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Metals and metalloid in medicinal plants: occurrence and risk assessment to human health

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Abstract

Aim: This study was aimed at determining the levels of trace elements in six medicinal plants of tropical origin.

Methods: The levels of As, Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn in *Albizia glaberrima* (AG), *Aristolochia ringens* (AR), *Brysocarpus coccineus* (BC), *Ipomoea asarifolia* (IA), *Sansevieria liberica* (SL), and *Telfairia occidentalis* (TO) were determined using an inductively coupled plasma-mass spectrometry. The estimated dietary intakes of the metals, hazard quotients (HQ), and hazard index (HI) were calculated.

Results: The highest levels of Cd, Pb, Zn, and Fe were detected in IA. BC had the highest levels of Mn and Ni while AR had the highest levels of Cu, Co, and As. However, the levels of the metals were mostly below the permissible limits in the plants. The estimated dietary weekly intakes (EWIs) were below the provisional tolerable weekly intake for each chemical element. The EWIs range values were 21.566–643.114 μg/kg per day (kg is the unit of body weight), 0.008–1.529 μg/kg per day, 0.6–7.815 μg/kg per day, 67.569–215.889 μg/kg per day, 4.305–185.451 μg/kg per day, 0.225–1.704 μg/kg per day, 1.03–10.2 μg/kg per day, 0.933–2.286 μg/kg per day, and 62.554–854.4 μg/kg per day for Cu, Cd, Pb, Zn, Mn, Co, Ni, As, and Fe, respectively. The HQ values of the elements were less than 1 except for Cu in AR (1.321). The values of lifetime cancer risks exceeded the permissible limit in all the plant materials.

Conclusions: The findings from the study revealed that the consumption of TO, SL, and AG for medicinal purposes has no inherent non-carcinogenic toxicity while the consumption of AR, IA, and BC has some risks of non-carcinogenic toxic. However, the six plant materials showed inherent risks of carcinogenic events, as such their use for medicinal purposes must be cautious, maybe by reducing both the ingestion rate and the frequency of intake.

Keywords

Traditional medicine, medicinal plants, toxic elements contamination, health risk assessment, inductively coupled plasma-mass spectrometry

Introduction

The awareness of medicinal plants' potential in treating several human ailments has increased considerably over the years [1, 2]. The increased acceptance of medicinal plants in human treatments could be partly due to their availability, cost-effectiveness, and potency, with little or no side effects, compared to orthodox medicines that are often associated with certain side effects [3, 4]. Traditionally, herbal medicines are taken as a decoction in which the bioactive ingredients in the plant materials are extracted in solvents such as water or ethanol [5].

The tropical and subtropical climates support the cultivation of important botanicals that exhibit medicinal properties [6–8]. The pharmacological properties of these botanicals have been attributed to certain bioactive constituents and secondary metabolites such as flavonoids, polyphenols, saponins, and tannins [9, 10]. The potential of plant materials has been optimally explored in some countries, especially in Asia, where plant-based traditional medicine and herbal remedies are quite popular [11, 12].

The six plant materials being considered in this study have demonstrated ample medicinal properties. The different parts of *Sansevieria liberica* (SL, Agavaceae), commonly referred to as the "African bowstring hemp", have shown to be promising in treating human diseases. The juice extracted from its leaf has been used to treat venereal diseases, including gonorrhea. The leaf sap is used for treating ulcers, and when topically applied, it is used for treating toothache. The fermented rhizome has also been used for malaria treatment, and root decoction has been used to treat convulsions [13, 14]. Similarly, the various leaf extracts have demonstrated anticancer potentials both *in vitro* and *in vivo* [15]. *Ipomoea asarifolia* (IA, Convolvulaceae), commonly known as "morning glory", has been used to treat malaria, diabetes, rheumatism, elephantiasis, and syphilis [16]. The leaf extracts of *Brysocarpus coccineus* (BC) are analgesic, antidiarrheic, sedative, and antipyretic [17]. Also, the extracts of *Albizia glaberrima* (AG) have analgesic, anti-inflammatory, and antipyretic properties [18]. The leaf extracts of *Telfairia occidentalis* (TO) were anti-inflammatory and antinociceptive [19], while the root extract of *Aristolochia ringens* (AR) had anticancer activity [20].

Notwithstanding the numerous health benefits of medicinal plants, their inherent contamination with toxic chemical elements is a public health concern. Some studies have reported elevated levels of toxic elements in medicinal plants from different parts of the world. Luo et al. [21] detected Cd, Pb, As, and Hg in Chinese medicinal herbs at levels that pose serious risks to human health. In a study on Indian medicinal plants, the levels of Cd and Hg were detected at concentrations that exceeded the permissible levels for the elements in medicinal plants [22]. In Brazilian medicinal plants, the detected levels of most elements were within the acceptable limits except for Cd which was present at levels higher than the acceptable limit [23]. The contamination of medicinal herbs with toxic elements has been linked to various human anthropogenic activities, which release the toxic chemical elements (including toxic metals and metalloids) into the environment and are subsequently uptake by the plants from the soil [24]. The literature is rich on the adverse effects of toxic chemical elements on humans such as carcinogenicity, immunotoxicity, oxidative stress, organ damage, and competition with essential elements such as Zn and Gu, thus limiting their bioavailability [25–28].

The regulation of contaminants (toxic metals, in particular) in medicinal plants is lacking or poorly enforced in several countries, especially in Africa [29, 30]. Given the evidence that toxic metals sometimes accumulate within the plant tissues and the wide consumption of medicinal plants for health purposes, studies on health risk assessment of contaminants in medicinal plants become imperative. Therefore, this study aimed to determine the levels of some metals and metalloids in six Nigerian medicinal plants and perform a risk assessment of the elements through the consumption of these plants.

Materials and methods

Collection and preparation of plant materials

The plant materials used in the study were the roots of AR and SL, the leaves of BC, IA, and TO, and the stem bark of AG. The plant materials were obtained from different parts of Nigeria; the details, including classification, source, and reported medical benefits, are shown in Table 1. The plant materials were identified and authenticated at the Forestry Research Institute of Nigeria (FRIN), Ibadan, Nigeria, and the Department of Botany, Faculty of Science, University of Lagos, Lagos, Nigeria.

Table 1. Some details about the medicinal plants used in the study

Medicinal plant	Common name	Family	Collection site	Medicinal uses	References
AG	White nongo	Leguminosae	Abatadu village, Ikire Osun State, Nigeria (7°30'0"N, 4°30'0"E)	Fever, pain, epilepsy, rheumatism, and inflammation	[18, 50]
AR	Dutchman's pipe or Snakework	Aristolochiaceae	Mushin, Lagos State, Nigeria (6°32'0"N, 3°21'0"E)	Cancer, asthma, skin diseases, typhoid, sores, snake poison, diabetes, parasitic infections, inflammation	[20, 51–53]
BC	Crimson thyme	Connaraceae	Iju-Ogundimu, Ifako-Ijaiye, Lagos State, Nigeria (6°39'50"N, 3°20'17"E)	Swellings, tumors, hemorrhage, pain, diarrhea, skin and mouth disorders, German measles, jaundice, gonorrhea, urinary problems, impotence, anemia, primary and secondary sterility	[17, 50, 54–56]
IA	Morning glory	Convolvulaceae	Akinmorin Town, Oyo State, Nigeria (7°46'59"N, 3°57'0"E)	Malaria, diabetes, rheumatism, elephantiasis, syphilis, neuralgia, arthritic pain, and stomach ache	[16, 57]
SL	African bowstring hemp	Agavaceae	Mushin, Lagos State, Nigeria (6°32'0"N, 3°21'0"E)	Cancer, gonorrhea, ulcer, toothache, malaria, convulsion	[13–15]
TO	Fluted pumpkin	Cucurbitaceae	Oshodi, Lagos, Nigeria (6°30'51"N, 3°18'31"E)	Cancer, diabetes, cardiovascular diseases, infertility, anaemia, inflammation	[19, 58]

N: northern latitude; E: east longitude

The roots of AR and SL, and the stem bark of AG were chopped into small pieces and allowed to air-dry in the laboratory until constant weights were obtained. Also, fresh leaves of BC, IA, and TO were air-dried at room temperature until constant weights were obtained. The dried plant materials were pulverized into powder using a blender. The plant powder was digested following the methods reported by Adeyemi et al. [31]. A portion of 100 mg of each powder was weighed in triplicate into a polypropylene tube of 15 mL, followed by the addition of 1 mL of nitric acid (20% v/v, CAS: 7697-37-2, Sigma-Aldrich) and 2 mL of hydrogen peroxide (30% v/v, CAS: 7722-84-1, Sigma-Aldrich). The mixture was placed in a microwave oven (Ethos D, Milestone, Sorisole, Italy) for 40 min to effect digestion. The digests were allowed to cool and made up to 10 mL with ultrapure water (Milli-Q System).

Determination of levels of elements in the plant materials

The levels of the following elements, As, Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn were determined in the digests of the plant materials using an inductively coupled plasma mass spectrometer (ICP-MS) equipped with a reaction cell (DRC-ICP-MS ELAN DRCII, PerkinElmer, Sciex, Norwalk, CT, USA). The equipment was operated with high-purity argon (99.999%, Praxair, Brazil). The samples were introduced into the equipment through a quartz cyclonic spray chamber and a Meinhard nebulizer connected by Tygon® tubes to the ICP-MS's peristaltic pump (set at 35 r/min). The ICP-MS was operated with a Perkin Elmer platinum sampler and skimmer cones. The standards were prepared by the multi-element stock solution containing 10 mg/L of each element. The internal standard (10 mg/L Rh, CAS: 7440-16-6, Perkin Elmer) was added online. Before each run, 0.005% (v/v) Triton X-100 (CAS: 9036-19-5, Sigma-Aldrich) in 2% (v/v) nitric acid (HNO_3, CAS: 7697-37-2, Sigma-Aldrich) was prepared and applied as the rinse solution.

Quality control of data

The accuracy of the method used for the elemental analyses was checked by determining the levels of elements in a standard reference material, SRM 8415 whole egg powder, which was obtained from the National Institute of Standards and Technology (NIST). The whole egg powder was digested along with the plant powders, and the digests were quantified for elemental composition. The measured concentrations of the elements were compared to the targeted values for each element, and the measured and targeted values were similar (Table 2). The method limit of detection (LOD) was determined using the equation formula:

$$LOD = 3.3 \times (SD/slope)$$

Where SD represents the standard deviation of twenty consecutive measurements of the blanks, and the slope was determined from the calibration curve. The LODs were 0.034 ng/g, 0.008 ng/g, 0.006 ng/g, 0.479 ng/g, 2,081 ng/g, 0.096 ng/g, 0.507 ng/g, 0.059 ng/g, and 7.302 ng/g for As, Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn, respectively. The method's precision for between- and within-batch analyses for the element was less than 14% and 5%, respectively (n = 10, SRM 8415 whole egg powder).

Table 2. The concentrations of elements in the NIST standard reference material (SRM 8415 egg powder)

Analytes	Target value	Detected value
As (ng/g)	10	14 ± 0.1
Cd (ng/g)	5	4 ± 0.2
Co (ng/g)	12 ± 5	17 ± 3
Cu (µg/g)	2.7 ± 0.35	3.1 ± 0.3
Mg (µg/g)	305 ± 27	290 ± 21
Mn (µg/g)	1.78 ± 0.38	1.74 ± 0.3
P (mg/g)	10.01 ± 0.32	9.74 ± 0.43
Sb (µg/g)	2	1.73 ± 0.12
Se (mg/g)	1.39 ± 0.17	1.44 ± 0.15
V (µg/g)	459 ± 81	471 ± 27
Zn (µg/g)	67.5 ± 7.6	66.2 ± 3.7

The values are mean ± SD of five replicates

Non-carcinogenic risk assessment of consumption of medicinal plants

Estimation of dietary intakes of metals/metalloid

The dietary intake of each element was calculated using the formula:

$$EDI = C_m \times IR/\text{body weight}$$

In the equation, EDI corresponds to the estimated dietary daily intake µg/kg per day (kg is the unit of body weight), C_m is the mean concentration of the element as determined in the samples (µg/g), and IR is the ingestion rate of the medicinal plant. The IR values in unfinished herbal products are lacking. However, the IR was assumed to be 200 g/day in this study, representing a worst-case scenario [32]. Subsequently, the estimated dietary weekly intakes (EWIs) were calculated by multiplying the EDI values by 3 (frequency of consumption per week). The EWI values were then compared with the provisional tolerable weekly intake (PTWI) values for each element obtained from the Joint Food and Agriculture Organization (FAO)/World Health Organization (WHO) Expert Committee on Food Additives (JECFA).

Estimation of chronic dietary daily intake of metals/metalloids

The chronic dietary daily intake of the elements was calculated based on the reported study by Geronimo et al. [33] using the formula:

$$CDI = EDI \times EFr \times ED_T/AT$$

Where CDI is the chronic dietary daily intake (µg/kg per day), EFr is the frequency of exposure, which is taken to be 90 days, the ED_T is the total exposure duration, taken as 30 years for a non-carcinogenic chronic exposure in an adult while AT is the average exposure time (days) for a non-carcinogenic event in an adult, which is taken as 30 years × 365 days/year = 10,950 days.

Estimation of target hazard quotients and total hazard index

The target hazard quotients (HQ) for each element were determined using the formula:

$$HQ = CDI/R\mathit{f}D$$

R*f*D is the oral reference dose for each element. The R*f*D values (µg/kg per day) used were obtained from the United States Environmental Protection Agency as follows: Cu: 40, Cd: 0.5, Pb: 3.5, Rb: 5, Zn: 300, Mn: 140, Se: 5, Co: 0.3, Ni: 20, As: 0.3, and Fe: 700. A target HQ (THQ) value (< 1) is considered no risk while THQ values (> 1) are considered to have non-carcinogenic risks. The total hazard index (THI) was calculated by finding the summation of the THQs for all the elements of each plant material.

Estimation of lifetime cancer risks

The lifetime cancer risks (CR) of As, Cd, Ni, and Pb were estimated using the formula:

$$CR = (EDI \times EFr \times ED_T^{*}/AT^{*}) \times SF$$

Wherethe ED_T^{*} is taken as 70 years for a carcinogenic chronic exposure in an adult while AT^{*} is the average exposure time (days) for a carcinogenic event in an adult, which is taken as 70 years × 365 days/year = 25,550 days, and SF is the slope factor taken as 1.5 mg/kg per day, 6.7 mg/kg per day, 0.91 mg/kg per day, and 0.0085 mg/kg per day for As, Cd, Ni, and Pb respectively.

Statistical analyses

The data on the levels of elements in the plant materials were first checked for normality using the Shapiro-Wilk test, and because the data did not fit the Gaussian distribution, significant differences in the mean concentrations were determined non-parametrically using the Kruskal-Wallis test. This was followed by Dunn's multiple comparison tests in circumstances of significant differences. The data were presented as mean ± SD. Statistical analyses were performed with GraphPad Prism (version 8), and statistical significance was assumed at $P < 0.05$.

Results

Levels of metals/metalloids in medicinal plants

The concentrations of the metals/metalloids in the plant materials are shown in Table 3. The mean levels of the elements differed significantly among the medicinal plants ($P < 0.05$). The highest Cd, Pb, Zn, and Fe levels were detected in IA. BC had the highest levels of Mn and Ni, while the highest Cu, Co, and As levels were detected in AR. Although several metals/metalloids were detected in the medicinal plants, however, the levels were mostly below the permissible limits for each of the elements set by the JECFA, except for Mn, As, and Fe in which the levels were above the permissible limits in some plants. The levels of detected Mn were above the permissible limit in five (BC, AG, AR, SL, and IA) of the six medicinal plants used in the study. The levels of As in IA were about 10-fold higher than the permissible limit, while the levels of detected Fe in AR, and IA were well above the allowable limit.

EWIs of metals/metalloids through consumption of medicinal plants

The EWIs values of the elements through the consumption of medicinal plants are shown in Table 4. The EWIs ranges were 21.566–43.114 µg/kg per day, 0.008–1.529 µg/kg per day, 0.281–7.815 µg/kg per day, 67.569–215.889 µg/kg per day, 4.305–185.451 µg/kg per day, 0.225–1.704 µg/kg per day, 1.03–10.2 µg/kg per day, 0.933–2.286 µg/kg per day, and 62.554–854.4 µg/kg per day for Cu, Cd, Pb, Zn, Mn, Co, Ni, As, and Fe respectively. The highest EWIs of Cd, Pb, Zn, and Fe were detected in IA, BC had the highest EWIs of Mn and Ni, while the highest EWIs of Cu, Co, and As were detected in AR.

Non-carcinogenic and carcinogenic risk assessments

The CDI and HQ/hazard index (HI) for the elements in the medicinal plants are shown in Tables 5 and 6, respectively. The non-carcinogenic risk assessment of the metals/metalloids through the consumption of

Table 3. Levels of metals and metalloids (μg/g) in Nigerian medicinal plants

Elements	BC	AG	AR	TO	SL	IA	PL
Cu	2.516 ± 0.121^{a}	2.794 ± 0.249^{a}	75.03 ± 0.202^{b}	3.626 ± 0.49^{a}	3.065 ± 0.136^{a}	3.159 ± 0.321^{a}	150
Cd	0.002 ± 0.000^{a}	0.001 ± 0.000^{a}	0.008 ± 0.001^{b}	0.003 ± 0.000^{a}	0.008 ± 0.000^{b}	0.178 ± 0.000^{c}	0.3
Pb	0.254 ± 0.001^{c}	0.033 ± 0.002^{a}	0.379 ± 0.034^{d}	0.084 ± 0.004^{b}	0.07 ± 0.000^{b}	0.912 ± 0.118^{e}	10
Zn	7.883 ± 0.119^{a}	8.997 ± 0.314^{a}	9.715 ± 0.056^{a}	10.528 ± 0.823^{a}	13.709 ± 1.499^{b}	25.187 ± 0.063^{c}	50
Mn	21.636 ± 3.47^{d}	2.016 ± 0.062^{b}	3.397 ± 0.164^{b}	0.502 ± 0.013^{a}	7.118 ± 0.033^{c}	2.098 ± 0.055^{b}	2
Co	0.158 ± 0.005^{c}	0.026 ± 0.002^{a}	0.199 ± 0.002^{c}	0.033 ± 0.000^{a}	0.093 ± 0.018^{b}	0.12 ± 0.006^{b}	0.48
Ni	1.19 ± 0.029^{c}	0.298 ± 0.017^{b}	0.748 ± 0.02^{bc}	0.369 ± 0.18^{b}	0.416 ± 0.091^{b}	0.12 ± 0.006^{a}	1.5
As	0.166 ± 0.024^{b}	0.122 ± 0.001^{a}	0.267 ± 0.019^{b}	0.206 ± 0.036^{a}	0.109 ± 0.001^{a}	0.138 ± 0.006^{a}	10
Fe	7.746 ± 0.1585^{a}	7.298 ± 0.024^{a}	33.53 ± 0.427^{b}	17.2 ± 1.46^{a}	14.58 ± 5.694^{a}	99.68 ± 4.044^{c}	20

Data with the same superscripts in the same row are not statistically different from one another. Values are mean ± SD of three replicates. The SD values which are less than 0.0001 were written as 0.000 in this table. PL: permissible limits

Table 4. EWIs (μg/kg per day) of metals and metalloids in Nigerian medicinal plants

Medicinal plants	Cu	Cd	Pb	Zn	Mn	Co	Ni	As	Fe
BC	21.566	0.014	2.177	67.569	185.451	1.351	10.2	1.424	66.394
AG	23.949	0.008	0.281	77.117	17.28	0.225	2.555	1.043	62.554
AR	43.114	0.065	3.247	83.271	29.117	1.704	6.409	2.286	287.4
TO	31.08	0.025	0.719	90.24	4.305	0.284	3.162	1.769	147.429
SL	26.271	0.073	0.6	117.506	61.011	0.797	3.567	0.933	124.971
IA	27.077	1.529	7.815	215.889	17.983	1.03	1.03	1.184	854.4
PTWI*	3,500	7	25	7,000	2,500	NE	35	15	5,600

* Values are obtained from the JECFA. NE: not estimated

medicinal plants was performed by calculating the values of HQs and HIs for each element. The HQ and HI values (< 1) are considered safe and non-carcinogenic, while HQ and HI values (> 1) pose health risks to consumers [21]. The HQ values of the elements were less than one except for Cu in AR in which the HQ was 1.321. The THI values were 1.035, 0.454, 2.601, 0.705, 0.652, and 1.271 for BC, AG, AR, TO, SL, and IA respectively. The plant materials can therefore be arranged as AR > IA > BC > TO > SL > AG with the first three considered non-carcinogenic risky.

Table 5. Estimated CDI (μg/kg per day) of metals and metalloids in Nigerian medicinal plants

Plants	Cu	Cd	Pb	Rb	Zn	Mn	Se	Co	Ni	As	Fe
BC	1.773	0.001	0.179	7.022	5.554	15.243	2.983	0.111	0.838	0.117	5.457
AG	1.968	0.001	0.023	8.916	6.338	1.42	2.588	0.019	0.21	0.086	5.141
AR	52.859	0.005	0.267	8.786	6.844	2.393	1.444	0.14	0.527	0.188	23.622
TO	2.555	0.002	0.059	16.559	7.417	0.354	2.177	0.023	0.26	0.145	12.117
SL	2.159	0.006	0.049	18.276	9.658	5.015	0.566	0.066	0.293	0.077	10.272
IA	2.226	0.126	0.642	17.744	17.744	1.478	1.544	0.085	0.085	0.097	70.225

Table 6. THQ and THI of metals and metalloids in Nigerian medicinal plants

Plants	Cu	Cd	Pb	Zn	Mn	Co	Ni	As	Fe	THI
BC	0.044	0.002	0.051	0.019	0.109	0.37	0.042	0.39	0.008	1.035
AG	0.049	0.001	0.007	0.021	0.01	0.062	0.011	0.286	0.007	0.454
AR	1.321	0.011	0.076	0.023	0.017	0.467	0.026	0.626	0.034	2.601
TO	0.064	0.004	0.017	0.025	0.003	0.078	0.013	0.485	0.017	0.705
SL	0.054	0.012	0.014	0.032	0.036	0.218	0.015	0.256	0.015	0.652
IA	0.056	0.251	0.184	0.059	0.011	0.282	0.004	0.324	0.1	1.271

The estimation of lifetime CR of four known carcinogenic metals (As, Cd, Ni, and Pb) is shown in Table 7. The range values of estimated CR were 0.004–0.842, 0.002–0.382, 0.077–0.763, and 0.115–0.282 for Cd, Pb, Ni, and As respectively.

Table 7. Lifetime CR of metals and metalloids in Nigerian medicinal plants

Plants	Cd	Pb	Ni	As
BC	0.007	0.002	0.763	0.176
AG	0.004	0.014	0.191	0.129
AR	0.036	0.159	0.479	0.282
TO	0.014	0.035	0.237	0.218
SL	0.04	0.029	0.267	0.115
IA	0.842	0.382	0.077	0.146

Discussion

The mean levels of the elements detected in the medicinal in this study were comparable to the levels determined for each element in studies from other countries of the world, such as Bangladesh, Brazil, Ghana, Turkey, and India [33–36]. The presence of metals in the plant tissues indicates possible contamination of the soils with toxic metals/metalloids, which were then taken up by the plants through the root [24, 37, 38].

Some elements were detected at levels lower than those detected in medicinal plants from other parts of the world. For example, the detected levels of cadmium in this study were about ten-fold lower than the values detected in medicinal plants from India (< LOD = 4×10^{-4}) and Brazil (< LOD = 7×10^{-4}) [33, 39]. The detection of metals in the plant materials at low levels in this study was due to the sensitivity of the equipment used for the elemental analyses (ICP-MS). The limits of detection for most of the elements were in the range of part per trillion. This was in contrast to the studies by Kulhari et al. [39] and Geronimo et al. [33], in which the sensitivity of the equipment for elemental analyses was low, and that could explain the reason why certain elements were detected even at low levels in this study.

Most of the elements detected in the medicinal plants in this study are essential elements known to play important physiological and biochemical roles in humans. In this context, Cu, Zn, and Mn are known to play essential roles in maintaining the redox homeostasis of the body through their potential to scavenge deleterious reactive oxygen species [40, 41]. Fe is an important component of hemoglobin, the molecule responsible for transporting oxygen and other nutrients within the body [42]. Co is a component of vitamin B12 required for red blood cell formation [43]. However, the plant materials also detected certain toxic elements such as Cd, Pb, As, and Ni. These elements are known to cause various physiological disorders in humans; Cd and Pb have been shown to be carcinogenic and nephrotoxic, causing damage to the kidney [44, 45]. They have also been able to cause oxidative stress in humans [46]. As has reportedly resulted in endocrine disruption, immune dysfunction, and disruption of cellular metabolism in humans [27, 28]. Ni is carcinogenic and causes damage to important body organs such as the lungs, stomach, and kidneys [26]. Comparing the EWI values of the elements in the plant materials to the PTWI values for each element revealed that the levels were below the limits for all the elements. Based on the PTWI values, the consumption of medicinal plants to treat ailments and diseases may not pose health risks to humans.

Although several studies have evaluated the risk assessment of toxic metals through the consumption of herbal medicines, however only one study has performed the risk assessment of AR of the six plant materials used in this study [47], while this is the first study to carry out a risk assessment of toxic metals in the remaining five plant materials. The use of HQ and hazard indices for risk assessments of toxicants in food or edible substances is quite popular [47, 48]. The data obtained from the calculation of the HQ alone implies that all six plant materials were safe for human consumption, considering their HQ values were less than 1. However, when considering the HI values, three plant materials were safe for consumption without risk of non-carcinogenic events. At the same time, the other three, AR, IA, and BC were found to have potential risks of non-carcinogenic toxicity. These findings were similar to the reports of Odukoya et al. [47], which also reported a high risk of non-carcinogenic toxicity due to the consumption of AR from Nigeria. In another study, Ghasemidehkordi et al. [49] reported an HQ value of less than 1 for Hg through consumption of herbs collected from Iran, which would imply a no risk of non-carcinogenic toxicity. However, this assumption could not be upheld when the HI value was considered. Hence, the risk assessment of non-carcinogenic toxicity of edible substances should include multiple parameters. Little is still known about the impacts of environmental contaminants in herbal products on human health probably due to the paucity of human biomonitoring studies on this topic, as such future research efforts should be geared in this direction, which will help to better understand the risks of environmental contaminants in herbal products.

The acceptable limits of CR of toxic metals ranged between 10^{-6} to 10^{-4} [21]. The estimated CR of the elements in all the six plants in the present study exceeded this range, hence there are potential risks of carcinogenic events through consumption of these medicinal plants. These findings are particularly unexpected since As, Cd, Ni, and Pb have been reported as carcinogens [21, 25–28].

In conclusion, the results from this study showed that the six medicinal plant materials used in this study contained the analyzed metals and metalloids at comparable levels or below those detected in medicinal plants from other parts of the world. More importantly, the elements were present at levels that were well below the permissible limits for each of the elements set by the Joint Committee of the FAO and WHO, except for occasional instances in a few plants where the levels of Mn, As, and Fe were above the permissible limits. The multi-parameter risk assessment of non-carcinogenic toxicity of the metals indicated that the consumption of TO, SL, and AG for medicinal purposes has no inherent non-carcinogenic toxicity while the consumption of AR, IA, and BC may come with certain risks of non-carcinogenic toxic effects. Although, the obtained results suggest that the consumption of most of the plants did not pose serious risks of non-carcinogenic toxicity, however, there are inherent risks of carcinogenic toxicity through consumption of the plants for medicinal purposes, as such their use for medicinal purposes must be cautious maybe by reducing both the IR and the frequency of intake.

Abbreviations

AG: Albizia glaberrima

AR: Aristolochia ringens

BC: Brysocarpus coccineus

CDI: chronic dietary daily intake

CR: cancer risks

EDI: estimated dietary daily intake

EWIs: estimated dietary weekly intakes

HQ: hazard quotients

IA: Ipomoea asarifolia

ICP-MS: inductively coupled plasma mass spectrometer

IR: ingestion rate

JECFA: the Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives

LOD: limit of detection

PTWI: provisional tolerable weekly intake

SD: standard deviation

SL: Sansevieria liberica

THI: total hazard index

THQ: target hazard quotients

TO: Telfairia occidentalis

Declarations

Author contributions

JAA: Conceptualization, Methodology, Formal analysis, Funding acquisition, Writing—original draft, Writing—review & editing. AJA: Conceptualization, Formal analysis, Data curation, Writing—original draft, Writing—review & editing. OSS, BAR, VCdOS, VOB, and MCOS: Methodology, Formal analysis, Data curation, Writing—original draft, Writing—review & editing. COA: Conceptualization, Formal analysis, Writing—review & editing, Supervision. FBJ: Conceptualization, Formal analysis, Funding acquisition, Writing—review & editing, Supervision.

Conflicts of interest

Bruno A. Rocha is the GE of Exploration of Foods and Foodomics, but he had no involvement in the journal review process of this manuscript. The authors declare that they have no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publication

Not applicable.

Availability of data and materials

The raw data supporting the conclusions of this manuscript will be made available by the author (Joseph A. Adeyemi, jaadeyemi@futa.edu.ng), without undue reservation, to any qualified researcher.

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