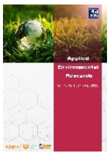
App. Envi. Res. 46(3) (2024): 034

Applied Environmental Research
- RESEARCH FOR SUSTAINABLE PLANET -



Research Article

Exposure to Metal Accumulation in Chicken Giblets and Human Health Risk in Lokoja, Nigeria

Jude Ehwevwerhere Emurotu*, Lami Habib, Ephraim Musa Dallatu, Adamu Shuaibu Onakpa, Aloysius Akaangee Pam

Department of Chemistry Federal University Lokoja, Lokoja Kogi State, Nigeria

*Correspondence Email: jude.emurotu@fulokoja.edu.ng

Abstract

When consumed, the toxic heavy metals in chicken giblets pose a grave risk to humans. An inductively coupled plasma optical emission spectrometer (ICP-OES) was used to measure the concentrations of metals (Al, Cd, Co, Cr, Ni, Mn, and Pb) in the liver, gizzard, and kidney of chickens from the Lokoja poultry market. Except for lead, which slightly exceeded the FAO/WHO limit of 0.1 mg kg^{-1}, the metal concentrations found were all within the threshold limit. The estimated daily intake (EDI), hazard quotient (HQ), hazard index (HI), and cancer risk (CR) were used to assess the risks that humans would face from consuming the chicken giblets. The Nigerian population's daily consumption of the metals under study was found to be less than the allowable dietary intake levels established by several international organizations. The giblets' estimated HI, which accounts for all the metals present, is 1.05E-01, meaning that the current intake level of consuming the giblets is safe. The carcinogenic risk associated with hazardous metals exhibits values below the 10^{-4} US-EPA reference limit, except for Cr. The risk due to Cr can be classified as a tolerable risk as Cr values were marginally above the threshold limit. The result indicated that Cr (56% in gizzard and 67% in liver) exposure was the main contributor to the overall cancer risk from the lifetime ingestion of Lokoja chicken giblets. The findings could not be regarded as cause for concern since the values of EDI, HQ, HI, and CR calculated were below their respective reference limits. It suggests that heavy metal exposure through the intake of Lokoja chicken giblets is not likely to cause potential health risks to consumers.

ARTICLE HISTORY
Received: 10 Mar. 2024
Accepted: 16 Jun. 2024
Published: 8 Aug. 2024

KEYWORDS
Heavy metal;
Chicken giblet;
Estimated daily intake;
Hazard quotient;
Hazard index;
Nigeria

Introduction

Meat consumption globally has increased tremendously in recent times [1]. As a result, meat output and consumption worldwide nearly quadrupled [2]. In most religions and cultures worldwide, chicken seems to be the most accepted and commonly consumed meat type [3]. Chickens are better feed efficiency converters and have a shorter supply chain than red meat animals [4]. The nourishing value of chicken meat and its products is the main reason for the high demand. Poultry meat is a nutrient-dense food, containing high levels of vitamins, minerals, essential amino acids, antioxidants, and essential trace elements. The edible parts of the animal typically offer a range of nutritional advantages. In developing nations, poultry feed is produced using protein concentrates derived from solid waste from tanneries. Feeds produced from tannery solid waste without passable treatment may contain metals. Metal contamination of poultry products may arise through drinking water, feeds, and chicken processing, posing a problem [5]. Consuming such chickens verminous with metals could pose a health risk to humans [6, 4]. When poultry feeds are contaminated with heavy metals, it affects not only the livestock's health and reproduction

https://doi.org/10.35762/AER.2024034

but also the products and human well-being. The buildup of metals varies by organ within a bird and is dependent on the dosage consumed, exposure period, animal breed, and age [7]. Some are considered essential metals (iron (Fe), cobalt (Co), manganese (Mn), copper (Cu), antimony (Sb), magnesium (Mg), and zinc (Zn) when their concentrations fall within thresholds for safety in food products. Non-essential and toxic metals include chromium (Cr), cadmium (Cd), arsenic (As), mercury (Hg), nickel (Ni), lead (Pb), and strontium (Sr) [8]. Essential metals are needed in small quantities in the body as they contribute to numerous biological and metabolic processes vital for body homeostasis and, when ingested in excess, may result in some health ailments [9]. Non-essential and toxic metals, even at low concentrations, can cause health disorders. Humans exposed to the endocrine-disrupting metal Cd develop kidney, liver, lung, and heart illnesses, bone abnormalities, and cardiac disorders. Hence, the classification of Cd as a human carcinogen [8, 10–11].

Ni interferes with bodily processes involving the neurological system, heart, and lungs. The focus on the toxicity of Ni to humans is due to nickel’s links to cancer [12]. Cr is another toxic metal. According to Wilbur et al. [13], Cr (IV) is a known carcinogen, and the IARC agrees, classifying it as a Group 1 human carcinogen [14]. There is a rising concern, as eating poultry and eggs that contain chromium may likely result in cancer [15]. The IARC has classified Pb as a Group 2B probable human carcinogen [14]. Lead exposure can result in a variety of disorders, including encephalopathy, and is characterized by irritability, seizures, ataxia, and altered consciousness in children. Lead toxicity can also result in neuropathy in adults [16]. The symptoms of lead poisoning in children are like those of attention deficit hyperactivity disorder (ADHD). Additionally, lead poisoning results in behavioral and cognitive impairments, anxiety, migraines, and numerous other related symptoms [17]. Consuming metal-tainted chicken over time could result in toxic metal buildup in several important organs, offering serious health risks [4]. To safeguard consumers from possible exposure to the resulting health hazards, it is required by law in most countries that all food categories be analysed periodically for their nutritional value and safety [18]. In northcentral Nigeria, there is a dearth of data on the level of potentially toxic metals (PTMs) in chicken giblets and the potential health risks associated with their consumption. Considering that continuous monitoring of the presence of PTMs in food samples is critical and indispensable, this study aims (i) to measure a range of PTMs in chicken giblets obtained from chicken purchased from the poultry market in Lokoja, Nigeria, using the inductively coupled plasma-optical emission spectrometry (ICP-OES) technique, and (ii) to estimate the risks of both cancer and non-cancer in the local population due to the associated metal exposures from the intake of chicken giblets. It is vital to evaluate the potential health risk that the consumption of poultry edibles poses to the local population.

Materials and method

1) Study area

Lokoja is located approximately at latitudes 7° 45′27.56′′ and 7° 51′04.34′′N and longitudes 6° 41′55.64′′ and 6° 45′36.58′′E of the Meridian, with a total land area of 63.82 km^2 (Adeoye 2012). Lokoja City is a strategic location in Nigeria. This historic city acts as a gateway from the west, south-south, and south-east to the country's northern region. It is a confluence town with a population estimated at 885,882. It is roughly 165-km southwest of Abuja. Felele, Adankolo, Kabawa, Otokiti, and Ganja are a few of the city's many suburbs. Residential districts in the city vary in terms of population density. The city has a year-round high temperature because it is located in Nigeria's tropical savanna climate zone. The three major markets in Lokoja are the old market, the Kpata Market, and the new (international) market. The old market houses both the poultry market and slaughterhouse in Lokoja. Shop owners were interviewed to ascertain that only chickens reared in Lokoja and not from any other place were bought.

2) Sampling

Within three months, 90 chicken organs (each of kidneys, livers, and gizzards), comprising 45 males (cocks) and 45 females (hens), were obtained from chicken purchased from the poultry market in Lokoja Kogi State, northcentral Nigeria. After each chicken was dissected, the liver, kidney, and gizzard were removed and placed in a zip-lock bag. The bag was then kept chilled in an ice chest before being transported to the lab for further processing. Each zip-lock back was labelled appropriately. Limitations may arise when the sampling method is not well defined and when an appropriate sample size is not collected, and the method chosen to collect the samples may also introduce bias. If the samples are not representative enough, it will reduce the reliability of the findings. Larger sample sizes (30–100) help to increase the reliability of the findings. Samples were collected randomly and over a period of time to avoid sampling bias.

3) Sample preparation

Samples were carefully cleansed with distilled deionized water at the lab to remove any surface contamination, including particulates. The samples were cut into small pieces with a stainless-steel knife to speed up the drying process. Then, it was dried for 15 hours each day for three days in a microwave oven (Pelco Biowave Pro+, Ted Pella, Germany) at 75 °C until a constant dried weight was achieved. Throughout the drying process, the samples were watched to prevent physical changes like heat burn. The samples were ground with a ceramic mortar and pestle, put in polyethylene bags, labelled, and kept dry and cool until acid digestion.

4) Calibration of instrument

Calibration and quality control (QC) solutions were prepared from the reference material PE-MECAL3-ASL-1, a multi-element calibration standard. Standards and QC solutions were prepared by diluting them with Ultrapure Merck Lichrosolv water. The solutions were stabilized with a high-purity, 2% v/v concentrated nitric acid. The serial dilution method was used to create working standard concentration ranges from the multi-element stock standard. The ICP-OES expert software was used to produce a worksheet into which the method's parameters and each sample code were programmed (Table 1).

5) Chemical analysis and quality assurance

A 0.5 g aliquot of each dried chicken giblet powder was transferred into a Pyrex flask and placed on a hot plate (Corning PC-600D, Japan). A mixture of 70% HNO_3 and 30% $HClO_4$ (3:1) (Sigma-Aldrich Munich, Germany) was added and heated to 120 °C to digest. The material continued to undergo digestion until it lost its colour. The digest was filtered into a 50 mL standard flask using Whatman No. 42 filter paper (Sigma-Aldrich) after cooling for a while. The flask was then properly filled with double-distilled, deionized water. The digests were kept in a plastic bottle and utilized to measure the concentrations of Al, Cd, Co, Cr, Ni, Mn, and Pb using ICP-OES (Agilent 720-ES, New York) [19]. The same volume and acid mixture were employed to prepare each procedural blank and standard according to the identical steps as those used to prepare the giblet sample. After thoroughly cleaning with Teepol, all analytical glassware was immersed in 2 M HNO_3 acid for 24 hours before being washed with deionized water. Stock-standard solutions were made using Analar R-grade salts. Diluted aliquot working standards were created from the stock solutions. Freshly prepared reagents' actual strengths were standardized. In order to verify methods and assess the precision and accuracy of geochemical data and processes, samples were spiked with a known amount of metal. The identical procedures as in unspiked were followed [20]. The metals recovered average between 91.7% and 98.5% of their original values (Supplementary Materials (SM) 1). Limit of detection (LOD) calculations followed Shrivastava and Gupta's instructions [21]. For Al, Cd, Co, Cr, Ni, Mn, and Pb, the respective limits of detection are 0.00197, 0.00011, 0.00074, 0.00125, 0.00072, 0.00006, and 0.00240 mg kg^{-1}.

6) Statistical analysis

Utilizing the Statistical Package for Social Sciences (SPSS) (Version 22 for Windows, Chicago, Illinois, USA), all statistical processes were performed using a one-way analysis of variance (ANOVA) at a significance level of 5%. OriginPro 2022 was used to plot graphs and doughnut charts and to generate a biplot PCA with a correlation matrix. Data obtained from the analysis of samples have no meaning until subjected to statistical analysis. The statistical tools employed were principal component analysis (PCA) and ANOVA. ANOVA is often used to compare significant differences between variables. Similarly, PCA is a potent data analysis technique for lowering dataset complexity while maintaining important information. It is accomplished by converting the initial variables into a new collection of variables, known as principal components, to analyse relationships.

Table 1 Operating conditions parameters of ICP-OES used in this study

Parameters	Setting
Type of detector	Charged couple devices (CCD)
Power	1 kw
Plasma gas flow	15 L min^{-1}
Auxiliary gas flow	1.5 L min^{-1}
Spray chamber type	Glass cyclonic
Torch	Standard axial torch
Nebulizer type	Sea Spray
Nebulizergas pressure	220 kPa
Pump speed	15 rpm
Sample uptake	30 s
Replicate read time	30 s
Number of replicates	2
Sample delay time	20 s
Stabilization	15 s
Rinse time	10 s
Fast pump	On
Wavelength (nm)	Al (396.152), Cd (214.439), Co (238.892), Ni (231.604), Pb (220.353), Mn (257.610), Cr (267.716)

7) Assessment of health risk

Based on the daily metal intake and other pertinent factors (e.g., body weight), an assessment was conducted to determine the health risks associated with consuming chicken giblets contaminated with metals. This is to estimate the possible health risks from exposures to substances that are both cancer-causing and non-cancerous.

8) Estimation of daily intake (EDI) of metals

In order to evaluate the likelihood of dietary risk in the general population, an estimation of EDI and health risk index (HRI) was specifically calculated for adults. The calculation of EDI was done using the recommended equation (Eq. 1) [5].

$$EDI = \frac{C_m \times I_{RT}}{B_{wt}} \qquad \text{(Eq. 1)}$$

Where C_m is the mean concentration of each metal (mg kg^{-1} dry weight), IRT is the intake rate, and B_{wt} is the body weight. B_{wt} of an adult stand for 70 kg [5]. The mean chicken meat consumption by the Nigerian population was 1.16 kg (= 3.18 g day^{-1}) in 2020, the data was obtained from an online source Helgilibrary.com as contained in FAOSTA [22]. The Nigerian population is estimated to consume approximately 0.32 g of chicken giblets per day if the average percentage of giblets in chicken meat is less than 10%. Hence, the ingestion rate corresponds to a rough nominal value of 0.32 g (0.32×10^{-3} mg kg^{-1}) of giblets consumed daily by the Nigerian population.

9) Estimation of average daily dose

The level of human exposure to residues in food can be estimated using the average daily dosage (ADD). The equation (Eq. 2) below can be used to compute the ADD (mg kg^{-1} day^{-1}) for a particular residue present in giblets consumed [5].

$$ADD = \frac{EDI \times L_T \times E_F}{T_P} \qquad \text{(Eq. 2)}$$

where EDI is the estimate of daily intake of metal from consuming chicken giblets, L_T is the length of time an individual is exposed to ingested metals during a lifetime (70 years, proportionate with the average life span of the Nigerian population), and E_F is the exposure regularity (200 days a^{-1}) considering that chicken giblets are typically consumed four days a week in the area from the local information obtained. For non-carcinogenic effects, T_P (the time over which the dose is averaged in days) is typically regarded as being equal to E_F (=365×L_T).

10) Hazard quotient (HQ) and hazard index (HI)

The non-cancer risk of metals from the EDI of giblets to exposed people was computed using the HQ and HI according to Eqs. 3-4. To understand the potential impacts of harmful metal additives on humans, one uses the HI. HI was calculated as the total of all HQs [23].

$$HQ = \frac{ADD}{RfD} \qquad \text{(Eq. 3)}$$

$$HI = \sum_{n=1}^{n} HQ_S \qquad \text{(Eq. 4)}$$

RfD is the oral reference dose for a specific metal. It represents the highest daily dose allowed that an exposed person could receive at this level over an extended period without experiencing adverse effects. RfD values (Al 1.0E+00, Cd 1.0E-04, Pb, 0.004, Ni 2.0E-02, Co 3.0E-04, Cr 0.003, and Mn 0.14) for different toxicants have been established by a variety of international organizations that provide regulatory advice, most frequently in units of mg/kg/day [24].

11) Cancer risk (CR)

The correlation between the amount of a cancer-causing metal ingested and the resulting effects can be used to describe the CR. The CR and total cancer risk (TCR) due to collective exposure of various metals through the intake of giblets were estimated according to Eq. 5–6 [25].

$$CR = CSF_O \times ADD \times LT \qquad \text{(Eq. 5)}$$

Where CSFo represents the carcinogenic slope factor or lifetime probability of developing cancer. Cd, Cr, Ni, and Pb have corresponding CSFo of 0.38, 0.5, 1.7, and 0.0085 mg kg^{-1} day^{-1} [26]. LT is taken to be 70 years old. Cancer risk values of 1.0×10^{-4} and multiple-element CR (MCR)<1.0×10^{-4} [27] are tolerated and do not increase the risk of having cancer throughout one's lifetime.

Multi-metal cancer risk

$$MCR = \sum_{i=1}^{n} CR \qquad \text{(Eq. 6)}$$

Results and discussion

1) Metal concentrations in chicken giblets

The mean concentration of essential metals (Al, Co, and Mn) and PTMs (Cd, Cr, Ni, and Pb) in chicken giblets and their estimated daily intake are presented in Table 2. The obtained range and mean of metals in the gizzard were Al 3.41-22.2 (16.2), Cd 0.02-0.04 (0.03), Co 1.48-3.08 (2.25), Cr 0.32-0.38 (0.36), Mn 0.10-0.18 (0.13), Ni 0.03-0.11 (0.07), and Pb 0.09-0.17 (0.14), in kidney Al 6.31-37.5 (19), Cd 0.02-0.07 (0.04), Co 0.12-5.07 (2.3), Cr 0.37-0.39 (0.38), Mn 0.07-0.23 (0.11), Ni 0.03-0.15 (0.08), and Pb 0.09-0.25 (0.14) and liver Al 12.9-18.1 (14.7), Cd 0.01-0.04 (0.03), Co 0.33-3.37 (1.9), Cr 0.26-0.82 (0.44), Mn 0.23-0.52 (0.38), Ni 0.03-0.11 (0.05), and Pb 0.09-0.17 (0.13) in hens. The corresponding values of metals in the gizzard, kidney, and liver of the cocks were not significantly different except for Al, where the concentrations were higher than the values obtained for the hen. Differences in diets, the agricultural environment, and the ability of the various tissues to absorb and hoard metals account for the range [5]. Although the effect of Al on the health of humans is a notion, there is evidence of its toxicity, its steady accretion in the brain, and its ensuing effects on the nervous system, the skeletal and haematopoietic system [5]. The interference of Al with physical and cellular processes has been reported [28]. The interaction between aluminum and the plasma membrane, which affects most cellular and physical processes in animals, may be the source of aluminum's toxicity [29]. Studies have shown that Al^{3+} can substitute Mg^{2+} and Fe^{3+} in humans, leading to disruptions in cellular development and intercellular communication, as well as neurotoxicity and secretory processes [30]. Al is associated with changes in the structure of neurons that resemble the degenerative lesions seen in Alzheimer's patients [28, 31–33]. Al concentration in liver of cock (41±51 mg kg^{-1}) was significantly higher than ($P<0.05$) corresponding value in liver sample obtained for hen (14.7±2.1 mg kg^{-1}). Similar trend was observed for gizzard and kidney. Of the determined metals, Al concentrations in chicken giblets were the highest. The results for Al were consistent with two studies: Kamaly and Sharkawy [7], where Al concentration ranged from 5.873 to 14.005 g g^{-1} in the liver of six brands, and Mahmoud and Abdel-Mohsein [34], which found that Al concentrations of 8.44 (Assiut) and 16.44 g g^{-1} (Qena) in the liver were the highest examined metal. An essential metal Co was next with mean concentrations of 2.25±0.60 (gizzard), 2.3±1.6 (kidney), and 1.9±1.0 (mg kg^{-1}) in the liver in the hen. Corresponding values in cock are 3.3±1.1 (gizzard), 2.1±1.5 (kidney), and 2.49±0.97 (liver) (mg kg^{-1}). Co is a necessary component of vitamin B12, although information about its toxicity is scarce in the literature [35]. However, it was determined by NRC [36] to be between 100 and 200 ppm for poultry. Co exposure can lead to adverse health outcomes such as hormone imbalances, neurological disorders (such as hearing loss and vision impairment), and cardiovascular issues. In healthy individuals, the harmful effects of cobalt do not manifest at blood levels of less than 300 μg L^{-1}. Cobalt is unrelated to variations in hemoglobin, red blood cell count, and hematocrit concentrations, as well as variations in thyroid, cardiac, or neurological function [28, 35, 37,]. Humans require the element Mn. Its deficiency causes serious abnormalities of the skeletal and reproductive systems in mammals [38]. However, an excess of it is reported to be toxic, and its accumulation in the brain is the basis for Parkinson-type syndrome [39]. The detrimental effects of Mn include a reduction in foetal weight, skeletal and internal organ retardation, and a drop in term-born infants birth weight. Mn poisoning can result in chromosomal abnormalities, damage to DNA, negative effects on the embryo and fetus, and the production of responsive oxygen species that can lead to oxidative stress [28,40–41].

Vital metals are essential to humans as they play a significant role in several metabolic enzymes and cell components. Regular consumption of contaminated foods derived from mammals may lead to an increase in heavy metal levels in humans. Critical metals in excess can poison people or injure other living things [38]. In this study, the highest Mn concentration (0.38±0.12 mg kg^{-1}) was found in the liver of chickens, followed by the gizzard (0.13±0.03 mg kg^{-1}) and kidney (0.11±0.06 mg kg^{-1}). Because the liver is the center of metabolism, a high Mn concentration in the liver would be anticipated [28]. This result agrees with a previous report where the Mn concentration was highest in the liver compared to other parts [28]. Similarly, Oforka et al. [42] have reported a mean con-centration of Mn in the liver (0.415 ppm) higher than in the muscle muscles (0.2657 ppm) and gizzard (0.1265 ppm). Akan et al. [43] have also reported a higher mean concentration (3.67±0.14 μg g^{-1}) of Mn in the liver than other parts. The maximum concentration (1.23 mg kg^{-1}) of Cr was recorded in the liver. This value was higher than 0.18 mg kg^{-1} in the liver, as reported by Bratty et al. [44]. A similarly high value of 1.412 mg kg^{-1} has also been reported by Hossain et al. [4]. The mean Cr content detected in this study was lower than the maximum permissible limit of 1.0 mg kg^{-1} in chicken meat by FAO/WHO, [45]. The US National Academy of Science has recommended a range of 50–200 μg day^{-1} for Cr intake [46]. The range of Cr in gibbets in this study is similar to 0.051 (kidney) to 0.286 mg kg^{-1} (gizzard) reported in southern Nigeria [38]. The mean concentration in this study is higher than 0.09 ug g^{-1} in the heart and 0.03 ug/g in the liver in the study by Chijioke et al. [5] in Malaysia. However, it is half the amount found in the liver and one-fourth of the gizzard values reported by Naseri et al. [47] in Iran. Cr as Cr (VI) is classified as a non-essential metal that has a destructive effect on the human body. Hence, exposure to high concentrations can lead to numerous biotoxic effects in the renal, hepatic, and hematological systems. Its toxicity is ascribed to its ability to be absorbed in the gastrointestinal tract and lungs [5]. An excessive amount of Cr in meals can cause hypoglycemia and gastrointestinal irritation. This harmful activity can lead to damage to the kidneys, liver, and nerves, which in turn can cause irregular heartbeats and increase the risk of lung cancer. It can also damage the circulatory system and cause nerve tissue collapse. Additionally, it can cause tissue irritation, cytotoxicity, inflammation, and DNA damage. Ultimately, all of these factors can contribute to the development of lung cancer [48–50]. Cr in the oxidation states of Cr (III) and Cr (VI) are the most prevalent. Both are documented to have potentially toxic and direct toxicities. The Cr (VI) form is classified as a human carcinogen and mutagen. According to Shrivastava et al. [51], the Cr (III) form is mutagenic and has lethal effects on levels of intracellular ATP, oxygen consumption, and multiple enzyme activity. The mean concentrations of Ni were 0.07±0.04 (gizzard), 0.08±0.04 (kidney), and 0.05±0.03 (liver) mg kg^{-1} in hens, and values in cocks were 0.08±0.03 (gizzard), 0.10±0.06 (kidney), and 0.09±0.08 0.05±0.03 (liver) mg kg^{-1}. This study's mean values were below the permissible limit of 0.1 mg kg^{-1} by JECFA and WHO [52]. Naseri et al. [47] in Iran reported a lower mean concentration for the liver (0.021 ±0.00 mg kg^{-1}), but the gizzard's concentration (1.04± 0.23) mg kg^{-1} was higher than this study. Mahmoud and Abdel-Mohsein have reported a higher concentration (mg kg^{-1}) of 4.1 in the liver and 4.78±3.3 in the muscle of poultry [34]. Cd is known to have damaging effects on the liver and kidneys of humans. It accumulates majorly in the proximal tubular cells. Its accumulation in humans often results in some issues, ranging from cancer to hepatic, renal, skeletal, and reproductive concerns [4]. The mean of Cd concentration in hens 0.03±0.01 (gizzard), 0.04±0.02 (kidney), and 0.03±0.01 (liver) mg kg^{-1} and corresponding values in cocks 0.06± 0.01 (gizzard), 0.04±0.03 (kidney), and 0.03±0.01 (liver) mg kg^{-1} are within the threshold limits of 0.5 mg kg^{-1} (liver) and 1.0 mg kg^{-1} (kidney) as given by FAO/WHO [45] and EC [53]. These concentrations were similar to concentrations reported by Hassain et al. in Dhaka district, Bangladesh [4], but are lower than reported values of 0.493±0.083 (liver) and 0.343±0.015 (gizzard) by Okoye et al. [54] in Awka southeast Nigeria, 1.41 µg g^{-1} by Mahmoud and Abdel-Mohsein [33] in Egypt, and 1.49 ug g^{-1} (liver) by Badis et al. [55] in Algeria. Pb is known for its toxicity to humans, as its intake has no human benefits. Exposure of animals and humans to Pb principally occurs through diet [7]. It affects the body in different ways, acute Pb poisoning can cause headaches, nausea, insomnia, kidney failure, dizziness, high blood pressure, and schizophrenia. Long-term intake leads to deformities, neurological damage, muscle weakness, weight loss, renal damage, autism, and death [8]. The maximum concentration of 0.25 mg kg^{-1} of Pb was found in the kidney. The mean concentrations of Pb in giblets were slightly above the permissible value of 0.1 mg kg^{-1} stipulated by FAO/WHO [45] and EC [53]. In this study, the concentration of Pb was slightly higher in the liver compared to the concentrations in the gizzard and kidney, but the differences are statistically insigni-ficant ($p>0.05$) (Table 2). These results are in agreement with the report of the study by Abbas et al. [16] in Pakistan and Naseri et al. [47] in Iran, but are lower than the reported mean value (mg kg^{-1}) of 0.2867± 0.0176 (gizzard) and 0.3042±0.0172 (liver) by Oforka et al. [42] in Nigeria, 0.494±0.3 mg kg^{-1} in liver and 0.747±0.2 mg kg^{-1} in gizzard by Hossain et al. (2023 of Dhaka district in Bangladesh [4], and 2.75 ug g^{-1} by Mahmoud and Abdel-Mohsein in Egypt [34].

Table 2 Concentrations of metal in chicken giblets and estimated daily intake (EDI) (mg kg^{-1} bw^{-1} day^{-1}) for adult due to the consumption of metals in chicken giblets

Metal		**Estimated daily intake (µg kg^{-1} day^{-1})**		
		Gizzard	**Kidney**	**Liver**
Al	Hen	7.41E-02	8.69E-02	6.72E-02
Cd		1.37E-04	1.83E-04	1.37E-04
Co		1.03E-02	1.05E-02	8.69E-03
Cr		1.65E-03	1.74E-03	2.01E-03
Mn		5.94E-04	5.03E-04	1.74E-04
Ni		3.20E-04	3.66E-04	2.29E-04
Pb		6.40E-04	6.40E-04	5.94E-04
Al	Cock	1.51E-01	1.78E-01	1.87E-01
Cd		2.74E-04	1.83E-04	1.37E-04
Co		1.51E-02	9.69E-03	1.14E-02
Cr		1.51E-02	9.69E-03	1.14E-02
Mn		1.74E-03	1.42E-03	2.93E-03
Ni		3.66E-04	4.57E-04	4.11E-04
Pb		6.40E-04	5.49E-04	9.60E-04

2) Many-variable Statistical Evaluation

By computing a summary index, the strength of the linear link between the pairs of variables can be determined using the Pearson correlation coefficient [56]. Therefore, the data on metal-to-metal correlation was measured as shown in Figure 2 using Pearson product moment correlation coefficients that were significant at the 95% confidence level. The pair of Cr-Mn (0.60) showed a significant correlation at the 95% confidence level, whereas a weak correlation exists for Cr-Pb (0.45), Mn-Pb (0.40), and weak but negative for Cd-Mn (-0.40). This correlation indicates that the sources of the metals may not be comparable.

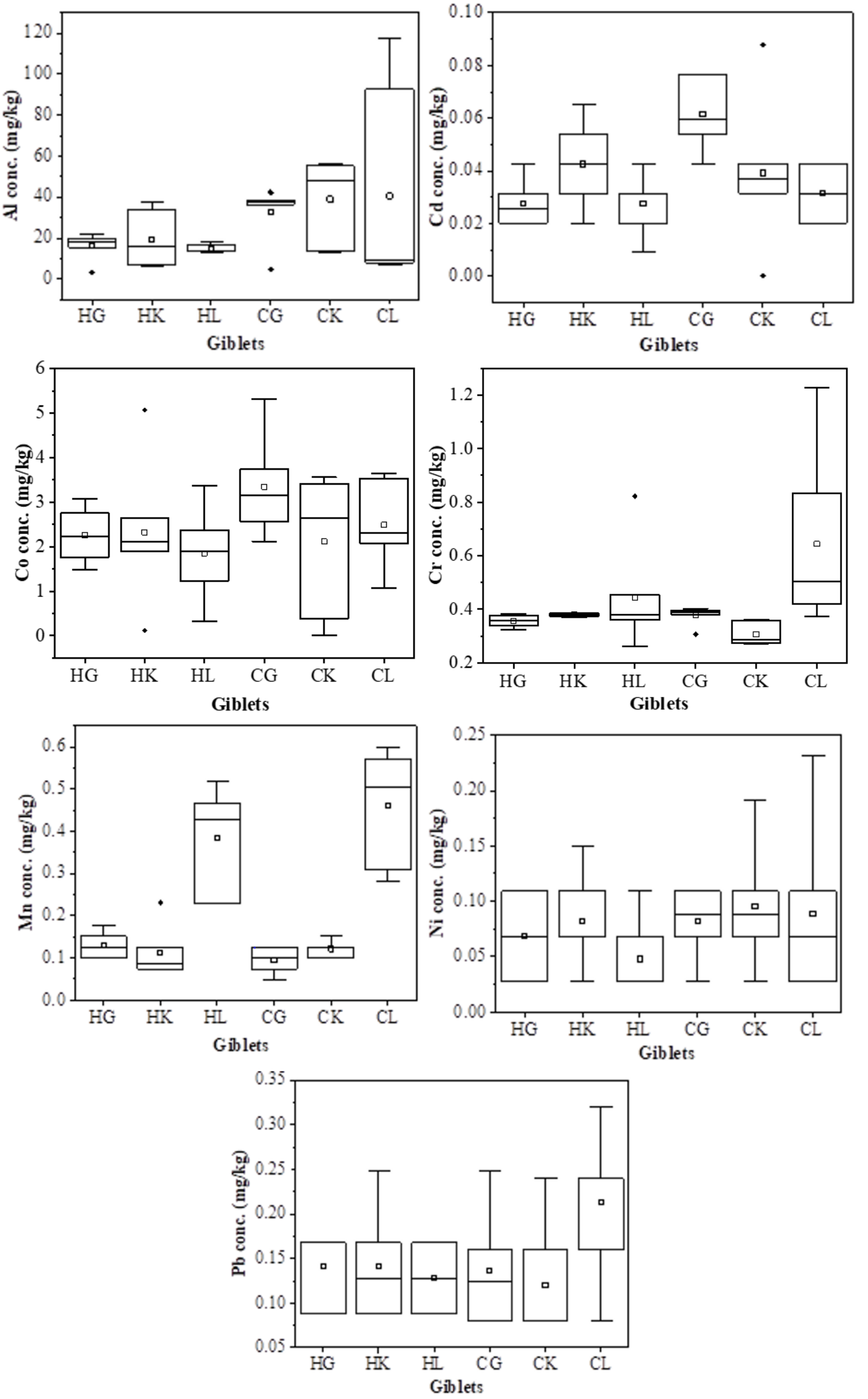


Figure 1 Box plot for concentrations of metal in chicken giblets. The small square represents the mean, stars circles represent outliers (mild outliers). The horizontal lines at the top, middle and bottom of the box plot correspond to the 75th percentile, median and 25th percentile, respectively.

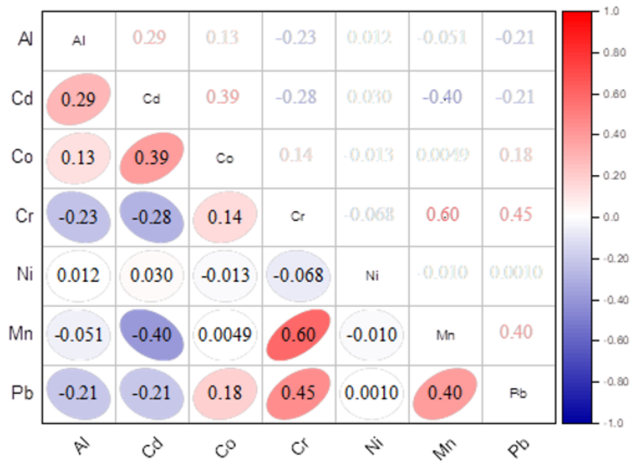


Figure 2 Correlation between the heavy metals in chicken giblets samples.

PCA using varimax-normalized rotation was then carried out to determine the factor loadings in each metal. Reducing many variables into a new set of reduced variables based on their reciprocal dependency and drawing attention to a potential trend was ascertained using PCA. A scree plot (Figure 3) was used to determine the significant number of PCs and to identify the structure of the underlying parameters. Our results show that three eigenvalues greater than one could account for over 67% of the total variance (Figure 3). SM 2 displayed the factor loadings that were computed, the cumulative percentage of variation, and the percentages of total variance that each component explained. The first factor, which accounted for about 32.95 percent of the variance overall and had the largest loadings for Cr (0.528), Mn (0.515), and Pb (0.450), was primarily generated from common sources. The second factor accounted for about 20.21 percent of the total variance, with high loadings for Co (0.739) and Cd (0.485). The third significant factor showed a variance of 13.32 percent with a very high loading for Ni (0.994) [57]. Factor 3 has been reported to be due to the metabolic process in the chicken body, as Mn is an essential metal [56]. Figure 2 (inset) shows a three-dimensional graphic of the PCA loadings, making the correlations between the heavy metals easily comprehensible. The first three PCs' estimates of the relationships between the heavy metals and the correlation study were in good agreement (Figure 1).

3) Human health risk assessment of daily intake of metals via the consumption of giblets

How and to what extent a group is exposed determines their health risk or hazard. Determining the level of exposure by pinpointing the pollutant routes to the target populations is crucial. Ingestion is the main route of metal exposure to humans through the food chain. This research investigated the potential health risks associated with the consumption of chicken giblets containing Al, Cd, Co, Cr, Mn, Ni, and Pb. Table 2 presents the EDI values for the studied metals. The EDI of the metals found through eating chicken giblets shows that, at this time, the average consumption of chicken giblets does not present a health risk because the resulting EDI value is lower than the recommended metal ingestion values set by the FAO and WHO. Even though the giblets contained detectable levels of all the metals determined, the potential health risk for the intake of chicken giblets was insignificant, probably due to the low intake rate (0.32 g day^{-1} estimated). The predicted HQ values of specific metals were found to be less than 1 (Table 3), indicating a low likelihood of negative health effects for the target population from ingestion of Lokoja chicken due to exposure to these toxic elements. For all metals determined, the values ranged from 6.81E-07 to 2.08E-02 in the liver. The highest value was found in Co, while the lowest was in Mn. The range of HQ values was lower than the reference dose (RfD) values of the respective metals, indicating no potential health risk in the entire lifetime of the consumers. The HI represents the non-carcinogenic risk associated with multiple metal exposures. Of all the elements determined in chicken giblets, Co and Cd are the most dangerous to human health, while Mn presents the least. The consumption of giblets containing all metals resulted in an overall HI of 1.05E-01, which is significantly below the hazardous threshold of 1. Therefore, it suggests that eating the chicken giblets of the Lokoja chicken in northcentral Nigeria does not present a substantial noncarcinogenic risk for alimentary exposure to metals. The HI values for adult populations owing to exposure to the studied metals in the giblets increased in the order Mn<Ni<Pb<Al<Cr<Cd<Co (hen) and Mn<Ni<Pb<Cr<Al<Cd<Co (cock). The liver contributed 38.6% to HI, followed by the kidney with 37.9%, and the gizzard accounted for 23.5%. The liver and kidney have been reported to be the main sites of heavy metals due to exposure and physiological responses of animals to detoxify the system [38]. We advise against excessive intake of the liver and kidney since they are the primary locations where heavy metals accumulate in animals' bodies due to exposure and their bodies' natural detoxification processes.

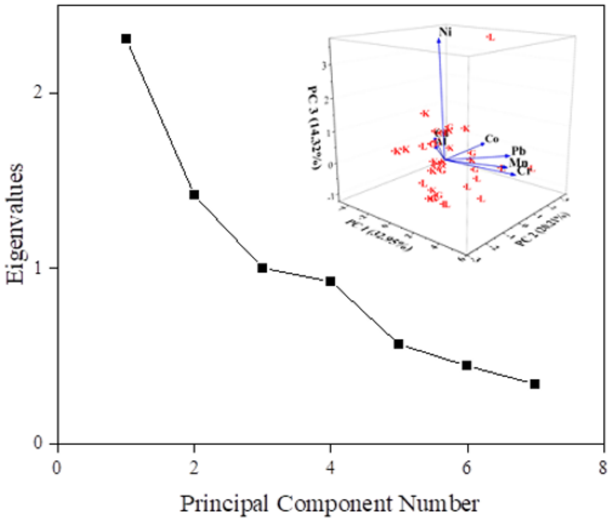


Figure 3 PCA of metals by scree plot of the distinctive origins (Eigenvalues) (inset is the 3D plot of the PCA loadings demonstrating the associations among the heavy metals).

The cancer risk (CR) associated with eating chicken giblets that exposed people to Cd, Cr, Ni, and Pb was calculated using the oral cancer slope factor (CSPo) (mg/kg/day) and EDI data as shown in the methodology section utilizing Eqs. 5–6. Table 3 shows the CR owing to exposure to Cd, Cr, Ni, and Pb through the ingestion of chicken giblets. Generally, the total CR ranged from 1.04E-04 to 6.09E-07 in hens. The corres-ponding cock value ranged from 1.17E-04 to 7.00E-07. Upon comparing the concentration of metals in chicken giblets, it is apparent that chromium Cr makes up 56% of the total concentration due to gizzard consumption, followed by Ni, Cd, and Pb at 38.4%, 5.2%, and 0.4%, respect-tively (Figure 3). A similar trend was observed for the kidney and liver. The largest contribution was from Cr (67%), primarily from the consumption of chicken liver. Following this, Ni, Cd, and Pb contributed 29.6%, 2.8%, and 0.3% of the total, respectively. The percentage contribution of Ni (44.8%) was highest in kidneys compared to gizzards (38.4%) and livers (29.6%). The result indicated that Cr exposure was the main contri-butor to the overall cancer risk from the lifetime ingestion of chicken giblets. Values of MCR below 10^{-6} are generally regarded as insignificant, values above 10^{-4} as risky, and values between 10^{-6} and 10^{-4} as tolerable risks [58]. In this study, the MCR for Cd, Ni, and Pb due to the ingestion of chicken giblets was within an acceptable range. The result indicated no chance of experiencing any carcinogenic risk of Cd, Ni, or Pb owing to ingesting chicken giblets from the region of the study at present. However, the cancer risk from Cr to the adult population through the ingesting of chicken giblets was positive, as the MCR of Cr was 1.04E-04 (hen) and 1.17E-04 (cock), exceeding the threshold value of 1.0×10^{-4}.

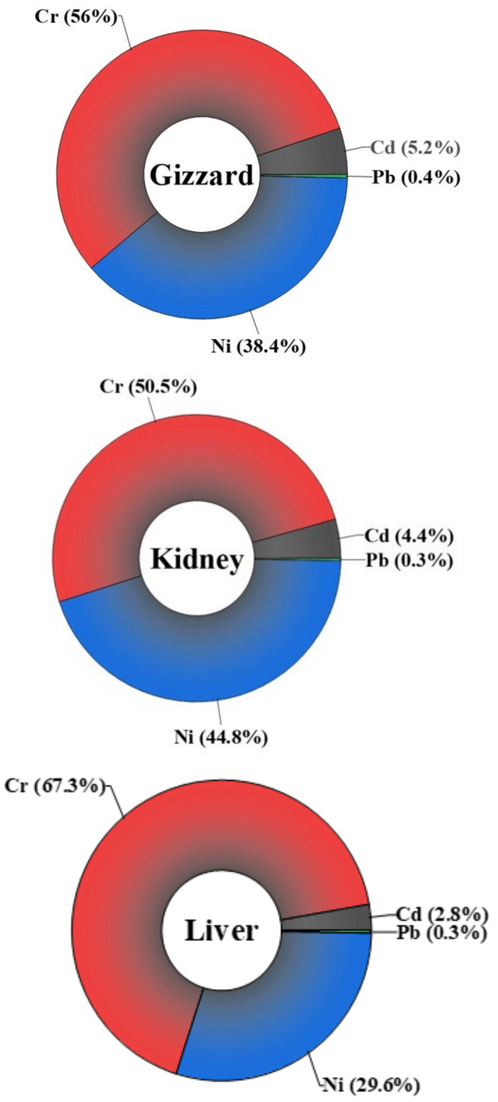


Figure 3 Contribution of health risks caused by the different metals according to HI.

Table 3 HRI and HI adult through the consumption of chicken giblets from the study area

Metal	Specie	Average daily dose (ADD) (mg kg^{-1} day^{-1})			Non-carcinogenic risk				Carcinogenic risk (CR)			
					Hazard quotient			Hazard index	Individual sample			Total
		Gizzard	Kidney	Liver	Gizzard	Kidney	Liver		Gizzard	Kidney	Liver	MCR
Al	Hen	4.06E-05	4.76E-05	3.68E-04	4.06E-05	4.76E-05	3.68E-04	4.66E-04	-	-	-	-
Cd		7.51E-08	1.00E-07	7.51E-08	7.51E-04	1.00E-03	7.51E-04	2.50E-03	2.00E-06	2.66E-06	2.00E-06	6.66E-06
Co		5.64E-06	5.75E-06	4.74E-06	1.88E-02	1.92E-02	1.59E-02	5.39E-02				
Cr		9.04E-07	9.53E-07	1.10E-06	3.01E-04	3.18E-04	3.67E-04	9.86E-04	3.16E-05	3.34E-05	3.85E-05	1.04E-04
Mn		3.25E-07	2.76E-07	9.53E-08	2.32E-06	1.97E-06	6.81E-07	4.97E-06	-	-	-	-
Ni		1.75E-07	2.01E-07	1.25E-07	8.75E-06	1.01E-05	6.25E-06	2.51E-05	2.08E-05	2.39E-05	1.49E-05	5.96E-05
Pb		3.50E-07	3.50E-07	3.25E-07	8.75E-05	8.75E-05	8.13E-05	2.56E-04	2.08E-07	2.08E-07	1.93E-07	6.09E-07
Al	Cock	8.25E- 05	9.75E-05	1.02E-03	8.25E- 05	9.75E-05	1.02E-03	1.12E-03	-	-	-	-
Cd		1.50E-07	1.00E-07	7.51E-08	1.50E-03	1.00E-03	7.51E-04	3.25E-03	3.99E-06	2.66E-06	2.00E-06	8.65E-06
Co		8.27E-07	5.31E-06	6.25E-06	2.77E-03	1.77E-02	2.08E-02	4.13E-02	-	-	-	-
Cr		9.53E-07	7.78E07	1.61E-06	3.18E-04	2.59E-04	5.36E-04	1.11E-03	3.34E-05	2.72E-05	5.64E-05	1.17E-04
Mn		2.50E-07	3.01E-07	1.15E-07	1.79E-05	2.15E-06	8.21E-07	2.09E-05	-	-	-	-
Ni		2.01E-07	2.51E-07	2.25E-07	1.01E-05	1.26E-05	1.13E-05	3.40E-05	2.39E-05	2.99E-05	2.68E-05	8.06E-05
Pb		3.51E-07	3.01E-07	5.26E-07	8.78E-05	7.53E-05	1.32E-05	1.76E-04	2.08E-07	1.79E-07	3.13E-07	7.00E-07
Hazard quotient (HQ) for individual giblet tissue					2.47E-02	3.98E-02	4.06E-02					
Hazard index (HI) due to all metals in giblets								1.05E-01				

Conclusion

Samples of chicken giblets were collected from Lokoja, located in central Nigeria. Al, Cd, Co, Cr, Mn, Ni, and Pb concentrations were evaluated, and EDI, HQ, HI, and CR were used to measure the possible risk to human health. The average metal concentrations in the chicken giblet were within the maximum permissible limit. Also, the EDIs did not surpass the daily maximum permitted consumption of metals. Hence, consuming chicken giblet in the area of study would not expose consumers to any noncarcinogenic risk because the computed HQ and HI values were less than 1. The CRs of Cd, Co, Cr, and Pb did not exceed the allowable range; however, the multi-element cancer risk for Cr was higher than allowed and could endanger consumer health owing to its presence in chicken giblet. The results may awaken legislators to their duties of constant monitoring and raising public awareness of appropriate poultry management. Customers will feel more confident if relevant regulatory bodies are continuously monitoring them. Poultry farm owners should be made more aware of the risks associated with feeding their birds tainted feed and water through education campaigns. Similarly, consumers should receive regular updates about the potential risks associated with consuming contaminated chicken giblets. Future researchers should expand the research to cover varied locations within the region.

References

[1] Milford, A.B., Le Mouel, C., Bodirsky, B.L., Rolinski, S. Drivers of meat consumption. Appetite, 2019, 141, 104313.

[2] Ritchie H, Rosado P, Roser M. Meat and Dairy Production 2017. [Online] Available from: https://ourworldindata.org/meat-production [Accessed 30 March 2023].

[3] Islam, M.J., Sayeed, M.A., Akhtar, S., Hossain, M.S., Liza, A.A. Consumers profile analysis towards chicke, beef, mutton, fish and egg consumption in Bangladesh. British Food Journal, 2018, 120, 2818–2831.

[4] Hossain, E., Nesha, M., Chowdhury, M.A.Z., Rahman, S.H. Human health risk assessment of edible body parts of chicken through heavy metals and trace elements quantitative analysis. PLOS ONE, 2023, 18(3), e0279043.

[5] Chijioke, N.O., Uddin Khandaker, M., Tikpangi, K.M., Bradley, D.A. Metal uptake in chicken giblets and human health implications. Journal of Food Composition and Analysis, 2020, 85, 103332.

[6] Mahmood, S., Ansar, A., Durham, J. Heavy metals in poultry products in Bangladesh: A possible death threat to future generations. Journal of Social and Political Sciences, 2019, 2(1), 98–105.

[7] Kamaly, H.F., Sharkawy, A.A. Health risk assessment of metals in chicken meat and liver in Egypt. Environmental Monitoring and Assessment, 2023, 195, 1–17.

[8] Codex. Codex General Standard for Contaminants and toxins in Foods. Codex Standard 193–1995, 1995, 1–20.

[9] Emami, M.H., Saberi, F., Mohammadzadeh, S., Fahim, A., Abdolvand, M., Dehkordi, S.A.E., ..., Maghool, F. A Review of heavy metals accumulation in red meat and meat products in the middle east. Journal of Food Protection, 2023, 26(3), 100048.

[10] Alexander, J., Benford, D., Cockburn, A., Cravedi, P., Dogliotti, E., Di Domenico, A., …, Peteghem, C.V. Marine biotoxins in shellfish – Pectenotoxin group. EFSA Journal, 2009,1019, 1–76.

[11] Hassanin, F.S., Mahmoud, A.M., Mohamed, E.A. Heavy metals residue in some chicken meat products. Benha Veterinary Medical Journal, 2014, 27(2), 256–263.

[12] MacOmber, L., Hausinger, R.P. Mechanisms of nickel toxicity in microorganisms. Metallomics, 2011, 3, 1153–1162.

[13] Wilbur, S., Abadin, H., Fay, M., Yu, D., Tencza, B., Ingerman, L. Toxicological profile for chromium. US Department of Health and Human Services. Public Health Service, Agency for Toxic Substances and Disease Registry, 2012, 24049864.

[14] IARC. IARC monographs on the evaluation of carcinogenic risks to humans. A review of human carcinogens. IARC Scientific Publications, 2012 100, 169–218

[15] Mohammadi, A.A., Zarei, A., Majidi, S., Ghaderpoury, A., Hashempour, Y., Saghi, M. H., ..., Ghaderpoori, M. Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. MethodsX, 2019, 6, 1642–1651

[16] Abbas, K.H. Detection of some heavy metals in poultry meats from some sources of meat and poultry rations. Al-Qadisiyah Journal of Veterinary Medicine Sciences, 2017, 16, 99–104.

[17] Adekanmi, A.T. Health hazards of toxic and essential heavy metals from the poultry waste on human and aquatic organisms. In Animal Feed

Science and Nutrition-Production, Health and Environment. IntechOpen, 2021, 99549

[18] Fung, F., Wang, H.S., Menon, S. Food safety in the 21st century. Biomedical Journal, 2018, 41, 88–95.

[19] Lehel, J., Laczay, P., Gyurcso, A., Janoska, F., Majoros, S., Lanyi, K., Marosбn, M. Toxic heavy metals in the muscle of roe deer (Capreolus capreolus)—food toxicological significance. Environmental Science and Pollution Research, 2016, 23, 4465–4472.

[20] Duncan, T.B, Klaus, D., Alan, T. Use of the terms recovery and apparent recovery in analytical procedures (IUPAC Recommendations 2002). International Union of Pure and Applied Chemistry. Analytical Chemistry Division, Commission on General Aspects of Analytical Chemistry. Pure Applied Chemistry, 2002, 74(11), 2201–2205

[21] Shrivastava, A., Gupta, V. Methods for the determination of limit of detection and limit of quantitation of the analytical methods. Chronicles Young Scientists, 2011, 2, 21–25.

[22] FAOSTA. Poultry Meat Consumption Per Capital in Nigeria. [Online] Available from https://www.helgilibrary.com/indicators/poultry-meat-consumption-percapita/nigeria/ [Accessed 29 June 2023].

[23] Ametepey, S.T., Cobbina, S.J., Akpabey, F.J., Duwiejuah, A.B., Abuntori, Z.N. Health risk assessment and heavy metal contamination levels in vegetables from tamale metropolis, Ghana. International Journal of Food Contamination, 2018, 5 (1), 1–8.

[24] Harmanescu, M., Alda, L.M., Bordean, D.M., Gogoasa, I., Gergen, I. Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat County, Romania. Chemistry Central Journal, 2011, 5, 1–10.

[25] Taiwo, A.M., Adekola, M B., Olatunde, K A., Abdullahi, K.L., Ogunkoya, P.K., Lawal, E.R., ... Oladimeji, G. Human health risk assessment of essential and non-essential metals in vegetables (Jute mallow, onions, celosia, spinach and tomatoes) from Ogun, Lagos and Oyo states, southwestern Nigeria. Vegetos, 2021, 34, 390–403.

[26] Gebeyehu, H.R., Danno, L., Id, B. Levels of heavy metals in soil and vegetables and associated health risks in Mojo area, Ethiopia. PLOS ONE, 2020, 15(1), e0227883.

[27] RSLs (Regional Screening Levels), Subchronic toxicity, and supporting table. Regional screening level (RSL) subchronic toxicity supporting table November 2021. [Online] Available from https://www.epa.gov/risk/regional-screening-levels-rsls-frequent-questions [Accessed 29 June 2023].

[28] Korish, M.A., Attia, Y.A. Evaluation of heavy metal content in feed, litter, meat, meat products, liver, and table eggs of chickens. 2020, 10, 1–23.

[29] Kochian, L.V., Piceros, M.A., Hoekenga, O.A. The physiology, genetics and molecular biology of plant aluminum resistance and toxicity. Plant Soil, 2005, 274, 175–195.

[30] Vardar, F., Ьnal, M. Aluminum toxicity and resistance in higher plants. Advances in Molecular Biology, 2007, 1, 1–12.

[31] Krewski, D., Yokel, R.A., Nieboer, E., Borchelt, D., Cohen, J., Harry, J., ..., Rondeau, V. Human health risk assessment for aluminium, aluminium oxide, and aluminium hydroxide. Journal of Toxicology and Environmental Health, Part B, 2007, 10 (S1), 1–269.

[32] Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B., Beeregowda, K.N. Toxicity, mechanism, and health effects of some heavy metals. Interdisciplinary Toxicology 2014, 7(2), 60–72.

[33] Shen, F., Liao, R., Ali, A., Mahar, A., Guo, D., Li, R., ..., Zhang, Z. Spatial distribution and risk assessment of heavy metals in soil near a Pb/Zn smelter in Feng County, China. Ecotoxicology and Environmental Safety, 2017, 139, 254–262.

[34] Mahmoud, M. A., Abdel-Mohsein, H.S. Health risk assessment of heavy metals for Egyptian population via consumption of poultry edibles. Advances in Animal and Veterinary Sciences, 2015, 3(1), 58–70.

[35] Leyssens, L., Vinck, B., Van Der Straeten, C., Wuyts, F., Maes, L. Cobalt toxicity in humans—A review of the potential sources and systemic health effects. Toxicology, 2017, 387, 43–56.

[36] NRC (National Research Council). Nutrient Requirements of Poultry. National Research Council. National Academy Press, Washington, DC, USA, 1994, 155pp.

[37] Tvermoes, B.E., Paustenbach, D., Kerger, B.D., Finley, B.L., Unice, K.M. Review of cobalt toxicokinetics following oral dosing: Implications for health risk assessments and metal-on-metal hip implant patients. Critical Reviews in Toxicology, 2015, 45(5), 367–387.

[38] Ogbomida, E.T., Nakayama, S.M., Bortey-Sam, N., Oroszlany, B., Tongo, I., Enuneku, A.A., ..., Ishizuka, M. Accumulation patterns and risk assessment of metals and metalloid in muscle and offal of free-range chickens, cattle and goat

in Benin City, Nigeria. Ecotoxicology and Environmental Safety, 2018, 151, 98–108.

[39] Aschner, M. Manganese: Brain transport and emerging research needs. Environmental Health Perspectives, 2000, 108(suppl 3), 429–432.

[40] Gerber, G.B., Leonard, A., Hantson, P.H. Carcinogenicity, mutagenicity and teratogenicity of manganese compounds. Critical Reviews in Oncology/Hematology, 2002, 42(1), 25–34.

[41] Grazuleviciene, R., Nadisauskiene, R., Buinauskiene, J., Grazulevicius, T. Effects of elevated levels of manganese and iron in drinking water on birth outcomes. Polish Journal of Environmental Studies, 2009, 18(5), 819–825.

[42] Oforka, N.C., Osuji, L.C., Onwuachu, U.I. Assessment of heavy metal pollution in muscles and internal organs of chickens raised in Rivers State, Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences, 2012, 3(3), 406–411.

[43] Akan, J.C., Abdulrahman, F.I., Sodipo, O., A., Chiroma Y.A. Distribution of heavy metals in the liver, kidney and meat of beef, mutton, caprine and chicken from Kasuwan Shanu market in Maiduguri metropolis, Borno state, Nigeria. Research Journal of Applied Sciences, Engineering and Technology, 2010, 2(8), 743–748.

[44] Al Bratty, M., Alhazmi, H.A., Ogdi, S.J., Otaiif, J.A., Al-Rajab, A.J., Alam, M.F., Javed, S.A. Determination of heavy metals in various tissues of locally reared (Baladi) chicken in Jazan region of Saudi Arabia: Assessment of potential health risks. Pakistan Journal of Zoology, 2018, 50(4), 1509–1517.

[45] FAO/WHO. Codex Alimentarius—general standards for contaminants and toxins in food. Schedule 1: maximum and guideline levels for contaminants and toxins in food. Joint FAO/ WHO Food Standards Programme, Codex Committee, Rotterdam, Reference CX/FAC 02/16. 2002.

[46] NRC (National Research Council). National research council (us) subcommittee on the tenth edition of the recommended dietary allowances. Recommended Dietary Allowances: 10th Edition. Washington (DC): National Academies Press (US); 1989. [Online] Available from: https://www. ncbi. nlm.nih.gov/books/NBK234932 [Accessed 15 July 2023].

[47] Naseri, K., Salmani, F., Zeinali, M., Zeinali, T. Health risk assessment of Cd, Cr, Cu, Ni and Pb in the muscle, liver and gizzard of hen's marketed in East of Iran. Toxicology Reports, 2021, 8, 53–59.

[48] Sonone, S.S., Jadhav, S., Sankhla, M.S., Kumar, R. Water contamination by heavy metals and their toxic effect on aquaculture and human health through food Chain. Letters in Applied Nano BioScience, 2020, 10(2), 2148–2166.

[49] Chen, F., Ma, J., Akhtar, S., Khan, Z.I., Ahmad, K., Ashfaq, A., ..., Nadeem, M. Assessment of chromium toxicity and potential health implications of agriculturally diversely irrigated food crops in the semi-arid regions of South Asia. Agricultural Water Management, 2022, 272, 107833.

[50] Shin, D.Y., Lee, S.M., Jang, Y., Lee, J., Lee, C.M., Cho, E.M., Seo, Y.R. Adverse human health effects of chromium by exposure route: A comprehensive review based on Toxicogenomic approach. International Journal of Molecular Sciences, 2023, 24(4), 3410.

[51] Shrivastava, H.Y., Ravikumar, T., Shanmugasundaram, N., Babu, M., Nair, B.U. Cytotoxicity studies of chromium (III) complexes on human dermal fibroblasts. Free Radical Biology and Medicine, 2005, 38(1), 58–69.

[52] JECFA, WHO. Summary and Conclusions of the sixty-fourth meeting of the Joint FAO/ WHO Expert Committee on Food Additives - Evaluation of certain food contaminants. JECFA, 2005, 1–47.

[53] EC (European Commission). Setting maximum levels for certain contaminants in foodstuff. Commission Regulation (EC) No. 1881/2006 of 19 December 2006.

[54] Okoye, C.O.B., Aneke, A.U., Ibeto, C.N., Ihedioha, I.J.N. Heavy Metals Analysis of Local and Exotic Poultry Meat. International Journal of Applied Environmental Sciences, 2011, 6(1), 49–55.

[55] Badis, B., Rachid, Z., Esma, B. Levels of selected heavy metals in fresh meat from cattle, sheep, chicken and camel produced in Algeria. Annual Research & Review in Biology, 2014, 4(8), 1260–1267.

[56] Ullah, A.A., Afrin, S., Hosen, M.M., Musarrat, M., Ferdoushy, T., Nahar, Q., Quraishi, S.B. Concentration, source identification, and potential human health risk assessment of heavy metals in chicken meat and egg in Bangladesh. Environmental Science and Pollution Research, 2022, 29, 22031–22042.

[57] Benson, N.U., Anake, W.U., Etesin, U.M. Trace metals levels in inorganic fertilizers commercially available in Nigeria. Journal of Scientific Research and Reports, 2014, 3, 610–620.

[58] USEPA. Risk-based concentration table. 2015. [Online] Available from: http://www.epa.gov/reg3hwmd/risk/human/index.htm [Accessed 20 October 2023].