

Concentration Levels and Health Risk Assessment of Carcinogenic and Non-Carcinogenic Heavy Metals in Chicken Tissues Marketed in Nsukka Metropolis, Nigeria

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Concentration Levels and Health Risk Assessment of Carcinogenic and Non-Carcinogenic Heavy Metals in Chicken Tissues Marketed in Nsukka Metropolis, Nigeria.

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ABSTRACT

This study evaluated the concentrations of carcinogenic and non-carcinogenic heavy metals in poultry chicken tissues (muscle, liver, and gizzard) obtained from major markets in Nsukka Metropolis, Enugu State, Nigeria, and assessed the associated human health risks. A total of 24 chicken samples were analyzed using Atomic Absorption Spectrophotometry (AAS) to determine the levels of lead (Pb), nickel (Ni), cadmium (Cd), chromium (Cr), zinc (Zn), and copper (Cu).

The results indicated that there were no significant differences ($p > 0.05$) in metal concentrations across the examined tissues. Mean concentrations of carcinogenic metals ranged from 0.15–0.32 mg/kg for Pb, 0.37 mg/kg for Ni, 0.02–0.05 mg/kg for Cd, and 0.04–0.15 mg/kg for Cr. Non-carcinogenic metals showed mean concentrations of 0.26–0.35 mg/kg for Zn and 0.02–0.07 mg/kg for Cu.

Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and Cancer Risk (CR) were calculated to evaluate health implications. THQ and HI values were below unity (<1), indicating a negligible non-carcinogenic risk. The cancer risk (CR) values for Pb, Cr, Cd, and Ni across the chicken muscle, liver, and gizzard in the samples are: Pb, (3.16×10^{-3}), (4.35×10^{-3}), (6.73×10^{-3}); Cr, (1.88×10^{-1}), (1.28×10^{-1}), (5.47×10^{-2}); Cd, (5.09×10^{-2}), (2.12×10^{-2}), (2.96×10^{-2}); Ni, (7.81×10^{-1}), (7.81×10^{-1}), (7.81×10^{-1}). The cancer risk values across all samples exceeded the acceptable WHO limit ($10^{-6} - 10^{-4}$), suggesting potential carcinogenic risks from prolonged consumption.

The findings highlight the presence of toxic heavy metals in poultry chicken marketed in Nsukka and emphasize the need for regular monitoring of poultry feed, environmental pollutants, and food safety regulations to protect public health.

Keywords: Heavy metals, poultry chicken, cancer risk, toxicology, food safety, Nigeria

1.0. Introduction

Meat is an essential component of the human diet, supplying vital nutrients required for normal metabolic and physiological activities [1]. Poultry products such as chicken meat, liver, and gizzard are among the most widely consumed animal products globally because they are nutritious, affordable, and rich in proteins, vitamins, and essential minerals [1]. In recent decades, consumers in Nigeria have increasingly preferred white meat, particularly chicken, over red meat, leading to a significant rise in poultry production and consumption [2].

Despite the nutritional benefits of poultry meat, contamination by heavy metals poses serious public health concerns [3]. Heavy metals are naturally occurring elements that can become toxic at elevated concentrations [3]. They enter the food chain through environmental and anthropogenic activities such as industrial emissions, mining, agricultural practices, and waste disposal [3]. These contaminants can accumulate in the soil, water, and feed used in poultry farming, ultimately leading to bioaccumulation in the tissues of chickens and subsequent biomagnification in humans upon consumption [4].

Certain heavy metals, including lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni), are known carcinogens and have been associated with numerous health disorders, including various cancers, organ dysfunction, and impaired immune response [2,4]. Other metals such as zinc (Zn) and copper (Cu) are essential micronutrients required for metabolic processes, enzyme activity, and cellular functions [5]. However, when present above permissible limits, even these beneficial metals can become toxic, leading to adverse physiological effects such as liver and kidney damage [6].

According to the World Health Organization, approximately 25% of human diseases are linked to long term exposure to environmental contaminants, including heavy metals [7]. Risk assessment studies, therefore, play a crucial role in determining the extent of human exposure to these contaminants and their potential carcinogenic and non-carcinogenic health risks [8].

Given the increasing demand for poultry meat and the potential risks associated with heavy metal accumulation, assessing the concentration and toxicity levels of both carcinogenic (Pb, Ni, Cr, Cd) and non carcinogenic (Zn, Cu, Cd, Cr) heavy metals in chicken tissues is essential for food safety. This study was therefore conducted to evaluate the levels of carcinogenic and non-carcinogenic heavy metals in poultry chicken tissues (muscle, liver, and gizzard) sold within Nsukka Metropolis, Enugu State, Nigeria. The study further estimated the potential health risks associated with the consumption of these chicken parts to ensure the protection of public health and enhance food quality monitoring systems in the region.

2.0. MATERIALS AND METHODS

2.1 Description of Study Area

In the course of procuring the samples used for the research work, we made use of two source areas, which are Ikpa Market and Ogige market, which is geographically represented in **figure 1**. Ogige market is the biggest and one of the major market located in Nsukka metropolis in Enugu State, South-East Nigeria. The study area lies between latitude 6° 44' N to 6° 56' N and longitude 7° 16' E to 7° 24' E. The market is also popularly known for where local commodities and where different livestock are been sold, but not in bulk compared to commodities in Ikpa. Ikpa is also one of the major market located in Nru Nsukka, Nsukka metropolis in Enugu State, southeast Nigeria. The study area lies between latitude 6° 52' N to 6° 64' N and longitude 7° 22' E to 7° 30' E. The market is popularly known for where local commodities and where different livestock are been sold in bulk especially poultry birds, which serves as meat for human consumption.

These two areas are in the humid tropical region with average monthly temperature fluctuating between 24°C and 29°C [9]. The two prominent climatic seasons in the area include the rainy season, lasting from April to October and the dry season lasting from November to March [8, 9]. The topography of the area presents undulating hills, streams, depressions, and valleys [10].

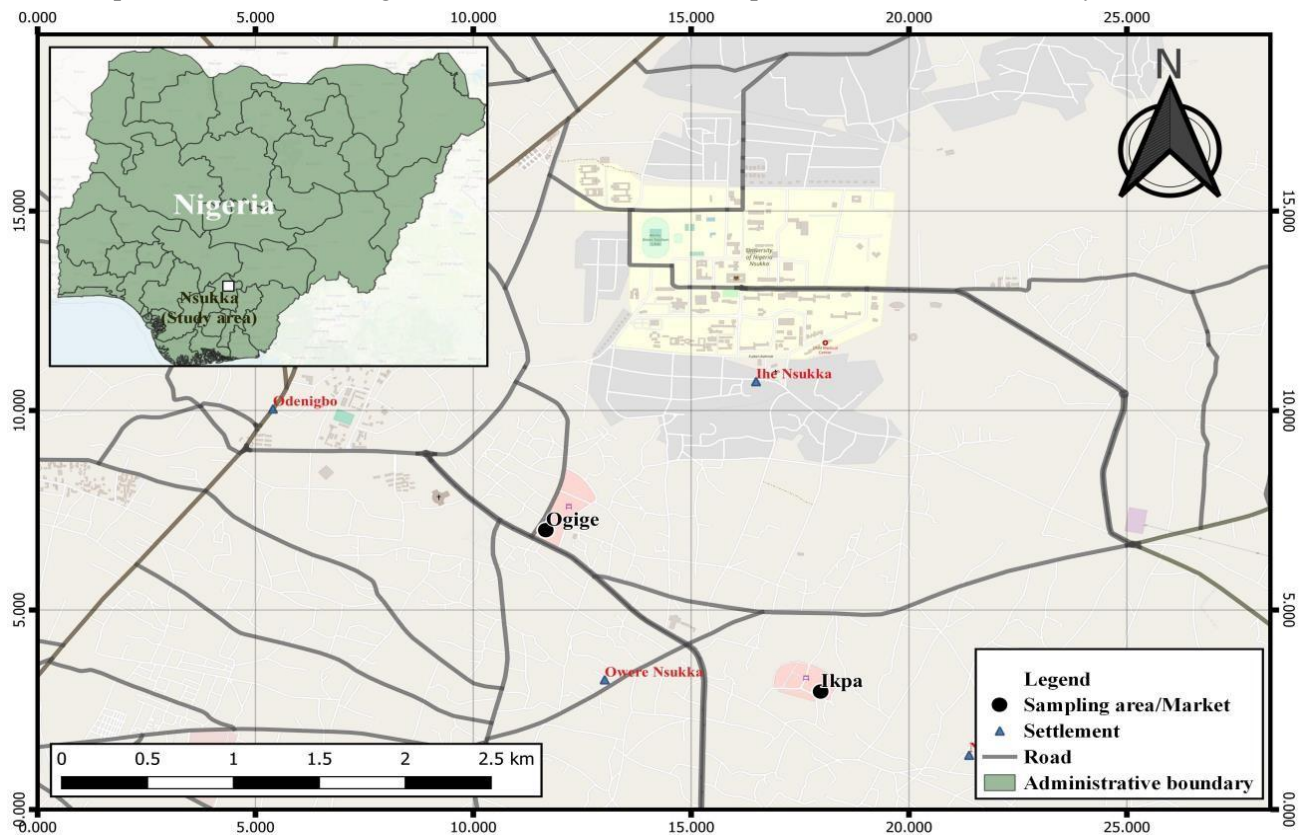


Figure 1. Geographical map of study location

2.2 Sample Collection

The poultry chicken sample were obtained directly from the Ogige market and Ikpa market from different retail sellers. All the chicken samples used were obtained from the point of sacrifice, about two samples of each poultry chicken parts (the liver, the muscle and gizzard) each was utilized. The poultry chicken slaughter sections of the selected slaughterhouses were visited twice in a week at intervals within (December to January—dry season) period. The total weight of the different samples was taken using an electronic balance and the weight ranged between 64.5g -200.3g. Thereafter, the different samples each for muscle, liver and gizzard tissues were collected into a decontaminated polythene bags, separately packaged, labelled and transported to the laboratory of the National Centre for Energy Research and Development, University of Nigeria, Nsukka for the detection and quantification of carcinogenic heavy metals: Pb, Ni, Cd, Cr, Zn, and Cu. The tissues collection and packaging was done with chemically cleaned instruments and the samples stored at freezing conditions (-20 °C) before the analysis. Eight meat samples (2 each for muscle, liver and gizzard tissues) from randomly selected poultry chicken carcasses were analyzed.

2.2. Chemicals and Reagents

30 cm³ of aqua regia (a mixture of HNO₃ and HCl in the ratio of 1:3); de-ionized water, double distilled water, conc HCl, 3 M HNO₃. The standard used for the sample analysis of these experiments were the Food and Agriculture Organization (FAO) and the World Health Organization (WHO).

2.3 Instrument and Apparatus:

Atomic Absorption Spectrometer model AA-7000 Shimadzu, Japan ROM version 1.01, S/N A30664700709 were used for the analysis. Weighing balance, crucible, fume cupboard, funnel, filter paper and 100 ml standard flask were used as well all glass wares used were soaked into 3 M HNO₃ overnight and washed with de-ionized water to reduce the chances of interferences.

2.4 Sample Digestion

One gramme each of the samples were weighed into digestion flask and 30 cm³ of aqua regia was added and digested in a fume-cupboard until clear solution was obtained, it was cooled, filtered and then made up to 50 ml mark in a standard volumetric flask with de-ionized water.

A blank sample was prepared to zero the instrument before running other series of samples. Standards (2 ppm, 4 ppm and 6 ppm) were prepared from 1000-ppm stock solution of the metals and used to plot the calibration curve. The curve was plotted automatically by the instrument. The standard used for the sample analysis of these experiments were the Food and Agriculture Organization (FAO) and the World Health Organization (WHO).

2.5 Preparation of Standard Concentration

Standard solutions (2 ppm, 4 ppm and 6 ppm) were prepared from 1000 ppm stock solution of the metals using the formula: $C_1 \cdot V_1 = C_2 \cdot V_2$

Where $C_1 = 1000$ ppm and $C_2 = 2$ ppm

$V_1 = ?$ $V_2 = 100$ ml

$$V_1 = (100 \times 2) / (1000) = 0.2 \text{ ml}$$

0.2 ml was pipette from 1000 ppm, Put into 100 ml flask and made to the mark with deionized water. This procedure was used in the preparation of 4 ppm and 6 ppm respectively. High temperature was produced in the ignition chamber and provided enhanced reducing settings for the atomization of the respective metals/minerals. Each standard was aspirated by nebulizer, converted into an aerosol, mixed with the gases and converted into atomic form. All the standard solutions were analyzed and the calibration curve was plotted automatically for the metal/mineral of interest. Each metal/mineral was analyzed using its respective wavelength after which its concentration was generated from the standard graph by the instrument.

2.6. Standards and statistical analysis

Standards used to compare the level of carcinogenic and non-carcinogenic heavy metals in chicken meat samples were the Food and Agriculture Organization (FAO) and the World Health Organization (WHO).

One-way analysis of variance (ANOVA) was applied to establish the differences in concentrations of metals in the tissues, in the course of the statistical analysis. The emergent data have been presented in terms of mean values $\pm$ Standard Error of Mean (SEM). The level of statistical significance was set at $p \leq 0.05$ (95% confidence interval).

2.7 Estimated daily intake of heavy metals

The estimated daily intake (EDI) of toxic metals (Cd, Cr, Cu, and Zn) was determined using **Equation 1**:

$$\text{EDI} = \frac{\text{MC} \times \text{FDC}}{\text{BW}} \quad (1)$$

Where (MC) is the mean concentration of metal in food (mg/kg, on a fresh weight basis); FDC represents the daily consumption of the specified food according to ISIRI (12968) (g/person/day); and BW is the average body weight. The local inhabitants consumed an average of 3g/day of offal (liver/kidney) and 30g/day of muscle for adults (BW = 60kg) and children (BW = 30kg), respectively. The calculated EDI values were compared with the tolerable daily intakes (TDI) recommended by the US EPA (2010).

2.8 Target hazard quotient

The target hazard quotient (THQ) was used to evaluate the potential health risks arising from the consumption of heavy metal-contaminated food. The THQ is defined as the ratio between the exposure dose and the oral reference dose (RfD). The RfD represents the safe daily exposure threshold of a contaminant over a lifetime. Following the methodology presented in the US EPA Region III Risk-Based Concentration Table and by Wang et al. (2010), the THQ was calculated using **Equation 2**:

$$\text{THQ} = \frac{\text{EFr} \times \text{ED} \times \text{FIR} \times \text{MC} \times 10^{-3}}{\text{RfD} \times \text{BW} \times \text{AT}} \quad (2)$$

Where EFr is the exposure frequency (365 days/year); ED is the exposure duration (72 years); FIR is the food ingestion rate (g/person/day); MC is the mean concentration of heavy metal in food (mg/kg, on a fresh weight basis); RfD is the oral reference dose (mg/kg/day); BW is the average body weight (60 kg for adults and 30kg for children); and AT is the averaging time (365 days/year X number of exposure years, assuming 72 for non-carcinogenic risks). A calculated THQ value of less than one ($THQ < 1$) indicates that exposed consumers face no significant health risks.

2.9 Hazard Index

The potential cumulative health risk from the concurrent consumption of multiple heavy metals in meat and offal was evaluated using the hazard index (HI). The HI was calculated by summing the target hazard quotients (THQ) of all evaluated metals (US EPA, 2010), as shown in **Equation 3**:

$$HI = \Sigma THQ = THQ_{Cd} + THQ_{Cr} + THQ_{Cu} + THQ_{Zn} \quad (3)$$

where ΣTHQ represents the summation of the individual hazard quotients, and THQ_{Cd} , THQ_{Cr} , THQ_{Cu} , and THQ_{Zn} are the hazard quotients calculated for cadmium, chromium, copper, nickel, and lead, respectively. An HI value greater than one ($HI > 1$) indicates the existence of potential adverse health effects for consumers [16].

3.0 Results and Discussion

3.1 Summary of the mean concentration and ranges of different heavy metals across different parts of the chicken samples.

Table 1: Shows the summary of the mean concentration and ranges of different heavy metals across different parts of the chicken samples.

	Liver	Muscle	Gizzard	
Heavy metals	$\bar{x} \pm SD$ (Min-Max)	$\bar{x} \pm SD$ (Min-Max)	$\bar{x} \pm SD$ (Min-Max)	P-value
Pb (mg/kg)	0.15 $\pm$ 0.14 (0.00-0.30)	0.20 $\pm$ 0.25 (0.00-0.60)	0.32 $\pm$ 0.20 (0.00-0.60)	P<0.05
Ni (mg/kg)	0.37 $\pm$ 0.46 (0.00-1.23)	0.37 $\pm$ 0.21 (0.00-0.62)	0.37 $\pm$ 0.48 (0.00-1.33)	P<0.05
Cd (mg/kg)	0.05 $\pm$ 0.04 (0.00-0.14)	0.02 $\pm$ 0.03 (0.00-0.07)	0.03 $\pm$ 0.03 (0.00-0.07)	P<0.05
Cr (mg/kg)	0.15 $\pm$ 0.20 (0.00-0.47)	0.10 $\pm$ 0.10 (0.00-0.23)	0.04 $\pm$ 0.06 (0.00-0.12)	P<0.05
Zn (mg/kg)	0.35 $\pm$ 0.06 (0.23-0.42)	0.26 $\pm$ 0.07 (0.18-0.37)	0.27 $\pm$ 0.11 (0.04-0.39)	P<0.05
Cu (mg/kg)	0.07 $\pm$ 0.05 (0.00-0.16)	0.02 $\pm$ 0.02 (0.00-0.03)	0.05 $\pm$ 0.05 (0.00-0.13)	P<0.05

(P<0.05: No significant difference)

Table 1 shows the mean concentration and ranges of different heavy metals across different parts of the chicken samples. The mean concentrations of lead were 0.15 $\pm$ 0.014, 0.20 $\pm$ 0.25, and 0.32 $\pm$ 0.20 mg/kg in the liver, muscle, and gizzard, respectively. The concentration of lead varies from 0.00-0.30, 0.00 – 0.60, and 0.00-0.60 in the liver, muscle, and gizzard, respectively. Mean concentrations of Nickel were 0.37 $\pm$ 0.46, 0.37 $\pm$ 0.21, and 0.37 $\pm$ 0.48 mg/kg in the liver, muscle, and gizzard, respectively. The concentration of Nickel varies from 0.00-1.23, 0.00-0.62, and 0.00–1.33 in the liver, muscle, and gizzard, respectively. Mean concentrations of cadmium were 0.05 $\pm$ 0.04, 0.02 $\pm$ 0.03, and 0.03 $\pm$ 0.03 mg/kg in the liver, muscle, and gizzard, respectively. The concentration of cadmium varies from 0.00-0.14, 0.00-0.07, and 0.00-0.07 in the liver, muscle, and gizzard, respectively. Mean concentrations of chromium were 0.15 $\pm$ 0.20, 0.10 $\pm$ 0.10, and 0.04 $\pm$ 0.06 mg/kg in the liver, muscle, and gizzard, respectively. The concentration of chromium varies from 0.00-0.47, 0.00-0.23, and 0.00-0.12 in the liver, muscle, and gizzard, respectively. The mean concentrations of zinc were 0.35 $\pm$ 0.06, 0.26 $\pm$ 0.07, and 0.27 $\pm$ 0.11 mg/kg in the liver, muscle, and gizzard, respectively. The concentration of zinc varies from 0.23-0.42, 0.18-0.37, and 0.04-0.39 in the liver, muscle, and gizzard, respectively. Mean

concentrations of copper were 0.07 ± 0.05 , 0.02 ± 0.02 , and 0.05 ± 0.05 mg/kg in the liver, muscle, and gizzard, respectively. The concentration of copper varies from 0.00-0.16, 0.00-0.03, and 0.00-0.13 in the liver, muscle, and gizzard, respectively. There were no significant differences ($p < 0.05$) in the levels of heavy metals in the organs studied.

The variation in the concentration of heavy metals across different chicken tissues is illustrated in **Figures 2–7**.

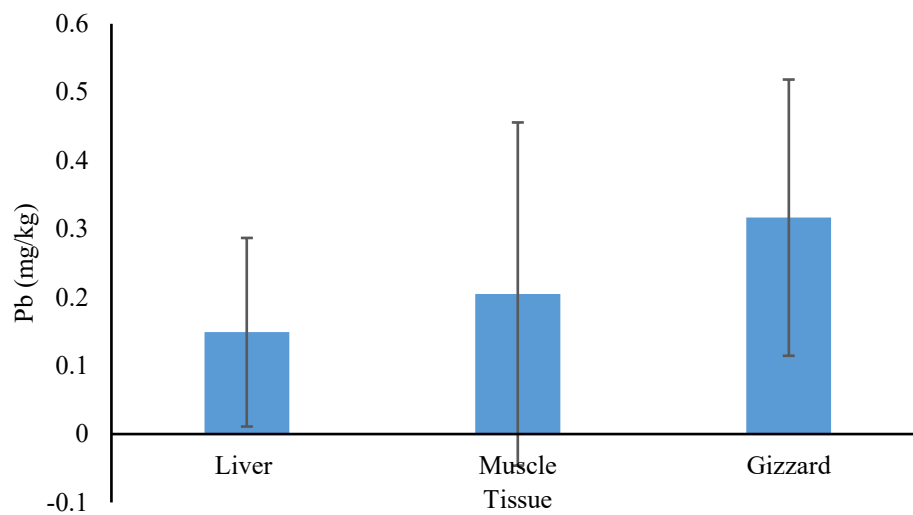


Figure 2. Variation in the concentration of lead in the various tissues

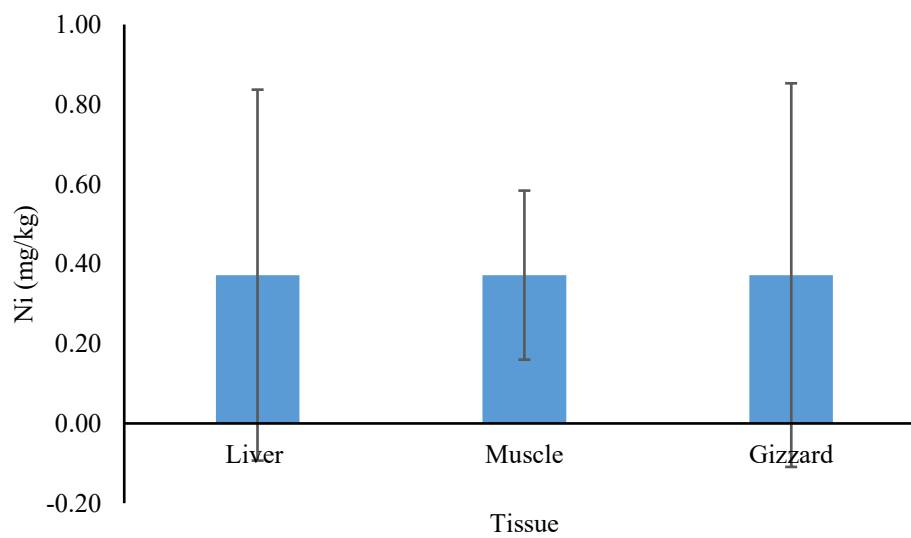


Figure 3. Variation in the concentration of nickel in the various tissues

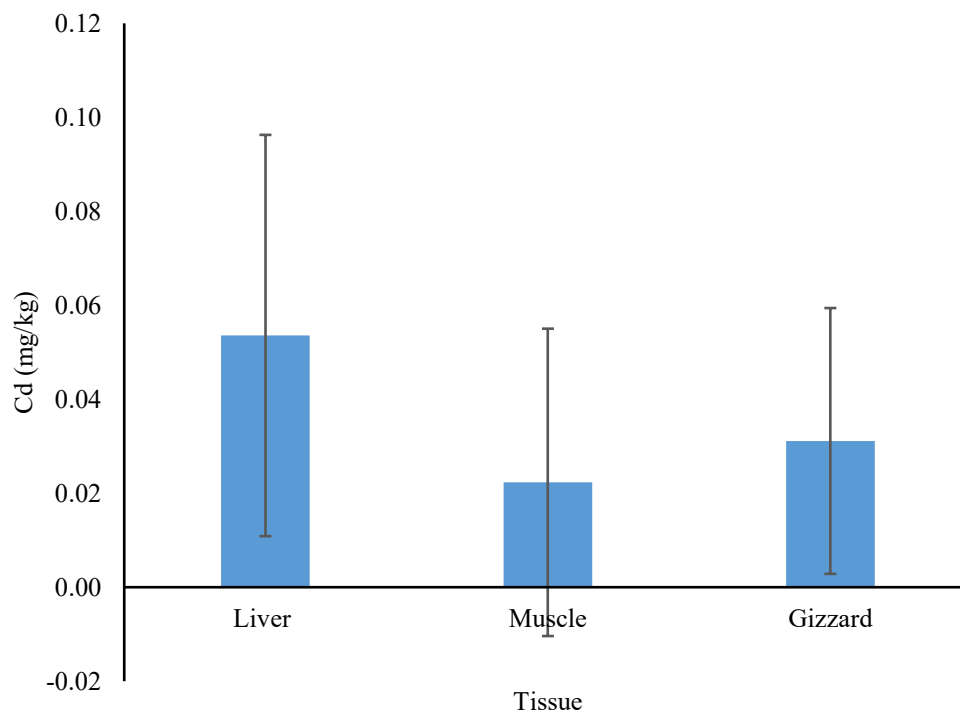


Figure 4. Variation in the concentration of cadmium in the various tissues

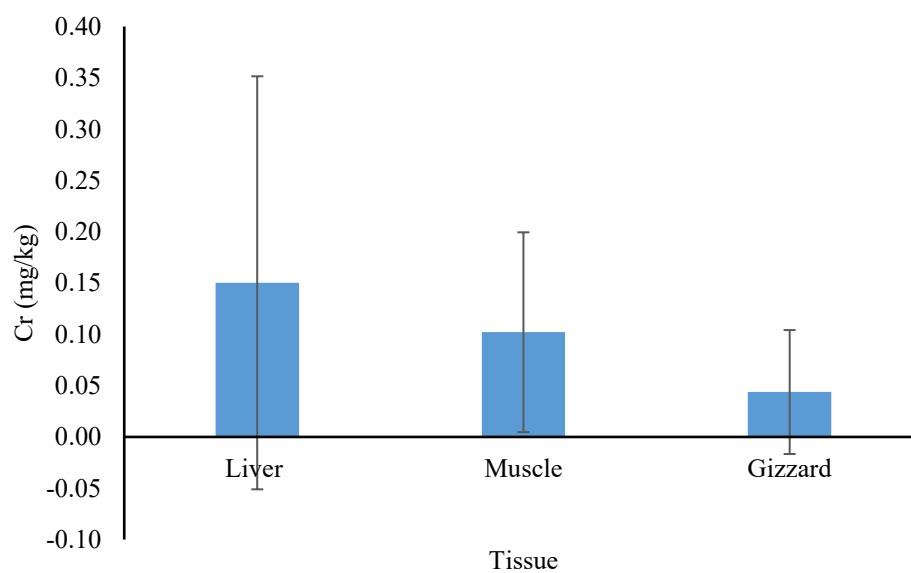


Figure 5. Variation in the concentration of chromium in the various tissues

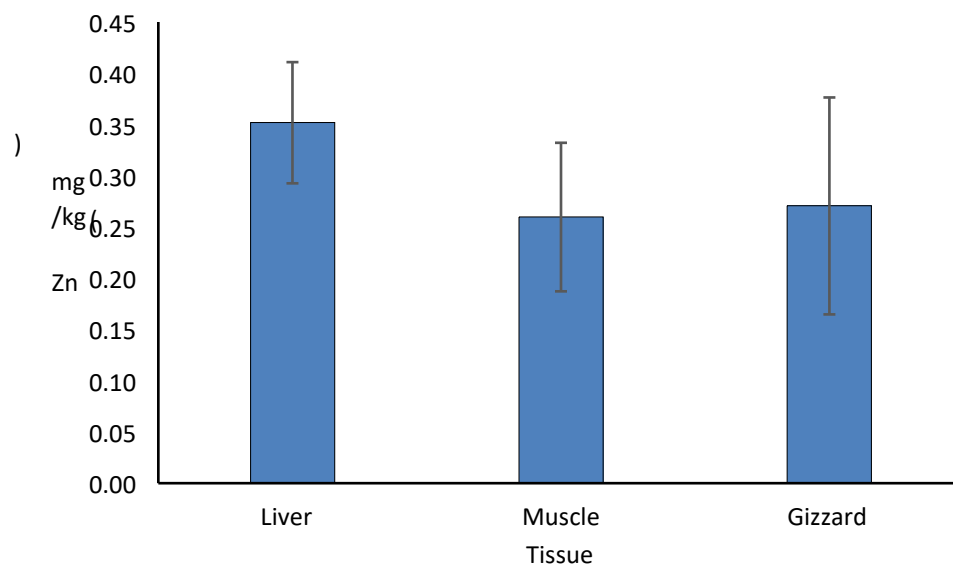


Figure 6. Variation in the concentration of zinc in the various tissues

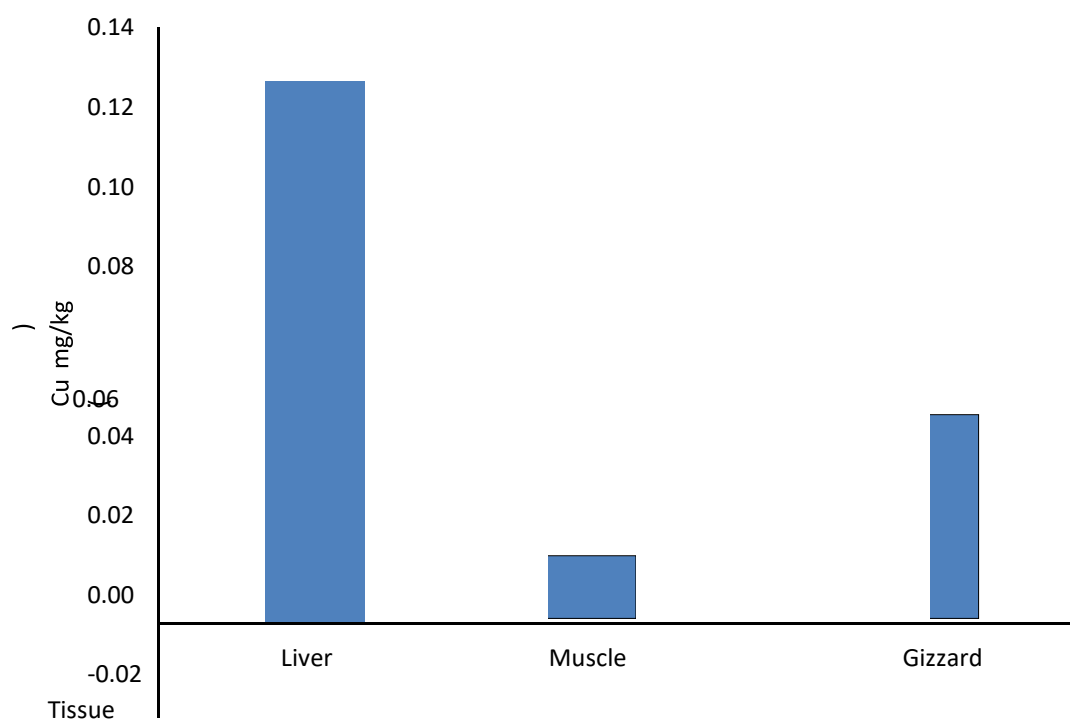


Figure 7. Variation in the concentration of copper in the various tissues

3.2. Estimated Daily Intake (EDI) and Tolerable Daily Intake (TDI) of carcinogenic and non-carcinogenic heavy metals (Pb, Ni, Cd, Cr, Zn, and Cu) through the Consumption of Chicken, liver, and Gizzard (mg/kg/day) in both Adults and Children.

Table 2 shows the summary of the estimated daily intake (EDI) and tolerable daily intake (TDI) of heavy metals of carcinogenic and non-carcinogenic heavy metals (Pb, Ni, Cd, Cr, Zn, and Cu) through the Consumption of Chicken, liver, and Gizzard (mg/kg/day) in both Adults and Children.

	Muscle		Liver		Muscle		TDI
Heavy metals	Adults	Children	Adults	Children	Adults	Children	mg/kg
Pb (mg/kg/day)	0.3723	0.4965	0.5119	0.6825	0.7912	1.0549	0.0036
Cr (mg/kg/day)	0.3756	0.5008	0.2552	0.3403	0.1094	0.1459	1.500
Cd (mg/kg/day)	0.1339	0.1785	0.0558	0.0744	0.0778	0.1038	0.001
Ni (mg/kg/day)	0.9295	1.2393	0.9295	1.2393	0.9295	1.2394	0.0028
Zn (mg/kg/day)	0.8793	1.1724	0.6493	0.8658	0.6764	0.9019	1.000
Cu (mg/kg/day)	0.1802	0.2403	0.0404	0.0538	0.1313	0.1751	0.040

The Tolerable Daily Intake [12].

Table 2 shows the estimated daily intake for lead in both the adult and child populations ranges across the different organs; the muscle, liver, and gizzard were 63, 0.5119, and 0.6825, 0.7912, and 0.0549, respectively. The estimated daily intake (EDI) of lead in children and adults was found numerically higher than the tolerable daily intake (TDI). The estimated daily intake for nickel in both the adult and children population ranges across the different organs; the muscle, liver, and gizzard, respectively, are 0.9295 and 1.2393, 0.9295 and 1.2393, 0.9295 and 1.2394. The estimated daily intake (EDI) of nickel in both adults and children across the muscle, liver, and gizzard was found numerically higher than the tolerable daily intake (TDI). The estimated daily intake for chromium in both the adult and child populations ranges across the different organs; the muscle, liver, and gizzard, respectively, are 0.3756 and 0.5008, 0.2552 and 0.3403, 0.1094 and 0.1459. The estimated daily intake (EDI) of chromium in both adults and children across the muscle, liver, and gizzard was found numerically lower than the tolerable daily intake (TDI). The estimated daily intake for cadmium in both the adult and children population ranges across the different organs; the muscle, liver, and gizzard, respectively, are 0.1339 and 0.1785, 0.0558 and 0.0744, 0.0778 and 0.1038. The estimated daily intake (EDI) of cadmium in both adults and children across the muscle, liver, and gizzard was all found numerically higher than the tolerable daily intake (TDI). The estimated daily intake for zinc in both the adult and children population ranges across the different organs; the muscle, liver, and gizzard, respectively, are 0.8793 and 1.1724, 0.6493 and 0.8658, 0.6764 and 0.9019. The estimated daily intake (EDI) of zinc in children with respect to the muscle was found numerically higher than the tolerable daily intake (TDI), while others were found below the tolerable daily intake. The estimated daily intake for copper in both the adult and the child population ranges across the different organs; the muscle, liver, and gizzard, respectively, are 0.1802 and 0.2403, 0.0404 and 0.0538, 0.1313 and 0.1751. The estimated daily intake (EDI) of copper in both adults and children across the muscle and the gizzard was found numerically higher than the tolerable daily intake (TDI), while only the estimated daily intake (EDI) of copper in adults across the liver was found equal to the tolerable daily intake

3.3 Targeted hazard quotient (THQ) and Hazard index (HI) in carcinogenic and non-carcinogenic risk assessment of metals (Zn, Cu, Cd, Cr) through the consumption of chicken muscle, liver and gizzard (mg/kg/day) in both adults and children.

Table 3: The targeted hazard quotient (THQ) and hazard index (HI) values

	Muscle		Liver		Gizzard	
	Adult	Children	Adult	Children	Adult	Children
Zn	0.0029	0.0039	0.0022	0.0029	0.0023	0.0030
Cu	0.0045	0.0060	0.0010	0.0013	0.0033	0.0044
Cr	0.0003	0.0003	0.0002	0.0002	0.0001	0.0001
Cd	0.1339	0.1785	0.0558	0.0744	0.0778	0.1038
HI	0.1416	0.1888	0.0591	0.0788	0.0834	0.1112

Table 3 shows the targeted hazard quotient of zinc across the chicken muscle, liver and gizzard (mg/kg/day), respectively in both adult and children population ranges from (0.0029, 0.0039), (0.0022, 0.0029), (0.0023, 0.0030), respectively. The targeted hazard quotient of copper across the chicken muscle, liver, and gizzard (mg/kg/day), respectively, in both adult and children populations ranges from (0.0045, 0.0060), (0.0010, 0.0013), (0.0033, 0.0044), respectively. The targeted hazard quotient of chromium across the chicken muscle, liver, and gizzard (mg/kg/day), respectively, in both adult and children populations ranges from (0.0003, 0.0003), (0.0002, 0.0002), (0.0001, 0.0001), respectively. The targeted hazard quotient of cadmium across the chicken muscle, liver and gizzard (mg/kg/day) respectively in both adult and children populations ranges from (0.1339, 0.1785), (0.0558, 0.0744), (0.0744, 0.1038) respectively. The value of the different targeted quotients across this population in both adult and children was numerically lower than one (<1) indicating negligible non-carcinogenic risk (THQ <1), as recommended by [14]. The hazard index of heavy metals through consumption of muscle, liver, and gizzard of the chicken in both adults and children was found numerically lower than one (<1), indicating no significant cumulative non-carcinogenic health risk, as recommended by [14].

The graphical representation of THQ and HI values is shown in **Figures 8–10**.

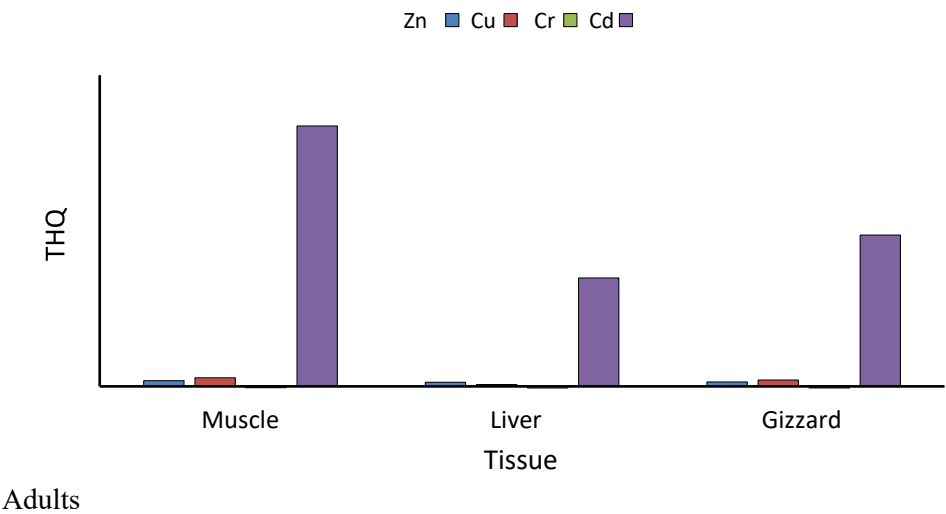


Figure 8: Targeted hazard quotient of the heavy metals across different tissue of chicken based on adult consumption.

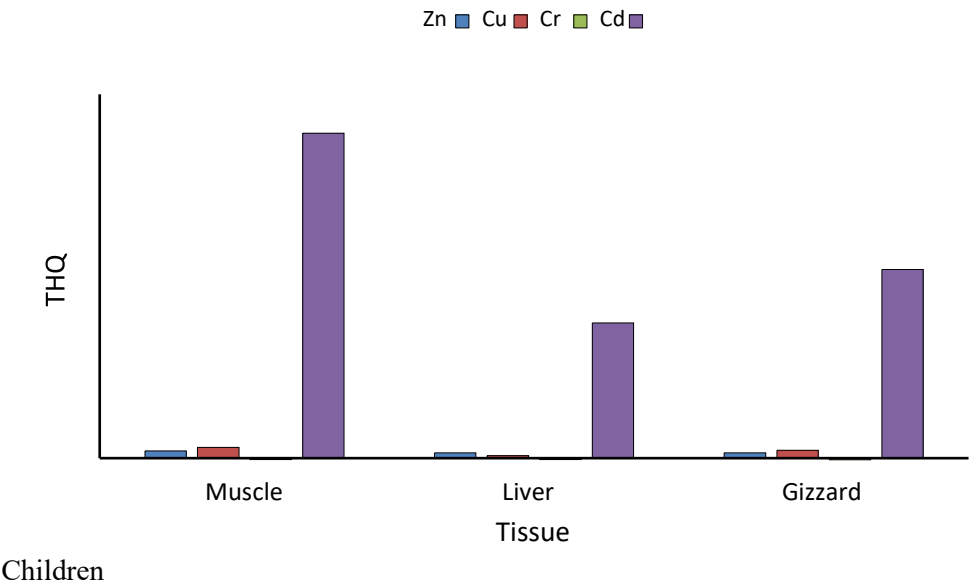


Figure 9. Targeted hazard quotient of the heavy metals across different tissue of chicken based on children consumption.

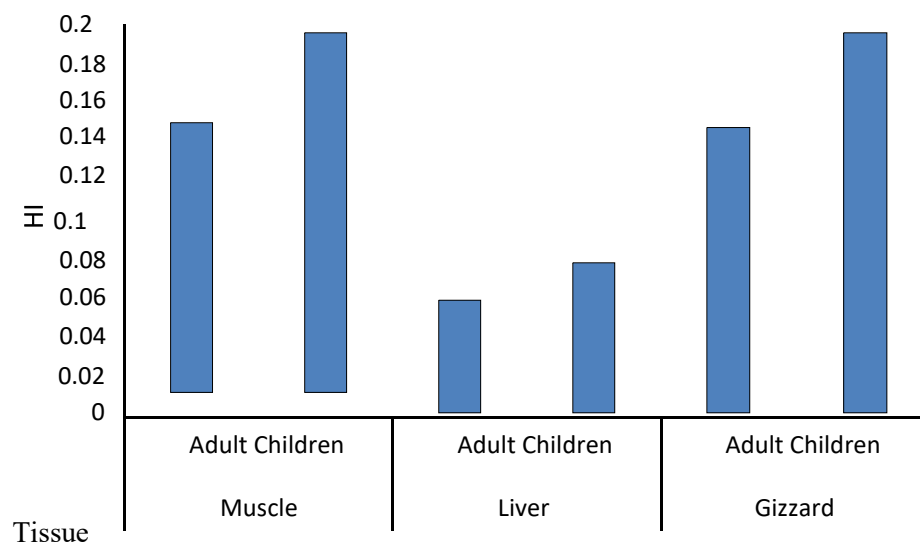


Figure 10: Hazard index of heavy metals through consumption of muscle, liver and gizzard of the chicken in both adults and children

3.4 Cancer Risk (CR) Assessment of Carcinogenic Heavy Metals (Pb, Ni, Cd, Cr) Through the Consumption of Chicken Muscle, Liver, and Gizzard

Table 4: The cancer risk (CR) assessment results

	Muscle	Liver	Gizzard
Pb	3.16E-03	4.35E-03	6.73E-03
Cr	1.88E-01	1.28E-01	5.47E-02
Cd	5.09E-02	2.12E-02	2.96E-02
Ni	7.81E-01	7.81E-01	7.81E-01

Cancer risk [12]

The cancer risk of lead across the chicken muscle, liver and gizzard respectively in the samples are (3.16E-03), (4.35E-03), (6.73E-03) respectively. The cancer risk of chromium across the chicken muscle, liver and gizzard, respectively in the samples are (1.88E-01), (1.28E-01), (5.47E-02) respectively. The cancer risk of cadmium across the chicken muscle, liver and gizzard respectively in the samples are (5.09E-02), (2.12E-02), (2.96E-02) respectively. The cancer risk of nickel across the chicken muscle, liver and gizzard of the sample are (7.81E-01), (7.81E-01), (7.81E-01) respectively. The value of the different cancer risk across all the different samples exceeded the acceptable range of E-4 to E-6 as recommended by [12]. The cancer risk due to Pb, Cr, Cd and Ni was unacceptable. The distribution of cancer risk across samples is illustrated in **Figure 11**.

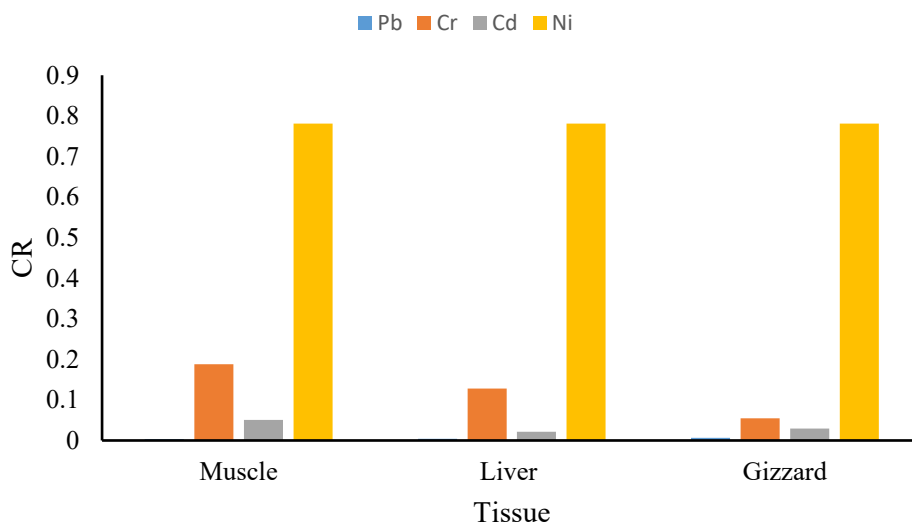


Figure 11: Cancer risk of the heavy metals across different samples

4.0. Conclusion

This study has demonstrated that both carcinogenic (Pb, Ni, Cr, Cd) and non-carcinogenic (Zn, Cu, Cr, Cd) heavy metals are present in measurable concentrations within the edible tissues of poultry chicken sold for human consumption in Nsukka Metropolis, South-Eastern Nigeria. The detected levels of these metals pose varying degrees of health risk, ranging from non-carcinogenic toxicity to potential carcinogenic effects, depending on their concentration, frequency of consumption, and cumulative exposure over time.

The results revealed that while the Estimated Daily Intake (EDI) of some metals fell below the Tolerable Daily Intake (TDI) recommended by the [14], others, particularly Pb, Ni, and Cd, exceeded safe limits in certain tissues. The Target Hazard Quotient (THQ) and Hazard Index (HI) for the non-carcinogenic metals were generally below unity, indicating minimal non-carcinogenic risk. However, the Cancer Risk (CR) values for the carcinogenic metals exceeded the acceptable range of $1 \times 10^{-4} - 1 \times 10^{-6}$, suggesting significant carcinogenic potential associated with long-term consumption of contaminated chicken meat.

These findings highlight the persistent challenge of environmental contamination from anthropogenic sources such as the indiscriminate use of agrochemicals, poor waste management, and industrial effluents. As these heavy metals accumulate in soils, water, and poultry feeds, their transfer into animal tissues becomes inevitable, thereby increasing human exposure through the food chain.

It is therefore recommended that routine screening of poultry meat, feed, and water sources be implemented at both farm and slaughterhouse levels to ensure compliance with international food-safety standards. Policymakers and regulatory agencies should strengthen surveillance and establish stricter enforcement of agricultural and industrial waste disposal practices.

Future studies should focus on identifying the spatio-temporal distribution of heavy metals across different poultry farms and markets using robust statistical tools such as regression modelling and principal component analysis. Such efforts will provide predictive insights that can inform regional and national policies aimed at minimizing heavy-metal contamination and protecting public health.

Ultimately, this study provides valuable evidence of the toxicological and carcinogenic safety status of poultry meat in Nsukka, offering a critical foundation for environmental health management and food safety policymaking in Nigeria and beyond.

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Author Contributions: O.J.O. conceptualized and designed the study. I.M.E. supervised the research work. O.J.O., U.M., A.O.I., S.A.A., U.G.N., A.M.U and C.V.A. conducted the experiments and data collection. O.J.O. performed data analysis and drafted the manuscript. All authors reviewed, edited, and approved the final manuscript.

Conflict of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

Data Availability: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval: This study did not involve human participants or live animals. No ethics approval was required

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