

Heavy Metal Analysis of Some Branded Herbal Products Using Atomic Absorption Spectroscopy

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Abstract

Herbal products are preparations made from medicinal plants which contribute significantly to traditional medicine, having a long-lasting history of therapeutic application worldwide. The quality and safety of herbal products have become a significant concern, particularly regarding contamination from heavy metals. This research investigated the prevalence and concentration of heavy metals, specifically cadmium, chromium, lead, nickel, and iron in selected herbal products (labeled P1- P9) using atomic absorption spectroscopy for precise quantification. The samples were prepared by treating with concentrated HNO₃ and HCl. After treatment and filtration, the samples were examined using an Atomic Absorption Spectrometer. The samples were analyzed three times to ensure accuracy and precision. Statistical significance was defined as a P-value of less than 0.05. Quantitative analysis of herbal product samples selected confirmed the presence and concentrations (mg/L) of lead (0.0435 – 1.6163), cadmium (0.0060-0.1477), chromium (0.0042- 0.4317), nickel (0.0141-0.0640), and iron (0.5339-12.1509). The results showed that lead, cadmium, chromium, and iron were above permissible limits of consumption in all the samples analyzed. The result underscores the importance of quality control measures during the processing and production of these herbal products, considering the potential for long-term accumulation and synergistic toxic effects of multiple heavy metals.

Keywords: Herbal products; Heavy metals; Atomic Absorption Spectroscopy; Carcinogen

Introduction

Herbal products from plants have a long history of use in various cultures because of their supposed medicinal qualities and health advantages. However, the rising demand for these plant-based products globally has sparked worries about their quality and safety, especially with regard to contamination from heavy metals [1]. This contamination can come from different sources, including environmental pollution of the soil and water where the plants are grown, or poor manufacturing processes [2, 3]. Heavy metals often enter herbal products through environmental contamination, farming practices, and processing methods, significantly affecting their safety and effectiveness. Even in low concentrations, these heavy metals can build up in the human body, potentially resulting in chronic health problems due to their toxicity [3, 4]. For instance, herbal supplements containing heavy metals may interfere with nutrient absorption by replacing essential elements like calcium and zinc, which can lead to cancer and reproductive issues [4]. The International Agency for Research on Cancer grouped several of these elements, including cadmium, beryllium, nickel, and chromium, as carcinogens (Group 1). This highlights the need for standardized assessment of such harmful

contaminants in herbal products [5]. As a result, thorough analysis of heavy metal content and health risk assessment are crucial for ensuring the safety and effectiveness of these commonly used natural health products [6]. This study specifically examines levels of potentially toxic elements like chromium, iron, nickel, cadmium, and lead in herbal medicines frequently used in Enugu State, Nigeria. It compares these concentrations with established permissible limits to evaluate possible health risks [7]. Past research has shown that some herbal preparations contained heavy metals exceeding maximum permissible limits set by organizations like the WHO, creating serious drug safety risks and negatively affecting public health [3]. For example, certain herbal products analyzed for anxiety treatment in Brazil displayed varying levels of barium, cadmium, cobalt, chromium, and copper, generally below permissible limits. However, lead content was particularly variable, with instances exceeding United States Pharmacopoeia standards [7]. This inconsistency emphasizes the urgent need for strict regulations and consistent surveillance of heavy metal concentrations in herbal products to protect the masses' health from potential toxicities [7]. Since some elements like iron and copper are necessary yet toxic in excess, and others, such as

Table 1: Table showing the composition, dosage form, and expiry date of the herbal products

Code	Composition	Dosage form	Expiry date
P1	<i>Carica papaya</i> , Aloe vera, <i>Moringa oleifera</i> , <i>Azadirachta indica</i> , <i>Antiaris toxicaria</i> , treated water	Liquid	7/09/2027
P2	<i>Zingiber officinale</i> root, <i>Citrus limonia</i> , Cymbopogon citratus, <i>Carica papaya</i> leaves,	Liquid	03/01/2026
P3	<i>Mangifera indica</i> bark, <i>Moringa oleifera</i> leaf, <i>Allium sativum</i> , water <i>Aquilaria agallacha</i> , <i>Nymphaea lotus</i> leaf, <i>Moringa oleifera</i> leaf, <i>Aloe</i> <i>barbadensis</i> , <i>Psidium guajava</i> , and water.	Liquid	19/06/2026
P4	<i>Gongroneria latifolium</i> , <i>Aloe barbadensis</i> , <i>Xylopia aethiopica</i> , water	Liquid	04/12/2026
P5	<i>Lotus blanca</i> , Golden Seal, <i>Neem</i> , <i>manguera</i> , <i>Carica papaya</i>	Liquid	26/01/2026
P6	N/A	Liquid	08/2028
P7	N/A	Liquid	27/07/2027
P8	N/A	Liquid	01/02/2027
P9	N/A	Liquid	06/2027

NB: N/A- not available

chromium, cadmium, nickel, and lead, are cancer-causing, examining their presence in herbal products is vital for preventing harmful health effects [7, 3]. Therefore, understanding the health implications of consuming herbal medicines contaminated with heavy metals is critical for effective public health measures [5, 7]. This requires a detailed look at both essential and non-essential heavy metals to measure their levels and assess their potential impact on human health [5].

Atomic Absorption Spectroscopy (AAS) is a common method for measuring trace metal concentrations in different materials, including herbal products. It is preferred for its high sensitivity, selectivity, and cost-effectiveness. The process includes atomizing the sample, often through a flame or graphite furnace, converting the metallic compounds into atomic vapor, which then absorbs light at specific wavelengths [8]. The amount of light absorbed directly correlates with the concentration of the target element, allowing for quantitative analysis. While AAS is effective for elemental analysis, it usually measures one element at a time, making multi-element analysis more time-consuming compared to techniques like inductively coupled plasma mass spectrometry [9]. Nevertheless, its simplicity and availability make it a key technique for routine quality control in many laboratories that analyze herbal products [10].

The high global consumption of herbal products, combined with the rise in health-conscious individuals seeking natural alternatives to conventional medicine, has raised concerns about the quality and efficacy of herbal products. Although herbal products are regarded as a natural and safer alternative to synthetic drugs, the presence of contaminants especially heavy metals poses significant health risks that are often overlooked [11]. Therefore, the study was carried out to determine the presence of heavy metals-lead, chromium, cadmium, iron, and nickel contamination in some selected branded herbal products using the Atomic Absorption Spectroscopy technique.

Materials and methods

Sample collection

Nine different brands of herbal medicine products were used in this study. They were coded as P1-P9. The compositions, dosage forms, and expiry dates of the herbal products are shown in Table 1. These were purchased from various medicine

stores and herbal shops in Ogi market, Nsukka, Enugu State. The contents, packaging, and expiration dates of these products were carefully checked before purchasing to ensure optimal sample quality. All glassware used in this study was washed with filtered water and soaked in a 10% v/v nitric acid solution for twenty-four hours. They were rinsed multiple times with deionized water, dried at room temperature, and stored in a clean space.

Metal analysis

25 ml of each sample was measured into a beaker. The samples were treated with 4 mL of concentrated HNO₃ and 2 mL of HCl. The samples were allowed to stand at ambient temperature for twenty-four hours in a fume cupboard and heated gradually using a hot plate to 60 °C for 24 hours inside a fume cupboard to facilitate pre-digestion. The samples were heated gradually at 60 °C until the solution became clear, indicating complete digestion. The solution was allowed to cool before being filtered into a beaker and analyzed using the iCE 3000 Thermo Scientific AAS Instrument (USA). The AAS was calibrated using the prepared standard solutions for each metal. The wavelength and lamp current were set according to the manufacturer's specifications for each metal. Each sample was analyzed in triplicate to ensure accuracy and precision. Standards from another batch were analyzed to confirm the accuracy of the readings.

Statistical analysis

Data were presented as mean $\pm$ standard deviation (SD) of triplicate determination. Statistical significance was defined as a P-value of less than 0.05.

Results and Discussions

Atomic absorption results of herbal product samples selected showed the presence of lead (0.0435 mg/L – 1.6163 mg/L), cadmium (0.0060 mg/L - 0.1477 mg/L), chromium (0.010 mg/L - 0.4317 mg/L), nickel (0.0141 mg/L - 0.0640 mg/L), and iron (0.5339 mg/L -12.1509 mg/L) as shown in Table 2. The WHO permissible limit for each metal is also shown in Table 2.

Table 2: Herbal products with their mean concentration (mg/L) for different heavy metals analyzed

Sample Code	The concentration of the heavy metal (mg/L)				
	Lead	Cadmium	Chromium	Nickel	Iron
P1	0.0470±0.011*	0.0438±0.041	0.0163±0.031	ND	1.3782±0.852
P2	0.0441±0.010*	0.0060±0.001*	0.0860±0.011*	0.0141±0.001*	2.3146±0.081*
P3	0.0630±0.001*	0.0084±0.012	0.1376±0.010*	0.0284±0.003*	1.2144±0.051*
P4	0.0435±0.013*	0.0077±0.022	0.2223±0.013*	ND	1.0842±0.011*
P5	0.0759±0.013*	0.0109±0.003*	0.1538±0.002*	ND	0.5339±0.052*
P6	0.0303±0.004*	0.0158±0.001*	ND	ND	1.1866±0.054*
P7	0.0408±0.002*	0.0189±0.001*	0.010±0.006*	ND	5.034±0.138*
P8	0.1246±0.030*	0.0151±0.002*	0.4317±0.036*	0.0640±0.042	12.1509±0.454*
P9	1.6163±0.961	0.1477±0.110	0.1360±0.014*	ND	3.0353±0.100*
WHO	0.01	0.003	0.05	0.07	0.3

Values are expressed as mean ± SD of triplicate determinations.

* Indicates significant difference compared with WHO permissible limits at $p < 0.05$.

ND = Not detected.

Heavy metals' concentrations in the selected herbal products are displayed in Table 2. Some of the values were not statistically significant, possibly due to the large variability observed among replicate measurements. The findings indicated that all of the samples had levels of lead and cadmium above WHO limits (lead - 0.01 mg/L and Cadmium - 0.003 mg/L). Heavy metals, for example, arsenic, cadmium, and lead, are harmful even at trace levels. Their cumulative toxicity and potential to cause a variety of negative health effects make their presence in herbal products, even at low concentrations, a serious public health concern. P9 has a lead concentration of 1.616 mg/L, which is extremely high. Lead is a strong neurotoxin that is harmful even at trace levels. Because of its ionic radius and charge, lead easily spreads throughout the body after absorption, interfering with a variety of cellular structural elements and enzymatic functions [12]. Additionally, cellular damage and dysfunction are greatly exacerbated by lead's ability to produce reactive oxygen species, resulting in oxidative stress and depleting antioxidant reserves [13]. All of these processes work together to explain how lead can impair children's neurological development, cause hypertension, and affect renal function [14]. Lead easily crosses the placental barrier, which can be very bad for the development of the fetus, causing problems with brain development and poor birth weight [15]. Lead exposure in children is linked to developmental delays, learning challenges, irritability, and fatigue, highlighting its significant effects on cognitive and behavioral functions. In adults, lead exposure results in neurological disturbances, including headaches, memory impairment, and mood disorders, frequently accompanied by gastrointestinal symptoms such as abdominal pain and vomiting [16]. The endocrine system is another important area that lead exposure can affect. It can stop skeletal muscle growth, reproduction, and mess up how the thyroid gland works. Lead levels above 0.01 mg/L are harmful to health and need immediate attention because there is no safe level for lead. According to the WHO, the safe level of Cadmium is 0.003mg/L. The WHO limit was exceeded by all the herbal products. P9 with the concentration of 0.1477mg/L is many times higher than what is safe. Cadmium is another well-known heavy metal pollutant having no known positive effects on the body, but is very dangerous to health because it is common in the environment and is very poisonous. Cadmium toxicity is pernicious because it can interfere with basic cellular functions, causing extensive systemic harm [17]. For instance, cadmium disrupts calcium homeostasis, causes oxidative stress, and interferes with enzyme systems, all of which contribute to

osteotoxicity, nephrotoxicity, and carcinogenesis [18, 19]. Cadmium has the ability to mimic vital elements, which can disrupt antioxidant balance and interfere with metabolic processes, resulting in a lot of health issues [20]. Prenatal cadmium exposure is connected with a high risk of spontaneous abortion, premature delivery, and hormonal imbalance [21]. Chronic contact with low levels of cadmium may result in long-term health issues, such as children's neuropsychiatric disorders, emphasizing the need for stringent environmental monitoring and remediation [22, 23].

Several samples (P3, P4, P5, P8, P9) exceed the provisional WHO value of 0.05mg/L for chromium, with P8 having the highest concentration of 0.4317. Although chromium is a microelement necessary for metabolic activities, it is much more toxic, highly soluble, and mobile, posing a significant health risk [24]. Although there is not enough evidence to support its classification as essential, trivalent chromium, which is frequently found naturally, has been determined to be an important microelement for the metabolism of carbohydrates and fats [25, 14]. The oxidation state of chromium has a significant impact on its toxicity; because of its increased cellular permeability and reactivity with biological molecules, hexavalent chromium is far more dangerous than trivalent chromium [26]. Because of its increased reactivity, hexavalent chromium can easily enter cells and undergo reduction, producing unstable intermediates and reactive oxygen species that can harm lipids, proteins, and DNA, resulting in genotoxicity and carcinogenicity [27]. Its classification as a strong human carcinogen is ultimately a result of this process [28]. Hexavalent chromium's high solubility and oxidizing capacity allow it to enter the respiratory system deeply, where it causes lung cell DNA damage, oxidative stress, and inflammation [29]. In addition to allergic reactions, prolonged or high-level dermal exposure can cause skin ulcers, irritant contact dermatitis, and in extreme situations, systemic absorption with subsequent hepatic and renal complications [30].

The concentrations of all the samples were below the WHO guideline of 0.07mg/L for Nickel. Depending on the chemical form, exposure route, and duration, its toxicity spectrum can range from allergic reactions to serious carcinogenic effects [31]. Nickel exposure is significantly linked to fibrosis in the lungs, allergic contact dermatitis, and high risk of respiratory tract cancer, especially in environments like welding, electroplating, and refining [32]. Furthermore, chronic nickel exposure has been connected to hepatic toxicity, kidney issues, and

cardiovascular diseases in epidemiological research and animal models [33]. Exposure to nickel and its compounds can cause cancers of the paranasal sinuses, nasal cavity, and lung [34].

Most samples exceeded the WHO guideline of 0.3mg/L for iron, except P4, which was $\leq 0.3\text{mg/L}$. P8 with the concentration of 12.1509 is extremely high. Although iron is a necessary micronutrient for energy metabolism, DNA synthesis, and oxygen transport, excessive iron accumulation, or iron overload, can cause serious organ dysfunction and cellular damage. Iron overload primarily affects the liver, heart, and endocrine glands, resulting in cirrhosis, cardiomyopathy, and diabetes, respectively. Furthermore, because iron promotes DNA damage and cellular proliferation, unchecked iron accumulation can worsen neurodegenerative diseases and accelerate the growth of some cancers. Hereditary hemochromatosis, a genetic disorder, is a common cause of iron overload, leading to progressive organ damage if left untreated. Excess iron can cause cardiomyopathy and heart failure in the heart and cirrhosis and an increased risk of hepatocellular carcinoma in the liver [35]. The accumulation of iron can also activate programmed cell death pathways and alter mitochondrial dynamics, further exacerbating cellular dysfunction [36].

Combined exposures can drastically change the toxicological result when compared to individual exposures. For example, co-exposure to cadmium and lead may have synergistic neurotoxic effects that are more potent than either metal alone [37,38]. On the other hand, a combination of some metals may exhibit antagonistic effects, in which the toxicity of one metal is reduced by the presence of another. Although these are less frequent and often context-dependent. Furthermore, by competing for binding sites or boosting antioxidant defenses, essential metals like zinc can occasionally provide protection against the toxicity of non-essential heavy metals [39].

Conclusion

Heavy metals (cadmium, iron, chromium, and lead) were detected in all the herbal product samples investigated except P6, which did not show the presence of chromium. Nickel was detected in herbal products labeled P2, P3, and P8 only. In most cases, the heavy metals were all above the permissible limit, except nickel, where the data were below the limit. Herbal products containing heavy metals such as lead, cadmium, even at low concentrations, raise significant public concerns because of their cumulative toxicity, synergistic toxic effects of multiple heavy metal exposure, and potential to induce various health problems. Stringent quality control measures and regular testing are imperative to mitigate these risks and protect public health.

Conflict of Interest

None

Authors' contributions

PFU designed the study; ERI and MOO carried out the experiments. CMO analyzed the data and wrote the manuscript.

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