 mL) at various concentrations were added to 2.9 mL of methanolic DPPH radical solution (6×10^{-5} M). The mixture was shaken vigorously and left to stand for 45 min at 25 °C in the dark, and then the absorbance of the mixture at 517 nm was measured with a spectrophotometer (UV-2450, Shimadzu, Japan) using the negative control as a blank. BHT was used as a positive control, whereas the reaction mixture without mushroom extract was used as a negative control. The percentage inhibition and EC_{50} were calculated following the description in Section 2.5.1. Lower absorbances indicate higher free radical scavenging activity.

2.6.2. Reducing power

The reducing power of the extracts was determined as described by Oyaizu (1986) with modifications. Mushroom extracts (1 mL) at various concentrations were mixed with 1 mL of 200 mM sodium phosphate buffer (pH 6.6) and 2 mL of 1% potassium hexacyanoferrate solution (w/v). The mixtures were incubated in a water bath at 50 °C for 20 min. An equal volume of 10% trichloroacetic acid (w/v) was added immediately after cooling, and the solutions were subsequently centrifuged at 3000*g* for 10 min. The upper layers (2 mL) were mixed with 2 mL of deionized water, and 1 mL of 0.1% ferric chloride ($FeCl_3$) was added to develop the color. The absorbances of these solutions at 700 nm were measured using a UV-2450 spectrophotometer. Absorbance readings positively correlated with reducing power. The effective concentration at which the absorbance is 0.5 ($EC_{0.5}$) was calculated from the graph of absorbance at 700 nm versus extract concentration. BHT and the reaction mixture without mushroom extract were served as positive and negative controls, respectively.

2.6.3. Metal chelating activity

The chelating activity of the extracts was measured using the ferrozine method (Dinis, Madiera, & Almeida, 1994) with minor modifications. Extracts (0.1 mL) at various concentrations, positive control (EDTA), and negative control (reaction mixture without the mushroom extract) were mixed with 0.05 mL of $FeCl_2$ (2 mM). After 5 min, the reactions were initiated by adding 0.1 mL of 5 mM ferrozine, and the total volumes were adjusted to 3 mL with absolute ethyl alcohol. The mixtures were shaken vigorously and then incubated at room temperature for 10 min. The absorbances of the mixtures at 562 nm were determined. The percentage inhibition and EC_{50} were calculated following the description in Section 2.5.1.

2.7. Statistical analysis

All assays were carried out in triplicate, and raw data were analyzed using one-way ANOVA. Tukey's test ($\alpha = 0.05$) was used to estimate the significance of values. Pearson correlation analyses were used to estimate the correlation of parameters ($\alpha = 0.01$). Analyses were carried out using the SPSS 18.0 software.

3. Results and discussion

3.1. Chemical composition

3.1.1. Proximate composition

The proximate compositions of the studied mushrooms, expressed on a dry weight (dw) basis, are presented in Table 2. The contents determined, in descending order, were total carbohydrates (49.18–62.58 g/100 g dw), crude protein (21.72–30.59 g/100 g dw), ash (4.32–9.83 g/100 g dw), and crude fat (1.96–7.87 g/100 g dw).

The moisture content of these mushrooms (80.32–90.93 g/100 g fresh weight [fw]) was similar to that observed in previous studies (86.00–94.00 g/100 g fw) (Lau et al., 2013; Liu et al., 2012; Mattila, Vaananen, Konko, Aro, & Jalava, 2002). The moisture contents of Suibo.2 (80.32 g/100 g fw) and Suibo.1 (81.43 g/100 g fw), both representing *S. bovinus* (average moisture content: 80.88 g/100 g fw), are lower than this range (86.00–94.00 g/100 g fw). This may explain the longer shelf life of fresh *S. bovinus*. However the nutritional content of mushrooms is more directly reflected by the dry matter content than by the moisture content (Mattila et al., 2002). Fresh mushrooms contain 5–15% dry matter according to previous reports (Ouzouni, Petridis, Koller, & Riganakos, 2009), and the dry matter contents of the mushrooms in this study range from 9.07% to 19.68%, which suggests these mushrooms have a high level of nutrition. Total carbohydrate and crude protein are the dominant compounds, whereas the crude fat content is extremely low, suggesting that boletus from Southwest China is a natural source of protein with a low fat content. This is consistent with previous results (Barros et al., 2008; Beluhan & Ranogajec, 2011; Liu et al., 2012). In contrast, Suibo.1 has a relatively lower protein content (23.72 g/100 g dw) and higher fat content (7.87 g/100 g dw) than the other samples in our study, while another *S. bovinus* sample from Yunnan Province exhibited moderate protein and fat contents. The geographic and climactic conditions in Sichuan Province are thought to be responsible for these differences. Moreover, species seems to be the determining factor for the moisture content of mushrooms, but no obvious correlation exists between the moisture content and that of other components (Table 2).

3.1.2. Amino acid composition

The free amino acid compositions of the mushrooms in this study (17 amino acids were detected) are shown in Table 3. Numerous studies have reported that mushrooms are a potential source of essential amino acids (Akindahunsi & Oyetayo, 2006; Díez & Alvarez, 2001). Mdachi, Nkunya, Nyigo, and Urasa (2004) reported that boletus mushrooms contain a greater number of amino acids (15) than other species of edible mushrooms. The numbers of amino acids detected in our samples ranged from 13 (Boled.4) to 17 (Suilu.3), confirming this conclusion. The ratios of the essential to nonessential amino acids range from 0.37 to 0.66. Based on the reference value of 0.6 recommended by the FAO/WHO (Ohtsuka et al., 1973), *S. luridus* (Suilu.1:0.66; Suilu.2:0.65; Suilu.3:0.65; Suilu.4:0.56) is the most nutritive of the species studied here. It has an average ratio of 0.63, which was significantly higher than others (Table 6). Flavor is important for consumer acceptance, and amino acids are reportedly among the main non-volatile compounds responsible for the flavor of mushrooms. Among the amino acids, glutamate is responsible for palatable taste and glycine is responsible for sweet taste (Beluhan & Ranogajec, 2011). In our study, the glutamate and glycine contents appear to be the highest among the 17 detected amino acids, explaining the delicacy of boletus mushrooms. Glutamic and aspartic acids appear in significantly high concentrations in BolviCh, which belongs to *B. violaceo-fuscus* Chiu. The glutamic acid content in samples of *S. luridus* is average 9.49% (Table 6), which is significantly lower than those in the remaining samples. Thus, the lower glutamic acid content of *S. luridus* may distinguish this specie from the other species in this work. Histidine, an essential amino acid for babies, is present at 2.96% in Boled.2, which is significantly higher than that in the other species in this study.

3.1.3. Mineral and heavy metal composition

The concentrations of different elements in the mushrooms studied here are shown in Table 4, which suggest that these mushrooms are good source of minerals in accordance with the recommended dietary allowance (National Research Council & & National Academy of Sciences, 1989).

The order of mineral contents is as follows: K (9863–27944 μg/g) > Mg (574–1583 μg/g) > Ca (384–1482 μg/g) > Na (365–1275 μg/g), these results are consistent with previous reports (Liu et al., 2012). Potassium was the most abundant mineral element in the samples and Na was the fourth. The K/Na ratios of fruit and vegetables are usually >2, whereas the ratios in our samples (Table 4) ranged from 8.4 to 58.0. Ratios this high are considered to be a nutritional advantage because NaCl intake and diets with low K/Na ratios have been related to the incidence of hypertension (Chen, Xia, Zhou, & Qiu, 2010). The K/Na ratios of BolviCh and Boled.4, both of which were collected in Luquan, Kunming,

Table 2
Moisture (g/100 g fw), macronutrients (g/100 g dw) and total energy (kJ/100 g dw).

Sample	Components					
	Moisture	Ash	Crude protein	Crude fat	Total carbohydrate	Total energy
Bolae.1	90.31 ± 3.73de	9.73 ± 1.48i	29.64 ± 0.37e	5.19 ± 0.63e	50.94 ± 4.42b	1561.89 ± 10.58c
Bolae.2	90.22 ± 3.45de	4.32 ± 0.73a	29.64 ± 0.64e	5.37 ± 0.66f	59.84 ± 6.35fg	1719.85 ± 0.42g
Suibo.1	81.43 ± 1.02a	6.07 ± 0.83c	23.72 ± 0.84b	7.87 ± 0.24j	60.45 ± 8.57g	1722.08 ± 5.69g
Suibo.2	80.32 ± 4.57a	9.83 ± 1.02ij	30.19 ± 0.72fg	6.04 ± 0.69g	49.18 ± 7.43a	1572.77 ± 8.85c
Suilu.1	88.17 ± 3.43cd	9.83 ± 1.11ij	28.35 ± 1.02d	6.72 ± 0.31h	54.83 ± 7.35c	1662.70 ± 6.06f
Suilu.2	89.39 ± 1.28de	5.03 ± 0.38b	21.72 ± 0.79a	2.11 ± 0.56c	62.58 ± 5.39h	1511.17 ± 4.53ab
Suilu.3	90.24 ± 1.34de	6.93 ± 0.93d	30.32 ± 1.04g	2.11 ± 0.08bc	55.14 ± 4.72c	1530.89 ± 7.98b
Suilu.4	90.14 ± 1.11de	7.73 ± 0.74f	30.11 ± 0.74efg	1.97 ± 0.12a	54.85 ± 7.62c	1517.21 ± 1.60a
Boled.1	86.35 ± 2.75bc	8.13 ± 0.79g	26.84 ± 1.14c	4.11 ± 0.09d	58.66 ± 6.59de	1605.57 ± 5.6d
Boled.2	88.52 ± 1.74d	6.93 ± 0.53d	30.59 ± 0.63g	2.17 ± 0.13c	58.23 ± 5.54d	1590.23 ± 0.5d
Boled.3	90.34 ± 2.07de	9.73 ± 1.01ij	29.94 ± 0.43ef	6.93 ± 0.21i	50.82 ± 5.93b	1629.33 ± 1.29e
Boled.4	90.93 ± 2.86e	7.19 ± 0.38e	30.17 ± 0.66fg	1.96 ± 0.07a	59.13 ± 3.51ef	1590.62 ± 1.11d
BolviCh	86.35 ± 1.44b	8.71 ± 0.83h	28.66 ± 0.75d	2.07 ± 0.11b	59.11 ± 4.97ef	1568.68 ± 2.20c

Each value is expressed as the mean ± SD (n = 3). Means with different letters within a row are significantly different ($p < 0.05$).

Table 3
Free amino acid composition (percent) of the mushrooms.

Amino acids	Sample												
	Bolae.1	Bolae.2	Suibo.1	Suibo.2	Suilu.1	Suilu.2	Suilu.3	Suilu.4	Boled.1	Boled.2	Boled.3	Boled.4	BolviCh
Val	5.24 ± 0.46c[C]	7.52 ± 0.53f	4.35 ± 0.04a	6.41 ± 0.16e	5.99 ± 0.61d	5.46 ± 0.16c	5.22 ± 0.28c	4.93 ± 0.11b	4.95 ± 0.24b	4.11 ± 0.54a	4.35 ± 0.53a	5.34 ± 0.75c	7.35 ± 0.37f
Thr	2.24 ± 0.5b	4.07 ± 0.06f	3.34 ± 0.67e	4.37 ± 0.58g	4.82 ± 0.53h	4.26 ± 0.26fg	3.24 ± 0.13de	3.24 ± 0.07de	3.11 ± 0.08d	1.47 ± 0.16a	3.18 ± 0.46de	2.95 ± 0.11c	6.24 ± 0.38i
Met	2.03 ± 0.11e	3.82 ± 0.94i	3.04 ± 0.01h	2.74 ± 1.03g	1.09 ± 0.11b	2.24 ± 0.01f	1.42 ± 0.04d	1.35 ± 0.02cd	ND	0.74 ± 0.05a	1.33 ± 0.08cd	ND	1.26 ± 0.07c
Leu	5.14 ± 0.05c	7.89 ± 0.26i	6.03 ± 0.37f	6.59 ± 0.48g	5.83 ± 0.27e	5.65 ± 0.03d	5.21 ± 0.21c	5.24 ± 0.14c	5.15 ± 0.12c	4.39 ± 0.15b	4.07 ± 0.09a	5.95 ± 0.44e	6.94 ± 0.44h
Ile	ND	3.92 ± 0.02d	3.58 ± 0.05c	ND	4.38 ± 0.07e	ND	2.73 ± 0.11b	ND	ND	ND	2.56 ± 0.34a	ND	ND
Phe	ND	ND	ND	3.56 ± 0.04c	ND	5.01 ± 0.13e	5.24 ± 0.25f	4.85 ± 0.05e	4.07 ± 0.16d	2.86 ± 0.34b	2.44 ± 0.86a	4.96 ± 0.44e	2.86 ± 0.13b
Trp	5.63 ± 0.83c	3.96 ± 0.83a	7.09 ± 0.83fg	6.47 ± 0.73d	7.03 ± 0.13fg	6.93 ± 0.83e	7.94 ± 0.24i	7.45 ± 0.27h	6.96 ± 0.53f	6.75 ± 0.84e	4.78 ± 0.83b	6.96 ± 0.22f	ND
Lys	6.79 ± 0.02c	8.42 ± 0.49e	7.11 ± 0.28d	9.09 ± 0.61g	10.97 ± 1.22i	9.79 ± 0.02h	8.45 ± 0.22e	8.92 ± 0.24f	6.24 ± 0.24b	6.84 ± 0.25c	4.98 ± 0.64a	7.03 ± 0.26d	11.05 ± 0.74j
Gly	25.21 ± 0.77gh	12.27 ± 0.14b	18.03 ± 0.04c	8.71 ± 0.13a	18.20 ± 0.42c	20.58 ± 0.77d	21.13 ± 0.15de	22.74 ± 0.14ef	27.73 ± 0.63i	25.45 ± 2.25h	23.32 ± 0.25f	23.64 ± 2.65fg	11.73 ± 0.73b
His	0.54 ± 0.09a	1.49 ± 0.02d	2.73 ± 0.59g	2.07 ± 3.39f	1.02 ± 0.05c	ND	0.94 ± 0.04c	1.42 ± 0.03d	1.66 ± 0.05e	2.96 ± 0.05h	0.72 ± 0.03b	ND	2.63 ± 0.22g
Tyr	ND	ND	2.81 ± 0.11a	3.82 ± 0.04d	2.73 ± 0.07a	3.52 ± 0.18b	3.64 ± 0.03c	3.63 ± 0.25c	4.02 ± 0.04e	ND	ND	3.55 ± 0.07bc	4.73 ± 0.24f
Asp	7.72 ± 0.83d	9.44 ± 0.83h	6.90 ± 0.73b	10.54 ± 0.09i	9.09 ± 0.03g	8.02 ± 0.83e	8.04 ± 0.45e	7.94 ± 0.29de	9.54 ± 0.16h	7.34 ± 0.36c	6.35 ± 0.38a	8.34 ± 0.47f	13.50 ± 0.43j
Ser	5.72 ± 0.24gh	4.67 ± 0.32bc	4.69 ± 0.25c	5.62 ± 0.68fg	5.34 ± 0.26e	5.63 ± 0.14fg	5.04 ± 0.21d	5.45 ± 0.27e	5.84 ± 0.14h	4.35 ± 0.35a	4.46 ± 0.85ab	5.47 ± 0.64ef	6.78 ± 0.65i
Cys	0.14 ± 0.02ab	0.37 ± 0.03f	0.28 ± 0.01de	0.34 ± 0.08ef	0.17 ± 0.04abc	0.21 ± 0.03bcd	0.17 ± 0.01abc	0.25 ± 0.03cde	0.16 ± 0.06ab	0.11 ± 0.01a	0.22 ± 0.04bcd	0.19 ± 0.01abcd	0.10 ± 0.01a
Arg	6.08 ± 0.01gh	5.43 ± 0.13f	6.03 ± 0.83g	4.14 ± 0.12c	3.90 ± 0.07b	4.68 ± 0.11de	3.47 ± 0.22a	4.44 ± 0.07d	ND	7.07 ± 0.14i	4.80 ± 0.25e	ND	6.21 ± 0.84h
Ala	9.62 ± 2.74c	9.17 ± 0.21ab	9.03 ± 2.74a	9.86 ± 0.06d	9.32 ± 1.92b	8.92 ± 2.74a	8.95 ± 0.24a	9.05 ± 0.86a	9.13 ± 1.00ab	11.43 ± 0.56g	10.47 ± 1.09f	11.43 ± 0.95g	10.14 ± 1.11e
Glu	17.90 ± 0.05g	18.08 ± 1.07g	14.96 ± 3.21e	15.67 ± 0.49f	10.57 ± 1.17b	9.10 ± 0.05a	9.17 ± 0.44a	9.10 ± 1.93a	11.44 ± 0.14c	14.13 ± 1.22d	15.24 ± 0.97e	14.19 ± 0.74d	22.43 ± 2.31h
EAA/ NEAA	0.37 ± 0.01a	0.65 ± 0.00hi	0.53 ± 0.00f	0.65 ± 0.00hi	0.66 ± 0.01i	0.65 ± 0.01h	0.65 ± 0.02h	0.56 ± 0.00g	0.44 ± 0.00c	0.37 ± 0.01a	0.42 ± 0.00b	0.50 ± 0.00e	0.46 ± 0.00d

Each value is expressed as the mean ± SD (n = 3). Means with different letters within a row are significantly different ($p < 0.05$). Essential amino acids are presented in boldface. Val, valine; Thr, threonine; Met, methionine; Leu, leucine; Ile, isoleucine; Trp, tryptophan; Phe, phenylalanine; Lys, lysine; Gly, glycine; His, histidine; Tyr, tyrosine; Asp, aspartic acid; Ser, serine; Cys, cysteine; Arg, arginine; Ala, alanine; Glu, glutamate; ND, not detected; EAA/NAA, Essential amino acids/Nonessential amino acids.

Table 4
Concentrations of different elements in mushrooms and soil (μg/g dw).

Elements	Sample												
	Bolae.1	Bolae.2	Suibo.1	Suibo.2	Suilu.1	Suilu.2	Suilu.3	Suilu.4	Boled.1	Boled.2	Boled.3	Boled.4	BolviCh
Mushrooms													
K	18512 ± 3291g	14947 ± 1733d	12434 ± 1479c	9863 ± 1307a	21654 ± 3833i	19167 ± 2064h	14779 ± 2211d	16639 ± 2770f	27944 ± 6503l	23358 ± 4373j	25486 ± 3530k	15744 ± 2294e	10685 ± 1134b
Zn	117 ± 8h	19 ± 2ab	46 ± 5cd	9 ± 1a	93 ± 8g	59 ± 4e	35 ± 2c	21 ± 2b	159 ± 14i	83 ± 6f	88 ± 7fg	76 ± 7f	47 ± 5de
Fe	351 ± 42e	97 ± 12b	286 ± 24d	56 ± 5a	342 ± 33e	227 ± 32c	102 ± 19b	94 ± 11b	524 ± 42f	253 ± 7cd	358 ± 21e	221 ± 15c	88 ± 4ab
Na	503 ± 42cd	389 ± 21ab	479 ± 65bc	402 ± 42ab	529 ± 46de	639 ± 77f	582 ± 35ef	365 ± 32a	482 ± 35cd	836 ± 77g	617 ± 63f	1184 ± 96h	1275 ± 117i
Ca	973 ± 34g	638 ± 53d	763 ± 64e	519 ± 23b	1083 ± 72h	1482 ± 0.35i	977 ± 87g	731 ± 55e	634 ± 83d	582 ± 53c	863 ± 76f	384 ± 39a	593 ± 43c
Mg	1269 ± 113h	773 ± 352d	963 ± 45f	897 ± 76e	1583 ± 207i	973 ± 93f	959 ± 105f	748 ± 44cd	1083 ± 99g	673 ± 91b	708 ± 64bc	574 ± 65a	619 ± 57a
Mn	24 ± 3ab	63 ± 6g	29 ± 4bc	35 ± 5cd	22 ± 5a	49 ± 6f	47 ± 6ef	69 ± 5g	42 ± 7de	28 ± 2bc	69 ± 6g	33 ± 5c	28 ± 4bc
Cu	44 ± 3de	29 ± 2b	51 ± 8f	48 ± 5ef	58 ± 4g	53 ± 5fg	37 ± 6cd	32 ± 3bc	57 ± 7g	73 ± 8h	49 ± 5ef	19 ± 4a	33 ± 3bc
Pb	2.1 ± 0.5e	ND[B]	0.7 ± 0.1b	ND	2.3 ± 0.6e	1.7 ± 0.4d	0.9 ± 0.1b	0.3 ± 0.0a	2.5 ± 0.4e	1.3 ± 0.4c	1.9 ± 0.4e	5.5 ± 0.7g	4.7 ± 0.5f
Cd	1.1 ± 0.3b	0.7 ± 0.1a	1.1 ± 0.2b	ND	1.2 ± 0.1b	2.6 ± 0.6d	ND	0.8 ± 0.1a	1.7 ± 0.3c	ND	1.6 ± 0.3c	2.8 ± 0.4d	3.4 ± 0.9e
As	1.6 ± 0.3cd	ND	0.8 ± 0.3b	0.4 ± 0.1a	1.4 ± 0.2c	1.7 ± 0.2de	1.1 ± 0.2b	ND	1.9 ± 0.3e	2.8 ± 0.7f	1.8 ± 0.2de	1.8 ± 0.3de	1.7 ± 0.5de
K/Na	36.8 ± 0.2e	38.4 ± 1.2e	26.0 ± 3.6cd	24.5 ± 0.3c	40.9 ± 0.9e	30.0 ± 0.9d	25.4 ± 0.6c	45.6 ± 2.4f	58.0 ± 0.2g	27.9 ± 1.1cd	41.3 ± 1.5e	13.3 ± 0.1b	8.4 ± 0.2a
Soil													
K	611 ± 36e	531 ± 45d	663 ± 37h	467 ± 53c	748 ± 86i	635 ± 44f	548 ± 65d	543 ± 49d	735 ± 93i	646 ± 73fg	650 ± 73gh	411 ± 79b	348 ± 38a
Zn	41 ± 4fg	12 ± 2ab	37 ± 6f	7 ± 2a	43 ± 6g	27 ± 3de	15 ± 1b	12 ± 2ab	44 ± 5g	24 ± 5cd	29 ± 3e	24 ± 4cd	21 ± 2c
Fe	616 ± 57h	217 ± 39c	587 ± 63g	277 ± 41e	563 ± 49g	404 ± 71f	236 ± 33d	193 ± 27b	603 ± 55h	219 ± 27c	416 ± 51f	179 ± 17ab	170 ± 28a
Na	277 ± 32c	231 ± 37b	236 ± 27b	194 ± 14a	265 ± 22c	307 ± 41d	393 ± 39e	221 ± 19b	259 ± 22c	572 ± 64f	314 ± 40d	784 ± 54h	734 ± 73g
Ca	834 ± 97de	583 ± 69c	793 ± 92d	502 ± 44b	863 ± 83e	1223 ± 98g	863 ± 75e	563 ± 45c	837 ± 77de	835 ± 67de	1193 ± 106f	440 ± 33ab	439 ± 51a
Mg	353 ± 44gh	174 ± 23a	337 ± 27fg	317 ± 37f	362 ± 35h	221 ± 37c	283 ± 17e	168 ± 19a	349 ± 57g	253 ± 48d	203 ± 20bc	196 ± 17b	166 ± 31a
Mn	163 ± 27b	339 ± 26f	170 ± 16b	194 ± 14c	169 ± 25b	249 ± 26d	277 ± 33e	321 ± 43f	172 ± 13b	133 ± 15a	268 ± 25e	159 ± 21b	154 ± 10b
Cu	12 ± 2bc	8 ± 2a	14 ± 4d	15 ± 3de	14 ± 2cd	10 ± 1ab	9 ± 2a	9 ± 1a	16 ± 4e	21 ± 3f	10 ± 1ab	8 ± 1a	11 ± 2b
Pb	1.4 ± 0.3d	ND	0.6 ± 0.1c	ND	1.2 ± 0.3d	0.5 ± 0.0bc	0.2 ± 0.0a	ND	1.4 ± 0.2d	0.5 ± 0.1bc	0.3 ± 0.0ab	2.5 ± 0.6f	2.1 ± 0.4e
Cd	ND	ND	ND	ND	ND	0.4 ± 0.0b	ND	ND	ND	ND	0.1 ± 0.0a	1.4 ± 0.3d	1.2 ± 0.2c
As	0.7 ± 0.2b	ND	0.5 ± 0.1a	0.3 ± 0.0a	0.7 ± 0.1b	1.1 ± 0.3c	0.7 ± 0.1b	ND	0.8 ± 0.2b	1.4 ± 0.3d	0.8 ± 0.2b	0.7 ± 0.1b	0.8 ± 0.2b

Each value is expressed as the mean ± SD (n = 3). Means with different letters within each row are significantly different ($p < 0.05$). ND, not detected. Detection limit, 0.02 μg/g.

Yunnan, China are significantly lower than those of the others, indicating a considerable habitat effect among the samples.

The order of heavy metal contents is as follows: Fe (56–524 μμg/g) > Zn (9–159 μg/g) > Cu (19–73 μg/g) > Mn (22–69 μg/g) > Pb (ND–5.5 μg/g) > Cd (ND–3.4 μg/g) > As (ND–2.8 μg/g), which are consistent with previous reports (Liu et al., 2012). Ze, Fe, Mn, and Cu are essential elements in the human body because they are components of key enzyme complexes,. For an average adult (70 kg body weight), the recommended daily intake for Zn, Fe, Mn, and Cu, set by the U.S. Food and Drug Administration (1995) are 15, 18, 2 and 2 mg/day respectively. Since the converted mean contents of these four heavy metals were 6.55, 23.07, 4.14 and 4.49 mg/kg fw (90% moisture content), respectively, our samples represent a potentially useful source of Fe, Mn, and Cu. As accumulators of Zn, Fe, Mn, and Cu (Liu, Zhang, Li, Shi, & Wang, 2012), mushrooms contain higher amounts of these elements than most plants. The concentrations of Zn, Fe, Mn, and Cu in our samples are at levels that typically carry no known health risks (Liu, Zhang, et al., 2012; Liu et al., 2012). Pb, Cd, and As, which are the principal toxic metals in food, produce progressive toxicity with infinitesimal tolerable weekly intakes (Pb, 0.025 μg/g bw; Cd, 0.007 μg/g bw; As, 0.015 μg/g bw) (CODEX STAN 193-1995, 2010). The highest concentrations of Pb, Cd and As were 5.5 μg/g dw (Boled.4), 3.4 μg/g dw (BolviCh), and 2.8 μg/g dw (Boled.2). As estimated above (70 kg body weight for an average adult, 90% moisture content for the mushroom sample), the weekly intakes of the corresponding mushrooms must reach 3.18, 1.44, and 3.75 kg, respectively, before they may pose a health hazard. Furthermore, the Chinese national standard, GB 2762-2012 (2012), has provided standard limits for Pb (10 μg/g dw), Cd (2 μg/g dw), and As (5 μg/g dw). The concentrations of these three metals in our mushrooms are notably at safe levels, excluding that of Cd, which exceeded the corresponding standard in three samples (Suilu.2, 2.6 μg/g dw; Boled.4, 2.8 μg/g dw; and BolviCh, 3.4 μg/g dw). This result indicates that the risk associated with Cd in boletus from Southwest China requires monitoring. Our findings are consistent with those of other publications, which demonstrated that Cd is the most deleterious among the toxic metals present in mushrooms from Yunnan, China (Yin et al., 2012) and that the serum level of cadmium increases considerably after mushroom consumption (Kalač & Svoboda, 2001).

The concentrations of these 11 elements in the soil surrounding the samples were also determined (Table 4). K and Ca are the dominant minerals in soil samples, whereas Pb, Cd, and As are still the lowest three, which is in accordance with the corresponding composition of the mushroom samples. Concentrations of different elements in mushrooms are all higher than those of soil samples, excluding Fe, Ca, and Mn. Therefore, we can speculate that these investigated mushroom species can accumulate at least eight elements, including K, Zn, Na, Mn, Cu, Pb, Cd, and As. The ability of edible mushrooms to accumulate mineral elements and toxic metals has been previously studied. Isiloglu, Yilmaz, and Merdivan (2001) pointed out that wild edible mushrooms accumulate Zn, and Cd is readily accumulated by edible mushrooms (Ouzouni et al., 2007; Schmitt & Meisch, 1985). *Agaricus* species (Vetter, 2005) and eight mushroom species from Yunnan Province (Liu et al., 2015) readily accumulate both Cd and As. *B. edulis* reportedly accumulates Se (Liu, Zhang, et al., 2012). Based on the ratios of element contents of mushrooms and soil, these boletus mushrooms exhibited the highest accumulation of K, with accumulation ratios ranging from 18.75 to 39.21 (average, 30.57), while the accumulation ratios of Zn, Na, Mg, and Cu were in the range of 1.24–5.30. Most of the ratios of Pb, Cd, and As could not be calculated because their contents in the soil samples were undetectable. The ability of these mushrooms to accumulate toxic metals warrants further research because it can introduces a health risk for boletus con-

Table 5
Antihyperglycemic and antioxidant activity assays.

Index	Sample													
	Bolae.1	Bolae.2	Suibo.1	Suibo.2	Suilu.1	Suilu.2	Suilu.3	Suilu.4	Boled.1	Boled.2	Boled.3	Boled.4	BolviCh	Positive control
α-GI	56.3 ± 10.7b	97.6 ± 18.7d	189.7 ± 12.6h	44.7 ± 5.2b	72.3 ± 6.7c	53.5 ± 6.4b	154.3 ± 10.2f	24.5 ± 6.1a	78.8 ± 7.7c	55.2 ± 5.9b	128.2 ± 8.5e	268.1 ± 24.0i	174.0 ± 13.4g	27.6 ± 3.4a
α-AI	149.4 ± 17.5d	171.3 ± 14.7e	74.7 ± 7.9bc	78.0 ± 6.9bc	407.3 ± 39.6g	193.4 ± 19.8e	361.3 ± 49.0f	54.3 ± 9.2ab	619.4 ± 33.7i	89.6 ± 11.4c	186.9 ± 30.9e	452.4 ± 72.5h	377.4 ± 64.0f	44.8 ± 7.5a
DPPH	1830.2 ± 204.5l	594.5 ± 74.6i	973.2 ± 55.4j	1473.9 ± 114.5k	146.8 ± 14.2d	73.8 ± 8.4ab	294.9 ± 47.8f	105.7 ± 8.5bc	225.8 ± 17.5e	96.3 ± 6.3abc	479.8 ± 59.6h	119.5 ± 5.7c	339.5 ± 74.4g	63.6 ± 5.5a
RP	723.3 ± 97.5i	274.5 ± 32.7d	1174.4 ± 184.5j	619.7 ± 76.4h	155.8 ± 23.3b	174.6 ± 14.7bc	422.7 ± 76.8f	255.5 ± 42.4d	2811.4 ± 532.6k	754.3 ± 103.2i	209.2 ± 17.4c	553.3 ± 39.8g	362.3 ± 24.3e	114.9 ± 4.5a
FI	1865.7 ± 836.8l	412.7 ± 36.3bc	883.8 ± 88.3i	492.3 ± 59.8de	383.7 ± 48.3b	452.4 ± 62.4cd	1649.7 ± 248.4k	1083.4 ± 103.4j	759.3 ± 118.4h	569.3 ± 73.2fg	519.4 ± 34.3ef	513.5 ± 53.3ef	612.4 ± 71.9g	254.5 ± 10.5a

Each value is expressed as the mean ± SD (n = 3). Means with different letters within a row are significantly different ($p < 0.05$). α-GI, α-glucosidase inhibitory activity (μg/mL); α-AI, α-amylase inhibitory activity (μg/mL); DPPH, effective concentration at which 50% of DPPH radicals are scavenged (μg/mL); RP, reducing power, effective concentration at which the absorbance is 0.5 (μg/mL); FI, effective concentration at which 50% of ferrous ions are chelated (μg/mL). Positive controls were: α-GI and α-AI, acarbose; DPPH and RP, BHT; FI, EDTA.

Table 6
The arithmetical means of all analyzed parameters for different mushroom species.

Parameters	Species					Parameters	Species				
	B. aereus	*S. bovinus*	*S. luridus*	*B. edulis*	*B. violaceo-fuscus* Chiu		*B. aereus*	*S. bovinus*	*S. luridus*	*B. edulis*	*B. violaceo-fuscus* Chiu
Moisture	90.27c	80.88a	89.49c	89.04c	86.35b	Fe	224.0d	171.0b	191.3c	339.0e	88.0a
Ash	7.03a	7.95c	7.38b	8.00c	8.71d	Na	446.0a	440.5a	528.8b	779.8c	1275.0d
Crude protein	29.64e	26.96a	27.63b	29.39d	28.66c	Ca	805.5c	641.0b	1068.3d	615.8a	593.0a
Crude fat	5.28d	6.96e	3.23b	3.79c	2.07a	Mg	1021.0d	930.0c	1065.8e	759.5b	619.0a
Total carbohydrate	55.39b	54.82a	56.85c	56.71c	59.11d	Mn	43.5bc	32.0a	46.8c	43.0b	28.0a
Total energy	1640.87d	1647.43d	1555.49a	1603.94c	1568.68b	Cu	36.5b	49.5d	45.0c	49.5d	33.0a
Val	6.38c	5.38b	5.40b	4.69a	7.35d	Pb	1.1b	0.4a	1.3c	2.8d	4.7e
Thr	3.16b	3.86c	3.89c	2.68a	6.24d	Cd	0.9b	0.6a	1.2c	1.5d	3.4e
Met	2.93e	2.89d	1.53c	0.52a	1.26b	As	0.8ab	0.6a	1.1b	2.1c	1.7d
Leu	6.52d	6.31c	5.48b	4.89a	6.94e	K/Na	37.5d	25.3b	34.2cd	29.7c	8.4a
Ile	1.96d	1.79c	1.78c	0.64b	0.00a	*K*	571.0b	565.0b	618.5c	610.5c	348.0a
Phe	0.00a	1.78b	3.78e	3.58d	2.86c	*Zn*	26.5c	22.0ab	24.3bc	30.3d	21.0a
Trp	4.80b	6.78d	7.34e	6.36c	0.00a	*Fe*	416.5c	432.0c	349.0b	354.3b	170.0a
Lys	7.61b	8.10c	9.52d	6.27a	11.00e	*Na*	254.0a	215.0a	296.5b	482.3c	734.0d
Gly	18.70c	13.36b	20.63d	25.00e	11.7a	*Ca*	708.5c	647.5b	878.0e	826.3d	439.0a
His	1.02b	2.40d	0.85a	1.34c	2.63e	*Mg*	263.5b	327.0c	258.5b	250.3b	166.0a
Tyr	0.00a	3.32c	3.38d	1.89b	4.73e	*Mn*	251.0c	182.0b	254.0c	183.0b	154.0a
Asp	8.58c	8.70c	8.27b	7.89a	13.5d	*Cu*	10.0a	14.5b	10.5a	13.8b	11.0a
Ser	5.20b	5.16ab	5.37c	5.03a	6.78d	*Pb*	0.7b	0.3a	0.5a	1.2c	2.1d
Cys	0.26cd	0.31d	0.20bc	0.17ab	0.10a	*Cd*	0.0a	0.0a	0.1b	0.4c	1.2d
Arg	5.76d	5.09c	4.12b	2.97a	6.21e	*As*	0.4a	0.4a	0.6b	0.9c	0.8c
Ala	9.40b	9.45b	9.06a	10.62d	10.14c	α-GI	77.0a	117.2b	76.2a	132.6c	174.0d
Glu	17.99d	15.32c	9.49a	13.75b	22.43e	α-AI	160.4b	76.4a	254.1c	337.1d	377.4e
EAA/NEAA	0.51c	0.59d	0.63e	0.43a	0.46b	DPPH	1212.4d	1223.6d	155.3a	230.4b	339.5c
K	16729.5c	11148.5b	18059.8d	23133.0e	10685.0a	RP	498.9c	897.1d	252.2a	1082.1e	362.3b
Zn	68.0c	27.5a	52.0b	101.5d	47.0b	FI	1139.2d	688.1b	892.3c	590.4a	612.4a

Each value is expressed as the mean ± SD (n = 3). Means with different letters within a row are significantly different ($p < 0.05$). Moisture, g/100 g fw; Macronutrients, g/100 g dw; Total energy, kJ/100 g dw; Amino acids, percent; Concentrations of different elements in mushrooms, μg/g dw; Concentrations of different elements in soil (in italics), μg/g dw; Parameters of biochemistry analysis, μg/mL. Not detected was treated as 0 in calculations.

sumption. Furthermore, these data can provide a reference for the design of appropriate artificial media for the cultivation of edible boletus mushrooms.

The impact of the element content of soil on that of mushroom is influenced by many factors. Factors such as soil substrate, mushroom species, elemental properties, and the ability of the mushrooms to accumulate each metal have been investigated previously (Liu et al., 2015; Vetter, 2005; Yin et al., 2012). Based on the results of Pearson correlation analysis, the Pearson correlations between the concentrations of different elements in mushrooms and concentrations of different elements in soil is +0.434 ($p < 0.01$), suggesting a positive correlation between them; However, there seems to be no particularly significant correlation between the contents of Cu in mushrooms and that in the soil ($p = 0.01$). In addition, *B. edulis* was revealed to be the only one species that cannot accumulate Ca (Table 6).

3.2. Antihyperglycemic and antioxidant activity

The EC_{50} values of aqueous extracts obtained from the 13 mushroom samples in the antihyperglycemic and antioxidant activity assays are shown in Table 5; higher EC_{50} values indicate lower activity. The positive control for α-glucosidase and α-amylase inhibitory activity was acarbose, BHT was the positive control for the DPPH radical scavenging and reducing power assays, and EDTA was the positive control for the metal chelating activity. Most of the samples displayed antihyperglycemic and antioxidant activities, and some of them were even comparable with their corresponding positive controls. Similar results have been reported by Wong and Chye (2009). For example, Suilu.4 exhibited strong antihyperglycemic activity, as it possessed the lowest EC_{50} values for both α-glucosidase inhibitory activity (24.5 μg/mL) and α-amylase inhibitory activity (54.3 μg/mL). These EC_{50} values were not significantly different from those of the appropriate positive controls ($p > 0.05$), and they were significantly lower than those of the other samples. Both Suilu.1 and Suilu.2 exhibited great antioxidant activity, Suilu.1 possessed the highest reducing power and metal chelating activity (155.8 and 383.7 μg/mL, $p < 0.05$), and Suilu.2 possessed the highest DPPH radical scavenging activity (73.8 μg/mL, $p > 0.05$), although each of these activities were slightly lower than those of the positive controls. Furthermore, Suilu.4, Suilu.1 and Suilu.2 were all examples of *S. luridus*, and we can see its superiority of antidiabetic activity in Table 6. Therefore, *S. luridus* seems to have potential as a nutritional supplement for diabetes. It is possible that the chemical composition of mushrooms exerts a significant effect on their biological activities. In this study, several mushroom samples (Bolae.1, Suilu.1, and Suilu.2) with high essential to non-essential amino acid ratios exhibited high antioxidant activity, suggesting a correlation between amino acid content and antioxidant activity. Similar results were found in other studies; phenolics and flavonoids contribute to the antioxidant activity of mushrooms (Al-Laith, 2010; Barros et al., 2008; Chen et al., 2010; Yaltirak, Aslim, Ozturk, & Alli, 2009).

4. Conclusions

The results of this study demonstrate that boletus mushrooms from Southwest China are nutritive and can be suggested as a potential source of protein with low fat. Habitat, especially the mineral content of the soil, affected the mineral content of mushrooms significantly. Samples in our study accumulated eight elements, including K, Zn, Na, Mg, Cu, and three toxic metals (Pb, Cd, As) from the soil. While almost all of the metals were present at desirable levels, the cadmium content may pose a risk. The antihyperglycemic and antioxidant activities of these mushrooms vary

with species and location. Those of *Suillellus luridus* are remarkably superior among the 13 samples, making it appropriate for use as a natural antioxidant and antihyperglycemic. Therefore, *S. luridus* can be developed as a functional food for diabetes and cardiovascular disease.

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