Trace Metal Determination in the Medicinal Plant *Hyoscyamus* (Solanaceae) by Inductively Coupled Plasma Optical Emission Spectrometry

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INTRODUCTION

The term “herbal medicine” is defined as a plant-derived material or preparation with therapeutic or other human health benefits, which contains either raw or processed ingredients from one or more plants. Included are also medical and aromatic compounds that have become of special interest as a complementary choice to conventional medicine due to their efficiency in the treatment of diseases such as gastric ulcers, asthma, and Parkinson’s disease (1,2). The majority of herbal drugs are extracted, purified, and characterized from plants. Thus, it could easily be concluded that herbal plants are a successful strategy as an alternative to synthetic chemical procedures. Additionally, it could eliminate the use of toxic chemicals, lowering the production cost and sustainability. Plants and their different extracts can be consumed either as a liquid or solid. In 2005, the World Health Organization (WHO) highlighted the increasing use of herbal medicinal plants as complementary and an alternative to medicine (CAM) in many developed and developing countries (3). Many countries such as Europe and North America approved the use of some herbal plants and their extracts as a product containing vitamins, minerals, amino acids, herbs, or other

ABSTRACT

The concentrations of Cd, Ni, Cu, Pb, Cr, Fe, B, and Al were determined in four different medicinal plants of the *Hyoscyamus* species: *Hyoscyamus reticulatus* L., *Hyoscyamus leptocalyx* STAPF, *Hyoscyamus aureus* L., and *Hyoscyamus albus* L. by ICP-OES. By considering the sensitivity of ICP-OES with respect to the trace level determination of Cd, Ni, Cu, Pb, Cr, Fe, B, and Al in the studied plant samples and the limitations of sample amount possible in a microwave digestion procedure, the ashing method was applied before analysis and proved the quantitative measurements of the elements.

The accuracy of the method was verified by comparison to the certified reference sample NCSZC 73014 Tea Leaves. The RSD values were between 0.14–10.4%, while the error values were in the 90–107% range. The results show that with the proposed method higher concentrations of Ni, Cr, Pb, Fe, and B were determined in *H. aureus*. Interestingly, the concentration of Cu in *H. reticulatus* was approximately 48.5 times higher than the mean Cu values of the other three *Hyoscyamus* species, while the Pb concentration levels in *H. aureus* were 17.8 times higher than in the *H. reticulatus* L., *H. leptocalyx* STAPF, and *H. albus* L. species.

botanical concentrates according to regulatory agencies such as FAO (Food and Agriculture Organization) / WHO (4-6).

The *Hyoscyamus* species are known as rich sources of pharma-

ceutically valuable tropane alkaloids, which have the 8-azabicyclo [3.2.1] octane structure in common due to structure activity relationship (7-9). It has been reported that the *Hyoscyamus* species of Anatolia have a high alkaloid content which could cause poisoning in children due to improper use (10). The incidence of plant poisoning in Turkey is about 6% (10). Among these are tropane alkaloids such as Hyoscyamine (also known as daturine), scopolamine, and atropine which can cause pharmacological and toxic effects such as reduced muscle spasms in the digestive or urinary tract, and reduced fluid secretions from certain glands or organs (11). Tropane alkaloids are known to be competitive antagonistic chemicals of the muscarinic acetylcholine receptor and are classified as anticholinergic agents (8,12). However, they can be used in the treatment of motion sickness and as an analgesic before an operation (13). Psychoactive properties using *Hyoscyamus niger* include hallucinations and a sensation of flight (14). The effects of these alkaloids contribute to stimulation and depression of the central nervous system (15). Antioxidative, anti-inflammatory, antipyretic, antihyperuricemic, and xanthine oxidase inhibitory effects of the *Hyoscyamus* species have also been reported (16-19). In addition to tropane alkaloids, seven non-tropane alkaloids (Calystegin A3, Calystegin B1, Calystegin B2, deoxynojirimycin, Australine, Swainsonine, Castanospermine) known as calystegins were also determined in the *Hyoscyamus* species (20).

Herbal plants are known to have in general been originated in

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ancient times in Africa, the Asian subcontinent, and in North, Central, and South America (21). In 1996, FAO reported that Turkey has a rich diversity of plants which include 163 families, 1,225 genera, and 9,000 species (22,23). According to recent studies, Turkey has approximately 12,000 plant taxa, of which nearly 3000 are endemic (24). The majority of studies focus on the use of endemic species as medicinal plants. However, the quality of medicinal plants depends on their chemical constituents. Sustainability of medicinal plant production is dependent on the quality of the product. Heavy metals, especially toxic ones, limit the use of medicinal plants. It is known that heavy metals accumulate in plants through their root system and show their distribution in the root, leaf, and fruit. Thus, herbal plants could also be employed as biomonitors. According to our literature survey, reports on endemic *Hyoscyamus* species in the southeastern region of Anatolia, Turkey, are limited. In this study, we investigated four endemic *Hyoscyamus* species (*Hyoscyamus reticulatus* L., *Hyoscyamus leptocalyx* STAPF, *Hyoscyamus aureus* L., and *Hyoscyamus albus* L.) which were collected from local sources and their Cd, Ni, Cu, Pb, Cr, Fe, B, and Al concentrations determined by inductively coupled plasma optical emission spectrometry (ICP-OES). The elements were selected due to their bioavailability in the studied plants and due to toxicity of some. By considering the possible antimicrobial, antifungal, etc., effects of the volatile oils contained in these plants, the metal concentrations in the hexane and methanole fractions were also determined.

EXPERIMENTAL

Instrumentation

Concentrations of Cd, Ni, Cu, Pb, Cr, Fe, B, and Al were determined

by using a PerkinElmer® Optima™ 2100 DV ICP-OES (PerkinElmer, Inc., Shelton, CT, USA). The wavelengths of the elements and the instrumental operating conditions (25,26) are listed in Table I.

Standard Solutions and Reagents

The stock solutions of Cd, Ni, Cu, Pb, Cr, Fe, B, and Al were prepared from their individual standard solutions at 1000 µg mL⁻¹ (High Purity Standards, Charleston, SC, USA). Required dilutions were performed for lower concentrations. During the study, all chemicals used were of high purity reagent grade unless otherwise stated. Doubly distilled water was used for all experimental studies using a Milli-Q® purification system (Millipore Corporation, USA). All glass materials were cleaned with 1.0 mol L⁻¹ of HNO₃ and kept permanently full of

1.0 mol L⁻¹ of nitric acid when not in use. HNO₃ (65%), H₂O₂ (35%), and HCl (36.5–38.0%) were obtained from Sigma Aldrich, Germany.

Certified reference material (CRM) NCS ZC 73014 Tea Leaves was obtained from the China National Analysis Center for Iron and Steel (Beijing, P.R. China) and used to check the accuracy of the results.

Collection of Plant Samples

Hyoscyamus species were collected at the flowering stage from different locations in the vicinity of Mardin in 2012 by Dr. Cumali Keskin (co-author). Voucher specimens were deposited at the Dicle University Herbarium, Department of Biology, Faculty of Science, Diyarbakır, Turkey. Taxonomic identification of the plant materials

TABLE I
Instrumental Operating Conditions for ICP-OES

Parameters	
RF power	1450 W
Plasma gas flow rate	15 L/min
Auxiliary gas flow rate	0.2 L/min
Nebulizer gas flow rate	0.8 L/min
Sample flow rate	1.5 L/min
View mode	Axial-Radial
Read	Peak area
Source equilibration time	15 s
Read delay	60 s
Replicates	3
Background correction	2-point (manual point correction)
Spray chamber	Scott-type spray chamber
Nebulizer	Cross-Flow GemTip™ Nebulizer (HF resistant)
Detector	CCD (charge-coupled device)
Purge gas	Nitrogen
Shear gas	Air
Gas	Argon
Analytical wavelengths	Cd 228.804 nm, Ni 231.604 nm, Cu 327.393 nm, Cr 267.716 nm, Pb 220.353 nm, Fe 238.204 nm, B 249.772 nm, Al 396.153 nm

was confirmed by Dr. A. Selçuk Ertekin from the same institution. For experimental studies, the materials were individually stored in polyethylene bags, and brought to the laboratory for preparation and treatment.

Preparation and Digestion of Plant Species

The plants were first washed under freshly running tap water, followed with distilled water to avoid possible heavy metal contamination from tap water and to eliminate any foreign substances such as soil, bugs, and thoroughly rinsed again with deionized water. Then the samples were cleaned twice with distilled water, finally dried at room temperature for 48 hours, and stored in polyethylene containers.

It is well known that digestion with strong acids and their mixtures does not give quantitative results for heavy metals. On the other hand, sample amount is a disadvantage with a microwave method. Above 0.25 g of sample, excess gas pressure in Teflon® vessels causes problems. However, considering the low level concentrations of heavy metals present in the studied plants, sample amount is a limitation in the microwave method. By considering the sensitivity of ICP-OES and the above-mentioned limitations, the ashing method was selected for digestion of the plants.

Before digestion, the samples were dried again in an oven at 75 °C for 48 hours and then ground in a porcelain mortar to obtain a fine powder. Approximately, 3.0 g of the powdered samples was placed into porcelain crucibles and left standing in an ash oven for one day at 100 °C. The samples were then ashed at 525 °C for 5 hours, 3.0 mL of concentrated nitric acid was added, and the mixture heated on a heater for 2 hours at 525 °C until

dryness was achieved. Finally, 3.0 mL of HNO₃ and HCl (3:1, v/v) was added to the crucibles and heated to dryness. Then, 10.0 mL of 1.0 M of HNO₃ was added to the samples, transferred to the PTFE tubes, and analyzed by ICP-OES.

Certified reference material NCS ZC 73014 Tea Leaves was also digested using same procedure as described above to check the accuracy of the method.

RESULTS AND DISCUSSION

Analytical Characteristics

Stock standard solutions of Cd, Ni, Cu, Pb, Cr, Fe, B, and Al were diluted with 1.0 mol L⁻¹ of nitric acid to the desired concentration values. The intensities of the diluted metal solutions at the concentration range of 50–2000 ng mL⁻¹ were measured by ICP-OES. Linear calibration equations were obtained by plotting the concentration values versus the related intensities for each of the elements. The analytical characteristics of the ICP-OES method listed in Table II were evaluated by considering the linear range, slope, intercept, and correlation coefficient of the linear plot, limit of detection (LOD), limit of quantification (LOQ), and relative standard deviation (RSD). Three times the standard deviation of the

slope ratio was employed to calculate the LOD, while 10 times the ratio was accepted as the LOQ. The %RSD was calculated from the ratio of the standard deviation to the mean signal.

The accuracy of the ICP-OES method was verified by analyzing certified reference material NCSZC 73014 Tea Leaves and Table III lists the certified and found values which compared well with each other. However, the certified value for Al is not included because it is not provided for this CRM.

The detailed statistical approaches were considered and show the applicability of the ashing method before ICP-OES measurement of the elements. The standard deviation (SD), relative standard deviation (RSD), and the error percentages are also listed in Table III. By considering the SD and RSD values, it can be said that the method has high precision levels. The RSD values were found lower than 5% for Ni, Cu, Pb, Cr, B, and Al, and 10.4% for Fe and Cd. The accuracy of the method as well as all other important analytical parameters were also considered by evaluating the error percentages which were in the 90–107% range. Thus, these high precision and accuracy values show the applicability of this method for the analysis of real plant samples.

Distribution of Cd, Ni, Cu, Pb, Cr, Fe, B, and Al in the *Hyoscyamus* (Solanaceae) Species of Herbal Plants

The ashing method was applied to the analysis of the *Hyoscyamus* species and was validated through the analysis of the certified reference material NCS ZC 73014 Tea Leaves for the determination of Cd, Ni, Cu, Pb, Cr, Fe, B, and Al. For this purpose, four different *Hyoscyamus* species (*Hyoscyamus reticulatus* L., *Hyoscyamus leptocalyx* STAPF, *Hyoscyamus aureus*

TABLE II
Analytical Characteristics
of ICP-OES

Element	Linear Range (µg mL ⁻¹)	LOD (ng mL ⁻¹)	LOQ
Cd	0.05-1.5	3.3	11
Ni	0.05-1.5	5.1	17
Cu	0.05-1.5	2.8	9.2
Cr	0.05-1.5	4.3	14
Pb	0.05-1.5	9.0	30
Fe	0.05-1.5	4.2	14
B	0.05-1.5	12.0	40
Al	0.05-1.5	3.2	11

L., and *Hyoscyamus albus* L.) were sampled, powdered, and ashed for the determination of their metal concentrations by ICP-OES. The concentrations of the metal ions are listed in Table IV. All of the analyses were performed in triplicate. The SD and RSD values are included in this table to evaluate the precision of the results. As shown, the RSD values were found to be below 10%. Considering the favorable results, further experiments were not performed.

Cd and Pb Concentrations

All of the elements of interest were found at concentration levels that could be determined by ICP-OES after the ashing method, except for cadmium (Cd). The con-

centrations of Cd were found to be lower than the LOQ in *H. reticulatus*. The highest concentration of Cd was found in *H. albus* at 0.87 mg/kg, whereas the lowest value was determined in *H. leptocalyx* at 0.14 mg/kg. The provisionally tolerable weekly intake value for lead (Pb) and cadmium (Cd) reported by FAO/WHO is 7 µg/kg/week (27). Thus, the Pb levels found in the *Hyoscyamus* species are below WHO limits. The Cd concentrations in medicinal plants are reported to range from 0.731 to 1.121 mg/kg dry plant material with an average value of 0.878 mg/kg (28). Thus, the Cd concentrations found in the samples studied are lower than the mean permissible values reported in the literature.

Ni Concentrations

It is reported that plants require nickel (Ni) at lower (0.01–5.0 mg/kg dry weight) concentrations, while at higher concentrations they may cause toxic effects to plants (29). In addition, Ni has been known to play an important role in the production of insulin (30). Ni amounts in medicinal plants from the Negev Desert of Israel are in the concentration range of 0.5–19.3 mg/kg on dry weight (29). In this study, the Ni concentrations in the *Hyoscyamus* species were measured in the 1.9–14.0 µg g⁻¹ range. The permissible limit set by FAO/WHO (1984) in plants was reported at 1.63 mg/kg, while no regulated value is available for medicinal plants (30).

TABLE III
Accuracy of Digestion Method for Cd, Ni, Cu, Pb, Cr, Fe, B and Al in CRM NCS ZC 73014 Tea Leaves (n=3)

Parameters	Cd (µg g ⁻¹)	Ni (µg g ⁻¹)	Cu (µg g ⁻¹)	Pb (µg g ⁻¹)	Cr (µg g ⁻¹)	Fe (µg g ⁻¹)	B (µg g ⁻¹)	Al (µg g ⁻¹)
Certified value	0.062	3.40	18.6	1.50	0.45	242	14.0	-
Found value	0.060	3.52	19.9	1.53	0.44	235.5	12.6	597.2
SD ^a	0.005	0.152	0.028	0.007	0.014	24.6	0.155	22.7
RSD ^b (%)	8.4	4.3	0.14	0.46	3.2	10.4	2.0	3.8
Error (%)	96.8	103	107	102	97.8	97.3	90.0	-

^a Standard deviation.

^b Relative standard deviation.

TABLE IV
Distribution of Cd, Ni, Cu, Pb, Cr, Fe, B, and Al in *Hyoscyamus* Species (n=3)

Plant	Cd (µg g ⁻¹)	Ni (µg g ⁻¹)	Cu (µg g ⁻¹)	Pb (µg g ⁻¹)	Cr (µg g ⁻¹)	Fe (µg g ⁻¹)	B (µg g ⁻¹)	Al (µg g ⁻¹)
<i>H. reticulatus</i>	<LOQ ^a (1.6) ^b	5.4±0.086 (1.3)	530.2±7.00 (6.9)	1.27±0.087 (0.4)	3.50±0.016 (2.7)	602±16.1 (3.4)	17.2±0.59 (5.5)	1147±62.9
<i>H. leptocalyx</i>	0.14±0.0098 (7.0)	1.9±0.061 (3.2)	5.8±0.20 (3.5)	0.18±0.008 (4.4)	1.39±0.139 (10.0)	268±19.7 (7.4)	7.8±0.66 (8.5)	930±28.4 (3.0)
<i>H. aureus</i>	0.26±0.0042 (1.6)	14.0±1.101 (7.9)	15.6±1.34 (8.6)	21.69±1.172 (5.4)	8.21±0.439 (5.4)	1278±117.0 (9.2)	20.7±1.75 (8.5)	1089±71.4 (6.6)
<i>H. albus</i>	0.87±0.0558 (6.4)	9.3±0.353 (3.8)	11.4±0.50 (4.4)	2.23±0.098 (4.4)	5.15±0.349 (6.8)	794±67.0 (8.4)	20.5±0.45 (2.2)	1370±37.3 (2.7)

^a <LOQ: Under the limit of quantification. ^b The RSD values are given in parentheses.

Cu Concentrations

The permissible copper (Cu) concentration in edible plants is 3.0 mg/kg as regulated by FAO/WHO. However, there is no regulation available for Cu levels in medicinal plants (31). Concentrations of Cu were found at 530.2, 5.8, 15.6, and 11.4 mg/kg, for *H. reticulatus*, *H. leptocalyx*, *H. aureus*, and *H. albus*, respectively. Interestingly, the concentration of Cu in *H. reticulatus* was found to be approximately 48.5 times higher than the mean Cu values of the other *Hyoscyamus* species. The Cu concentrations in 33 medicinal plants were reported to be in the 1.4–18.1 mg/kg range (32). In our study, the results agreed well with the literature values, except for *H. reticulatus*. Additionally, phytotoxicity was reported when the Cu concentration was higher than 20 mg/kg (33). However, no information is available in the literature for comparison of the Cu levels in *H. reticulatus*. Since high Cu concentration levels lead to headache and hypoglycemia, it is recommended not to use *H. reticulatus* for medicinal purposes (33).

Pb Concentrations

Lead (Pb) is known as one of the most toxic heavy metals and is dangerous to human and animal health. The provisional tolerable weekly intake value for Pb is reported at 50 µg/kg/week by FAO and WHO (27) and the permissible limit of Pb in edible plants at 0.43 mg/kg by FAO/WHO (31). Pb concentrations of some medicinal plants (*Baccharis trimera*, *Maytenus aquifolia*, *Mikania glomerata*, *Pfaffia paniculata*) sampled from local city markets in Brazil were found in the 3.37–7.03 mg/kg range (34). In the present study, it was found that the total Pb concentration in *H. aureus* was 17.8 times higher than the mean value of the other three plants which were 1.27, 0.18, and 2.23 mg/kg, for *H. reticulatus*,

H. leptocalyx, and *H. albus*, respectively, indicating that all species were below permissible levels.

Cr Concentrations

Chromium (Cr) concentrations were determined in the 1.39–8.21 µg g⁻¹ range. The highest concentration of Cr was found in *H. aureus*, whereas the lowest was determined in *H. leptocalyx*. In another study, the Cr concentrations were found in the range of 0.56–1.51 mg/kg in herbal plants collected in the Kisii region, southwest Kenya (31). The concentrations of Cr in 33 plants obtained from Romanian markets were found to be in the range of 0.1–5.7 mg/kg (32). In another study, the Cr concentrations in 16 different parts of medicinal plant samples collected in Lebanon, Syria, Egypt, Italy, and India were found to be in the range of 3.1–55.4 mg/kg (35). The EU Recommended Daily Allowance (RDA) for chromium(III) of 40 µg was set by the Commission Directive 2008/100/EC9, which is equivalent to 12 µg chromium per serving (36).

Fe Concentrations

Iron (Fe) is known as an essential element for humans and animals and Fe³⁺ is an essential component of hemoglobin. On the other hand, the deficiency of the bioavailable form of iron on the 2+ oxidation state causes many diseases such as anemia (37). Fe contributes to the oxidation of carbohydrates, proteins, and fats to control body weight (38). Fe concentrations were determined in the 33.2–206.7 mg/kg range in seven medicinal plants (*Artemisia vulgaris*, *Asparagus adscendens*, *Cyamopsis tetragonoloba*, *Galium aparine*, *Mucuna pruriens*, *Stevia rebaudiana*, *Withania somnifera*) collected from Peshawar, Pakistan (38). In another study, 33 different types of medicinal plants were obtained from local Romanian mar-

kets and their Fe concentrations were determined by FAAS (flame atomic absorption spectrometry) ranging from 23–826 mg/kg (32). The proton-induced X-ray emission technique was employed to determine trace element concentrations in other samples, including Fe in medicinal plants sampled from Manipur, India, which ranged from 311.1–820.4 mg/kg (39). In our study, the Fe concentrations were determined at 268, 602, 794 and 1278 mg/kg, respectively, for *H. leptocalyx*, *H. reticulatus*, *H. albus*, and *H. aureus*. The reported daily intake of iron in food – the major source of exposure – ranges from 10 to 14 mg (7,8). Drinking water of 0.3 mg/litre would contribute about 0.6 mg Fe to the daily intake. Intake of iron from air is about 25 µg/day in urban areas (40). So, it could be stated that the consumption of the studied plants at high amounts should be avoided due to their high amounts of Fe and other toxic metals such as Ni, Cr, and Pb.

B Concentrations

Boron is known as one of the most essential elements to plants. Boron deficiency in plants could result in reduced growth, yield loss, and even plant death, depending on the severity of deficiency under 1 mg/kg of boron, while excess of B is toxic to plants (41). B concentrations were found at 7.8, 17.2, 20.5, and 20.7 mg/kg for *H. leptocalyx*, *H. reticulatus*, *H. albus*, and *H. aureus*, respectively. In *H. aureus*, the Fe and B concentrations were also found to be higher than the mean values of the other species. A permissible value of B is in the range of 0.8 to 1.9 mg/day according to the U.S. Food and Drug Administration Total Diet Studies and the United Kingdom National Food Survey (42).

Al Concentrations

The highest Al concentrations at 1370±37.3 mg/kg were determined

in *H. albus*, whereas the lowest amount of 930 ± 28 mg/kg was determined in *H. leptocalyx*. The presence of some heavy metals, including Al in selected medicinal plants belonging to the *Lamiaceae*, *Guttiferae*, *Gentianaceae*, *Acanthaceae* families were investigated and the Al concentrations were reported to be in the 1.45–4.07% range (43). Lower concentrations of Al at 154–412 mg/kg were determined in medicinal plants sampled from Arak, Iran (44). ICP-OES was employed to determine the Al concentration in medicinal plants from Morocco and the results were in the range of 1.22–7.91% (45). The FAO/WHO permissible Al level reported is 7 mg/kg body weight/week to 1 mg/kg body weight/week (46).

CONCLUSION

The trend to using medicinal plants for improving health has increased worldwide. Some plants are directly used for primary health care. However, they can contain heavy metals many of which are toxic. Thus, it is very prudent to evaluate the metal concentrations of these plants. In this study, the Cd, Ni, Cu, Pb, Cr, Fe, B, and Al concentrations in the *Hyoscyamus* (*Solanaceae*) species (*Hyoscyamus reticulatus* L., *Hyoscyamus leptocalyx* STAPF, *Hyoscyamus aureus* L., and *Hyoscyamus albus* L.) were determined. The accuracy of the method was controlled by the certified reference material NCS ZC 73014 Tea Leaves with satisfactory results. This study showed the applicability of the ashing method for quantitative digestion of heavy metals in plant samples and thus the limitations in sample amount and sensitivity are overcome. The study showed the applicability of the ashing method, followed by ICP-OES determination, for metals in medicinal plants.

The concentrations of Cd, Ni, Cu, Pb, Cr, Fe, B, Al and others in plants are known to vary greatly depending on their concentrations in soil, the role in their metabolism and physiological pathways, the environmental conditions such as stress, temperature, etc. Concentrations of Cu in *H. reticulatus* were found higher than in the other species, whereas the Cd concentrations were as low as the quantification limit. The Pb concentration was found at 21.69 ± 1.172 $\mu\text{g g}^{-1}$ for *H. aureus*, while it was clearly lower than in the other species. The concentrations of Fe and Al in the studied plants were found in the range of 268 ± 19.7 – 1278 ± 117.0 $\mu\text{g g}^{-1}$ for Fe and 930 ± 28.4 – 1370 ± 37.3 $\mu\text{g g}^{-1}$ for Al. It is well known that Fe and Al are also found in soil at higher amounts. Thus, higher concentrations are expected in plants. This could be attributed to environmental factors and plant physiologies. There were no significant differences found in the Ni, Cr, and B concentrations of the studied plants. From these results, it can be concluded that *H. aureus* contained high amounts of Ni (14.0 ± 1.101 $\mu\text{g g}^{-1}$), Pb (21.69 ± 1.172 $\mu\text{g g}^{-1}$), and Cr (8.21 ± 0.439 $\mu\text{g g}^{-1}$). The highest Cu concentration was determined in *H. reticulatus* at 530.2 ± 7.00 $\mu\text{g g}^{-1}$. The Fe (268 ± 19.7 – 1278 ± 117.0 $\mu\text{g g}^{-1}$), B (7.8 ± 0.66 – 20.7 ± 1.75 $\mu\text{g g}^{-1}$), and Al (930 ± 28.4 – 1370 ± 37.3 $\mu\text{g g}^{-1}$) concentrations agreed well with literature values.

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