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Comparative Evaluation of Metal Content and Health Risk Assessment of *Garcinia huillensis* Using Acid Digestion and Hot-Water Extraction Methods

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ABSTRACT

Metal composition and health risk assessment of *Garcinia huillensis* (Clusiaceae) were investigated. Root, stem, and leaf samples were analysed using two extraction methods: acid microwave digestion and hot water extraction, and the results were compared. ICP-OES was employed to determine the concentrations of metals present in the samples. Both extraction methods revealed high concentrations of essential nutritional metals. Acid digestion showed elevated levels of potassium (6628.64–15764.52 mg kg^{-1}), calcium (5452.39–38158.925 mg kg^{-1}), magnesium (424.86–2071.71 mg kg^{-1}), and sulfur (736.86–2918.33 mg kg^{-1}). Similarly, hot water extraction recorded potassium levels of 6709.11–14203.98 mg kg^{-1}, calcium 705.19–2380.59 mg kg^{-1}, magnesium 232.64–2213.93 mg kg^{-1}, and sulfur 316.35–1897.01 mg kg^{-1}. Heavy metal analysis indicated the presence of aluminium (Al), zinc (Zn), copper (Cu), and iron (Fe), whereas lead (Pb), manganese (Mn), lithium (Li), and vanadium (V) were not detected in the extracts. The acid digestion method generally produced higher metal concentration values compared to the hot water extraction method. Hot water extraction method was found to be safe for consumers, as all detected heavy metals had estimated daily intake (EDI) values of less than 1. These findings suggest that *G. huillensis* is safe for traditional medicinal use.

KEYWORDS

Health risk assessment, Heavy metal Content, *Garcinia huillensis*, Medicinal plant, Hot water extraction

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INTRODUCTION

Interest in medicinal plants among scientists has steadily increased because of their therapeutic potential.[1,2] Plant-based remedies have long been used to treat various ailments, particularly in rural areas where access to medical facilities is limited. In addition, the incorporation of plant remedies into modern healthcare practice has increased significantly. Owing to this growing interest in traditional medicine, the efficacy and safety of these remedies must be scientifically validated. Such validation can also provide evidence supporting their potential as sources of beneficial nutrients.[1,2]

Garcinia huillensis belongs to the Clusiaceae family, which comprises a wide variety of Garcinia species. The plant contains a broad range of natural compounds, including flavonoids, phenolics, terpenoids, and xanthones. *Garcinia huillensis* has traditionally been used to treat ailments such as diabetes, inflammation, and stomach disorders.[3,4]

Plants contain both nutritional and toxic elements, including heavy metals. Nutritional elements play essential roles in supporting human health and well-being. Elements such as calcium (Ca), magnesium (Mg), zinc (Zn), and potassium (K) are important for maintaining normal body functions.[5,6] On the other hand, the presence of high concentrations of heavy metals such as cobalt (Co), aluminium (Al), and lead (Pb) poses significant risks to human health.[7] It is therefore important to analyse both nutritional and toxic metals in this medicinal plant to determine its safety. Although some studies have investigated the metal content of *G. huillensis,* only the microwave acid-digestion extraction method has been employed previously.[8] In the present study, two extraction methods—microwave acid digestion and hot water extraction—were used, and the resulting metal concentrations were compared. This evaluation will help determine the safety of the plant's use as a traditional medicine.

The root, stem, and leaf extracts of *G. huillensis* (Clusiaceae) were analysed for the presence of nutritional elements and heavy metals. The plant samples were collected from Mufulira, a town predominantly associated with copper (Cu) mining activities, which are known sources of heavy metal contamination.[9] Consequently, heavy metal pollution is a major concern in Mufulira, as is common in many mining towns. Mining activities can result in the accumulation of toxic metals such as Pb, Cu, Co, and Al, thereby affecting soil and water quality.[10] Studies have reported adverse effects on human health resulting from exposure to heavy metals.[11,12] Other studies have also investigated heavy metal contamination in areas associated with mining activities.[13–18] Owing to its extensive industrial and mining activities, there is a high likelihood of soil contamination with heavy metals, which may subsequently influence metal accumulation in plants.[19]

This study therefore aims to evaluate the metal content of *G. huillensis* by comparing two extraction methods, acid microwave extraction and hot water extraction, and to assess the safety of the hot-water extraction method traditionally used by healers, thereby providing valuable information on the plant's safety for use in traditional medicine and its potential incorporation into modern healthcare practices.

EXPERIMENTAL

Plant samples

The plant was identified and verified at the Herbarium of the Forest Department of the Ministry of Green Economy and Environment in Kitwe, Zambia. Fresh plant samples were collected in Mufulira town. The stems, roots, and leaves of *G. huillensis* were harvested, washed with ultra-pure water, and packed in UV-resistant brown envelopes. They were then dried in the shade. The materials were then pulverized using an electric motor into a fine powder for further analysis.

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Chemicals

The chemicals used in this study were obtained from Merck, Johannesburg, South Africa. These included HPLC-grade acetonitrile (ACN, ≥99.9%), 65% HNO_3, and H_2O_2. Ultra-pure water was obtained from the laboratory at the University of the Witwatersrand. A multi-element standard solution was used for the calibration of inductively coupled plasma optical emission spectroscopy (ICP-OES) (Spectro, Kleve, Germany) with concentrations ranging from 0.1 mg L^{-1} to 10 mg L^{-1}. The standards were prepared from a 1000 mg L^{-1} stock solution dissolved in 5% HNO_3. Ultra-high-purity argon gas was used during ICP-OES operation to ensure accurate measurements. [20, 21]

Metal extraction

Acid microwave digestion

The microwave acid-metal extraction of plant samples was done using the method by Thabit et al. with some modifications.[22] Briefly, dried, pulverised plant samples were sieved using a 25-micron sieve. Thereafter, 0.25 g of the samples was weighed directly into 50 mL poly (PTFE-TFM) digestion vessels. This was followed by the addition of 18 mL concentrated HNO_3 and 3 mL of H_2O_2; the well-closed vessels were placed in the microwave 5000 digester (Anton Paar, Switzerland). The heating parameters of the microwave were set at 80 °C for 10 min, then increased to 180 °C and kept constant for 30 min. The digested samples were allowed to cool, then filtered using 0.22 µm PTFE filters and diluted to a final volume of 50 mL using ultra-pure water. Blank sample preparations followed the same protocol as the test samples. Triplicate samples were analysed in each case.

Hot-water extraction

The hot-water metal extraction was done by first measuring 2 g of powdered sample into heating beakers. Then, 40 mL of ultra-pure water was added and heated at a temperature between 90 and 95 °C and was left to boil for 10 min. The extract was cooled and centrifuged at 4000 rpm for 20 min to separate solids from the solution. A 0.22 µm PTFE filter was then used to filter the extract. Triplicate samples were analysed in each case.

Quality control and assurance

The glassware was carefully handled and cleaned to ensure accuracy and reliability of the results. Rinsing of glassware and dilution of reagents were done using ultra-pure water. To calibrate the instrument, blank analytes were used. To ensure accuracy and precision, the analysis was repeatedly checked. The validation of the method was done through the limits of detection (LOD) and the limit of quantification (LOQ), including the spike recovery test. The method as outlined by Chibuye et al. was used for the calculation of LOD, LOQ, and recoveries.[23]

Metal concentration determination

Measurement and Analysis of various concentrations of metals were done using the ICP-OES (Spectro, Kleve, Germany). The analysis was done for metals such as aluminium, calcium, cobalt, chromium, copper, iron, potassium, magnesium, sodium, nickel, lead, molybdenum, lithium, silicon, titanium, and vanadium. To identify and measure the metals, the method described by Chibuye et al. was used.[23] External standard solutions of 1000 mg L^{-1} concentration were used to determine the level of each metal before calibration. The instrument's parameters were well set to achieve accuracy and precision. Metal analysis was done with the following parameters: nebulizer flow at 1.0 mL min^{-1}, nebulizer pressure at 2.81 bar, plasma power at 1400 W, a pump speed of 2 rpm, a coolant flow at 14 mL min^{-1}, a replicate read time was set at 10 s, a rinse time at 10 s, a sample uptake delay at 30 s, an auxiliary flow of 1.5 mL min^{-1}, and an instrument stabilization time at 20 s. The tests were run in triplicate, and the results are reported as the average ± standard deviation (SD).

Assessment of human health risks of metals

Assessment of health risks was done by use of estimated daily intake (EDI) calculations of metals, the hazard indices (HI), and the hazard quotient (HQ). The EDI value was calculated using equation (1).[23]

$$EDI = \frac{C_{metal} \times IR}{Bw} \quad (1)$$

C_{metal} is the concentration of metals (mg kg^{-1}) as determined in the raw plant material. IR is the daily average consumption rate of raw material from a medicinal plant, estimated at 0.06 kg/day.[23, 24] Bw is the average body weight and is estimated to be 70 kg for the Zambian adult.[23, 24]

The hazard quotient (HQ) used to determine the health dangers of non-cancerous substances was evaluated using the formula in equation (2).[23, 24]

$$THQ = \frac{EDI}{RfD} \quad (2)$$

Where R_fD represents the recommended daily intake of the metal amounts.

The hazard index (HI) used to evaluate the overall non-cancerous health risk is the sum of hazard quotients.

Carcinogen risk (CR) was evaluated using the formula given in equation (3).[23, 24]

$$CR = EDI \times CPSo \quad (3)$$

Where, CPSo is the oral slope factor.

Statistical analysis

Microsoft Excel was used to plot the graphs for the metal concentration. All measurements were done in triplicate and are expressed as a mean ± standard deviation (SD). Statistical significance differences were calculated using the t-test and one-way ANOVA, with $p<0.05$.

Toxicity analysis using ProTox-II

The toxicity prediction and analysis of toxic heavy metals was done using the online web tool ProTox-II (https://ox-new.charite.de/protox) accessed on 02/12/2025.

RESULTS AND DISCUSSION

In this study, we determined the metal content of the medicinal plant *G. huillensis*. Two extraction methods were employed: acid microwave digestion and hot-water extraction, and the results were compared. The findings showed that acid microwave digestion yielded higher metal concentrations, whereas hot-water extraction resulted in lower metal concentrations.

We also assessed the potential health risks associated with the medicinal use of the plant by calculating the estimated daily intake (EDI) of metals, as well as the hazard quotient (HQ) and hazard index (HI) for heavy metals. The results indicated that samples obtained through acid microwave digestion contained metal ions at high concentrations, with calculated values exceeding the recommended safe limits, suggesting potential health risks if consumed over a prolonged period. In contrast, the assessment of hot-water extracts showed that the calculated health risk values were within acceptable safe limits, indicating no significant danger when the extracts are used for medicinal purposes.

Quality assurance

The R^2 (coefficient of determination) values were all above 0.995. R^2 measures how well the experimental data fit a calibration curve or regression line. It indicates the degree of correlation between the concentration of an analyte and the instrument response. To assess the metal content in various parts of the medicinal plant, concentrations

of several metal ions were measured. The limits of detection (LOD), limit of quantification (LOQ), and the recovery rates were determined and are presented in Table 1.

The spike recovery results demonstrated acceptable analytical accuracy for most metal ions, having recoveries ranging between 90–110%. However, low recoveries has been seen for Na, Mo, Si, S, Mn, Ti, and K, which could suggest possible matrix interferences, incomplete digestion, ionization effects, and spectral overlaps.[25] The extremely low recovery for Si particularly could indicate inefficient dissolution of silicate matrices during digestion.[26] These findings may require further optimization of sample preparation and instrumental conditions to quantify these elements accurately.

Total metals in the plant biomass and comparison with hot water extraction

The evaluation of raw plant extracts of *G. huillensis* revealed the presence of various metal ions in different quantities across the stem, root, and leaf extracts. The metal ions detected in the stem, root, and leaf extracts are: K, Na, Ca, Mg, Al, Cr, Cu, Fe, Mn, Si, Ti, and Zn. The sample extracts were also evaluated for the presence of metals such as Co, Ni, Pb, Mo, Li, and V, which were not detected in the samples. Two extraction methods were explored in this study: acid digestion and hot water extraction. The results for the acid digestion method are presented in Table 2, while those for the hot water extraction method are presented in Table 3. Figure 1 compares the concentrations of the metal ions obtained by the two extraction methods. The results show the concentrations of the metal ions (mean ± SD, N = 3) together with the maximum and minimum values (mg kg-1) on a dry weight basis. The EDI, measured in mg/day, is presented in Table 4 for acid digestion and in Table 5 for hot water extraction. The HQ and hazard index are reported in Table 6 for acid digestion and in Table 7 for hot water extraction. Analysis of cancer risk (CR) associated with the prolonged consumption of these various parts of the *G. huillensis* plant is provided for acid digestion and hot water extraction.

A comparison of Tables 2 and 3, indicate the acid digestion method shows higher mean concentrations across all metals compared to the hot-water extraction.

Human health risk assessment

The evaluation of the plant extracts from the root, stem, and leaf of *G. huillensis* has revealed the presence of both nutritional metal ions and heavy metal ions (toxic metals). The nutritional ions identified are K, Na, Ca, Mg, and S. All these ions are important to human health. However, high metal concentrations can be harmful to the human body.[27, 28] As the results indicate, all these ions are present at higher concentrations in all three parts of the plant using both extraction methods: acid digestion and hot water extraction (Figure 1). For instance, among the nutritional metals, calcium was found to have the highest concentration in the root sample at 38180.3 ± 29.0 mg kg^{-1}, whereas the same calcium had a concentration of 2380.7 ± 0.2 mg kg^{-1}, which was the highest concentration recorded in the leaf sample using the hot water extraction method. This trend was observed across all the metal ions for the two extraction methods (Figure 1).

The observed high concentrations of these nutritional ions indicate that *G. huillensis* could be a good source of these nutrients. However, their concentrations should be closely monitored, as they are significantly higher than the recommended values. For instance, the recommended dietary allowance (RDA) for potassium is 3400 mg/day, for calcium it is 1200 mg/day, while that of magnesium is 420 mg/day. These nutrients may contribute to the traditional therapeutic benefits of the plant; however, consumption patterns should remain moderate since the RDA values are lower than the plant's dry-weight concentration values.

Regarding the heavy metal concentration analysis in *G. huillensis*, it can also be observed that the acid digestion method recorded higher concentrations of these metals in the plant samples compared to the concentrations obtained using the hot water extraction method. For example, aluminium (Al) was found to have the highest concentration in the stem sample at 18059.6 ± 59.4 mg kg^{-1} (Table 2), compared to the highest concentration of 1141.8 ± 0.1 mg kg^{-1} for the same aluminium in the leaf sample using the hot water extraction method (Table 3). In general, the acid digestion method indicated higher concentrations of these metal ions in the sample extracts, whereas the hot water extraction method indicated lower concentrations of the metals (Figure 1).

Table 1: Instrumental LOD, LOQ, and percent recovery.

Metal	LOD (mg L^{-1})	LOQ (mg L^{-1})	R^2	Spike Recovery (%)
Al	0.170	0.523	0.999	86.76
Co	0.154	0.471	0.999	99.95
Cr	0.072	0.226	0.995	90.18
Cu	0.431	1.305	0.999	98.14
Fe	0.140	0.421	0.999	100.23
K	0.978	2.987	0.998	79.66
Na	1.233	3.726	0.995	24.98
Ca	0.146	0.447	0.999	102.35
Mg	0.072	0.221	0.999	104.67
S	0.122	0.368	0.999	53.59
Mn	0.063	0.179	0.999	58.84
Ni	0.214	0.641	0.999	96.68
Pb	0.189	0.584	0.999	102.10
Mo	0.037	0.117	0.999	25.34
Li	0.174	0.313	0.995	78.46
Si	0.205	0.618	0.999	8.73
Ti	0.181	0.324	0.999	74.83
Zn	0.118	0.358	0.999	99.97

Table 2. Microwave acid digestion, total metal concentration (mg kg^{-1}) of the root, stem, and leaf of *G. huillensis*.

	Leaf			Root			Stem		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Nutritional metals									
K	9092.2±13.8	9108.6	9083.6	6660.8±54.9	6724.3	6629.5	15872.1±110.1	15984.5	15764.5
Na	8509.9±3.6	8512.9	8506.0	452.3±2.4	455.1	450.4	539.8±0.5	540.3	539.3
Ca	12740.4±106.0	12862.3	12669.3	38180.3±29.0	38213.4	38158.9	5453.1±0.6	5453.7	5452.3
Mg	2075.3±5.2	2081.3	2071.7	425.1±0.3	425.5	424.5	1352.6±2.1	1355.1	1351.2
S	2950.2±53.6	3012.0	2918.3	799.8±1.3	801.2	798.58	738.3±2.4	741.0	736.8
Heavy Metals									
Al	340.7±0.2	340.9	340.6	1387.4±31.9	1424.3	1368.8	18059.6±59.4	18127.4	18016.6
Cr	ND	ND	ND	ND	ND	ND	129.9±0.1	130.0	129.8
Cu	ND	ND	ND	21.95±0.3	22.3	21.64	167.8±0.1	167.9	167.7
Fe	265.4±0.8	266.3	264.9	515.7±0.3	516.0	515.34	4255.3±10.5	4267.3	4247.3
Mn	1780.9±0.1	1781.0	1780.8	187.6±0.6	188.1	186.8	45.6±0.2	45.8	45.4
Si	347.0±0.5	347.5	346.6	1092.8±0.4	1092.5	1091.6	6446.2±9.8	6457.5	6440.1
Ti	40.4±0.8	41.35	39.8	50.3±1.1	51.4	49.2	83.1±0.5	83.7	82.6
Zn	25.8±0.2	25.97	25.6	41.6±0.3	42.0	41.3	77.5±0.4	77.9	77.0

Key: ND= Not detected.

Table 3. Hot water extraction, metal concentration (mg kg^{-1}) of the root, stem, and leaf of *G. huillensis*.

	Leaf			Root			Stem		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Nutritional metals									
K	14210.0±3.0	14210.0	14203.9	6710.5±1.4	6712.0	6709.1	6798.4±3.6	6802.0	6794.6
Na	97.6±0.1	97.7	97.5	23.8±0.1	23.9	23.7	ND	ND	ND
Ca	2380.7±0.2	2381.0	2380.5	705.6±0.4	706.0	705.1	1078.4±0.2	1078.6	1078.2
Mg	2214.4±0.8	2215.3	2213.9	264.9±0.8	265.8	264.4	232.5±0.1	232.8	232.5
S	1897.5±0.6	1898.2	1897.0	419.8±0.0	419.9	419.8	316.6±0.2	316.8	316.3
Heavy Metal									
Al	1141.8±0.1	1141.9	1141.6	48.7±0.2	48.9	48.4	9.6±0.1	9.8	9.5
CO	2.9±0.1	3.03	2.8	ND	ND	ND	ND	ND	ND
Cr	3.7±0.1	3.8	3.7	ND	ND	ND	ND	ND	ND
Cu	ND	ND	ND	0.9±0.1	1.0	0.8	5.1±0.0	5.2	5.1
Fe	5.6±0.2	5.8	5.4	ND	ND	ND	ND	ND	ND
Si	1075.3±10.7	1087.7	1068.5	786.3±0.6	787.0	785.8	982.5±0.2	982.6	982.2
Ti	ND	ND	ND	6.6±0.1	6.7	6.5	5.6±0.2	5.8	5.4
Zn	19.8±0.2	20.1	19.6	11.3±0.0	11.4	11.2	11.6±0.2	11.8	11.3

Key: ND= Not detected.

Studies have reported the health risks associated with heavy metal contents in medicinal plants used traditionally, and most of these studies have been based on acid digestion method analyses. [23, 24, 29-31] The comparative analysis conducted in this study tends to suggest that such analyses may overestimate the risks associated with the consumption of these metal ions in medicinal plants. As demonstrated in this study, the hot water extraction method appears to be a moderate and effective method, as the metals extracted were within acceptable standard limits, posing minimal health risks associated with the consumption of these heavy metal ions when the plant is used traditionally as a medicinal remedy.

It should be noted that the low levels of metal concentrations recorded in the hot water extraction method can be attributed to the fact that many metals are insufficiently soluble in neutral water to be effectively extracted, especially when they are present in solid matrices. Acid digestion, on the other hand, is capable of breaking down solid materials and converting them into soluble ions, leading to high recovery rates and, consequently, higher extraction of metals.[32]

Estimated daily intake for heavy metals

The daily intake dose (EDI) is calculated to quantify the acceptable amounts of metal ions that should go into the body system of a person based on their body weight.

The hot water extraction method shows moderate concentrations of heavy metals in *G. huillensis.* The EDI of heavy metals in the root, stem, and leaf of *G. huillensis* is generally low and within the acceptable levels set by the world health organisation (WHO) for the hot water method of extraction. With acid digestion, aluminium (Al) is found to be 0.292 mg kg^{-1}/day in leaf extract and 1.1 mg kg^{-1}/day in root, which are within the acceptable levels, except for the stem sample, which is said to be 15.4 mg kg^{-1}/day, far higher than the set limit of 1.0 mg kg^{-1}/

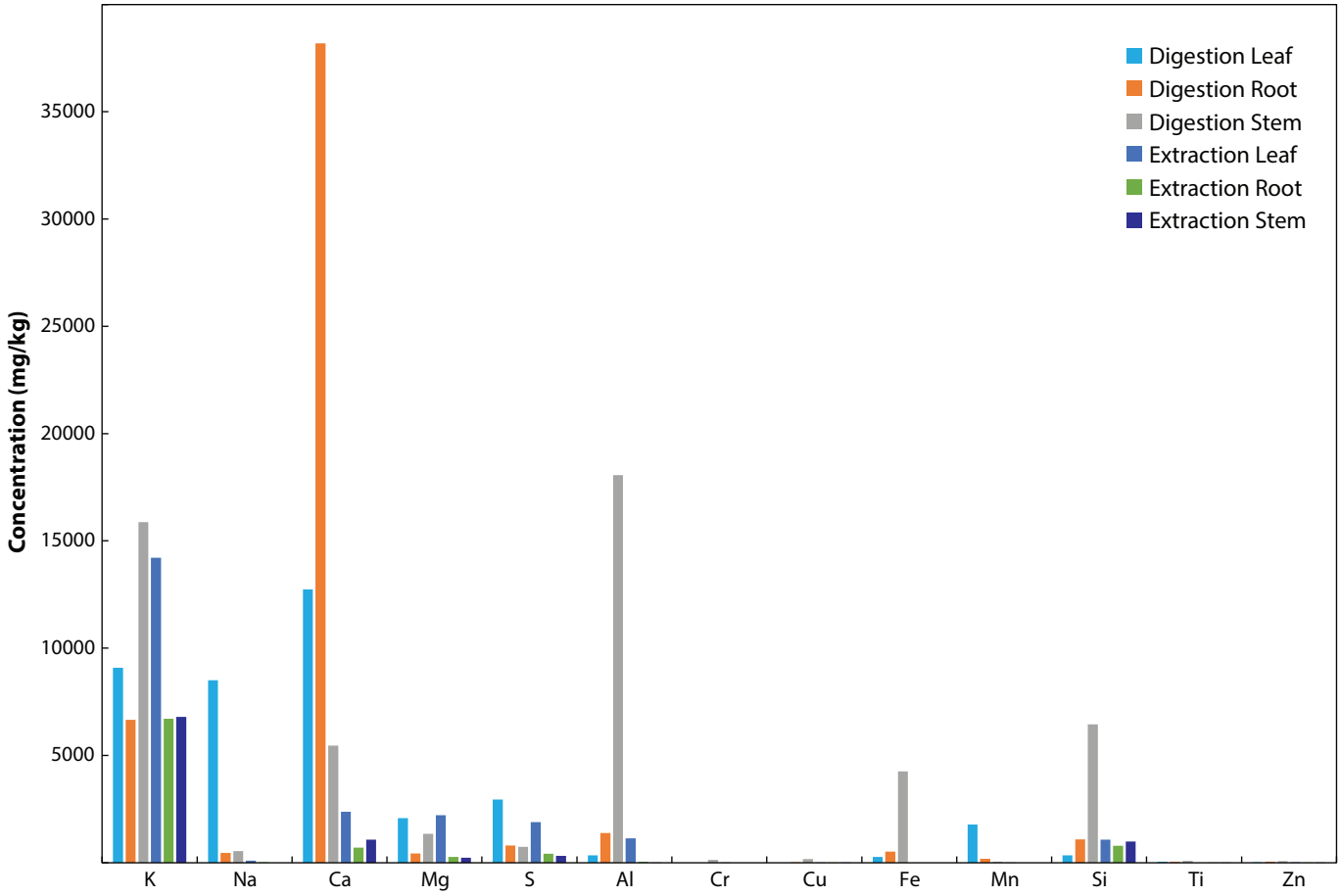


Figure 1: Comparison of metal concentration (mg kg^{-1}) in acid digestion and hot water extraction in leaf, root, and stem of *G. huillensis*.

Table 4. Estimated daily intake (EDI, mg kg^{-1}/day) of heavy metals in the stem, root, and leaf of *G. huillensis* (acid digestion).

Heavy metal	Leaf	Root	Stem bark	WHO/FAO Limit
Al	0.292	1.173	15.443	1.0
Cr	ND	ND	0.111	0.025-0.035
Cu	ND	0.018	0.144	0.5
Fe	0.227	0.442	3.641	8.0
Mn	1.526	0.160	0.039	1.8-2.3
Si	0.297	0.935	5.520	-
Ti	0.034	0.042	0.071	-
Zn	0.022	0.035	0.066	1.0

Key: ND= Not detected

Table 5. Estimated daily intake (EDI, mg kg^{-1}/day) of heavy metals in the stem, root, and leaf of *G. huillensis* (hot-water extraction).

Heavy metal	Leaf	Root	Stem bark	WHO/FAO Limit
Al	0.978	0.359	0.008	1.0
CO	0.002	ND	ND	0.05
Cr	0.003	ND	ND	0.025-0.035
Cu	ND	0.001	0.004	0.5
Fe	0.0047	ND	ND	8.0
Si	0.917	0.674	0.842	-
Ti	Nd	0.006	0.005	-
Zn	0.017	0.009	0.009	1.0

Key: ND= Not detected

Table 6: Hazard quotient (HQ) and hazard index (HI) of the root, stem, and leaf of *G. huillensis* (acid digestion).

Metal	Leaf	Root	Stem bark
Al	0.292	1.173	15.443
Cr	ND	ND	0.074
Cu	ND	0.450	3.600
Fe	0.324	0.631	5.201
Mn	10.900	1.142	0.278
Ti	0.011	0.014	0.024
Zn	0.073	0.012	0.220
Hazard Index (HI)	11.308	3.422	24.839

Table 7: Hazard quotient (HQ) and hazard index (HI) of the root, stem, and leaf of *G. huillensis* (hot-water extraction).

Metal	Leaf	Root	Stem bark
Al	0.098	0.359	0.008
Co	6.660	ND	ND
Cr	0.002	ND	ND
Cu	ND	0.021	0.110
Fe	0.007	ND	ND
Ti	ND	0.002	0.003
Zn	0.056	0.032	0.032
Hazard Index (HI)	6.82	0.414	0.154

day. However, when compared to the values of the same aluminium metal in the hot water extraction method, it indicates that all three samples, leaf, root and stem had the EDI values below the limit value, giving the values of 0.978 mg kg^{-1}/day for leaf, 0.359 mg kg^{-1}/day for root, and 0.008 mg kg^{-1}/day for the stem, which are all below the set limit of 1.0 mg kg^{-1}/day. These results indicate that the sample extracts of *G. huillensis* pose no risk to the consumer, with no significant health risk associated with their consumption, showing that the heavy metals present in this plant are within acceptable levels to human health. The hot water extraction method further gives justification as to its safety when using the plant for medicinal purposes.

Hazard quotient

Tables 6 and 7 give the HQ values for acid digestion and hot water extraction methods, respectively. Most metals had HQ values less than 1, except in the acid digestion method, where Al had a higher value of 15.4 in the stem, Mn with 10.9 in the leaf sample, Cu with 3.6, and Fe with 5.2 in the stem, indicating that they could pose some health risk when consumed over time. However, the HQ for all the heavy metals in the hot water extracted samples indicated a minimal presence of these metals across all the sample extracts, with values that are less than 1, except for Co, which had a value of 6.6. These results indicated that these metals posed no significant health risks. The HQ is used to determine the health dangers of non-cancerous substances to humans, which may come from long-term consumption of heavy metals, as they may be found in medicinal plants. When the value of HQ equals 1, it gives an indication of high potential health risks that might come with long-term consumption of the metal. These acceptable daily intake amounts are a guideline to the maximum quantity of a metal that is considered safe to be consumed per kilogram per day, proportionate to the body weight. The R_fD values for some metals are: copper (0.04 mg kg^{-1}), aluminium (1.0 mg kg^{-1}), zinc (0.3 mg kg^{-1}), iron (0.7 mg kg^{-1}), manganese (0.14 mg kg^{-1}), lead (0.0035 mg kg^{-1}), nickel (0.91 mg kg^{-1}), silver (0.005 mg kg^{-1}) and cobalt (0.0003 mg kg^{-1}) per day. [33, 34] When the Target Hazard Quotient (THQ) value is greater than 1, it indicates that the exposure to such a heavy metal could pose a health risk.[24, 35] Analysis of the overall HI, which is the summation of all THQ for detected heavy metals, indicates that the values are high in the acid digestion method, with the leaf at 11.308, the root at 3.422, and the stem at 24.839. The high value in the leaf can be attributed to Mn, which had an HQ value of 10.9, whereas the high value in the stem resulted from the elevated HQ values of Al (15.4) and Fe (5.2). As for the hot water extraction method, the overall Hazard Index (HI) for the detected heavy metals was less than 1 for both the root and stem extracts, with values of 0.414 and 0.154, respectively. However, the leaf extract had a HI value greater than 1 (6.82), which can be attributed to the high HQ value of Co (6.6). Overall, the hot water extraction method shows that the presence of these metals poses minimal or no risk to human health. Other studies have also reported samples having a higher health index, which was greater than 1.[36]

Cancer risk

Carcinogen risk (CR) gives the potential of developing cancer because of consuming a carcinogenic substance for a prolonged period of time by an individual. Looking at the potential cancer risk for these heavy metals, the results indicated that there is low or no risk, as most metals give values that indicate a non-carcinogenic effect. This is seen especially for the hot water extraction method, except for the stem extract in acid digestion, which gave a 3.088 value, which is more than the recommended value of 1.0**,** showing that long-term consumption of the stem extract can result in the development of cancer. Additionally, evaluation of the total cancer risk (CR) for heavy metals exposure indicates that these metals pose no carcinogenic danger that could come from consuming the extracts of *G. huillensis* over time. It should also be noted that heavy metals present in this plant, such as Ti, Zn, Cu, and Si, are classified as non-carcinogenic substances, hence posing no risk of causing cancer.[37, 38]

Statistical analysis

Statistically significant differences in metal ion concentration among the plant parts were calculated using the t-test and one-way ANOVA, with $p<0.05$. Results are presented in Tables 8 and 9 for acid microwave digestion and hot water extraction, respectively.

The metal ions analysis revealed significant variations ($p < 0.05$) in the concentrations of nutritional and heavy metal ions among the leaf, root, and stem samples. In hot water extraction, potassium was the most abundant nutritional metal ion in the leaves (14207.97 ± 3.49 mg kg^{-1}), followed by calcium and magnesium, indicating preferential accumulation of essential nutrients in foliar tissues. Leaves generally exhibited significantly higher concentrations of most nutritional metal ion compared to roots and stems.

Among the heavy metals, aluminum and silicon showed significantly higher accumulation in leaves than in other plant parts with concentrations of 1141.77 ± 0.15 and 1077.17 ± 9.75, respectively. Copper concentrations were significantly higher in stems than in roots, while titanium was significantly higher in roots than in stems. Metal ions such as cobalt, chromium, and iron were only detected in one plant organ.

Toxicity predictions of heavy metals

In this study, we predicted hepatotoxicity, neurotoxicity, nephrotoxicity, respiratory toxicity, cardiotoxicity, carcinogenicity, clinical toxicity, nutritional toxicity, and LD50 for the toxicity analysis of heavy metals. Table 10 shows the results of this analysis from *G. huillensis*.

The toxicity analysis of heavy metals present in *G. huillensis* shows both health and environmental implications. The hot water extraction method, which has proven to be the safer method of extraction, showed the presence of Al, Si, and Zn in root, stem, and leaf extracts, while Cu and Ti were present in root and stem extracts. All these heavy metals are predicted to be active for blood–brain barrier (BBB) penetration and ecotoxicity. Their ability to cross the blood–brain barrier increases

Table 8: Statistical analysis of metal ion composition of leaf, root, and stem samples for acid microwave digestion.

Metal	Leaf (mg kg^{-1})	Root (mg kg^{-1})	Stem (mg kg^{-1})
	Nutritional		
K	9094.8 ± 12.7^{b}	6671.5 ± 47.7^{c}	15873.7 ± 110.0^{a}
Na	8509.6 ± 3.5^{a}	452.6 ± 2.4^{c}	539.8 ± 0.5^{b}
Ca	12757.3 ± 98.0^{b}	38184.2 ± 27.4^{a}	5453.0 ± 0.7^{c}
Mg	2076.1 ± 4.8^{a}	425.0 ± 0.5^{c}	1353.0 ± 2.0^{b}
S	2960.2 ± 47.2^{a}	799.9 ± 1.3^{b}	738.7 ± 2.1^{c}
	Heavy		
Al	340.7 ± 0.2^{c}	1393.5 ± 28.4^{b}	18067.9 ± 55.8^{a}
Cr	ND	ND	129.9 ± 0.1
Cu	ND	22.0 ± 0.3^{b}	167.8 ± 0.1^{a}
Fe	265.5 ± 0.7^{c}	515.7 ± 0.3^{b}	4256.6 ± 10.0^{a}
Mn	1780.9 ± 0.1^{a}	187.5 ± 0.7^{b}	45.6 ± 0.2^{c}
Si	347.0 ± 0.5^{c}	1092.3 ± 0.6^{b}	6447.9 ± 8.9^{a}
Ti	40.5 ± 0.8^{c}	50.3 ± 1.1^{b}	83.1 ± 0.6^{a}
Zn	25.8 ± 0.2^{c}	41.6 ± 0.4^{b}	77.5 ± 0.5^{a}

* Values are presented as mean ± SD (n = 3). Means followed by different superscript letters within the same row are significantly different at $p < 0.05$ according to one-way ANOVA followed by pairwise t-test comparison. ND = Not Detected.

Table 9: Statistical analysis of metal ion composition of leaf, root, and stem samples for hot water digestion.

Metal	Leaf (mg kg^{-1})	Root (mg kg^{-1})	Stem (mg kg^{-1})
	Nutritional		
K	14207.97 ± 3.49^{a}	6710.53 ± 1.45^{c}	6798.33 ± 3.70^{b}
Na	97.60 ± 0.10^{a}	23.80 ± 0.10^{b}	ND
Ca	2380.57 ± 0.40^{a}	705.57 ± 0.45^{c}	1078.40 ± 0.20^{b}
Mg	2214.53 ± 0.71^{a}	265.03 ± 0.71^{b}	232.60 ± 0.17^{c}
S	1897.57 ± 0.60^{a}	419.83 ± 0.06^{b}	316.57 ± 0.25^{c}
	Heavy		
Al	1141.77 ± 0.15^{a}	48.67 ± 0.25^{b}	9.63 ± 0.15^{c}
Co	2.91 ± 0.12	ND	ND
Cr	3.73 ± 0.06	ND	ND
Cu	ND	0.90 ± 0.10^{b}	5.13 ± 0.06^{a}
Fe	5.60 ± 0.20	ND	ND
Si	1077.17 ± 9.75^{a}	786.37 ± 0.60^{c}	982.43 ± 0.21^{b}
Ti	ND	6.60 ± 0.10^{a}	5.60 ± 0.20^{b}
Zn	19.83 ± 0.25^{a}	11.30 ± 0.10^{c}	11.57 ± 0.25^{b}

*Values are presented as mean ± SD (n = 3). Means followed by different superscript letters within the same row are significantly different at $p < 0.05$ according to one-way ANOVA followed by pairwise t-test comparison. ND = Not Detected.

Table 10. Toxicity analysis of heavy metals in *G. huillensis*.

	Al	Ti	Cu	Si	Zn
Predicted LD50 (mg kg^{-1})	5000	420	413	3160	2000
Predicted toxicity class	5	2	4	5	4
Hepatotoxicity (prediction / probability)	I/0.98	I/0.98	I/0.98	I/0.98	I/0.98
Neurotoxicity (prediction / probability)	A/0.59	A/0.59	A/0.59	A/0.59	A/0.59
Nephrotoxicity (prediction / probability)	I/0.84	I/0.84	I/0.84	I/0.84	I/0.84
Respiratory toxicity (prediction / probability)	I/0.77	I/0.77	I/0.77	I/0.77	I/0.77
Cardiotoxicity (prediction /probability)	I/0.98	I/0.92	I/0.99	I/0.92	I/0.99
Carcinogenicity (prediction / probability)	I/0.71	I/0.65	I/0.62	A/0.56	I/0.62
Immunotoxicity (prediction /probability)	I/0.99	I/0.99	I/0.99	I/0.99	I/0.99
Mutagenicity (prediction / probability)	I/0.76	I/0.76	I/0.76	I/0.82	I/0.76
Cytotoxicity (prediction / probability)	I/0.79	I/0.79	I/0.79	I/0.79	I/0.79
BBB-Barrier	A/1.0	A/1.0	A/1.0	A/1.0	A/1.0
Ecotoxicity	A/0.85	A/0.85	A/0.85	A/0.80	A/0.85
Clinical toxicity (prediction / probability	I/0.84	I/0.84	I/0.84	I/0.86	I/0.84
Nutritional toxicity (prediction /probability)	I/0.53	I/0.53	I/0.53	I/0.68	I/0.53

Note: I = Inactive, A = Active

their potential to cause neurological damage, leading to chronic health issues.[39] Their ecotoxicity also suggests that their presence in the environment could have harmful effects on ecosystems. Al is predicted to have low acute toxicity, with a predicted toxicity class of 5 and a high LD50 of 5000 mg kg^{-1}. However, its presence in *G. huillensis* should still be of concern due to its predicted neurotoxicity, BBB penetration, and ecotoxicity.

Zn has a predicted toxicity class of 4, with a predicted LD50 of 2000 mg kg^{-1}. However, its activity for neurotoxicity, BBB penetration, and ecotoxicity suggests that it should be closely monitored. Si shows a similar trend to the other metals. Although it has low acute toxicity, with a predicted toxicity class of 5, its predicted activity for neurotoxicity, carcinogenicity, BBB penetration, and ecotoxicity means that it can be harmful to human health and may contribute to environmental pollution.[40] Cu and Ti showed trends similar to those of Zn and Al.

It is important to emphasize that, while *G. huillensis* may offer medicinal benefits and the hot water extraction method has been shown to yield low concentrations of these heavy metal ions, their potential for neurotoxicity and ecotoxicity, as well as their ability to cross the blood–brain barrier, suggests that caution should be exercised when using the plant for medicinal purposes.

Implications as a traditional medicine

The analysis of the results of *G. huillensis* has highlighted the potential as well as the risks that might be associated with its use as a medicinal plant. Results from the two methods of extraction have indicated that the plant tissue has a high amount of nutritional ions such as K, Ca, Mg, and S, which are essential nutrients with positive contributions to the medicinal value of the plant and are good for human health.[41]

The presence of these high-value nutritional ions as well as the variety of phytochemicals such as Flavonoids, Phenols, Terpenoids and Xanthones could be attributed to its therapeutic potential as used traditionally in the treatment of diseases like diabetes, inflammations, and other metabolic disorders.

The evaluation of the toxic heavy metal ions present in this plant has indicated that overall, the metal ions present do not pose any risk to human health, especially when the hot water extraction method is used. This result, therefore, suggests that *G. huillensis* is safe to use traditionally as a medicinal plant. However, the presence of heavy metal ions in *G. huillensis,* together with their potential neurotoxicity, ecotoxicity, and ability to cross the blood-brain barrier, suggests the need for caution regarding its medicinal use. The limitation of these findings is that the study was done in a single geographical area. Furthermore, the concentrations of the metal ions are also influenced by the composition of the soil due to variation in geographical areas.

CONCLUSION

The metal content evaluation of *G. huillensis* revealed the presence of both nutritional and heavy metal ions in the plant extracts. The high levels of nutritional ions, such as potassium, calcium, magnesium, and sulfur, underscore the nutritional value of this plant, as well as their positive contribution to its effectiveness as a medicinal plant. These elements, together with the wide range of natural products found in *G. huillensis*, could contribute to its therapeutic use in the treatment of diseases such as diabetes and other metabolic disorders.

The evaluation of heavy metal content also showed that *G. huillensis* contains moderate amounts of heavy metal ions when the hot water extraction method is employed. The levels of heavy metal ions detected were found to be mainly within acceptable standard limits, thereby posing no significant risk to human health that could arise from prolonged consumption of different parts of the plant. A comparison of the two extraction methods revealed that the hot water extraction method is the safer method when the plant is used for medicinal purposes. These findings provide insight into the potential dangers that these extracts might pose. The hot water extraction method demonstrated that the extracts from all three plant parts are safe for human health.

It can therefore be stated that the use of the acid digestion extraction method to evaluate the risks associated with metal content in medicinal plants may overestimate the dangers or risks linked to the medicinal use of the plant. In contrast, the method traditionally used by healers, namely hot water extraction, allows metal ions to be extracted in moderate concentrations that are considered safe and, according to these findings, pose no significant health risks.

However, this study had some limitations. The research was conducted in only one geographical area, which may have limited the range of detectable metal contents. In addition, bioavailability studies were not carried out. Further studies on *G. huillensis* should focus on several key areas to improve understanding of its medicinal properties. Toxicological studies should be conducted to provide robust evidence regarding the safety of the plant extract for medicinal use. For example, the toxicological effects of these metals on liver and kidney function should be evaluated. Comparative studies with other *Garcinia* species should also be carried out to identify unique or common trends. Additionally, both *in vitro* and *in vivo* studies should be conducted to validate the medicinal potential of the plant. Finally, this study should be replicated in other geographical areas in order to compare the metal content of the plant, as the concentrations of these metals are highly influenced by soil composition and environmental factors.

SUPPLEMENTARY INFORMATION

There is no Supplementary Information for this article.

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AUTHOR CONTRIBUTIONS

Chimuka Luke: Supervision, Methodology, Writing- review & editing. Monyai Mokgaetji: Visualisation, Methodology, Data acquisition. Singh S Indra: Methodology, Resources. Writing- review & editing, Supervision. Ngwenya Nkazimulo: Data acquisition, investigation, Methodology. Maseka K Kakoma: Supervision, Methodology. Chanshi Christopher: Resources, Data acquisition, software. Chibuye Bitwell: Methodology, Writing- review & editing. Mukuta Misheck: Methodology, Writing- Original draft, review & editing, Resources, Software, Analysis, Data acquisition, Project administration.

DECLARATION OF COMPETING/FINANCIAL INTERESTS

All authors declare not to have any known competing interests regarding this work.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES

The authors wish to state that the AI tool (ChatGPT) was used to proofread the manuscript.

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