

Original Research

Heavy Metal Concentration and Health Risk Assessment of Selected Fruits Sold in Jos Metropolis

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Advances in Chemical Research
2021, volume 3, issue 2
doi:10.21926/acr.2102013

Received: February 27, 2021
Accepted: April 27, 2021
Published: May 12, 2021

Abstract

The present study investigated the level of heavy metals in selected fruits sold commonly in Jos, Nigeria. The fresh fruits (Avocado pear, Black currant, Egg Plant, Golden melon, and Soursop) were purchased from five major markets (Terminus, Farin Gada, Building materials, Bukuru, and Fobur) in Jos. Each fruit sample was collected in triplicate and analyzed using standard procedures. The concentration of heavy metals (Fe, Cu, As, Cd, Zn, Pb, Mn, and Cr) was determined using Graphite Furnace Atomic Absorption Spectrophotometer. The data obtained were subjected to descriptive statistics and then compared with the WHO/FAO acceptable limits. The results revealed low concentrations of Fe (0.125–0.241 mg/kg), Cu (0.015–0.020 mg/kg), Zn (0.925–1.135 mg/kg), Mn (0.025–0.045 mg/kg), Cr (0.018–0.029 mg/kg), and Pb (0.031–0.055 mg/kg) in all five fruits studied. Only cadmium exceeded the acceptable limit of 0.020 mg/kg stipulated by WHO/FAO, with the highest cadmium concentration of 0.085 mg/kg detected in Soursop. Accumulation of cadmium in the kidneys leads to kidney damage and osteoporosis. The Estimated Daily Intake (EDI) values of all



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metals were lower than the recommended tolerable daily intake values, except for arsenic, for which the hazard quotient greater than 1 was also detected in all the fruits studied. This could be as a result of pollution in the environment of the regions where the fruits were cultivated. Long-term exposure to inorganic arsenic causes cancer. Environmental pollution raises health challenges to the consumers and therefore, drastic measures should be implemented to control it.

Keywords

Fruits; heavy metals; health risk; Jos metropolis; pollution

1. Introduction

Environmental pollution refers to the release of substances that are harmful to humans and other living organism in the environment [1]. These harmful substances could be released into any of the environmental compartments, including soil, water, air, and their interfaces [2], either naturally or through anthropogenic activities. Environmental pollution is a consequence of exponentially increasing population, industrialization, and urbanization [3], which occur in most developing as well as developed nations across the world.

Heavy metals are metals or metalloids with a relatively high density; their atomic density is usually higher than 4 g/cm³ or five times the density of water [4]. Heavy metals are hazardous even at low concentrations as they are not biodegradable and have long biological half-lives [5-7]. Heavy metals occur naturally in the earth crust, and contaminate the environment through natural mineral rock weathering and various anthropogenic activities [8], such as sludge dumping, municipal wastes, electroplating, fertilizer and pesticide application, mining and smelting of metalliferous ores and metal scraps, etc.[9, 10]. Examples of heavy metals include chromium (Cr), mercury (Hg), silver (Ag), platinum (Pt), iron (Fe), copper (Cu), arsenic (As), cadmium (Cd), zinc (Zn) [4], magnesium (Mg), and manganese (Mn) [11], among others. Plants uptake heavy metals either through absorption from deposits on the plant parts exposed to polluted environmental media or through irrigation with contaminated water [7]. Heavy metal uptake and bioaccumulation along the food chain raises a great threat and health challenges to humans as well as animals [4]. Heavy metals may also be referred to as trace elements as they are present in minute amounts in different environmental matrices [10, 12]. Certain heavy metals, such as chromium, copper, iron, manganese, magnesium, and zinc, are among the essential nutrients required by the human body for biochemical and physiological processes; and their inadequate supply may lead to deficiency diseases or syndromes. The heavy metals that have no biological significance, such as beryllium, arsenic, aluminium, gallium, gold, mercury, and silver, are considered non-essential. Even though a few of the heavy metals are beneficial or essential, their excessive presence may cause cellular and tissue damage resulting in adverse effects and diseased conditions [10].

Soil pollution has increased dramatically at a high rate over the past few years due to the use of agrochemicals (such as chemical manures, fertilizers, sewage sludge, and pesticides) to increase agricultural productivity [5, 12]. Although these agrochemicals have been effective in solving the problem of global food insecurity, they have also contributed further to environmental issues [1].

These agrochemicals contain heavy metals, and their repeated use leads to a high accumulation of these heavy metals in the soil, thereby polluting the agricultural soils [13]. Plants absorb heavy metals from the contaminated soil, store them within their tissues, and then transfer them to humans via the food chain [14-16]. The use of polluted water for irrigation is another source of heavy metal contamination. Owing to a lack of regulated waste disposal systems, most of the industrial, municipal, and domestic effluents are usually dumped into streams and other water bodies. Farmers use these streams and abandoned contaminated mining ponds to collect water for irrigating their agricultural lands [8, 17]. Therefore, pollutants from all these sources enter the food chain and eventually bioaccumulate in organisms, thereby causing health hazards.

Fruits are a part of the daily diet of humans and are used widely along with other foods for culinary purposes [4]. Lately, in Nigeria, the awareness regarding the health benefits of fruit consumption due to their high nutrient composition, which assists in maintaining good health and vitality, has increased [18]. Fruit composition is also being used as a preventive and curative measure against various diseases [19, 20]. Jos, the capital city of Plateau State, Nigeria, is known for the cultivation of a wide range of fruits and vegetables, facilitated by its cool weather and other favorable climatic conditions; the city is therefore referred to as the “fruit and vegetable basket” of the nation [21].

Several cases of food poisoning linked to heavy metal exposure have been reported in Nigeria. Recent example is the case of food poisoning due to acute lead exposure from artisanal mining and processing of gold. This occurred in Zamfara State in March 2010 and killed over 500 children within seven (7) months [22-24]. The University of Port Harcourt Teaching Hospital (UPTH) Cancer registry (2009–2013) reported the prevalence of cancer among the Nigerian people, which has also been linked to heavy metals exposure [25]. The improper use of agrochemicals on agricultural products is reported to be responsible for most of these cases.

The recent increase in awareness regarding the health benefits of fruit consumption in Nigeria [18] has raised a necessity to analyze the heavy metal composition of the fruits that are commonly grown and sold in Jos metropolis. The present research was, therefore, aimed to, determine the levels of heavy metals in the fruits commonly purchased in the region and the health risks associated with the daily intake of these fruits in terms of their potential toxicities. Foreign fruits are expensive and, therefore, accessible to only a small section of the population. Therefore, in the present study, only the locally available fruit varieties were sampled, and their levels of heavy metals were compared to the WHO/FAO recommended limits, to generate necessary information on the risks raised to human health.

2. Materials and Methods

2.1 Description of the Study Area

Jos is the largest city of Plateau State. It is located within $9^{\circ}56^1\text{N}$ and $8^{\circ}53^1\text{E}$ and is approximately 1280 m (4200 ft) above sea level. Annual rainfall within the city is approximately 1400 mm, and the average monthly temperature ranges between 21-25 °C [17, 26]. The city is majorly known for the cultivation of fruits and vegetables, although it also has numerous abandoned mines and ponds from the mining activities that began in the 20th century during the colonial period [21]. The contaminated old mines and ponds now serve as sources of water for

irrigation exposing the farmers to health risks. Farmers that depend on streams for irrigation are also at the risk of contacting contaminated water as wastes are dumped into these streams [8].

2.2 Sample Collection

Sample collection was conducted using the methods described in [27, 28]. Fresh samples of five (5) commonly consumed fruits were purchased from five (5) majorly patronized markets located in Jos metropolis, Nigeria. The markets are the Terminus market, Farin Gada market, Building materials (Express) market, Bukuru (Kugia) market, and Fobur market. Each of the fruits was collected randomly in triplicate from different traders in each market, wrapped in polythene bags, labeled appropriately, and carried to the laboratory for analysis. The details regarding the fruits are provided in Table 1.

Table 1 Fruits used in the present study.

S/No	Botanical name	Common name	Local/Hausa name	Family
1	<i>Annona muricata</i>	Soursop	Fasadarur	<i>Annonaceae</i>
2	<i>Persea americana</i>	Avocado pear	Avocado	<i>Lauraceae</i>
3	<i>Solanum melongena</i>	Egg plant	Garko	<i>Solanaceae</i>
4	<i>Cucumis melo</i>	Golden or Sweet melon	Zakikankana	<i>Cucurbitaceae</i>
5	<i>Ribes nigrum</i>	Black currant	Baki currant	<i>Grossulariaceae</i>



Plate 1: Soursop



Plate 2: Avocado pear



Plate 3: Eggplant



Plate 4: Golden melon or Sweet melon



Plate 5: Blackcurrant

2.3 Sample Preparation

The collected fresh fruit samples were washed thoroughly, first with tap water and then with distilled water, to remove the attached soil particles and other extraneous substances. Each sample was formulated into a composite sample, chopped into smaller pieces using a stainless knife, air-dried for 48 h and then oven-dried at 70 °C for approximately 72 h [27], and finally ground using a porcelain mortar and pestle. The homogenized samples were stored in air-tight bottles and labeled. Representative samples were subsequently digested and analyzed.

2.4 Heavy Metal Analyses

The concentrations of different heavy metals in the fruits were determined using the wet acid digestion method. Briefly, 0.2 g of the homogenized fruit sample was placed in a cleaned and dried Kjeldahl flask, to which, 5 mL nitric acid and 1 mL perchloric acid were further added, followed by stirring with glass rods. The flask was then placed on the Kjeldahl heater and heated inside a fume cupboard until its contents became colorless. The digested sample was cooled and filtered into a 100 mL volumetric flask, and deionized water was added upto the mark on the flask. The solution was then aliquoted into metal-free sample bottles in triplicate and labeled properly for subsequent metal analysis. The concentrations of different heavy metals (iron, copper, arsenic, cadmium, zinc, lead, manganese, and chromium) in the digested solutions of each sample were determined using a graphite furnace atomic absorption spectrophotometer (GFAAS)-PG500, PG Instruments Ltd., Leicestershire, England [29]. The parameters of the GFAAS are presented in Table 2 below.

Table 2 Working Parameters of GFAAS.

Element	Wavelength (nm)	Flame gases
Arsenic	193.7	Argon
Cadmium	228.8	Argon
Chromium	357.9	Argon
Copper	324.7	Argon
Iron	248.3	Argon
Lead	217.0	Argon
Manganese	279.5	Argon
Zinc	213.9	Argon

2.5 Health Risk Assessment Indices

The health risks raised by the transfer of contaminants from food to humans have been widely studied previously. These risks may be determined using certain indices, such as EDI (Estimated Daily Intake), Hazard Quotient (HQ), Target Hazard Quotient (THQ), Hazard Index (HI), and Daily

Dietary Intake (DDI), amidst others [30-32]. Two of these indices, EDI and HQ, were considered in the present study.

2.5.1 Estimated Daily Intake (EDI)

The daily intake of each of the evaluated heavy metals was determined to estimate the daily concentration of these metals ingested into the human body. EDI was calculated based on the metal concentration in the fruits, the daily consumption amount of the fruits, and the average body weight, using the method described in [30].

$$EDI = \frac{C_{metal} \times D_{fruit\ intake}}{BW_{average}} \quad (1)$$

where EDI = estimated daily intake ($\mu\text{g}/\text{kgbw}/\text{day}$), C_{metal} = concentration of the heavy metal in the fruit samples (mg/kg) [30], $D_{fruit\ intake}$ = daily intake of the fruit (a minimum of 400 g of fruits is required per day in less developed countries to reduce micronutrient deficiencies and prevent diseases [33, 34]), $BW_{average}$ = average body weight of a Nigerian individual = 62 kg (considering the general population) [31].

2.5.2 Hazard Quotient

The risk accompanying the consumption of contaminated food may be evaluated by calculating the hazard quotient [35, 36]. In the present study, the hazard quotient for adults, associated with the consumption of metals in the selected fruits sold in Jos metropolis, was determined using the following formula:

$$HQ = \frac{(D) \times (C_{metal})}{(R_f D) \times BO} \quad (2)$$

where D = the daily intake of fruits (kg/day ; a minimum of 400 g (0.4 kg) of fruits is required per day in less developed countries [33, 34], C_{metal} = concentration of the heavy metal (mg/kg), $R_f D$ = reference oral dose of the heavy metal (mg/kg of body weight/day), and BO = body weight (kg), the average body weight of a Nigerian individual was considered to be 62 kg [31]. The reference oral doses (in $\text{mg}/\text{kg}/\text{day}$) for each of the evaluated heavy metals are as follows: Arsenic-0.0003; Cadmium-0.0010; Chromium-0.0030; Copper-0.0400; Iron-0.7000; Lead- 0.0040; Manganese-0.1400; and Zinc-0.3000 [36-41].

2.6 Statistical Analysis

The recorded data were subjected to descriptive statistical analysis to reveal central tendency and dispersion.

3. Results and Discussion

The results of the mean concentration of heavy metals in the analyzed fruits are presented in Figure 1.

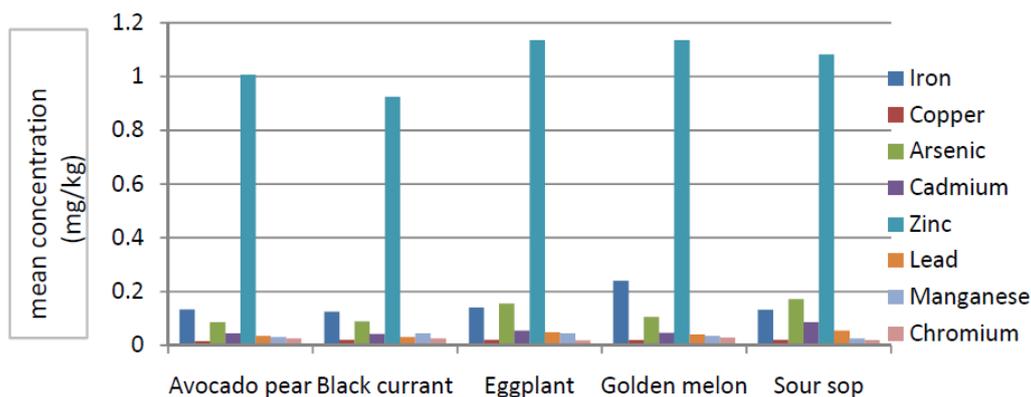


Figure 1 Mean concentrations of heavy metals in the analyzed fruits.

The heavy metal concentrations were then compared to the WHO/FAO acceptable or permissible limits, which are listed in Table 3.

Table 3 WHO/FAO acceptable limits of a few metals.

Parameters	WHO/FAO Acceptable Limits (mg/kg)
Iron	1.00
Copper	2.00
Cadmium	0.02
Zinc	1.50
Lead	0.50
Manganese	5.00

Source: (Oyareme et al., [42])

The Estimated Daily Intake (EDI) values for each of the evaluated heavy metals are presented in Figure 2.

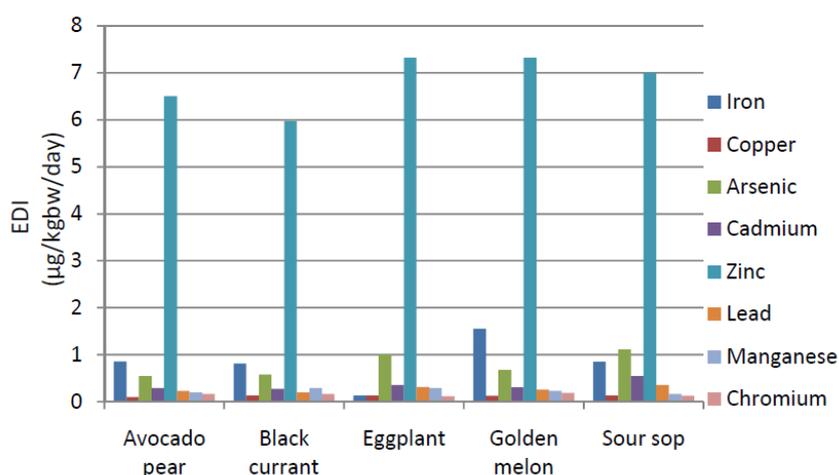


Figure 2 Estimated Daily Intake (EDI) values for metals (µg/kgbw/day) based on the consumption of 400 g of fruits per day in less developed countries.

The estimated daily intake values and the hazard quotients for the evaluated heavy metals are presented in Figure 2 and Table 4, respectively.

Table 4 Hazard quotients of the evaluated metals in the analyzed fruits.

Fruits	Fe	Cu	As	Cd	Zn	Pb	Mn	Cr
Avocado	0.0012	0.0024	1.8280	0.2903	0.0216	0.0565	0.0014	0.0538
pear								
Black currant	0.0012	0.0032	1.9140	0.2710	0.0199	0.0500	0.0021	0.0538
Eggplant	0.0013	0.0032	3.3333	0.3548	0.0244	0.0774	0.0021	0.0387
Golden melon	0.0022	0.0031	2.2581	0.3032	0.0244	0.0645	0.0016	0.0624
Soursop	0.0012	0.0032	3.6989	0.5484	0.0233	0.0887	0.0012	0.0409

Fe-Iron, Cu-Copper, As-Arsenic, Cd-Cadmium, Zn-Zinc, Pb-Lead, Mn-Manganese, Cr-Chromium

Heavy metals interfere with the nutritive value of fruits. The presence of heavy metals in excessive amounts harms human health. Various national and international bodies have established regulations regarding the permissible limits of toxic metals in foods consumed by humans. These limits are expected to be strictly adhered to in order to limit the heavy metal concentration in foods [42] to the recommended daily intake values and thereby reduce the risks to human health. Although a few of the heavy metals evaluated in the present study are essential nutrients and play beneficial roles in the physiological and biochemical processes occurring within the human body when consumed in minute amounts, they might become toxic when consumed at higher concentrations.

Iron serves as a cofactor in different metabolic processes occurring at the cellular level, such as lipid metabolism, tricarboxylic acid cycle, respiration, and DNA (deoxyribonucleic acid) synthesis [43]. Iron may form free radicals and become toxic at high concentrations; increased iron absorption causes siderosis (high concentration of iron in tissues) and hemochromatosis, a disorder that leads to diabetes, cirrhosis, liver cancer, and heart disease [43]. The concentration of iron detected in all the analyzed fruits (from Jos metropolis) ranged between 0.125 and 0.241 mg/kg, which is well within the WHO/FAO acceptable iron limit of 1.00 mg/kg reported by Oyareme et al., [42]. This suggests that the fruits consumed within Jos metropolis do not contain high levels of iron. Egharevba et al., [19] observed a higher mean concentration of iron ranging between 171.62 and 304.44 mg/kg in fruits and vegetables sold in Benin City, Nigeria. An iron concentration of 1.24 mg/100 g was reported by Malgorzata and Piotr [44] in black currant fruit from Poland. In the present study, the estimated daily intake of iron, presented in Figure 2, ranged from 0.129 to 1.550 $\mu\text{g}/\text{kgbw}/\text{day}$, with eggplant presenting the lowest value while golden melon presented the highest value. These values are lower than the recommended tolerable daily intake value of 12,500 $\mu\text{g}/\text{day}$ reported in [30, 45]. A hazard quotient of less than 1 indicates that the level of risk raised by the metal is negligible, while that higher than 1 indicates that the metal may cause serious health risks to the consumer [36]. The hazard quotient for iron in all the fruits

analyzed in the present study was less than 1, as presented in Table 4, implying that the consumption of these fruits is not hazardous with respect to iron.

Copper is an essential mineral that serves as a cofactor for various enzymes required for connective tissue synthesis, iron metabolism, and energy production [46]. Prolonged exposure to copper causes diarrhea, vomiting, headache, and dizziness. High uptake of copper may damage the liver and the kidneys, and may even lead to death. WHO/FAO recommends an acceptable limit of 2.00 mg/kg for copper [42]. The fruits analyzed in the present study had copper in concentrations ranging from 0.015 to 0.02 mg/kg, which does not exceed the acceptable limit. The levels of copper in avocado pear fruit analyzed in the present study were lower than the 3.10 mg/kg value reported in [47]. The estimated daily intake of copper, presented in Figure 2, ranged from 0.097 to 0.129 $\mu\text{g}/\text{kgbw}/\text{day}$, which is also below the Recommended Daily Intake of 2 mg [48]. The hazard quotient of copper in all the analyzed fruits was less than 1.

Arsenic plays vital roles in growth, survival, fertility, and reproduction in humans and other mammals. Arsenic may ensure optimum mitochondrial membrane function in cardiac muscle cells [49]. Ingestion of inorganic arsenic (trivalent arsenite and pentavalent arsenate) may reduce blood cell production, which could lead to abnormal heart rhythm and fatigue. Long-term oral exposure to inorganic arsenic leads to the appearance of dark patches on the skin and, in certain cases, cancer [50]. Among all the fruits analyzed in the present study, soursop had the highest concentration of arsenic, i.e., 0.172 mg/kg. The Provisional Tolerable Daily Intake (PTDI) for inorganic arsenic was determined to be 0.0002 mg/kg bodyweight (0.2 $\mu\text{g}/\text{kg}$ body weight) for a 60-kg adult in [51]. The estimated daily intake for arsenic calculated in the present study was in the range of 0.548–1.110 $\mu\text{g}/\text{kgbw}/\text{day}$, and its hazard quotient was greater than 1 in all the analyzed fruits, as presented in Figure 2 and Table 4, respectively. The EDI of arsenic was higher than the permissible limit and the same was true for the hazard quotient. Therefore, it is inferred that the analyzed fruits may raise a high health risk to consumers due to the detected levels of arsenic in them.

Cadmium is a highly toxic heavy metal; it is non-degradable, relatively soluble in water, and has a high tendency to bioaccumulate. Cadmium accumulates in the kidneys and leads to kidney damage, kidney stones, hypercalciuria, osteoporosis, and disturbance in the calcium metabolism, among other toxic effects [52]. Ikechukwu et al. [31] detected cadmium at a concentration of 0.036 ppm (0.036 mg/kg) in soursop fruit purchased from the Ubani market in Umuahia, Abia State, Nigeria. The concentration of cadmium in all the fruits analyzed in the present study was higher than the WHO/FAO acceptable limit of 0.02 mg/kg, with the highest concentration (0.085 mg/kg) observed in soursop, a highly beneficial fruit [53]. The highest estimated daily intake value of 0.548 $\mu\text{g}/\text{kgbw}/\text{day}$ recorded for cadmium was also in soursop. Despite the high concentration of cadmium in all the analyzed fruits, the hazard quotient (health risk) for each fruit was less than 1. A high cadmium concentration was also observed in all the fruits analyzed by Ikechukwu et al. [31], who also reported a hazard quotient below 1 for each of the fruits. This indicates that cadmium raises no adverse health threats.

Zinc is a dietary trace element that performs catalytic, structural, as well as regulatory functions. Zinc maintains the structure of enzymes, such as Cu.Zn superoxide dismutase, and also regulates gene expression [54, 55]. All the fruits analyzed in the present study had zinc within the acceptable limit of 1.50 mg/kg, with blackcurrant presenting the lowest zinc concentration of 0.925 mg/kg. A zinc concentration of 0.38 mg/100 g was reported in the blackcurrant fruit from

Poland [44]. The estimated daily intake of zinc calculated in the present study ranged from 5.970 to 7.320 $\mu\text{g}/\text{kgbw}/\text{day}$, which is lower than the recommended daily intake of 40, 000 $\mu\text{g}/\text{day}$ for adults [30]. The hazard quotient for zinc in all the analyzed fruits was less than 1.

The levels of lead detected in the analyzed fruits ranged between 0.031 mg/kg and 0.055 mg/kg. None of the fruits had lead concentrations exceeding the acceptable limit of 0.50 mg/kg. Kalagbor and Diri [47] reported a lead concentration of 1.69 mg/kg in the avocado pear from Rivers State, Nigeria, while a lower concentration of 0.035 mg/kg was detected in the present study. Lead is toxic even at low concentrations. Lead has no role in cell metabolism [56]. It persists in the environment for longer durations and has become a global environmental hazard [57]. It is also a threat to human health due to its effects on the renal, hepatic, neurological, immunological, and cardiovascular systems in humans [36]. The highest estimated daily intake of lead in the fruits analyzed in the present study was 0.355 $\mu\text{g}/\text{kgbw}/\text{day}$, which is below the WHO recommended tolerable daily intake of 240 $\mu\text{g}/\text{day}$ for adults [30, 58]. The hazard quotient for lead in all the analyzed fruits was less than 1.

Manganese is crucial for carbohydrate, lipid, protein, and amino acid metabolisms, and is involved in the synthesis and activation of several enzymes, such as manganese superoxide dismutase, glutamine synthetase, transferases, lyases, and isomerases [59, 60]. Chronic exposure to manganese causes extrapyramidal syndrome (having similarities with Parkinson's disease), while its acute exposure causes manganism [59]. The concentration of manganese in the fruits analyzed in the present study was below the acceptable or permissible limit of 5.00 mg/kg. A mean concentration of manganese ranging from 0.558 to 0.692 mg/kg was reported by Egharevba et al. [19] in the fruits and vegetables sold in Benin City. The Estimated daily intake ranging from 0.161 to 0.290 $\mu\text{g}/\text{kgbw}/\text{day}$ was detected in the present study, which is lower than the 2–11 mg/day value recommended by the National Research Council of Canada (NRC) as the safe and tolerable daily manganese intake value for adults [30, 61]. The hazard quotient for manganese in all the analyzed fruits was less than 1.

Chromium could either be beneficial or hazardous, depending on its oxidation state. Chromium enters the environmental media (soil, water, and air) in the form of chromium (III) and chromium (VI) through various natural processes and anthropogenic activities. Uptake of Chromium (III) by plants is quite common. Chromium (III) is a vital nutrient that occurs naturally in fruits, vegetables, grains, and meat. It plays a major role in lipid, protein, and carbohydrate metabolisms, and may also act as an antioxidant. Consumption of chromium (III) at high concentrations may cause skin rashes. The adequate intake levels of chromium for adult males range between 35 μg and 51 μg , while those for adult females are in the range of 20–24 μg [62, 63]. Chromium (IV) and (VI) are dangerous to human health [63]. Adverse health effects of chromium (VI) include dermatitis, ulceration and perforation of the nasal septum mucous membrane, and cancer [64]. The concentration of chromium in the fruits analyzed in the present study was between 0.018 and 0.029 mg/kg, with the highest estimated daily intake of 0.187 $\mu\text{g}/\text{kgbw}/\text{day}$ in golden melon. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has recommended a daily intake of 200 $\mu\text{g}/\text{day}$ for chromium [51]. The hazard quotient for chromium in all the analyzed fruits was less than 1.

It is recommended to conduct further studies involving the analysis of soil samples from the sites where these fruits are cultivated to assess the possible transfer of cadmium and arsenic from these soils to the fruits.

4. Conclusion

Among all the heavy metals analyzed in the present study, the concentration of only cadmium (0.045–0.085 mg/kg), in the analyzed fruits, exceeded the limits recommended by WHO and FAO (0.02 mg/kg). However, this should not be of major concern as this would not lead to any toxicological risk, considering the fact that the hazard quotient values for all fruits were less than 1. However, the estimated daily intake (EDI) values (0.548–1.110 µg/kgbw/day) and the hazard quotient (HQ) of 1.8280–3.6989 units detected for arsenic in each of the fruits exceeded the permissible limits. This could be attributed to the pollution in the environments in which these fruits were cultivated. Exposure to the high levels of arsenic in fruits may raise health challenges to consumers. It is further suggested that farmers should be educated regarding the proper use of agrochemicals, and the government should ensure strict regulatory measures and policies to implement acceptable protocols for crop protection and yield improvement. Mandatory monitoring of fruits by food and agricultural agencies, including the Standards Organization of Nigeria (SON), to assess the toxic heavy metals in fruits would ensure the prevention of the bioaccumulation of these metal contaminants along the food chain.

Acknowledgement

The authors are grateful to the staff of the Biochemistry Division of the National Veterinary Research Institute, Vom, Jos, Nigeria for the assistance rendered in the course of this research.

Author Contributions

Bayo D. co-designed the study, was responsible for the collection of some of the fruit samples within the study areas and revised the manuscript. Adeniyi O. the corresponding author, designed the study, prepared and wrote the manuscript. Adeniyi A. also collected some of the fruit samples, supervised the experiments and edited the manuscript. Ariwoola O. carried out the data analysis and edited the manuscript.

Competing Interests

The authors have declared that no competing interests exist.

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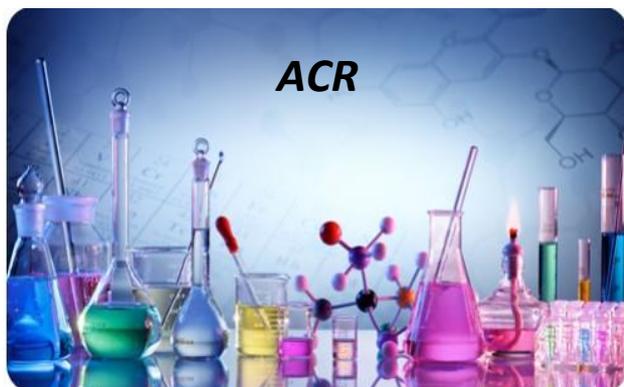
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