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Assessment of Heavy Metal Contamination across Five Selected Roadside Marketed Fruits in Erin-Osun, Osun State, Nigeria

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Abstract
Background: The contamination of fruits with heavy metals is a growing concern due to potential health risks associated with their consumption. **Objectives:** This study assessed the level of heavy metals in five selected (apple, orange, African cherry, pineapple and watermelon) fruits marketed by the roadsides in Erin-Osun, Irepodun Local Government, Osun State. **Methodology:** Data were collected using a well-structured questionnaire, and five fruits were randomly collected from two different (Elerin and Oke-Ila) markets in triplicates for 30 samples, digested, and analysed for heavy metals using an Atomic Absorption Spectrophotometer. Descriptive and inferential statistics were adopted for the laboratory gathered data to gather frequency, mean, standard deviation, and separated means. Furthermore, multivariate (precisely Pearson correlation, multiple regression, and Principal Component) analyses were conducted. **Results:** The study found that most vendors sourced their fruits from local farms, used fertilisers or pesticides, stored and transported fruits in baskets, and had positive views about the safety of fruits sold by roadside vendors. The results showed that the Zn-level ranged from 0. 10 mg/kg in Apple to 0.35 mg/kg in orange. The heavy metal mean values in some fruit samples were within, while others exceeded WHO permissible limits for safe levels in food. Contaminants of concern were As, Cr, Zn and Pb. **Conclusion/ Recommendations:** The study revealed that heavy metal levels in the fruits, particularly As and Cr, could pose health risks to consumers. The findings suggested continuous monitoring and regulation of heavy metals in food by adhering to the dietary standards for human health safety.

Keywords: Food safety, AAS, multivariate analysis, WHO food standards, health risk

Introduction

Fresh fruits are of great value and widely used for dietary purposes because of the presence of vitamins, mineral salts, water, calcium, iron, sulphur and potassium (Hebden *et al*., 2017). They are critical protective foods for health maintenance and disease prevention and treatment (Mintah *et al*., 2012). A fruit is the edible and fleshy seed-associated structures of certain plants, which could be sweet, such as apples, oranges, grapes, strawberries, juniper berries and bananas or non-sweet, such as lemon and olives, in their raw forms (Mauseth, J. D. 2014). The benefits of consuming fruits are a longer life span, improved mental health, better cardiovascular health, reduced risks of cancers and weight management, among others. In the USA, a lower risk of obesity was observed among healthy middle-aged women who consume fruits (USDHH/USDA 2020). Specifically, fruits contain sufficient potassium, which reduces the effect of bone loss and the occurrence of kidney stones. According to the author, fruits assist in the proper functioning of the brain as they stimulate memory recall and supply the human body with the fibre needed for a healthy digestive system. Fruits are rich in dietary nutrients such as potassium, antioxidants and folic acid, so consuming fruits guarantees optimum health, gives instant energy to the body and provides vitamins and minerals that are beneficial to body functionality. Despite the benefits of fruit consumption on human health, the toxic contents hinder the supposed benefit of fruits when they exceed the recommended health levels or bio-accumulate in the body over a long period (USDHH/USDA 2020).

Plants bearing fruits are prone to containing essential and ono-essential (i.e., toxic) metals in various concentrations, necessitating food safety as a significant public concern.

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Interestingly, unlike in Asia and Africa, the sources of heavy metals in American, European, and Oceanic countries are usually modern intensive agricultural practices (Khan *et al*., 2008). For example, extensive case studies of food crops sampled from North and South America have found that the metal concentrations are attributable to the agricultural use of Cu-based fungicides and fertilisers and originating particulate matter from vehicles and industrial sites (Zhang *et al*., 2016).

Heavy metals in industrially processed foodstuffs/ pharmaceuticals were noted in several developed countries, possibly posing serious human health risks. During the past decades, the increasing demands for food safety have stimulated research on the risk of consuming food products contaminated by heavy metals, pesticides and toxins (Atikpo *et al*., 2023: Emurotu *et al*., 2024).

Heavy metal pollution has spread over the globe, threatening the environment and posing serious health hazards to humans (Prabhat *et al*., 2019).. The root causes of this problem are generally the rapid pace of urbanisation, land use changes, industrialisation, and, at times, the high population. Technological advancements have challenged the environment's integrity by discharging heavy metal effluents (Fulekar *et al*., 2009). Wastewater, treated effluent, and sludge contaminated with heavy metals have frequently been used as low-cost sources of irrigation in parts of Asia and Africa, which has caused food quality and health to deteriorate (Prabhat *et al*., 2019).

It was further stated that highly populated countries (e.g., India and China) and underdeveloped countries (e.g., Nigeria and Zambia) have soil crop subsystems affected by wastewater irrigation and sludge amendment patterns, with food safety and ecotoxicology consequences. Long-term wastewater irrigation in India has been shown to contaminate food crops with heavy metals (concomitantly changing the physiology and biochemistry of crop plants) and pose health hazards (Rai *et al*., 2019).

China has also focused intensively on ecotoxicological, environmental, and food safety because of its extremely high population and need to expand farmlands due to rapid (especially mining and smelting) industrialisation and urbanization (Wang *et al*., 2020). Other than water and soil, foods may also be contaminated with trace metals due to increased usage of chemicals, sprays, preservatives, industrialisation, mining activities and fertilisers (Zhang *et al*., 2015). Although heavy metals are natural constituents of the earth's crust, they are mostly considered persistent environmental contaminants since they cannot be degraded or destroyed. Heavy metals are not biodegradable. Most heavy metals are highly toxic because of their solubility in water. Hence, they can enter the body through food, air and water (Singh *et al*., 2010; Nabulo *et al*., 2011). Food chain contamination is one of the most important pathways for entering these toxic pollutants into the human body (Wang *et al*., 2011; Harmanescu *et al*., 2011). They have long biological half-lives with the potential for body organ accumulation; this bio-accumulation could occur over a while, and the potential for accumulation in the different body organs leads to unwanted side effects (Omoyajowo *et al*., 2017). The diverse and emerging food security issues have become a global concern, particularly their inextricable association with human health (Säumel *et al*., 2016). Heavy metals such as Pb, Cd, Cr, Ni, Cu and many others are potentially toxic to humans and widely dispersed in the environment (Morais *et al*., 2012).

Unlike the study of Adegbite *et al*., (2024), which used three fruit (orange, watermelon, and apple) samples sourced at Okinni, Egbedore Local Government Area, Osun State, the current study added two other fruit (African cherry and pineapple) samples and sourced at Erin-Osun, Irepodun Local Government Area, Osun State, Nigeria with the view to assessing heavy metal levels.

Materials and methods

Study area

Erin-Osun is located in Osun State, Nigeria. It is about 18 kilometres by road southeast of Osogbo, 2 kilometres North of Ilobu; it is situated on latitude $7^0\ 5^1$ and $7^0\ 3^0$ by Ilobu town

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and longitude 7^0 49 and 7^0 121^0 east of Okinni/ Osogbo.

Vendor-related information and sample collection

Data were gathered using a well-structured and closed-ended questionnaire about the sources, storage, and transportation methods of the fruits to the vendors; this data was necessary to identify potential sources of heavy metal contamination and make recommendations for reducing heavy metal contamination in the fruits. Five fruits (apple, orange, African cherry, pineapple and watermelon) were randomly bought from roadside vendors in two markets (Elerin and Oke-Ila) in Erin-Osun, Irepodun Local Government Area, Osun State. For each fruit, three samples were bought from each market, making the total number thirty (30) (Table 1). The fruits were collected into appropriately labelled sacks and conveyed to the laboratory for analysis. All chemicals used for the analysis were high-purity analytical grade reagents; HNO_3 (69 % LR, Breckland Scientific Supplies, UK) and 30 %H_2O_2 were used to digest the sample. Certified reference materials of Cd, Zn, Pb, Cu and Ni were obtained from a Europe-accredited laboratory and used to prepare standard samples.

Sample treatment

The fruits were rinsed with tap water and then with distilled water. About 200 mL of juice from each fruit was squeezed into separate beakers. The juice was filtered, mixed well, and stored in a refrigerator before analysis, and 50 mL of the sample was measured into a 250 mL beaker, followed by 50 mL of aqua regia (concentrated 36 % HCl and 63 % HNO_3) prepared from analytical grade. The mixture was covered with a watch glass, heated, and refluxed on a hot plate. An additional 10 mL of the aqua regia was added, and the heating continued until the colour became very light yellow. The last step was repeated, and the solution evaporated until the volume was about 15 - 20 mL. The solution was cooled, and 10 mL of 30 % H_2O_2 was added and heated without boiling until effervescence was minimal to ensure complete digestion. The heating was continued until the volume reduced to about 10 mL. The beaker was removed from the hot plate, cooled, and the walls washed down with double distilled.

The digest was filtered using Whatman No. 4 filter paper into a 50 mL volumetric flask and then diluted with double distilled water to the 50 mL mark. All the other fruit samples and the spiked and blank samples were digested using the same digestion method. All the digested samples were analysed for Cd, Zn, Pb, Cu and Ni using an atomic absorption spectrometer (AAS).

Table 1: The total number of samples collected for analysis

S/N	Sample	Elerin Market	Oke-Ila Market
1.	Watermelon	3	3
2.	Apple	3	3
3.	Africa cherry	3	3
4.	Orange	3	3
5.	Pineapple	3	3
	Total	15	15

Results

Table 2 presented the processed data for the scientific information, having assessed the various fruits for macro elements (Na, K, Ca, Mg, and Zn) and their up-taken or associated microelements (Pb, Cd, Cu, Ni, and Mn), which necessitated the study for their concerns on human health. None of the fruits had Na at all, i.e., below the detection level of the analytical instrument (BDL), so its results were not presented. Watermelon (WM) had the least K-content, African cherry (AC) had the least

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Ca-content BDL, Orange (OM1) had the least Mg-content, and AC had the least Zn-contents. On the other hand, their highest concentrations were determined across K-, Ca-, Mg-, and Zn determined in AC, WMM2, PM2 (pineapple sourced at market 2), and WMM2, respectively. The results further indicated that the least Pb, Cd, Cu, Ni, and Mn levels were determined in ACM2, AC, AC, AC, and AC, respectively. The (Pb, Cd, Cu, Ni, and Mn) highest contents were determined across PM2, PM1, A (apple), OM1, and O, respectively.

Pearson's correlation verified the likely associations across the fruits' analysed parameters, especially between AvW (average fruit weight) and macro elements, AvW and microelements, and macro elements and microelements (Table 3). The AvW had a moderate (0.40-59) correlation, statistically significant at 0.01 level, with macro element Mg and microelement Pb. The implication was that the size of the selected fruits moderately and significantly (at 0.01 or 99.99 %) determined the presence of each of the two elements (Mg: 69.57 % and Pb: 72.35 %). The macro element K-content had a weak (0.20-39) negative correlation with Pb and Ni. The association was statistically significant (at 0.05 level or 99.95), which implies that the presence of K-content in the selected fruits restricted the microelement Pb and Ni by 60.74 % and 62.61 %, respectively. The macro element Ca-content had a strong (0.60-0.79) and moderate (0.40-59) correlation with Pb and Cu, respectively. The association was statistically significant at 0.01 level, which implies that the presence of Ca-content influenced the presence of the microelement Pb and Cu by 79.18 % and 68.99 %, respectively. The microelement Pb-content had a strong (0.60-0.79) and moderate (0.40-59) correlation with Mg at 0.01 level and Cd at 0.05 level, respectively, to imply that the Pb-content influenced the determination of the macro element Mg by 81.61 % and microelement Cd by 65.04 %, respectively. In addition, the microelement Cd-content had a moderate (0.40-59) and strong (0.60-0.79) correlation at 0.01 significant level with Ni and Mn, respectively, to imply that the Cd-content influenced the determination of the microelements Ni by 69.14 % and Mn by 80.19 %, respectively. Lastly, microelements Ni and Mn had strong (r^2 = 0.756 at 0.01 significant level) correlation with each other to the extent that the presence of one influenced 86.95 % of the other.

Table 4 indicated the unit of each element (under the model row) that contributed to the fruits' average weight, whose 63.20 % variance was explained by the regression model with a strong correlation: 0.795 between AvW and elements. The model showed that Cu-content was reduced by 2.465 units with a significant impact ($p < 0.05$).

Table 5 shows that the respondents/ fruit vendors sourced their fruits through wholesale (66.7%) and local farmers (33.7%), with an indication of chemical/ fertiliser (16.7%) usage. The respondents made use of baskets (50%) to convey their fruits from the farm to their destination/ markets, where they sell daily (66.7%) and weekly (33.3%). Moreover, 100% of the respondents have been selling the fruit for over 5 years, and 66.7% have received Food Safety and hygiene training. Approximately 50% of the respondents heard about the heavy metal contamination in fruits, and 50% agreed that those fruits sold by roadside vendors in Erin-Osun are unsafe for consumption. They never tested their fruits for heavy metal contamination, and 100% of the respondents did not use any method to test for heavy metal contamination in the fruits.

Regular cleaning of storage containers should be practised to prevent heavy metal contamination in fruits was picked by 50% of the respondents. 66.7% of the respondents agreed that there should be regulations and guidelines regarding heavy metal contamination in fruits sold by roadside vendors. In comparison, 50% of the respondents suggested that there should be regular training on food safety and hygiene to reduce the risk of metal contamination in fruits.

Table 2: Results of the mean, standard deviation, and analysis of variance

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	Average weight (g)		Potassium (mg/ L)		Calcium (mg/ L)		Magnesium (mg/ L)		Zinc (mg/ L)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
ACM1	38.12	2.31	15.03	9.73	BDL		19.57	18.20	0.28	0.12
ACM2	38.27	3.91	10.07	2.00	BDL		25.93	2.83	0.32	0.06
WMM1	282.64	53.07	0.73	0.85	21.80	4.57	62.47	6.09	15.77	26.18
WMM2	258.71	24.69	2.80	0.36	85.97	7.76	32.67	4.04	0.71	0.17
OM1	130.68	17.12	6.17	0.45	9.33	8.33	3.33	1.53	3.04	0.38
OM2	134.68	10.08	5.23	0.75	16.00	5.29	72.67	16.17	2.35	0.61
PM1	955.25	79.00	6.27	2.16	41.33	10.07	49.33	7.77	1.90	0.77
PM2	959.32	31.95	7.60	3.05	43.00	21.70	75.33	17.24	1.63	0.51
AM1	95.48	3.33	7.90	4.88	58.33	7.77	37.33	3.06	0.76	0.17
AM2	96.14	2.83	5.20	1.64	66.00	16.37	43.00	17.69	0.99	0.22
p-value	0.000		0.013		0.000		0.000		0.509	

	Lead (mg/ L)		Cadmium (mg/ L)		Copper (mg/ L)		Nickel (mg/ L)		Manganese (mg/ L)	
ACM1	10.50	10.19	0.04	0.01	0.29	0.07	0.18	0.28	BDL	
ACM2	4.47	3.67	0.03	0.02	0.66	0.09	0.06	0.02	BDL	
WMM1	80.30	13.40	0.32	0.11	3.21	1.24	6.42	1.97	0.01	0.00
WMM2	63.03	19.66	0.21	0.04	2.19	0.55	3.07	0.51	BDL	
OM1	9.87	6.61	0.52	0.13	4.92	1.30	9.47	5.95	0.02	0.01
OM2	43.23	50.20	0.39	0.16	4.19	0.95	5.93	2.19	0.02	0.01
PM1	75.57	4.49	0.52	0.16	2.83	0.51	3.66	0.45	0.01	0.00
PM2	92.50	3.72	0.33	0.07	2.16	0.39	5.13	0.84	0.01	0.00
AM1	75.43	11.45	0.42	0.17	195.33	10.60	3.03	0.06	0.01	0.00
AM2	81.27	10.14	0.37	0.09	214.33	8.14	3.27	0.82	0.01	0.00
p-value	0.000		0.000		0.000		0.001		0.000	

AC: African cherry, WM: watermelon, O: orange, P: pineapple, A: apple, M1: market 1, and M2: market 2.

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Table 3: Correlations among the fruits' average weight (AvW), macro and microelements

	AvW (g)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Pb (mg/l)	Zn (mg/l)	Cd (mg/l)	Cu (mg/l)	Ni (mg/l)	Mn (mg/l)
AvW (g)	1	-0.123	0.227	0.484**	0.522**	0.047	0.350	-0.297	0.162	0.029
K (mg/l)		1	-0.319	-0.202	-0.369*	-0.209	-0.290	-0.032	-.0392*	-0.342
Ca (mg/l)			1	0.231	0.627**	-0.054	0.194	0.476**	0.021	0.002
Mg (mg/l)				1	0.666**	0.133	0.165	-0.041	0.161	0.082
Pb (mg/l)					1	0.066	0.423*	0.345	0.104	0.150
Zn (mg/l)						1	-0.024	-0.111	0.207	0.034
Cd (mg/l)							1	0.230	0.478**	0.643**
Cu (mg/l)								1	-0.124	0.115
Ni (mg/l)									1	0.756**
Mn (mg/l)										1

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). 0.00-0.19 very weak, 0.20-39 weak, 0.40-59 moderate, 0.60-0.79 strong, 0.80-1.0 very strong.

Table 4: Results of the regression analysis

Regression Analysis Coefficients

	Model	Unstandardised Coefficients B	Unstandardised Coefficients Std. Error	Standardised Coefficients Beta	t	Sig.
1	(Constant)	-171.439	179.423		-0.956	0.351
	K (mg/l)	11.874	11.648	0.169	1.019	0.320
	Ca (mg/l)	1.614	2.381	0.139	0.678	0.506
	Mg (mg/l)	0.755	2.974	0.054	0.254	0.802
	Pb (mg/l)	5.033	2.716	0.528	1.853	0.079
	Zn (mg/l)	-0.787	6.129	-0.019	-0.128	0.899
	Cd (mg/l)	703.893	367.191	0.390	1.917	0.070
	Cu (mg/l)	-2.465	0.736	-0.590	-3.348	**0.003**
	Ni (mg/l)	10.093	25.084	0.096	0.402	0.692
	Mn (mg/l)	-13756.274	13992.272	-0.252	-0.983	0.337

a. Dependent Variable: Average Weight (g)

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2178780.861	9	242086.762	3.809	**0.006[b]**
	Residual	1271024.045	20	63551.202		
	Total	3449804.906	29			

a. Dependent Variable: Average Weight (g)

b. Predictors: (Constant), Manganese (mg/l), Calcium (mg/l), Zinc (mg/l), Magnesium (mg/l), Potassium (mg/l), Copper (mg/l), Cadmium (mg/l), Nickel (mg/l), Lead (mg/l)

Model Summary

R (correlation)	R Square (explained % variance)
0.795[a]	0.632

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Table 5: Results of the administered questionnaire result

S/N	Variable	Respondent
1	Occupation	Farmer 0%, Vendor 100%, Others 0%
2	Source of fruits	local farm 33.3%, Wholesale 66.7%, Others area 0%
3	Chemical/ pesticides for storage use	Yes 16.7%, No 83.3%
4	fruits transportation before selling	In plastic bags 33.3%, In baskets 50%Other 16.7%
5	Selling fruits	Daily 66.7% Weekly 33.3% Monthly 0%
6	Years of selling fruits	Less than 1 year 0%, 1-5 years 0% More than 5 years 100%
7	Training received on food safety and hygiene	No 33.3%, Yes 66.7%
8	Information about heavy metals in fruits	Yes 50%, No 50%
9	Safety of fruits for consumption	Strongly agree 33.3%, agree 50% neutral 16.7%, disagree 0% and strongly disagree 0%
10	Testing of fruits for heavy metals	occasionally 0%, never 100%
11	The method used for testing heavy metals in fruits	Laboratory analysis 0% visual inspection 0% others 0% not applicable 100%
12	Measures taken to prevent heavy metal contamination in fruits	Regulate use of organic fertiliser 16.7%, proper disposal of chemical waste 16.7%, regular cleaning of the storage container 50%, Others 0%, None 16.7%
13	Regulation and guidelines regarding heavy metal	Strongly Agree 0%, Agree 66.7%, Neutral 16.7%, Disagree 16.7%, strongly disagree 0%
14	Heavy metals contamination option	Proper disposal of chemical waste 16.7%, Regular cleaning of storage containers 33.3%, Provision of training on food safety & hygiene 50%

Discussion

The five fruit varieties (African cherry (AC), watermelon (WM), orange (O), pineapple (P), and apple (A)) considered in this study are inevitable by the ordinary Nigerians; this confirms their familiarity with the markets and their consumption for the persuasive and beneficial advocacy is also familiar from the allied health and medical sectors (Sobukola *et al.*, 2007). Consuming these fruits assists the body with immunity boosters and against the ill-health of their macro elements' supplements (K, Na, Ca, and Mg) and various human systems. Such elements are naturally associated with microelements, at which the scientific worlds such as WHO, FAO, and related health stakeholders have been immemorially frowning; this was to avoid consumption of abiotic-disease-causing materials called heavy metals, which do not biodegrade but bio-magnify when got into the human body with various bedding/ clinical effects (Divrikli *et al.*,2013). Such an effect becomes devastating as the more one consumes fruits, the more one is prone to ingesting more microelements, which bio-magnify and displace the beneficial macro elements across human body systems. The mentioned macro elements are the heavy metals (such as Zn, Pb, Cd, Cu, Ni, and Mn), which are hazards to human health and prone to elicit health risks (Türkdoğan *et al.*, 2003; Rehman *et al.*, 2013). Uroko *et al.* (2019) mentioned the permissible limits that were compared with the values determined across the sampled vegetables and fruits as 2.00, 0.01, 0.01, 0.001, 0.02, and 0.3

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ppm for the Zn, Pb, Cu, Cd, Ni, and Mn, respectively. Of all the analysed microelements, only the Mn conformed to the compared limit; this conformed to the study by Uroko *et al*., 2019). The WHO/FAO. (2013) stipulated 6.00, 0.30, 4.00, and 0.20 mg/ kg for Zn, Pb, Cu, and Cd, respectively. The value of Zn determined in all but WMM2, Pb in all, Cu in orange/ apple, and Cd in all but African cherry in this study exceeded the WHO/ FAO (2013.

Determination of the referred micro elements above their limits was said not to be uncommonly found across the edibles such as fruits and related consumptive materials (Jaishankar et al., 2014); their high occurrence cause metal poisoning in the body, especially once their levels are exceeded against the target cells by initiating oxidative stress with possible mental retardation (Kim and Seo, 2012; Jaishankar *et al*., 2014). It may expose consumers to health risks (Díez *et al*., 2009). Rai *et al*. (2019) also proclaimed that crop contaminants have recently and unexpectedly affected human health, food quality, and security, which may adversely disturb human metabolomics, resulting in morbidity and mortality in the worst case. Khalid *et al*., 2017) informed of the commonly present microelements in the soil matrix, including Zn, Pb, Cd, Cu, Ni, Mn, Co, Hg, As, Cr, and Al. Lead and cadmium were considered and were among the top 20 listed by the Agency for Toxic Substances and Disease Registry as hazardous substances.

Exceedance of the Zn to the stipulated limit can instigate infants' congenital malformations in the nursing female gender (Silbergeld, 2003), while their shortage associate with anorexia, dermatitis, poor wound healing, growth retardation, hypogonadism with impaired immune function, depressed mental function, and impaired reproductive capacity (Prasad, 2012; Adah *et al*., 2013). The Zn may shortly cause symptoms such as dyspeptic nausea, vascular shock, diarrhoea, vomiting, damage of hepatic parenchyma cells and pancreatitis (Salgueiro *et al*., 2000). High Zn-level restricts Cu absorption, thereby making Cu deficient (Gyorffy & Chan, 1992); both Cu and Zn can adsorb on the same metallothionein protein; Zn has a lower affinity for metallothionein than Cu (Krezel & Maret, 2007). The microelement Cu is minimally essential as a biocatalyst required for human body pigmentation, prevention of anaemia and maintenance of a healthy central nervous system (Sobukola *et al*., 2007). Long-term exposure may interfere with physiological processes and damage the kidneys and liver (Adewole & Uchegbu, 2010). A previous study (Gowd *et al*., 2010) observed higher Cu- and Cd-contents in edible fruits than the permissible limits determined in this study.

The study by Adewole & Uchegbu (2010) reported that Cd-fruits accumulation from the soil had times been more efficient than any other microelements through the elemental absorption and translocation routes. Excessive Cd affects the renal tubules with proteinuria damage and the reabsorption of protein enzymes in kidney tubules (Manahan, 2003). Trichopoulos (1997) also views the situation worse and points to Cd and Pb as carcinogens. Another author (Zhou *et al*., 2016; El-Kady & Abdel-Wahhab, 2018) linked the possibility of bone fractures and malformation, kidney dysfunction, cardiovascular complications, hypertension, and severe (immune system, nervous system, lung and liver) diseases to Cd and Pb. There is the possibility that children's short intelligence quotients will disrupt the central nervous, reproductive, and immune systems, as well as other effects on both blood and kidneys from the microelement Pb (Neal & Guilarte, 2012). The studies of Zhou *et al*., 2016) and Al-Saleh et al., 2017) reported that children were prone to suffering from Pb-contamination with mental growth causing cardiovascular and neurological diseases; it is an indication of what consumers of any of the five fruits that this study considered because of the determined levels of Pb, which exceeded the compared limit.

Conclusion and recommendations

Having analysed and found the referred microelements above the set limits across the selected five fruit varieties reiterated that they are commonly found across the edibles such as the fruits and related consumptive materials. Continuous contact with the microelements in the consumed fruits may subject the consumers to health risks. Food quality and security have recently and unexpectedly been affected by crop contaminants, which may adversely disturb human metabolomics with resultant

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morbidity and mortality in the worst case. Consumption of such fruits, which are commonly found across markets, subject the consumers to a high occurrence of metal poisoning in the body, especially once their levels are exceeded across the target cells by initiating oxidative stress with various ill-health afflictions. Based on the findings of this study, the following recommendations are proposed:

- *Regular monitoring of heavy metal concentrations in fruits:* Continuous monitoring of heavy metal concentrations in fruits, particularly those sold by roadside vendors, should be conducted to ensure food safety and prevent potential health risks associated with heavy metal contamination.
- *Education and awareness programmes:* Consumer education and awareness programs should be implemented to raise awareness about the importance of food safety, including the risks associated with heavy metal contamination in fruits; this can include dissemination of information on safe food handling practices, proper washing of fruits, and avoidance of fruits from roadside vendors.
- *Implementation of good agricultural practices (GAPs):* Farmers and fruit vendors should be educated and encouraged to adopt Good Agricultural Practices (GAPs) in fruit production, such as proper use of fertilisers, irrigation water quality management, and avoiding the use of contaminated soil or water sources.
- *Compliance with regulatory guidelines:* There is a need for strict adherence to WHO/ FAO Permissible limits and regulatory guidelines for heavy metal concentrations in fruits. Regular monitoring and enforcement of regulatory standards can help ensure that fruits sold in the market are safe for consumption.
- *Collaboration among stakeholders:* Collaborative efforts among stakeholders, including researchers, government agencies, farmers, vendors, and consumers, are essential to address the issue of heavy metal contamination in fruits. Regular communication and coordination among stakeholders can lead to more effective strategies to ensure food safety and protect public health.
- *Further research:* More research is needed to identify specific sources of heavy metal contamination in fruits in the study area and assess the potential health risks associated with long-term consumption of fruits with slightly elevated heavy metal concentrations; this can help inform targeted interventions and mitigation strategies.

Research implications of the study

- *Public health awareness*: The study highlights the need for increased awareness of consuming fruits contaminated with heavy metals, particularly As and Cr, which pose significant health risks.
- *Regulatory policies*: The findings suggest the necessity for stricter regulatory policies and continuous monitoring of heavy metal levels in fruits to ensure they meet WHO permissible limits for safe consumption.
- *Agricultural practices*: The study underscores the importance of adopting safer agricultural practices, such as reducing harmful fertilisers and pesticides, to minimise heavy metal contamination in fruits.
- *Market surveillance*: The research indicates the need for regular market surveillance and testing of fruits sold by roadside vendors to ensure they are safe for consumption.
- *Consumer behaviour*: The study provides insights into consumer behaviour and perceptions regarding the safety of fruits sold by roadside vendors, which can inform public health campaigns and interventions.

Study Limitations

- *Sample size*: The study was limited to 30 fruit samples, which may not represent all fruits sold in the region.
- *Geographical scope*: The research was conducted in only two markets within Erin-Osun, Irepodun Local Government, Osun State, which may

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limit the generalizability of the findings to other regions.

- *Temporal scope*: The study was conducted at a specific time, and seasonal variations in heavy metal levels in fruits were not considered.
- *Self-reported data*: Using self-reported data from vendors regarding their sourcing and handling practices may introduce bias and affect the accuracy of the findings.
- *Limited heavy metals*: The study focused on a limited number of heavy metals (As, Cr, Zn, and Pb), and other potentially harmful heavy metals were not assessed.

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Ethical approval

The study does not require ethical approval.

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