



RESEARCH ARTICLE

Determining the content of toxic elements (Pb, Cd, and As) in herbal plants collected from different sites in northern Vietnam

Phân tích hàm lượng của các nguyên tố độc hại (Pb, Cd và As) trong các cây thảo dược được thu hái tại các khu vực khác nhau ở miền bắc Việt Nam

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Plants might contain heavy metals from the surrounding polluted environment. Medicinal herb and plants, commonly used in Vietnam, may pose a risk to public health when polluted with heavy metals such as Pb, Cd and As. This study aims to investigate the content of Pb, Cd, and As in five selected herb plants (*Phyllanthus urinaria* L., *Plantago asiatica* L., *Eleusine indica* L., *Wedelia chinensis* (Osbeck) Merr, and *Artemisia vulgaris* L.). The samples were collected from natural sites in some provinces in northern Vietnam. The concentrations of Pb, Cd, and As were determined by the Inductively coupled plasma mass spectrometry (ICP-MS) method. The content of Pb, Cd and As was $0.247 \div 32.080 \text{ mg kg}^{-1}$, $0.000 \div 1.099 \text{ mg kg}^{-1}$, $0.000 \div 2.261 \text{ mg kg}^{-1}$, respectively. A total of 50 out of the 58 investigated samples had concentrations of Pb, Cd, As lower than the permissible values of the World Health Organization (WHO). The remaining samples had contents of Pb or Cd or As significantly higher than the permissible limit defined by WHO.

Thực vật có thể bị ô nhiễm do hấp thụ kim loại nặng từ môi trường ô nhiễm xung quanh. Các loại cây thảo dược được sử dụng phổ biến làm thuốc chữa bệnh ở Việt Nam. Chúng có thể gây nguy hiểm cho sức khỏe cộng đồng khi bị ô nhiễm kim loại nặng (Pb, Cd...vv.). Nghiên cứu này nhằm điều tra hàm lượng Pb, Cd và As trong năm loại cây thảo dược (cây Diệp Hạ Châu, cây Mã Đề, cây Cỏ Mần Trầu, cây Sài Đất và cây Ngải Cứu). Các mẫu cây này được lấy từ các địa điểm mọc tự nhiên ở một số tỉnh khác nhau thuộc khu vực miền bắc Việt Nam. Hàm lượng của Pb, Cd, và As được xác định bằng phương pháp ICP-MS. Hàm lượng Pb, Cd và As trong các mẫu phân tích lần lượt nằm trong khoảng là $0.247 \div 32.080 \text{ mg. Kg}^{-1}$, $0.000 \div 1.099 \text{ mg. Kg}^{-1}$, $0.000 \div 2.261 \text{ mg. Kg}^{-1}$. 50 trên 58 mẫu phân tích có hàm lượng Pb, Cd, As thấp hơn giới hạn cho phép do tổ chức y tế thế giới (WHO) quy định. Có 8 trên 58 mẫu cây phân tích có hàm lượng Pb hoặc, Cd hoặc As cao hơn tiêu chuẩn giới hạn của WHO.

Keywords: heavy metal; herbal plants; lead; cadmium; arsenic

1. Introduction

Herbs and plants have been popularly used as oral medicine in many countries around the world because of their low cost and effectiveness (Dghaim et al., 2015; Li et al., 2018). Several studies have examined that toxic metals such as cadmium (Cd), arsenic (As) and lead (Pb), could be present in some herbs (Chizzola et al., 2003; Filipiak-Szok et al., 2015; Miroslawski & Paukzsto, 2018; Queralt et al., 2005).

Heavy metal pollution in soils has become a severe environmental issue (Hazrat et al., 2019; Wuana & Okiyeimen, 2014; Zwolak et al., 2019). Soils have been severely polluted by heavy metals released from ore mining and other industrial activities. When herbal plants are grown in polluted soils, they can also be contaminated

with heavy metals. Some plants can accumulate heavy metals more than others (Dghaim et al., 2015). As a result, heavy metals are transferred into the food chain from plants to animals or humans (Intawongse & Dean, 2006). When people consume polluted herbal plants as oral medicines, their health can be threatened by the heavy metals' toxic effects even at low content (Dghaim et al., 2015). Arsenic, lead and cadmium are extremely toxic elements to the human body when their consumption is above the permissible (Dghaim et al., 2015; Korfali et al., 2013).

Some studies have recently reported that herbal plants and products, sold in the market, are contaminated by heavy metals. For example, some herbs usually sold in South Africa, have cadmium contents higher than the WHO's permissible limits (Okem et al., 2012). Dghaim et al.

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(2015) reported that various herbal plants, used as medicines in the United Arab Emirates, have cadmium and lead contents much higher than the permissible limit set by WHO (Dghaim et al., 2015). These findings required constant quality control of herbal plants collected in nature or in the market to identify potential health risks for consumers.

Various modern techniques have been used to analyze elements in herbal plants and medicinal products. These techniques consist of atomic absorption spectroscopy and plasma techniques. The atomic absorption spectroscopy (including flame atomic absorption spectrum (FAAS) and graphite furnace (GFAA)) was commonly used to detect single metal (Arpadjan et al., 2008; Başgel & Erdemoğlu, 2006a; Chizzola et al., 2003; Dghaim et al., 2015; Divrikli et al., 2006). Nowadays, plasma techniques, combined with inductance with a mass spectrometer, optical emission, and atomic emission spectrometer (ICP-MS, ICP-OES, and ICP-AES respectively) are the main analytical techniques utilized to determine multi-metals in herbal plants (Adusei-Mensah et al., 2019; Arpadjan et al., 2008; Karadaş & Kara, 2012; Tokaloğlu, 2012). It has been reported that ICP-MS is a method with the great sensitivity and accuracy for the simultaneous detection of multi-elements at trace concentrations in herbal products (de Oliveira et al., 2018; Mulaudzi et al., 2017; Reinholds et al., 2017; Tokaloğlu et al., 2018a; Zhang et al., 2018).

Vietnam is a tropical country that has many diverse and rare plants. The use of plants for preparing medicines to treat diseases in Vietnam is widespread. People buy medicinal plants at the market and collect naturally grown medicinal plants for medicinal purposes. These plants grow naturally in different environmental areas such as industrial, mining, or near highways and residential areas. Therefore, medicinal plants taken in these areas may

contain a higher amount of heavy metals, overpassing the safe limit for the consumers' health.

Currently, in Vietnam, there is little available information about heavy metals and their content in medicinal plants. The present study aims to (1) evaluate the concentration of toxic elements (Pb, Cd, As) in the five commonly used medicinal plants (*Phyllanthus urinaria* L., *Plantago asiatica* L., *Eleusine indica* (L.), *Wedelia chinensis* (Osbeck) Merr, and *Artemisia vulgaris* L.) by using ICP-MS method and (2) define the levels of these elements in these herbs in comparison to the permissible limits of the World Health Organization.

2. Materials and methods

2.1. Sampling

A total of fifty-eight samples were randomly collected from the five aforementioned types of herbal plants. Samples were harvested from multiple places within six provinces (Thai Nguyen, Bac Kan, Bac Ninh, Hai Dương, Hai Phong, Quang Ninh) in northern Vietnam. Wooden tools were utilized to take plant samples in order to prevent contamination by heavy metals. The standard and scientific names, as well as the number of analyzed samples, are listed in Table 1.

The sample code of *Phyllanthus urinaria* L., *Plantago asiatica* L., *Eleusine indica* (L.) , *Wedelia chinensis* (Osbeck) Merr, and *Artemisia vulgaris* L. were marked as PUL, PAL, EI, WCM, and AVL, respectively. The code of these samples and collected locations are listed in the supplement information (Table S1). The samples were packed into polyethylene bags and labeled. The leaves of plant samples were milled and passed through a 1.5-mm sieve. Subsequently, they were marked and stored in plastic bags for further metal analysis.

Table 1. Information about medicinal plant samples collected in this study

Species name	Common name	Treatment/health effect	Number of samples (N = 58)
<i>Phyllanthus urinaria</i> L.	chamber bitter	Stabilize liver function, detoxify the liver, anti-virus (Guankui Du et al., 2018)	8
<i>Plantago asiatica</i> L.	Che Qian Zi / Chinese plantain	Anti-inflammatory, antiseptic, antitussive, treat liver disease, stomach problems (Yang et al., 2017)	8
<i>Eleusine indica</i> (L.) / <i>Eleusine indica</i> (L.) Gaertn	Indian goosegrass / Wire Grass	Treating hypertension, influenza, oliguria, and urine retention (Ong et al., 2017)	15
<i>Wedelia chinensis</i> (Osbeck) Merr	Chinese Wedelia	Treatment of wounds, seminal weakness and viral-hepatitis (Darah et al., 2013)	15
<i>Artemisia vulgaris</i> L.	mugwort	Treatment of diabetes/ epilepsy, anti-inflammatory, antispasmodic, carminative, and anthelmintic properties (Nigam et al., 2019)	12

2.2. Reagents and ICP-MS apparatus

Standard solutions of lead, cadmium and arsenic were prepared from standard solutions of 1000 mg.L⁻¹. The solutions of acid HNO₃ 65%, H₂O₂ 30% and standard solutions are pure chemicals (Merck Group, Germany).

Inductively coupled plasma mass spectroscopy (ICP-MS Agilent 7900, Agilent Technologies, USA) was used for analyzing Pb, Cd, and As. The optimized operating conditions of ICP-MS for the analysis of Pb, Cd, As in plant materials is described in Table S2 (see Supplement Information).

2.3. Digestion procedure

The wet digestion evaluation was carried out according to the standard of AOAC 2015.01 and EPA 200.8. The digestion evaluation was performed using a microwave system (Mars 6- CEM Corporation - USA). A mass of 0.5 grams of dried powder from each plant sample was weighed into PTFE vessels. Volumes of 1.0 mL of H₂O₂ (30%) and 5.0 mL of concentrated HNO₃ (65%) were then added into the vessels. The vessels were closed and placed in the microwave oven. The digestion was allowed to 11.72 bar and 170°C over 10 min and then maintained at 170°C for 10 min. After the microwave procedure, the digested solutions were filtered through filter paper (Whatman no. 42) and diluted into 50 mL of deionized water.

2.4. Recovery studies

The spike addition was conducted to evaluate the recovery of the analysis procedure of metallic elements. The medicinal plant samples were spiked with the known content of the metal standard solution. The spiked samples were prepared in triplicates and digested following the procedure mentioned above. Later, the samples were reanalyzed and compared with the blank sample to assess the content obtained (Ghasemidehkordi et al., 2018).

The recovery values were calculated as displayed in equation 1. The results showed that the mean recovery was within the acceptable range according the Environmental Protection Agency (EPA), with a mean recovery: 70 ÷ 120% for Pb, Cd, and As ions.

$$\% \text{Recovery} = \frac{(X_s - X_u)}{K} \cdot 100\% \quad (1)$$

where X_s is the measured value of the analyzed element for the spiked sample; X_u is the measured value for the unspiked sample; and K is the known value of the spike in the sample. The following equations determine the values of the limit of detection (LOD), the limit of quantitation (LOQ) of the measurement, and the relative standard deviation (RSD):

$$\text{LOD} = \frac{3 \cdot S_a}{b} \quad (2)$$

and

$$\text{LOQ} = \frac{10 \cdot S_a}{b} \quad (3)$$

where: S_a is the standard deviation of the corresponding function y = b * x + a; b is the slope of the linear calibration y = b*x + a. The relative standard deviation (RSD) is obtained from:

$$\% \text{RSD} = \frac{\text{SD} \cdot 100\%}{\bar{X}_{tb}} \quad (4)$$

where SD is the standard deviation; and X_{tb} is the mean value of triplicates. Parameters to evaluate analytical procedures including LOD, LOQ, linear coefficient, and the average recovery of the elements lead, cadmium and arsenic are presented in Table 2.

2.5. Data analysis

The experimental data were processed by utilizing Microsoft Excel 2019 for analysis of the means and the standard deviation. Results of toxic metals in the studied medicinal plants are expressed as the mean value (mg·kg⁻¹) of dry weight ± SD of three subsamples collected from the same source listed in Table 3. OriginPro 2016 software was used to draw the figures S1 (see the Supplement Information).

3. Results and discussions

3.1. Analysis method validation

3.1.1. Linear regression equation, correlation coefficient, limit of detection and limit of quantification

The linear coefficients of the linear calibration, LOD, LOQ, RSD, and the recovery of Pb, Cd, As are shown in Table 2. The linear coefficients of Pb, Cd, and As were all closed to 1 (values of 0.9999). This indicates that the linear degree of the calibration curve is excellent.

The LOD and LOQ values of Pb, Cd, and As were 0.010 and 0.033 ppb, 0.001 and 0.003 ppb, 0.029 and 0.097 ppb, respectively. These values were closed to the results obtained from previous studies when using ICP-MS. Kim et al., (2015) reported that the LODs and LOQs of Pb, Cd, and As were 0.036 ppb and 0.118 ppb, 0.02 ppb and 0.064 ppb, 0.011 ppb and 0.034 ppb, respectively. Similarly, when using ICP-MS to determine heavy metal in aromatic spices, the authors informed that the LOD and LOQ of Pb, Cd, and As were 0.010 and 0.042 ppb, 0.008 and 0.021 ppb, 0.015 and 0.052 ppb, respectively (Daniel Giuseppe Bua, Giovanni Annuario, Ambrogina Albergamo, Nicola Cicero, 2016).

Table 2. Results of linear coefficient (R2), LOD, LOQ, recovery of spiked addition

No	Element	R2	LOD (ppb)	LOQ (ppb)	RSD (%)	Recovery (%)
1	As	0.999	0.010	0.033	10.63	80.41
2	Cd	0.999	0.001	0.003	4.63	83.20
3	Pb	0.999	0.029	0.097	9.24	82.19

LOD: limit of detection; LOQ: limit of quantification; RSD: relative standard deviation, R²: linear coefficient.

3.1.2. Evaluate the recovery and repeatability of the analytical method

The accuracy of the method is assessed through the recovery efficiency of the spiked samples. Each sample was analyzed repeatedly three times. Table 2 shows that the Pb, Cd, As's average recovery ranged from 80.41 % to 83.20 %. The most commonly used estimate of precision for a method is the relative standard deviation (RSD), also known as the coefficient of variation (CV). The results show that the RSD from the analysis of the three elements ranged from 4.63 to 10.63 %.

Therefore, the mean recovery and RSD were within the guideline requirements of EPA, defining a mean recovery: 70 ÷ 120 %, RSD ≤ 20 % (Creed et al., 1994). Thus, the ICP-MS is a suitable method to detect Pb, Cd and As in plants. This is in agreement with previous studies as those presented by Filipiak-Szok et al., (2015) and Tokalioğlu et al., (2018b).

3.2. Content of Pb, Cd, and As in herbal samples

The total content of Pb, Cd, As in the five selected herbal plants, collected in the various natural sites in northern Vietnam, is listed in Table 3. The average concentrations of Pb, Cd, As in leaves/stem of the five medicinal plants were 0.440 ÷ 32.080 mg. kg⁻¹, 0.000 ÷ 1.099 mg. kg⁻¹, 0.000 ÷ 2.261 mg. kg⁻¹, respectively. Interspecies differences were observed in the average contents of Pb, Cd and As. In studied plants, the decreasing order of the concentration was Pb > As > Cd. This order is similar to the results of some previous studies. When analyzing the metals in medicinal plants in Iran, the average concentration of Pb, Cd, and As was in the same order as the present study (Kohzadi et al., 2019). Similarly, the average contents of Pb, Cd and As in most of the Asiatic and European medicinal plants were in the order of Pb > As > Cd, however, in some cases, the order was Pb > Cd > As (Filipiak-Szok et al., 2015). The variety of plant species and living environments might account for these differences.

Table 3. The concentration range of Pb, Cd, As in herbs (mg.kg-1) ± SD (n =3)

Herbs	Lead (Pb)	Cadmium (Cd)	Arsenic (As)
<i>Artemisia vulgaris</i> L. (AVL)			
Min	0.247 ± 0.021	0.068 ± 0.065	0.149 ± 0.028
Max	3.294 ± 0.081	0.389 ± 0.021	0.498 ± 0.012
Mean	1.474	0.196	0.343
<i>Plantago asiatica</i> L. (PAL)			
Min	4.087 ± 0.042	nd	1.255 ± 0.005
Max	8.583 ± 0.127	0.191 ± 0.006	2.119 ± 0.017
Mean	5.913	0.112	1.628
<i>Wedelia chinensis</i> (Osbeck) Merr (WCE)			
Min	0.481 ± 0.210	0.125 ± 0.021	nd
Max	1.628 ± 0.094	0.340 ± 0.053	
Mean	0.977	0.219	nd
<i>Eleusine indica</i> L. (EI)			
Min	0.440 ± 0.041	0.016 ± 0.006	0.040 ± 0.005
Max	1.430 ± 0.074	0.078 ± 0.006	0.283 ± 0.025
Mean	0.830	0.040	0.182
<i>Phyllanthus urinaria</i> L. (PUL)			
Min	7.153 ± 0.102	0.166 ± 0.008	0.021 ± 0.013
Max	32.080 ± 1.689	1.099 ± 0.015	0.503 ± 0.031
Mean	13.392	0.488	0.295

nd: no detection

3.2.1. Lead concentration

Table 3 shows that the average concentration of lead was highest in PUL (13.392 mg.kg⁻¹) and smallest in EI (0.830 mg.kg⁻¹). Among each plant species, the lead content was variable among samples collected at different sampling locations. The Pb's concentration in the five plant species AVL, PAL, WCM, EI and PUL were 1.474, 5.913, 0.977, 0.830, 13.392 mg.kg⁻¹, respectively.

This result was consistent with the results of some previous studies. Dghaim et al. analyzed the content of heavy metals in 8 medicinal plants in the United Arab Emirates. Results showed that the total lead content in these medicinal plants ranged from 1.44 ÷ 23.52 mg.kg⁻¹ (Dghaim et al., 2015). However, the results of this study are higher than the results of some other research.

The lead content in 18 Asiatic medicinal plants and 3 European herbal plants ranged from 0.38 to 0.62 mg.kg⁻¹. Similarly, the amount of Pb of herbal plants in Austria (Chizzola et al., 2003) and Turkey (Tokaloğlu, 2012) was in the range of 0.16 ÷ 2.08 mg.kg⁻¹ and 0.02 ÷ 3.01 mg.kg⁻¹, respectively. The variety of results might be attributed to the difference in plant species and collected sites.

3.2.2. Cadmium concentration

The average total cadmium content was highest in the leaves of PUL (0.448 mg.kg⁻¹) and smallest in the leaves of EI (0.040 mg.kg⁻¹). The cadmium content varied among samples of each plant species collected at different sampling locations as well. For example, in PUL samples, the lowest and highest content of cadmium were found in the PUL3 (0.016 ± 0.008 mg.kg⁻¹) and the PUL7 (1.099 ± 0.015 mg.kg), respectively. For the EI samples, the highest concentration of Cd was detected in the IE6 (0.016 ± 0.006 mg.kg⁻¹) sample, and the lowest value was in the IE15 (0.078 ± 0.006 mg.kg⁻¹) (see the detail in Supplement Table 2).

The average contents of cadmium in the five plants (AVL, PAL, WCM, EI and PUL) were 0.196, 0.112, 0.219, 0.040, 0.488 mg.kg⁻¹, respectively. These results are in agreement with the results of previous studies. The medicinal plants' cadmium content was found in the range of 0.02 ÷ 0.25 mg.kg⁻¹ (Filipiak-Szok et al., 2015). Similar results for cadmium contents in the medicinal plants were 0.1- 1.11 mg.kg⁻¹ (Dghaim et al., 2015), 0.01 ÷ 0.75 mg.kg⁻¹ (Chizzola et al., 2003) and 0,001 ÷ 0.44 mg.kg⁻¹ (Başgel & Erdemoğlu, 2006b).

Cadmium contents of the present study were lower than those reported by Divrikli et al. (2006) and Arpadjan et al. (2008). These authors informed that the cadmium contents in herbs were in the range of 0.2 ÷ 2.7 mg.kg⁻¹ and 0.2 ÷ 8.6 mg.kg⁻¹, respectively (Arpadjan et al., 2008; Divrikli

et al., 2006). Many factors, such as plant species and living environments, can be attributed to the varied results.

3.2.3. Arsenic concentration

Table 3 shows that the lowest and highest average contents of As were found in the WCM (0.000 mg.kg⁻¹) and PAL (1.628 mg.kg⁻¹), respectively. The total content of As varied from different investigated plant species. For each plant species, the arsenic levels were found to be variable among samples that were collected at different locations. The average levels of arsenic in AVL, PAL, WCM, EI and PUL were found as 0.343 mg.kg⁻¹, 1.628 mg.kg⁻¹, 0.000 mg.kg⁻¹, 0.182 mg.kg⁻¹ and 0.295 mg.kg⁻¹. This result was close to the results of some previous studies.

The level of arsenic in Asiatic and European plants was found in the range of 0.01 ÷ 0.38 mg.kg⁻¹ (Filipiak-Szok et al., 2015). Likewise, the level of arsenic in the five herbs in Bulgaria was found in the range from 0.012 to 0.225 mg.kg⁻¹ (Arpadjan et al., 2008). Similarly, Karadaş & Kara reported that the arsenic content in spices and herbs (mint, thyme, and rosemary) was in the range of 0.173 ÷ 0.277 mg.kg⁻¹ (Karadaş & Kara, 2012).

Queralt et al. detected that arsenic content in herbs was higher than that of the present and above studies. The authors informed that the arsenic level in the five commercial medicinal herbs traditionally used in Spain ranged from 4 to 7 mg.kg⁻¹ (Queralt et al., 2005).

The variation of elements content in the samples was explained by the difference of many factors such as plant species, collected locations, and living environment such as soil, water and air (Dghaim et al., 2015; Filipiak-Szok et al., 2015).

3.3. Comparison of the results to the limited standard set by WHO and nationals

The permissible limits established by the WHO and some nations for Pb, Cd, As are shown in Table 4. Our results were compared with the standards proposed by the WHO and some countries such as China, Thailand, Canada, and Singapore to evaluate the safety level of Pb, Cd, and As in the five investigated herbal plants. The comparison results are shown in Table 4 and Figure S1 (see Supplement Information).

The total content in 58 samples of the five investigated plants was lower than the permissible limits established by the WHO and some nations. Only one sample, PAL4 (2.119 ± 0.017 mg.kg⁻¹), showed an arsenic level higher than the china standard but still lower than those from Canada and Singapore (5 mg.kg⁻¹).

Table 4. Limited standards for Pb, Cd, and As in herbal plants of WHO and nations (WHO, 2007)

Permissible limit	As mg.kg ⁻¹	Pb	Cd
Canada	5	10	0.3
China	2	10	1
Singapore	5	20	-
WHO	-	10	0.3
Results of this study	0.000 ÷ 2.119	0.247 ÷ 32.080	0.000 ÷ 1.099

For cadmium, the standard established by the WHO and Canada is 0.3 mg.kg⁻¹ for raw materials, whereas that of China is 1.0 mg.kg⁻¹ (WHO, 2007). In all 58 analyzed samples, 54 samples had cadmium concentration below the maximum permissible according to the WHO and Canada. There were six samples (AVL1, AVL11, PUL1, PUL2, PUL3, PUL4), which had the cadmium content above the standard of WHO and Canada (see detail in Supplement Table S3). However, they were still lower than the limit standard set by China. When it comes to lead, its concentration in 54 samples was lower than the permissible limit set by WHO, Canada, and China. There were four samples (PUL1, PUL2, PUL4, PUL5: 32.080 mg.kg⁻¹, 17.433 mg.kg⁻¹, 10.833 mg.kg⁻¹, 12.358 mg.kg⁻¹ respectively) whose lead content was detected higher than the limit standard of WHO, Canada, and China. Only the PUL1 sample (32.080 mg.kg⁻¹) was higher than Singapore's standard (20 mg.kg⁻¹). Overall, 50 per 58 of the investigated samples had a safe content of Pb, Cd, As according to the WHO. A total of 8, out of 58 samples had the content of toxic elements (Pb, Cd or As) significantly higher than the permissible limit by the WHO and some nations.

4. Conclusion

Results from this study showed that ICP-MS is a suitable method to determine trace elements in plants that simultaneously analyzes multi-element. Results showed that the concentrations of toxic elements (Pb, Cd, and As) in the 58 analyzed samples varied in species, ranging from 0.440 ÷ 32.080 mg.kg⁻¹, 0.000 ÷ 1.099 mg.kg⁻¹, 0.000 ÷ 2.261 mg.kg⁻¹, respectively. The variety of the samples' element contents was attributed by the differences of many factors such as plant species, collected locations and living environment (soil, water, air). The present study results showed that the concentrations of Pb, Cd, and As in 50/58 samples were lower than the permitted limits of WHO and national standards. Some samples (8/58) had either Cd, As, or Pb contents higher than the WHO's permissible limit. Therefore, it is still necessary to check the concentrations of toxic metals in those herbal plants before its use, mainly when they are used as oral medicines for humans.

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6. References

- [1] Adusei-Mensah, F., Essumang, D. K., Agjei, R. O., Kauhanen, J., Tikkanen-Kaukanen, C., & Ekor, M. (2019). Heavy metal content and health risk assessment of commonly patronized herbal medicinal preparations from the Kumasi metropolis of Ghana. In *Journal of Environmental Health Science and Engineering*. <https://doi.org/10.1007/s40201-019-00373-y>
- [2] Arpadjan, S., Çelik, G., Taşkesen, S., & Güçer, Ş. (2008). Arsenic, cadmium and lead in medicinal herbs and their fractionation. *Food and Chemical Toxicology*, 46(8), 2871–2875. <https://doi.org/10.1016/j.fct.2008.05.027>
- [3] Başgel, S., & Erdemoğlu, S. B. (2006a). Determination of mineral and trace elements in some medicinal herbs and their infusions consumed in Turkey. *Science of the Total Environment*, 359(1–3), 82–89. <https://doi.org/10.1016/j.scitotenv.2005.04.016>
- [4] Başgel, S., & Erdemoğlu, S. B. (2006b). Determination of mineral and trace elements in some medicinal herbs and their infusions consumed in Turkey. *Science of the Total Environment*, 359(1–3), 82–89. <https://doi.org/10.1016/j.scitotenv.2005.04.016>
- [5] Chizzola, R., Michitsch, H., & Franz, C. (2003). Monitoring of metallic micronutrients and heavy metals in herbs, spices and medicinal plants from Austria. *European Food Research and Technology*, 216(5), 407–411. <https://doi.org/10.1007/s00217-003-0675-6>
- [6] Creed, J., Brockhoff, C., & Martin, T. (1994). Method 200.8 Determination of Trace Elements in Waters and Wastes By Inductively Coupled Plasma-Mass Spectrometry Environmental Monitoring Systems Laboratory Office of Research and Development U. In *US Environmental Protection Agency*.
- [7] Daniel Giuseppe Bua, Giovanni Annuario, Ambrogina Albergamo, Nicola Cicero, G. D. (2016). Heavy metals in aromatic spices by inductively coupled plasma-mass spectrometry. *Food Additives & Contaminants: Part B*, 9(3), 210–216. <https://doi.org/10.1080/19393210.2016.1175516>
- [8] Darah, I., Lim, S. H., & Nithianantham, K. (2013). Effects of methanol extract of *Wedelia chinensis* osbeck (asteraceae) leaves against pathogenic

- bacteria with emphasise on *Bacillus cereus*. Indian Journal of Pharmaceutical Sciences, 75(5), 533–539.
- [9] de Oliveira, L. M., Das, S., da Silva, E. B., Gao, P., Gress, J., Liu, Y., & Ma, L. Q. (2018). Metal concentrations in traditional and herbal teas and their potential risks to human health. *Science of The Total Environment*, 633, 649–657. <https://doi.org/10.1016/j.SCITOTENV.2018.03.215>
- [10] Dghaim, R., Al Khatib, S., Rasool, H., & Khan, M. A. (2015). Determination of heavy metals concentration in traditional herbs commonly consumed in the United Arab Emirates. *Journal of Environmental and Public Health*, 2015(Article ID 973878), 6 pages. <https://doi.org/10.1155/2015/973878>
- [11] Divrikli, U., Horzum, N., Soylak, M., & Elci, L. (2006). Trace heavy metal contents of some spices and herbal plants from western Anatolia, Turkey. *International Journal of Food Science and Technology*, 41(6), 712–716. <https://doi.org/10.1111/j.1365-2621.2005.01140.x>
- [12] Filipiak-Szok, A., Kurzawa, M., & Szlyk, E. (2015). Determination of toxic metals by ICP-MS in Asiatic and European medicinal plants and dietary supplements. *Journal of Trace Elements in Medicine and Biology*, 30, 54–58. <https://doi.org/10.1016/j.jtemb.2014.10.008>
- [13] Ghasemidehkordi, B., Malekirad, A. A., Nazem, H., Fazilati, M., Salavati, H., Shariatifar, N., Rezaei, M., Fakhri, Y., & Mousavi Khaneghah, A. (2018). Concentration of lead and mercury in collected vegetables and herbs from Markazi province, Iran: a non-carcinogenic risk assessment. *Food and Chemical Toxicology*, 113, 204–210. <https://doi.org/10.1016/j.fct.2018.01.048>
- [14] Guankui Du , Man Xiao , Siman Yu , Mengyi Wang , Yiqiang Xie, S. S. (2018). *Phyllanthus urinaria*: a potential phytopharmacological source of natural medicine. *International Journal of Clinical and Experimental Medicine*, 11(7), 6509–6520.
- [15] Hazrat, A., Ezzat, K., & Ilahi Ikram. (2019). Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. *Journal of Chemistry*, 2019, 1–14. <https://doi.org/10.1155/2019/6730305>
- [16] Intawongse, M., & Dean, J. R. (2006). Uptake of heavy metals by vegetable plants grown on contaminated soil and their bioavailability in the human gastrointestinal tract. *Food Additives and Contaminants*, 23(1), 36–48. <https://doi.org/10.1080/02652030500387554>
- [17] Karadaş, C., & Kara, D. (2012). Chemometric approach to evaluate trace metal concentrations in some spices and herbs. *Food Chemistry*, 130(1), 196–202. <https://doi.org/10.1016/j.foodchem.2011.07.006>
- [18] Kim, D., Hwang, K. H., Lee, M., Kim, J. H., Jung, K., & Park, S. K. (2015). Toxic metal content in 52 frequently prescribed herbal medicines on the Korean market. *Food Additives and Contaminants: Part B Surveillance*, 8(3), 199–206. <https://doi.org/10.1080/19393210.2015.1046405>
- [19] Kohzadi, S., Shahmoradi, B., Ghaderi, E., Loqmani, H., & Maleki, A. (2019). Concentration, Source, and Potential Human Health Risk of Heavy Metals in the Commonly Consumed Medicinal Plants. *Biological Trace Element Research*, 187(1), 41–50. <https://doi.org/10.1007/s12011-018-1357-3>
- [20] Korfali, S. I., Mroueh, M., Al-Zein, M., & Salem, R. (2013). Metal Concentration in Commonly Used Medicinal Herbs and Infusion by Lebanese Population: Health Impact. *Journal of Food Research*, 2(2), 70–82. <https://doi.org/10.5539/jfr.v2n2p70>
- [21] Li, J., Wang, Y., Yang, H., Yu, P., & Tang, Y. (2018). Five heavy metals accumulation and health risk in a traditional Chinese medicine Cortex Moutan collected from different sites in China. *Human and Ecological Risk Assessment*, 24(8), 2288–2298. <https://doi.org/10.1080/10807039.2018.1459181>
- [22] Mirosławski, J., & Pauksto, A. (2018). Determination of the cadmium, chromium, nickel, and lead ions relays in selected polish medicinal plants and their infusion. *Biological Trace Element Research*, 182(1), 147–151. <https://doi.org/10.1007/s12011-017-1072-5>
- [23] Mulaudzi, R. B., Tshikalange, T. E., Olowoyo, J. O., Amoo, S. O., & Du Plooy, C. P. (2017). Antimicrobial activity, cytotoxicity evaluation and heavy metal content of five commonly used South African herbal mixtures. *South African Journal of Botany*, 112, 314–318. <https://doi.org/10.1016/j.sajb.2017.06.024>
- [24] Nigam, M., Atanassova, M., Mishra, A. P., Pezzani, R., Devkota, H. P., Plygun, S., Salehi, B., Setzer, W. N., & Sharifi-Rad, J. (2019). Bioactive compounds and health benefits of *Artemisia* species. *Natural Product Communications*, 14(7), 1–17. <https://doi.org/10.1177/1934578X19850354>
- [25] Okem, A., Southway, C., Ndhala, A. R., & Van Staden, J. (2012). Determination of total and bioavailable heavy and trace metals in South African commercial herbal concoctions using ICP-OES. *South African Journal of Botany*, 82, 75–82. <https://doi.org/10.1016/j.sajb.2012.07.005>
- [26] Ong, S. L., Nalamolu, K. R., & Lai, H. Y. (2017). Potential lipid-lowering effects of *Eleusine indica* (L) Gaertn. Extract on high-fat-diet-induced hyperlipidemic rats. *Pharmacognosy Magazine*, 13(49), S1–S9. <https://doi.org/10.4103/0973-1296.203986>
- [27] Queralt, I., Ovejero, M., Carvalho, M. L., Marques, A. F., & Llabrés, J. M. (2005). Quantitative determination of essential and trace element content of medicinal plants and their infusions by XRF and ICP techniques.

- X-Ray Spectrometry, 34(3), 213–217. <https://doi.org/10.1002/xrs.795>
- [28] Reinholds, I., Pugajeva, I., Bavrins, K., Kuckovska, G., & Bartkevics, V. (2017). Mycotoxins, pesticides and toxic metals in commercial spices and herbs. *Food Additives and Contaminants: Part B Surveillance*, 10(1), 5–14. <https://doi.org/10.1080/19393210.2016.1210244>
- [29] Tokaloğlu, Ş. (2012). Determination of trace elements in commonly consumed medicinal herbs by ICP-MS and multivariate analysis. *Food Chemistry*, 134(4), 2504–2508. <https://doi.org/10.1016/j.foodchem.2012.04.093>
- [30] Tokaloğlu, Ş., Çiçek, B., İnanç, N., Zararsız, G., & Öztürk, A. (2018a). Multivariate Statistical Analysis of Data and ICP-MS Determination of Heavy Metals in Different Brands of Spices Consumed in Kayseri, Turkey. *Food Analytical Methods*, 11(9), 2407–2418. <https://doi.org/10.1007/s12161-018-1209-y>
- [31] Tokaloğlu, Ş., Çiçek, B., İnanç, N., Zararsız, G., & Öztürk, A. (2018b). Multivariate Statistical Analysis of Data and ICP-MS Determination of Heavy Metals in Different Brands of Spices Consumed in Kayseri, Turkey. *Food Analytical Methods*, 11(9), 2407–2418. <https://doi.org/10.1007/s12161-018-1209-y>
- [32] WHO. (2007). WHO Guidelines for assessing quality of herbal medicines with reference to contaminants and residues. In World Health Organization. <https://doi.org/10.1177/156482658000200103>
- [33] Wuana, R. A., & Okieimen, F. E. (2014). Heavy metals in contaminated soils: A review of sources, chemistry, risks, and best available strategies for remediation. *Heavy Metal Contamination of Water and Soil: Analysis, Assessment, and Remediation Strategies*, 2011, 1–50. <https://doi.org/10.1201/b16566>
- [34] Yang, Q., Qi, M., Tong, R., Wang, D., Ding, L., Li, Z., Huang, C., Wang, Z., & Yang, L. (2017). *Plantago asiatica* L. Seed extract improves lipid accumulation and hyperglycemia in high-fat diet-induced obese mice. *International Journal of Molecular Sciences*, 18(7), 1–14. <https://doi.org/10.3390/ijms18071393>
- [35] Zhang, N., Shen, K., Yang, X., Li, Z., Zhou, T., Zhang, Y., Sheng, Q., & Zheng, J. (2018). Simultaneous determination of arsenic, cadmium and lead in plant foods by ICP-MS combined with automated focused infrared ashing and cold trap. *Food Chemistry*, 264, 462–470. <https://doi.org/10.1016/j.foodchem.2018.05.058>
- [36] Zwolak, A., Sarzyńska, M., Szpyrka, E., & Stawarczyk, K. (2019). Sources of Soil Pollution by Heavy Metals and Their Accumulation in Vegetables: a Review. *Water, Air, and Soil Pollution*, 230(7). <https://doi.org/10.1007/s11270-019-4221-y>