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Food Additives & Contaminants: Part B
Surveillance

ISSN: 1939-3210 (Print) 1939-3229 (Online) Journal homepage: www.tandfonline.com/journals/tfab20

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To cite this article: Cigdem Er Caliskan, Vatimetou Ethmane, Harun Ciftci & Kubra Ozturk (2023) Macro- and trace elements in plants from Mauritania and risk assessment, Food Additives & Contaminants: Part B, 16:4, 375-383, DOI: 10.1080/19393210.2023.2253779

To link to this article: https://doi.org/10.1080/19393210.2023.2253779

Published online: 25 Sep 2023.

FOOD ADDITIVES & CONTAMINANTS: PART B
2023, VOL. 16, NO. 4, 375–383
https://doi.org/10.1080/19393210.2023.2253779

Macro- and trace elements in plants from Mauritania and risk assessment

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ABSTRACT

This study aimed to determine the content of elemental levels of eight plants species originating from Mauritania and used as medicinal plant and to assess their risk for human health. The range of elemental content in the studied plant parts of these plant species were 0.51–16.1 mg/g for Ca, 2.63–6.49 mg/g for Mg, 11.2–201 µg/g for Al, 6.5–28.2 µg/g for Zn, 5.6–453 µg/g for Fe, 1.1–6.4 µg/g for Ni, 11.0–302 µg/g for Mn and 0.7–9.0 µg/g for Cu. The Cr, Pb, Cd and Co levels were below the limits of detection in all samples. The estimated weekly intake (EWI) and target hazard quotient (THQ) were calculated. Except for Al the THQ values were below 1, so it could be concluded that these plant species have low probability of causing non-cancer health problems for the consumer.

ARTICLE HISTORY
Received 13 March 2023
Accepted 28 August 2023

KEYWORDS
Element; FAAS; medicinal plants; microwave; THQ

Introduction

Plants are used in many areas like food, pharmaceutical and cosmetic industries throughout history. Treatment with plants is used in many places around the world with different names like natural treatments, complementary therapy and traditional treatment (Krause and Tobin 2013).

In spite of developments in medical and pharmaceutical science in the twentieth century, the orientation towards herbal products for treatment of diseases has increased due to the expense of drugs and the harmful effects of synthetic products used in drug production in the present day (Lubbe and Verpoorte 2011). The World Health Organization (WHO) reported that 80% of people living in developing countries choose alternative medicine as a priority, mostly drugs obtained from medicinal plants (WHO 2002). Additionally, 11% of 252 basic drugs assessed by the WHO were plant derived and market research shows an increasing trend towards natural plant-derived products (Zengin et al. 2018; Elfalleh et al. 2019).

Bioactivity of medicinal plants is related to chemical compounds like flavonoids, alkaloids, terpenes, glycosides, volatile oils, vitamins, minerals and trace elements (Tran et al. 2020). Medicinal plants commonly contain trace elements like Al, Ar, Cu, Hg, Zn, Fe, Cd, Co, Pb, Sn, Ni, Se, Tl, and V and macro elements like Na, K, Ca and Mg (Tokalıoglu 2012). Plants tend to accumulate metals in their tissues, affecting food quality and safety (Roy and McDonald 2015). Previous studies show that medicinal plants can accumulate trace metals that have detrimental effects on human health (Karahan et al. 2020; Werdemberg dos Santos et al. 2022).

Before using medicinal plants for health purposes, identifying elemental levels by performing quality control is very important in terms of preventing negative outcomes on human health. If metal concentrations in the body are above physiological limits, cardiovascular dysfunction, liver and kidney injury, neurological problems, disruption of the endocrine system, haematological anomalies and cancerogenic effects occur (Balali-Mood et al. 2021).

The popularity of medicinal plants is connected with their therapeutic efficacy, ease of access, low cost and relatively low toxic effects. Many medicinal plants and their mixtures can present a health risk due to the presence of toxic elements. Element content of plants is affected by the geochemical characteristics of soil, climatic conditions, from anthropogenic sources and by the ability of herb species to accumulate elements (Cindrić et al. 2013; Begaa and Messaoudi 2019; Zinicovscaia et al. 2020). Monitoring the content of toxic elements is one of the most important aspects of controlling food safety (Khan et al. 2007). The WHO emphasised the importance of ensuring analytical checks of toxic metals, especially in medicinal plants, during quality control of herbal products (WHO 2015a).

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Techniques used for trace element analysis of medicinal plants are flame atomic absorption spectrometry (FAAS) (Seddigi et al. 2016), X-ray fluorescence (XRF) (Queralt et al. 2005; Giulian et al. 2007), electrothermal atomic absorption spectrometry (ETAAS) (Kalny et al. 2007), inductively-coupled plasma atomic emission spectrometry (ICP-AES) (Tahri et al. 2014), inductively-coupled plasma mass spectrometry (ICP-MS) (Zárate-Quiñones et al. 2021) and neutron activation analysis (NAA) (Zinicovscaia et al. 2020). High-resolution continuum-source flame atomic absorption spectrophotometry (HR CS FAAS) has been commonly chosen in recent years. HR CS FAAS is a frequently chosen method for element analysis due to performing analyses at low cost, making multi-element detection possible with a single radiation source (xenon arc) and having monochromator with high resolution (Welz 2005).

The literature reports a variety of studies to determine the levels of metals in medicinal and aromatic plants and to understand their pharmacological effects (Giulian et al. 2007; Seddigi et al. 2016; Brima 2017, 2018; Santos et al. 2017; Begaa et al. 2018; Messaoudi and Begaa 2018; Zinicovscaia et al. 2020; de Aragão Tannus et al. 2021; Zárate-Quiñones et al. 2021). These studies show that some medicinal and aromatic plants used by people may accumulate significant amounts of elements in the leaves, flowers, fruit, seeds. Therefore, there is a need to assess and monitor quality and safety of medicinal plants, content of elements that are necessary in the diet and elements that may cause negative effects on the human organism.

Assessments related to the preparation and marketing of herbal products are performed by organisations such as WHO, FAO (Food and Agriculture Organization of the United Nations) and EPA (Environmental Protection Agency) globally (Kilic 2018). For this reason, it is important to create a database containing element compositions of medicinal and aromatic plants to ensure verbal standardisation commonly used around the world.

The aim of this study was to determine the elemental contents of plant parts used as food in various plant species used frequently in Mauritania as medicinal plant and to evaluate their human health risks associated with the intake. In this context, concentrations of macro minerals (Ca and Mg), trace (Zn, Cu, Mn and Fe), and ultra-trace elements (Al, Pb, Cr, Co, Cd ve Ni) in eight plant species including *Acacia senegal* L. Willd, *Psoralea plicata, Acacia nilotica* L. Willd, *Hordeum vulgare* L., *Senna alexandrina, Balanites aegyptiaca* L. Delile, *Tamarindus indica* L. and *Maytenus Senegalensis*, widely used as medicinal plant in Mauritania were analysed. Additionally, the estimated weekly intake levels (EWI), target hazard quotient (THQ) and provisional tolerable weekly intake levels (PTWI) were calculated in samples. The information obtained from this study is important for food safety and environmental, human and public health.

Materials and methods

Concentrated nitric acid (65%), perchloric acid (72%), hydrogen peroxide (30%), and standard reference material (NIST SRM 1570a Trace Elements in Spinach Leaves; National Institute of Standards and Technology, Gaithersburg, USA) were purchased from Merck Co. (Darmstadt, Germany).

Gathering plant samples

The plant-based parts of the species frequently used as medicinal plants in Mauritania were bought from three different vendors for each herb from herbalists in Mauritania (Trarza, Adrar). Species identification was performed by Dr Abdellahi ould Hmeyde, a botanist in Nouakchott University Faculty of Science and Technology. Medicinal uses (Ebrahim et al. 2012; Okatch et al. 2012; Yamaura et al. 2012; Ghanem et al. 2016; Choi et al. 2019; Koul et al. 2019; Abdelaziz et al. 2020) and collection areas of studied plant species are given in Table 1. Before starting the drying processes for the plant samples, they were washed with tap water, followed by deionised distilled water (18.3 MΩ cm, Millipore, Bedford, MA, USA) and dried in an oven at 50°C for 24 h before being ground in a mortar to powder.

Digestion of samples

Equal amounts of dried samples (3 g each) were mixed and homogenised. Three samples, in the range of 0.25–0.3 g were taken from the dried and homogenised plant samples and placed in an oven at 50°C for 24 h until constant weight was reached (Kohzadi et al. 2019). The digestion procedure was completed in a microwave oven using 100 mL containers made of polytetrafluoroethylene (PTFE) which is resistant to pressure and temperature. Five mL nitric acid (65% HNO_3, (v/v)), 2 mL perchloric acid (72% $HClO_4$ (v/v)) and 1 mL hydrogen peroxide (30% H_2O_2 (v/v)) were added to each sample placed in the PTFE containers and left for 30 min. After closing the leak-proof lids of the containers, they proceeded the microwave digestion. The digestion programme was applied as 250 W for 5 min; 450 W for 5 min and 800 W for 10 min. After cooling down to room temperature, the lids were carefully opened in a fume hood to obtain the clear mixture. Insufficient clear samples were digested twice. The digests were completed to a volume of 10 mL with 0.1 mol L^{-1}

Table 1. Parts of plants analysed and medicinal use.

Plant	Medicinal use	Parts of plants	Region
Acacia Senegal	Treatment of diabetes, in lowering cholesterol level and chronic renal failure (Ebrahim et al. 2012).	Gum-like part secreted from roots and branches	Trarza
Psoralea plicata	Anthelmintic, laxative, diuretic, and to heal wounds (Koul et al. 2019).	Flower	Adrar
Acacia nilotica	Diarrhoea, dysenteryi, umigation,colds and fever (Ebrahim et al. 2012).	Seed	Trarza
Hordeum vulgare	Protective effects against fatty liver disease and neuroinflammation through inhibition of inflammatory responses, antioxidant, antidepressant, anticancer, antidiabetic and antiobesity activities (Yamaura et al. 2012; Choi et al. 2019).	Seed	Adrar
Senna alexandrina	As a laxative (Ebrahim et al. 2012).	Leaves	Adrar
Balanites aegyptiaca.	Antidiabetes, antihypertensive, constipation and cough (Ghanem et al. 2016; Abdelaziz et al. 2020)	Fruit	Trarza
Tamarindus indica	Antimalaria treatment and as a laxative (Ebrahim et al. 2012).	Seed	Trarza
Maytenus senegalensis	Antidysentery, snake bites, wounds and respiratory diseases (Okatch et al. 2012).	Leaves	Trarza

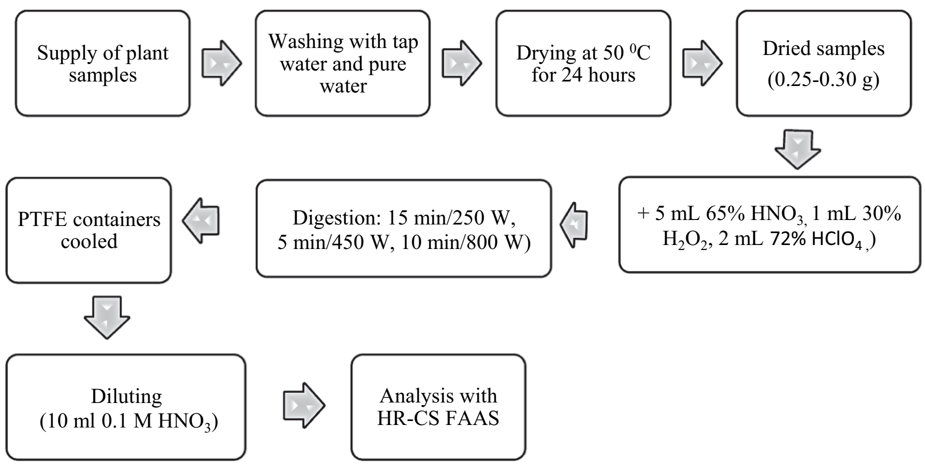

Figure 1. Sample preparation and analysis.

HNO_3 solution (Figure 1). A blank solution not containing plant content underwent the same procedures.

Instrumentation

HR CS FAAS device Analytik Jena ContrAA 300 (GLE, Berlin, Germany) Model was used for element analysis. To obtain calibration graphs, samples taken from metal stock solutions (Merck Co. Darmstadt, Germany) with 1000 mg/L concentration were diluted to the required volumes with 0.1 mol/L HNO_3. The HR CS FAAS device variables, limits of detection and the calibration variables obtained for the studied elements are given in Tables 2 and 3, respectively.

Risk assessment

The risk of heavy metal contaminated herbal preparations to human health was evaluated by considering estimated weekly intake (EWI) and the target hazard quotient (THQ). EWI (EPA 2019) was determined by $EWI = (M_c \text{ x } IR)/bw$, where M_C (μg/g) is an average weighted heavy metal content in traditional herbal preparations, IR (ingestion rate) is the average daily consumption of herbal preparations (g/day), bw is the body weight of the consumer (70 kg). Average daily consumption of herbal preparations for an adult is 2.2 g/day (Odukoya et al. 2021), while it was reported to be 159.9 g/day for *Hordeum vulgare* (Liu et al. 2020).

Table 2. HR CS FAAS parameters and limits of detection (3σ, 11 repetitions).

Variables	Pb	Ni	Cd	Al	Cr	Cu	Fe	Mn	Zn	Co	Ca	Mg
Wavelength, nm	217.0	232.0	228.8	396.15	359.34	324.75	248.32	279.48	213.85	240.72	422.67	285.2
N_2O-C_2H_2 flow rate, L/h	0	0	0	215	0	0	0	0	0	0	215	0
C_2H_2-air flow rate L/h	65	55	50	55	100	55	60	80	60	60	50	70
Burner height, mm	8	7	6	7	7	6	5	8	8	6	6	5
Evaluation Pixels, pm	3	3	3	3	3	3	3	3	3	3	3	3
LOD (mg/L))	.005	0.0012	0.0004	0.022	0.005	0.001	0.001	0.001	0.001	0.002	0.011	0.028

Table 3. Calibration curves by equation y = axe + b.

Metal	Calibration curve (mg/L)	Correlation coefficient (R^2)
Pb	y = 0.0249378×+0.000441	0.9984
Ni	y = 0.0453089× + 0.0029071	0.9951
Cd	y = 0.1668653×+0.0082612	0.9913
Al	y = 0.0019453× + 0.00039	0.9865
Cr	y = 0.0266211×+ 0.0029627	0.9820
Cu	y = 0.0961918× + 0.0034074	0.9982
Co	y = 0.0603994×+0.0017350	0.9987
Fe	y = 0.0369983×+0.0003667	0.9950
Mn	y = 0.1038852×+0.0074565	0.9940
Zn	y = 0.1929504×+0.0270448	0.9740
Ca	y = 0.0879944×+0.0698533	0.9985
Mg	y = 0.2780105×+0.1243556	0.9950

THQ represents the non-carcinogenic impact risk for the consumer. The exposure parameters in the calculation of THQ values were obtained from the studies by Ametepey et al. (2018), Odukoya et al. (2021) and Wongsasuluk et al. (2014). It was calculated by THQ = [(EF x ED x IR x Mc)/(RfD x BW x AT)] x 10^{-3}, where ED is the lifetime (69 year) exposure, EF is the exposure frequency (365 day/year), AT is the average exposure time (EF x ED: 25185) and RfD is the reference dose of the metal (mg/kg/day). RfD is the daily maximum acceptable oral dose of a toxic substance to which a consumer can be exposed without any significant risk of harmful health effects during his lifetime. RfD for Ni, Cu, Al, Cu, Fe, Mn and Zn is 0.02 mg/kg/day, 0.0004 mg/kg/day, 0.04 mg/kg/day, 0.7 mg/kg/day, 0.14 mg/kg/day and 0.3 mg/kg/day, respectively (EPA 2011a, 2011b, 2016). The PTWI values (FAO/WHO 2004, 2011; EPA 2014) are given in Table 4.

Results and discussion

Plant parts used as food of eight plant species obtained from herbalists in Mauritania were analysed for elemental content by FAAS. Accuracy of the analytical method was tested with the results obtained for the standard reference material NIST SRM 1570a (Trace Elements in Spinach Leaves). The relative error between certified and measured values was less than 5% (Table 5).

Table 4. Provisional tolerable weekly intake (PTWI) values for metals.

Metal	PTWI (µg/week/bw)	Reference	PTWI (µg/week/70 kg bw)
Pb	25	FAO/WHO (2004)	1750
Ni	35	FAO/WHO (2004)	2450
Cd	7	FAO/WHO (2004)	490
Al	28.6	FAO/WHO (2011)	2000
Cr	23.3	FAO/WHO (2004)	1631
Cu	3 500	FAO/WHO (2004)	245 000
Fe	5 600	FAO/WHO (2004)	392 000
Mn	980	EPA (2014)	68 600
Zn	7 000	FAO/WHO (2004)	490 000

Table 5. Certified reference material analysis in triplicate.

Element	Found (µg/g)	Certified (µg/g)	Relative error (%)
Ni	2.08 ± 0.12	2.14 ± 0.11	−2.8
Cd	2.96 ± 0.02	2.89 ± 0.06	2.4
Cu	12.8 ± 0.5	12.2 ± 0.61	4.9
Mn	74.8 ± 0.9	76.0 ± 1.2	−1.58
Zn	79.25 ± 3.22	82 ± 3.28	−3.35

Minimum and maximum values for each element in the parts of the studied plants were determined as 0.51–16.1 mg/g (mean 4.92 mg/g) for calcium, 2.63–6.49 mg/g (mean 3.70 mg/g) for magnesium, 11.2–201 µg/g (mean 62.5 µg/g) for aluminium, 6.5–28.2 µg/g (mean 16.01 µg/g) for zinc, 5.6–453 µg/g (mean 146 µg/g) for iron, 1.1–6.4 µg/g (mean 2.9 µg/g) for nickel, 11.0–302 µg/g (mean 54.5 µg/g) for manganese and 0.7–9.0 µg/g (mean 5.27 µg/g) for copper. Chromium, lead, cadmium and cobalt levels were below the limits of detection in all samples. The mean metal contents of plant parts studied of the plant species are given in Table 6.

Quantitative testing of a variety of trace element concentrations is important to determine the efficacy of medicinal plants for treatment of a variety of diseases and to understand their pharmacological effects (Abugassa et al. 2008; Seddigi et al. 2016; Ciftci et al. 2020). Also, the WHO emphasises the need to ensure analytical checks, especially toxic metals in medicinal plants, for quality control of herbal products (WHO 2015b). However, there are no standards for medical raw plant materials, which establish a maximum level of metals in such materials (Zinicovscaia et al. 2020). The WHO only mentions arsenic, cadmium and lead when it comes to define maximum levels in raw plant materials, which are 1.0, 0.3, and 10 mg/kg, respectively (Łozak et al. 2002). For this reason, other elemental levels in our study were compared with the maximum levels determined for vegetables according to the WHO (FAO/WHO 2004, 2007a, 2007b, 2011; WHO 2007). Some elements have no established maximum level in medical plants, so that the health risk can be evaluated by simple comparison with toxicological parameter controlled by regulatory authorities, in this case, the provisional maximum tolerable daily intake (PMTDI) or PTWI, when available, can be used (FAO/WHO 2004, 2011; EPA 2014). In general our results are consistent with those reported in previous studies in the literature. Specific findings in this study are given below as per element.

Iron serves as a cofactor in fundamental biochemical processes such as oxygen transport, energy metabolism, and DNA synthesis in almost all cells. It is abundant in red blood cells and muscle tissue. However, it's important to note that high doses of iron can potentially cause hepatotoxicity. There have been reports of acute liver

Table 6. Metal levels ($n = 3$) in some endemic medicinal plant species (*µg/g, **mg/g).

Plant name	*Fe	*Mn	*Cu	*Ni	*Zn	*Al	**Ca	**Mg
Acacia senegal	5.6 ± 0.3	11.0 ± 0.56	0.7 ± 0.05	1.1 ± 0.05	13.6 ± 0.68	11.2 ± 0.5	5.50 ± 0.29	2.84 ± 0.16
Psoralea plicata	86.0 ± 4.8	20.3 ± 1.12	9.0 ± 0.45	1.2 ± 0.07	28.2 ± 1.43	72.5 ± 1.5	4.20 ± 0.23	3.38 ± 0.28
Acacia nilotica	37.5 ± 2.3	27.1 ± 1.4	8.4 ± 0.43	6.4 ± 0.35	15.9 ± 0.9	11.2 ± 0.4	0.77 ± 0.05	3.20 ± 0.18
Hordeum vulgare	35.2 ± 1.8	13.1 ± 0.71	4.5 ± 0.26	1.9 ± 0.1	21.4 ± 1.1	14.6 ± 0.75	0.51 ± 0.03	2.86 ± 0.16
Senna alexandrina	323 ± 6.46	25.4 ± 1.30	2.5 ± 0.15	2.0 ± 0.1	6.5 ± 0.36	58.1 ± 1.2	16.1 ± 0.85	5.04 ± 0.28
Balanites aegyptiaca	165 ± 3.28	11.3 ± 0.60	5.5 ± 0.30	3.3 ± 0.18	6.8 ± 0.40	97.4 ± 1.9	1.57 ± 0.08	2.63 ± 0.17
Tamarindus indica	63.7 ± 3.35	26.5 ± 1.38	8.8 ± 0.46	3.1 ± 0.17	13.0 ± 0.68	34.5 ± 0.8	0.96 ± 0.06	3.13 ± 0.15
Maytenus senegalensis	453 ± 9.06	302 ± 6.03	2.8 ± 0.16	4.2 ± 0.23	22.7 ± 1.16	201 ± 4.1	9.70 ± 0.51	6.49 ± 0.32

failure in young adults following an overdose of ferrous sulphate. Iron deficiency due to eating disorders may cause anaemia (Daram and Hayashi 2005). In our study, the highest mean iron amount (453 ± 9.1 µg/g) was observed in the leaves of *Maytenus senegalensis* while the lowest amount (5.6 ± 0.3 µg/g) was identified in gum like part of *Acacia senegal*. Seddigi et al. (2016) assessed the metal content of plants commonly used in Saudi Arabia and determined iron levels of 48.8–231 µg/g (Seddigi et al. 2016). A study by de Aragão Tannus et al. (2021) identified iron levels as 8.54–628 µg/g in medicinal plants. The estimated iron levels in some vegetables were limited to 450 mg/kg according to WHO/FAO (WHO 2007). In our study, the iron levels in the parts of the plants examined slightly exceeded the limit for *Maytenus senegalensis*, while in the other plants they were within international standards.

Manganese is an essential element involved in several physiological processes in the body. It functions as a component of metalloenzymes responsible for the oxidation of cholesterol and fatty acids. Deficiency of manganese may cause bleeding disorders, while excessive amounts may cause speech disorders, leg cramps and encephalitis (EFSA Panel on Dietetic Products and Allergies 2013). In the investigated plants, the highest mean manganese amount (302 ± 6 µg/g) was observed in the leaves of *Maytenus senegalensis*, while the lowest amount (11.0 ± 0.56 µg/g) was found in gum like part of *Acacia senegal*. A study by Zinicovscaia et al. (2020) determined the mean manganese concentration as 90.8 mg/kg as a result of elemental analysis of medicinal and aromatic plants grown in the Republic of Moldova. Subramanian et al. (2012) identified the mean Mn content in two tropical plants as 47.3 and 1.8 mg/kg. The maximum manganese level permitted for vegetables by WHO/FAO is 500 mg/kg (FAO/WHO 2007a). The plants analysed were below his level.

Copper is an essential trace element involved in many physiological processes in the human body. It is a critical component of several transcription factors and enzymes. However, it's important to note that excessive copper intake can potentially cause liver damage and contribute to the development of Wilson's disease, a genetic disorder that affects copper metabolism. Conversely, copper deficiency can lead to adverse health effects, including an increased risk of aneurysms, vein damage, hernias, and nosebleeds (Araya et al. 2006). The highest mean copper amount (9.0 ± 0.45 µg/g) in plants investigated in our study was found in the flower of *Psoralea plicata*, while the lowest value (0.7 ± 0.05 µg/g) was found in the gum like part of *Acacia senegal*. A study by Santos et al. (2017), determined the macro and micro element contents of nine healing plants and herbal medications from Brazil. They identified the copper concentrations in samples as 0.32–7.82 µg/g. Singh et al. (2010) identified the level of copper in plants collected from India in their study as 3.7–30.1 mg/kg. FAO/WHO (2007b) determined the copper level for some vegetables as 40 mg/kg. The copper levels in the plants analysed were below this level.

Nickel is generally absorbed by the body as the Ni^{+2} ion and causes neurotoxicity with distribution to a variety of tissues including the brain. Nickel is cytotoxic for human lymphocytes and is associated with increased reactive oxygen species formation, potential collapse of mitochondrial membrane, glutathione consumption, lysosomal membrane injury, cellular proteolysis and caspase-3 activation (Genchi et al. 2020). The highest mean nickel amount (6.4 ± 0.35 µg/g) in the investigated plants was identified in the seeds of *Acacia nilotica*, with the lowest amount (1.1 ± 0.05 µg/g) found in the gum like part of *Acacia senegal*. Literature reported nickel levels in different medicinal plant samples of <LOD-32.2 µg/g (Soylak et al. 2012); 1.0–2.6 µg/g (Seddigi et al. 2016) and (< LOQ–0.99) µg/g (de Aragão Tannus et al. 2021). According to WHO, the daily nickel intake is limited to 100–300 µg (FAO/WHO 2004), far above the measured levels.

Zinc is a basic element and cellular zinc supports homoeostatic control to prevent accumulation of excess zinc. Exposure to excessive zinc may cause copper deficiency and cell apoptosis. Additionally, zinc deficiency is associated with suppressed immune responses. Zinc and copper are considered important to metabolise glucose and to lower cholesterol (Hambidge and Krebs 2007). The highest mean zinc amount (28.2 ± 1.43 µg/g) was observed in the flowers of *Psoralea plicata*, the lowest

(6.5 ± 0.36 µg/g) in the leaves of *Senna alexandrina*. A study in Brazil of nine medicinal plants and herbal medicine samples by Santos et al. (2017), identified Zn content as 2.96–20.9 µg/g. Zinicovscaia et al. (2020) measured mean Zn levels of 31.6 mg/kg in a study of 45 plant species belonging to the Lamiaceae family grown in the Republic of Moldova. The maximum zinc level for vegetables by WHO/FAO (2007b) is 60 mg/kg, which was not exceeded in the analysed plants.

Aluminium is a metal that is not essential for the human body. Acute and chronic aluminium exposure has several negative health effects including encephalopathy, dialysis dementia, Alzheimer and Parkinson disease (Ding et al. 2021). The highest mean aluminium level (201 ± 4.1 µg/g) in the investigated plants was observed in the leaves of *Maytenus senegalensis* and the lowest value (11.2 ± 0.4 µg/g) was identified in the seeds of *Acacia nilotica* and in the gum like part of *Acacia senegal*. Leal et al. (2013) reported aluminium levels in the leaves of *Maytenus ilicifolia* from 31 to 298 µg/g. Aluminium content of 648 mg/kg in plants from the *Lamiaceae* family grown in the Republic of Moldova was reported (Zinicovscaia et al. 2020). Al content of herbal medications from Brazil was determined as 20.2–1262 µg/g (de Aragão Tannus et al. 2021). According to FAO and WHO (2011) the PTWI of aluminium in food is 2 µg/g body weight. In a study conducted by Ding et al. (2021) to monitor aluminium content in foods and assess dietary exposure among residents of Northern China, the average dietary aluminium exposure was 1.82 mg/kg body weight/week, which is below the PTWI. They concluded that the management of Al-containing food additives should be strengthened and Al content in starchy products should be monitored. According to the aluminium levels found in this study, it is important to monitor the accumulation of toxic elements, especially if high amounts of these plants are consumed.

Calcium is an element most commonly found in the body and its intake definitely required. It plays a regulatory role in many enzyme systems. Calcium is the main compound in bones and teeth. This element acts in cell membranes and muscles by regulating endo-exoenzymes and blood pressure (Tahri et al. 2014). The highest mean calcium amount (16.1 ± 0.85 mg/g) in the investigated plants was found in the leaves of *Senna alexandrina*, with lowest amount (0.51 ± 0.03 mg/g) found in the seeds of *Hordeum vulgare*. Begaa et al. (2018), determined a calcium level of 14,040 mg/kg in *M. Spicata* species, which is used in the traditional medicine of Algeria, especially for the treatment of digestive disorders. Zinicovscaia et al. (2020) determined the calcium level in the plant species belonging to the *Lamiaceae* family grown in the Republic of Moldova as 16,910 mg/kg. Santos et al. (2017) determined the calcium levels ranging from 100.7–462.2 mg/kg in nine medicinal plants and herbal medicine samples taken from Brazil.

Magnesium is reported to be an important mineral (macro element) for many biological processes such as nerve conduction, muscle contraction and the occurrence of more than 300 enzymatic reactions (Ivy and Portman 2004). Mg found in the adult human body, nearly 40% is in muscles and soft tissue, nearly 1% is in extracellular fluids and the remainder is in the skeletal system (Council 1989). The highest mean magnesium level (6.49 ± 0.32 mg/g) in the investigated plants was observed in the leaves of *Maytenus senegalensis*, while the lowest amount (2.84 ± 0.16 mg/g) was found in the gum like part of *Acacia senegal*. Santos et al. (2017) reported 18.4–521 µg/g Mg in nine medicinal plant and herbal drug samples from Brazil. The results show that analysed plants may be a potential source of macronutrients contributing to treatment of disorders due to deficiencies of these elements (Ca, Mg).

In the literature, a variety of studies were performed to identify elemental levels in medicinal and aromatic plants and to understand their pharmacological effects. Studies show that the leaf, flower, fruit, seed portions of some medicinal and aromatic plants used by people may accumulate significant amounts of heavy metals or medicinal plants and phytomedicinals contain significant amounts of Ca, Cu, Fe, Mg, Mn and Zn (Santos et al. 2017; Begaa et al. 2018; Zinicovscaia et al. 2020; de Aragão Tannus et al. 2021). With the aim of assessing possible health risks due to consumption of these plant species, EWI and THQ calculations were performed and results are given in Tables 7 and 8, respectively. The calculated EWI values were compared with the PTWI values given in Table 4. The elemental levels in the analysed medicinal plants were below these limits. THQ was calculated to assess the non-carcinogenic health risks for the estimated toxic metals in the investigated plants. THQ values less than 1 do not cause a clear risk for the population exposed to the metals in the medicinal plants. If THQ is 1 or above, the risk is assessed as unacceptable. Only the THQ value for Al was above 1 for all plants, except *Acacia senegal* and *Acacia nilotica*. This variability in Al levels may be explained by environmental and agronomic conditions, growth in contaminated areas and storage conditions. Nevertheless Al in plants comprises a non-carcinogenic risk for consumers.

Table 7. EWI values for a consumer with 70 kg body weight.

Plant name	Fe	Mn	Cu	Ni	Zn	Al
Acacia senegal	0.18	0.35	0.02	0.04	0.43	0.35
Psoralea plicata	2.70	0.64	0.28	0.04	0.89	2.28
Acacia nilotica	1.18	0.85	0.26	0.20	0.50	0.35
Hordeum vulgare	80.4	29.9	10.3	4.34	48.9	33.4
Senna alexandrina	10.15	0.80	0.08	0.06	0.20	1.83
Balanites aegyptiaca	5.18	0.36	0.17	0.10	0.21	3.06
Tamarindus indica	2.00	0.83	0.28	0.10	0.41	1.08
Maytenus senegalensis	14.2	9.48	0.09	0.13	0.71	6.31

Table 8. THQ values for identified elements in the medicinal plant samples.

Plant name	Fe	Mn	Cu	Ni	Zn	Al
Acacia senegal	0	0	0	0	0	0.88
Psoralea plicata	0	0	0.01	0	0	5.70
Acacia nilotica	0	0.01	0.01	0.01	0	0.88
Hordeum vulgare.	0.11	0.22	0.26	0.22	0.16	83.4
Senna alexandrina	0.01	0.01	0	0	0	4.57
Balanites aegyptiaca	0.01	0	0	0.01	0	7.65
Tamarindus indica	0	0.01	0.01	0	0	2.71
Maytenus senegalensis	0.02	0.07	0	0.01	0	15.8

Conclusions

In conclusion, periodic assessment of metal concentrations in medicinal and aromatic plants used in traditional medicine and creation of quality control criteria for these products, due to unwanted high levels of toxic metal content, is important in terms of herbal product safety and public health. Additionally, it is necessary to perform comprehensive risk assessment for toxic elements in future studies to evaluate the public or patient health risks. In the study, it was identified that aluminium comprises a non-carcinogenic risk for consumers. As samples consisted only of 1 or few plants, it could be possible the total THQ value could exceed the value of 1, indicating a risk for consumers. Thus, more research is necessary to identify the total THQ for the actual consumption. According to the aluminium levels found in this study, when plants are consumed at high amounts, especially elemental accumulation should be monitored.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Cigdem Er Caliskan, Kubra Ozturk and Vatimetou Ethmane. The first draft of the manuscript was written by Harun Ciftci, Cigdem Er Caliskan and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was supported by the project numbered ZRT. A4.20.018 of Kırşehir Ahi Evran University Scientific Research Projects Unit.

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