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Health Risk Assessment of Exposure to Some Heavy Metals from Roasted Pork and Goat Meats Sold in Ishaka-Bushenyi Municipality, Uganda

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Abstract

Heavy metals like iron (Fe), manganese (Mn), and copper (Cu) in trace levels are vital for human health as they support a number of physiological processes. In contrast, lead (Pb) and cadmium (Cd) provide no health benefits and can cause significant health problems when accumulated in the body. The main sources of heavy metal contamination in humans include the consumption of unhygienic and contaminated food products. In Uganda, roasted pork and goat meats are highly consumed among the population. Therefore, this research aims to determine the levels of Mn, Cu, Cd, Pb, and Fe and the associated human health risks in roasted pork and goat meat samples collected from Ishaka-Bushenyi Municipality, Uganda. Results showed that the mean levels of heavy metals (mg/kg) in roasted pork were in the order of Fe (4.706) > Pb (2.220) > Cu (1.927) > Cd (0.766) > Mn (0.391), while in roasted goat meat, the order was Pb (8.152) > Fe (5.152) > Cu (1.834) > Cd (0.794) > Mn (0.388). Lead (Pb) was observed to have the highest concentration which is likely to pose a risk to both children and adults, while manganese had the lowest concentration. The estimation of human health risks revealed that the essential metals had target hazard quotient (THQ) values below threshold in all samples while the non-essential elements had THQ values above 1. The hazard index (HI) obtained for each sample was greater than 1 indicating non-carcinogenic health risks to consumers (HI > 1). In 88% of cases, cancer risks (CR) values were within 10^{-4} and acceptable. Additionally, children are more vulnerable to non-cancer risks than the adults due to lower body weight. This research highlights the need of regularly monitoring of locations where vendors sell processed meats, as well as implementing laws to mitigate the health hazards associated with consuming polluted roasted meats.

Keywords

Heavy Metals, Roasted Meat, Health Risk Assessment, Contamination

1. Introduction

The presence of heavy metals such as cadmium (Cd), lead (Pb), iron (Fe), copper (Cu), and manganese (Mn) in food in developing countries is a significant issue for public health [1]. Heavy metal pollution mostly arises from the cultivation of plants and is primarily caused by pesticides, fertilizers, industrial processes, and automotive exhaust emissions [2]. The contamination of heavy metals in the food chain presents a significant danger because of their poisonous properties, ability to accumulate in organisms, and tendency to increase in concentration as they go up the food chain. Furthermore, the potential risk associated with the presence of heavy metals in meat is a cause for alarm for human health [3]. Heavy metals do not degrade; thus, they persist and accumulate in animal organs and tissues including muscle, liver, and kidney leading to hazardous quantities that are harmful to consumers [3].

Kamal in 2022 reported that meat is a significant dietary source of proteins, vital amino acids, mineral components such as iron and zinc, and vitamins like B12 and D [4]. However, the positive perception of meat's health benefits has been diminished due to its association with non-nutritional concerns, such as the presence of toxic contaminants in modern times [5]. Consuming food that is polluted with these components may indeed lead to significant biochemical and neurological alterations in the human body, resulting in severe health hazards. In particular, neurological and behavioral abnormalities may be noticed following exposure to mercury, with symptoms comprising predominantly tremors, sleeplessness, loss of memory, headaches, cognitive and motor impairment [6]. A variety of disorders, mainly neurological are also related with the excess of Pb content in food, in addition to its significance in creating cardiovascular difficulties [7], while exposure to Cd causes several unfavorable consequences, including reduced renal function, poor fertility, frail bones, hypertension, and cancers [8]-[11].

Uganda is reported to be the African country with the highest consumption of pork and also second in the world after China (https://www.monitor.co.ug/uganda/magazines/life/pork-red-or-white-meat-2303910). Processed pork meat (roasted form) is frequently consumed alongside roasted goat meat daily by large number of the population. Therefore, in the context of food safety, it is important to determine the concentrations of toxic metals which could be present in the processed pork and goat meat that is consumed. It is also necessary to consider the estimated daily intake of the meat products without leaving out the human health risks associated with exposure to the metals through ingestion. Few articles have reported the toxicity of metals in meat and meat products in Uganda as a nation. These include the analysis of toxic metal contents in organ meats [12], raw beef [13], milk and beef [14], and processed meat [15]. To the best of our knowledge, Ishaka-Bushenyi Municipality which is located in the Western part of Uganda has never been considered before for processed pork and goat meats. In light of the aforementioned, the purpose of this study is to add to the information that is currently available through the following objectives: 1) to determine the amount of iron (Fe), cadmium (Cd), lead (Cd), copper (Cu), and manganese (Mn) in sampled roasted pork and goat meats; and 2) estimate the human health risk related to exposure to the toxic metals.

2. Materials and Methods

2.1. Sampling Area

Ishaka-Bushenyi Municipality is located in Igara county of Bushenyi District, Uganda. It is bordered by Bumbeire in the South, East by Kyeizooba, North by Kyabugimbi and Kakanju and in West by Nyabubare Sub Counties (https://bushenyi-ishakamc.go.ug). The Municipal Council is also reported to have a total population of 50,313 base on report from 2014 National Housing and Population Census (https://bushenyi-ishakamc.go.ug).

2.2. Sample Collection, Digestion and Instrumental Analysis

A total number of 16 samples of roasted pork and goat meats were collected within Ishaka-Bushenyi Municipality in October, 2023. Samples were only collected from local vendors who sell roasted meats by the roadside. The samples were labeled, placed in clean polythene bags and then transported to the lab for digestion and analysis. Approximately 200 g of each sample was dried in the oven to a constant weight at 105˚C in a clean crucible for 2.5 hours and later crushed into a fine powder. Then 0.5 g of each sample was digested with 5 mL of concentrated nitric acid (70% high purity HNO_3 and 65 % $HClO_4$, 4:1 v/v) on a hot plate at 80˚C. The digested solution was allowed to cool and then filtered using Whatman no 42. filter paper. The final volume was made up to 50 mL using deionized water and stored under 2˚C temperature [16]. Calibration curves were created by analyzing blanks and standard solutions in an approach similar to that of the digested sample solution. The heavy metals (Fe, Cd, Pb, Mn, and Cu) were quantitatively determined using a Thermo Electron Atomic Absorption Spectrometer (S SERIES). To ensure that the findings could be reproduced, analyses were performed in triplicate. The limit of detections (LODs) and limit of quantifications (LOQs) for each heavy metal are represented in **Table 1**.

Table 1. LODs and LOQs for heavy metals.

Metal	LOD (mg/L)	LOQ (mg/L)
Fe	0.0009	0.0027
Pb	1.32E−17	4E−17
Cd	0.0018	0.0054
Cu	0.0062	0.0187
Mn	0.0053	0.0160

3. Human Health Risk Assessment of Heavy Metals

3.1. Estimated Daily Intake

The following equation was used to compute the estimated daily intake (EDI) of Mn, Cd, Pb, Cu, and Fe through the ingestion of roasted pork and goat meats:

$$\text{EDI} = \frac{(\text{MC} \times \text{IR})}{\text{BW}} \tag{1}$$

where MC represents the mean concentration of metal in the sample, IR is the daily ingestion rate which is 120 g for adults and 56.7 g for children [14], and BW is the average body weight (60.7 kg for adults and 20.5 kg for children).

3.2. Non-Cancer Risk

The risk related to non-carcinogenic substances was evaluated using the target hazard quotient (THQ). The THQ is the ratio of a pollutant's measured dose to its standard dose level. The exposed population is unlikely to show explicit negative consequences if the ratio is less than 1.

$$\text{THQ} = \frac{\text{EFR} \times \text{ED} \times \text{IR} \times \text{MC}}{\text{RfD} \times \text{BW} \times \text{AT}} \times 10^{-3} \tag{2}$$

where IR is the ingestion rate (g/person/d), EFr is the exposure frequency (365 days/year), and ED is the exposure duration (70 years). The average concentration of metal in food is expressed as MC (μg/g). The oral reference dose is expressed as RfD (mg/kg/d), with Pb = 3.6×10^{-4} mg/kg/d, Cd = 1.0×10^{-3} mg/kg/d, Cu = 4.0×10^{-2} mg/kg/d, Fe = 0.70 mg/kg/d, and Mn = 0.14 mg/kg/d [17] [18] average body weights of adults and children are 60.7 kg and 20.5 kg respectively, and exposure time (AT) is the average number of exposure years (365 days/year), assuming 70 years in this research. The equation below was used to determine the Hazard Index (HI) for non-cancer risk, which is obtained by adding the hazard quotients of each heavy metal.

$$\text{HO} = \sum \text{THQ}_n \tag{3}$$

Samples with HI values greater than 1 could cause non-cancer health issues, whereas samples with HI < 1 are safe for consumption.

3.3. Carcinogenic Risk

The probability of developing cancer as a result of lifetime exposure to a possible carcinogen is known as the carcinogenic risk. The following formula is used to determine the carcinogenic risk resulting from exposure to heavy metals from consumption pork and goat meats:

$$CR = EDI \times CSF \tag{4}$$

Cancer slope factors (CSF) for Cd and Pb are 0.38 and 0.0085 mg/kg/day, respectively. CSF for Cu, Fe, and Mn is unavailable, and their carcinogenic risk cannot be calculated [19]-[21]. USEPA guidelines (20) state that a CR of less than 10^{-6} is negligible and that the cancer risk may be ignored. On the other hand, CR greater than 10^{-4} is regarded as significant and may raise the risk of cancer. The cumulative risk of all the individual metal incremental risks (Σ ILCR) associated with ingesting a certain kind of meat was considered to represent the overall cancer risk resulting from exposure to various pollutants.

4. Statistical Analysis

The Minitab® version 21 software package was employed for the analysis. Analysis of variance (ANOVA) was used to evaluate the data for homogeneity of variances at the significant level of $p < 0.05$. The mean and standard deviation were obtained for the descriptive statistics. Also, a correlation coefficient analysis was performed to investigate the relationship between the metals analysed.

5. Results and Discussion

5.1. Distribution of Heavy Metals in the Analyzed Samples

The accumulated composition of different metals investigated is presented as mean ± standard deviation (SD). The descriptive statistics of the measured heavy metal concentrations are presented in **Table 2**. The concentrations of Mn in roasted goat meat varied from 0.042 to 0.694 mg/kg with an average level of 0.388 ± 0.28 mg/kg. For pork, the levels of Mn varied from 0.214 to 0.534 mg/kg with an average level of 0.391 ± 0.14 mg/kg. The mean concentrations of Mn observed in this study align with the 0.19 - 0.80 mg/kg range reported for meats sold in Ghana's metropolitan areas [22], the 0.045 - 0.48 mg/kg range for meat cuts in Uruguay [23], and the 0.0024 - 1.39 mg/kg range for meat cuts in the Croatian capital [24]. These concentrations are below the permissible limits. The human body needs manganese (Mn) for a variety of chemical and biological reactions. It is essential for the development of bone structure, blood coagulation, glucose metabolism, nerve and brain growth, and cognitive function [25]. Overexposure to Mn leads to its accumulation in the body which can result in poor bone health, manganism (a neurogenerative disorder), and irreversible damage to human health. The Mn-polluted environment is primarily caused by fossil fuel combustion and the use of Mn in producing nonferrous metallurgy, low-carbon steels, batteries, electrodes, and catalysts [26]. The average levels of manganese recorded for the samples are below the regulatory limit of WHO/FAO in food, which is 2 - 9 mg/kg [27].

The measured concentrations of Cu in roasted goat meat ranged from 1.624 to

1.978 mg/kg with a mean value of 1.834 ± 0.17 mg/kg. Also, the levels of copper in roasted pork ranged from 1.245 to 2.293 mg/kg, with an average level of 1.927 ± 0.47 mg/kg. There is no significant difference (**Table 3**) in the mean values within and across the groups ($p > 0.05$). The mean concentration of copper in this study is comparable to a study carried out on beef in Uganda [28], Nigeria [29], EU countries [30], and Asia [31]. Copper is essential for the metabolism of iron and glucose and is involved in various biological processes including cell oxidation and signaling systems [32]. Neurologically, copper deficiency can lead to health conditions like myelopathy and peripheral neuropathy mimicking subacute combined degeneration. On the other hand, excessive amounts of copper in tissues may result in heart failure, cirrhosis of the liver and pancreas dysfunction [33].

The concentrations of Pb in roasted goat meat ranged from 1.997 to 25.090 mg/kg with a mean value of 8.152 ± 11.301 kg/mg. In roasted pork, the values of Pb measured varied from 1.427 to 2.655 mg/kg with a grand mean of 2.220 ± 0.542 mg/kg. Due to its carcinogenic nature, lead easily passes the blood-brain barrier accumulating in the brain and causing damaging effects on renal, hematopoietic, and reproductive functions as well as on the central nervous system. As a non-essential and non-biodegradable heavy metal, excessive lead in the body results in poisoning and death. Lead poisoning is a major issue in developing countries due to increasing industrial activities [34]. The elevated Pb content in this research is in line with several studies in Uganda [28] [35] [36], Nigeria [29], and the Middle East countries [16] [37]. The highest concentration of Pb (25 mg/kg) was observed in the goat meat sample collected from a vendor in Ishaka. This could be related to the vendor's proximity to vehicular emissions in street, type of material used for roasting and poor hygienic conditions. Since goats are not raised indoors, the significant increase in Pb could also result from the food intake containing high lead content or pasture forage contaminated by lead. There is no significant difference in the mean values of lead within and across the groups ($p > 0.05$). Additionally, the source of fire used by vendors should be considered, as many light fires with materials containing high lead content. The recommended permissible limit of Pb in food is 0.01 mg/kg. However, Pb concentrations in roasted goat and pork meat in this study exceeded this limit. Therefore, long-term consumption of street-roasted meat could potentially endanger consumer health.

The concentrations of Fe in roasted goat meat ranged from 4.107 to 8.424 mg/kg with an average value of 5.833 ± 1.83 mg/kg. Also, the values of Fe in roasted pork ranged from 2.758 to 6.680 mg/kg with an average concentration of 4.706 ± 1.91 mg/kg. One of the most important metals for human nutrition and life support is iron. It is essential for cell division, differentiation, oxygen and electron transport, and gene expression control. The red blood cell (RBC) pigment haemoglobin, which gives blood its red colour, binds around 70% of the iron in the human body. The unused iron is either kept within cells or attaches to other proteins including myoglobin, transferrin, and ferritin [38]. While iron is beneficial for the human body, excessive iron storage from dietary intake can lead to hemochromatosis, also known as iron overload [39]. The liver and heart, among other important organs, may sustain irreversible damage from this condition if left untreated. Iron deficiency and anemia may be caused by blood loss and a low dietary intake of iron. According to reports, inadequate iron intake is the most common dietary deficit worldwide. In developing countries, it is a serious health risk for children, young adults, pregnant women, and those with poor socioeconomic backgrounds [38]. The Fe concentrations observed in this study for both goat meat and pork were below the WHO regulatory limit of 425 mg/kg [40]. These findings are consistent with previous studies [13] [16] which also reported concentrations below the permissible limit. The lower concentrations of iron compared to the permissible limit can be attributed to the body's utilization of iron for various biological processes. There is a significant difference in mean values of Fe within the group ($p < 0.05$), but no significant difference was observed in mean values across the groups ($p > 0.05$).

The concentrations of Cd in roasted goat meat ranged from 0.762 to 0.837 mg/kg with an average value of 0.794 ± 0.032 mg/kg. In pork, the levels of Cd in roasted pork varied from 0.657 to 0.885 mg/kg with a mean value of 0.766 ± 0.118 mg/kg. Cadmium is a toxic and non-essential heavy metal which is mostly found in the environment as a result of industrial and agricultural processes. The primary routes of cadmium exposure include consumption of contaminated food and water, inhalation, and cigarette smoking [41]. It has been shown that exposure to cadmium (Cd) may result in pulmonary edema, testicular injury, osteomalacia, adrenal gland damage, and hemopoietic system damage [42]. The mean Cd concentration in this study is above the regulatory limit (0.1 mg/kg) for terrestrial animals by European Commission Regulation [30]. However, our results are similar with those reported for meat sold in Nigeria [29], Bangladesh [43], and EU countries [44]. The mean level of Cd (0.766 mg/kg) in this study is significantly lower than the mean value (5.49 mg/kg) of Cd reported in pork meat, Spain [45]. The high cadmium concentrations observed in pork and goat meat in this study could be attributed to several factors, including poor hygiene during meat processing and age of the animals as the cadmium concentration increases with age

Table 2. Descriptive statistics of heavy metals in pork and goat meat samples.

Parameter	Sample	Heavy metal (mg/kg)				
		Mn	Cu	Cd	Pb	Fe
Mean	Pork	0.391	1.927	0.766	2.220	4.706
	Goat	0.388	1.834	0.794	8.152	5.833
SD	Pork	0.135	0.465	0.117	0.542	1.909
	Goat	0.282	0.165	0.032	11.301	1.832
Range	Pork	0.214 - 0.534	1.245 - 2.293	0.657 - 0.885	1.427 - 2.655	2.758 - 6.680
	Goat	0.042 - 0.694	1.624 - 1.978	0.762 - 0.837	1.997 - 25.090	4.107 - 8.424

SD = standard deviation.

Table 3. ANOVA relationship between heavy metals at various groups and samples.

Variable	Group 1		Group 2		WG	AG
(mg/kg)	Mean	SD	Mean	SD		
Mn	0.391	0.13	0.388	0.28	C	C
Cu	1.927	0.47	1.834	0.17	C	C
Cd	0.766	0.12	0.794	0.03	C	C
Pb	2.220	0.54	8.152	11.30	C	C
Fe	4.706	1.91	5.833	1.83	D*	C

Group 1 = pork; Group 2 = goat; WG = within group; AG = across group; D* = statistically significant ($p < 0.05$); C = not significant.

due to its slow elimination rate from the body [44]. There is no significant difference ($p > 0.05$) in the average concentrations of cadmium within and across the groups.

5.2. Correlation Coefficient

The correlation analysis obtained for pork showed that there is a strong correlation between Cu and Cd ($r = 0.707$) and Cu and Fe ($r = 0.712$). In addition, there was a significant positive correlation between Cd and Fe ($r = 0.957$). The significant positive correlation between Cd and Fe indicates a direct relationship in terms of concentrations in samples and also the two variables' sources of contamination could be the same (**Table 4**). On the other hand, Mn showed a strong negative correlation with both Cd ($r = -0.776$) and Fe ($r = -0.925$). The strong negative correlation between Mn and Fe in pork meat means that the sources of contamination are different. Moreover, the correlation analysis obtained for goat meat showed that there is no relationship between the variables analysed (**Table 5**). This indicates that the sources of contamination in goat meat are different for all the measured variables. Therefore, an increase or decrease in concentration of a particular variable will not affect others (independent). It was observed that a positive correlation exists between Cu and Fe (0.712) for goat meat, while pork meat had negative correlation between Cu and Fe (−0.622). Since pigs and goats have different diet, the variations in correlation could be linked to differing amounts of Fe content in their respective feeds.

Table 4. Correlation analysis for pork samples.

	Mn	**Cu**	**Cd**	**Pb**	**Fe**
Mn	1.000				
Cu	−0.658	1.000			
Cd	**−0.776**	**0.707**	1.000		
Pb	−0.242	−0.082	0.630	1.000	
Fe	**−0.925**	**0.712**	**0.957**	0.504	1.000

*Values in bold indicate significant correlation.

Table 5. Correlation analysis for goat samples.

	Mn	Cu	Cd	Pb	Fe
Mn	1.000				
Cu	−0.672	1.000			
Cd	−0.604	0.150	1.000		
Pb	−0.200	−0.251	−0.296	1.000	
Fe	0.671	−0.622	0.182	−0.599	1.000

6. Human Health Risk Assessment

6.1. Estimated Daily Intake (EDI)

The EDI obtained for the heavy metals in pork for both adults and children had same decreasing order of Fe > Pb > Cu > Cd > Mn (**Table 6**). In addition, the decreasing trend in EDI for heavy metals in goat samples also had same order for both children and adults (Pb > Fe > Cu > Cd > Mn). The EDI (mg/kg/day) obtained in this study for essential elements (Fe, Mn, and Cu) were within the tolerable daily intake (0.7, 0.14, and 0.04 mg/kg/day respectively) for both adults and children [46]. On the other hand, the EDI values for the non-essential elements (Cd and Pb) were higher than the acceptable daily intake for children and adults. The high levels of Cd and Pb could be related to poor hygiene from the materials used for roasting leading to contamination. The high level of these non-essential elements could lead to health issues related to kidney and liver particularly in children with significantly high EDI values. Moreover, the process employed for processing the meats has the tendency to increase the concentration of heavy metals because most vendors roast meat in open air. In addition, the THQ values estimated for Cd and Pb were above the standard (THQ > 1) for all the samples (**Figure 1** and **Figure 2**) in children and adults leading to HI values > 1 for both pork and goat meats. The mean EDI obtained for Cd (pork) in this study is substantially higher than those obtained for children and adults (0.277 and 0.198 μg/kg/day) in Kampala, Uganda [15].

6.2. Non-Carcinogenic Risk

The hazard index values obtained for all the samples were higher than the regulatory limit (HI > 1); therefore, consumers would be at risk from the cumulative impact of the pollutants in the roasted sample. The HI values obtained in goat sample for adults and children were significantly higher than those obtained in pork sample (**Table 7**). Children had the highest HI value (195.0644), which could be related to the elevated Pb levels in the meat sample. Kasozi in 2018 also emphasized on the elevated concentrations of Pb detected in milk and beef samples collected in Bushenyi district [14]. The continuous report of high levels of Pb in some street foods (mostly meat) in Uganda is of great concern because Pb poison poses serious health issue in both adults and children. In addition, children are more vulnerable to non-cancer risk in the study area. Therefore, there is need for a revision in food safety policies in Uganda. Also, frequent monitoring of places where vendors sell processed meats is required by the environmental protection agency.

6.3. Carcinogenic Risk

Table 8 indicates the CR values of Pb and Cd in pork and goat meats computed for both adults and children. The cancer risk computed ranged from 4.01×10^{-5} (Pb) in adult to 1.87×10^{-3} (Cd) in children. Long-term exposure to carcinogens such as heavy metals may lead to different types of cancer. According to USEPA recommendations (20), CR below 10^{-6} is considered insignificant, and cancer risk can be ignored. In contrast, CR above 10^{-4} is considered significant and can contribute to cancer risk. All CR values for Pb were within the acceptable limit and will not pose carcinogenic risk to both adults and children. In addition, the CR values for Cd were acceptable for goat meat (adults and children) and pork (adults) consumption. In accordance with our findings, [15] and [47] reported CR values for Pb at acceptable levels and didn't pose a carcinogenic risk. The

Table 6. Modelled estimated daily intake of heavy metals in pork and goat meat samples.

	EDI of metals (mg/kg/day)									
Variables	Mn		Fe		Cd		Cu		Pb	
	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Pork										
Mean	0.0008	0.0108	0.0093	0.1302	0.0015	0.0212	0.004	0.053	0.005	0.066
Minimum	0.0004	0.0059	0.0055	0.0763	0.0013	0.0182	0.002	0.034	0.004	0.058
Maximum	0.0011	0.0148	0.0132	0.1848	0.0017	0.0245	0.005	0.063	0.005	0.073
SD	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.01	0.00	0.01
Goat										
Mean	0.0008	0.0011	0.0115	0.0161	0.0016	0.0022	0.0036	0.0051	0.0161	0.0225
Minimum	0.0001	0.0001	0.0081	0.0114	0.0015	0.0021	0.0032	0.0045	0.0039	0.0055
Maximum	0.0014	0.0019	0.0167	0.0233	0.0017	0.0023	0.0039	0.0055	0.0061	0.0085
SD	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.03

Table 7. Estimation of hazard index (HI) for non-cancer risk in meat samples.

	Hazard Index			
Sample	**Mean**	**Minimum**	**Maximum**	**SD**
Pork				
Adults	14.72508	12.90471	14.96992	1.463763
Children	20.60129	18.05447	23.03545	2.047893
Goat				
Adults	46.44886	12.59194	139.4252	62.0342
Children	64.98479	17.61689	195.0644	86.78962

Table 8. Incremental lifetime cancer risks in meat samples.

	Pork		Goat	
Metal	Adults	Children	Adults	Children
Cd	1.33×10^{-4}	1.87×10^{-3}	1.53×10^{-4}	2.14×10^{-4}
Pb	4.01×10^{-5}	5.61×10^{-4}	1.37×10^{-4}	1.92×10^{-4}
ΣILCR	1.74×10^{-4}	2.43×10^{-3}	2.90×10^{-4}	4.06×10^{-4}

ILCR = Incremental lifetime cancer risks.

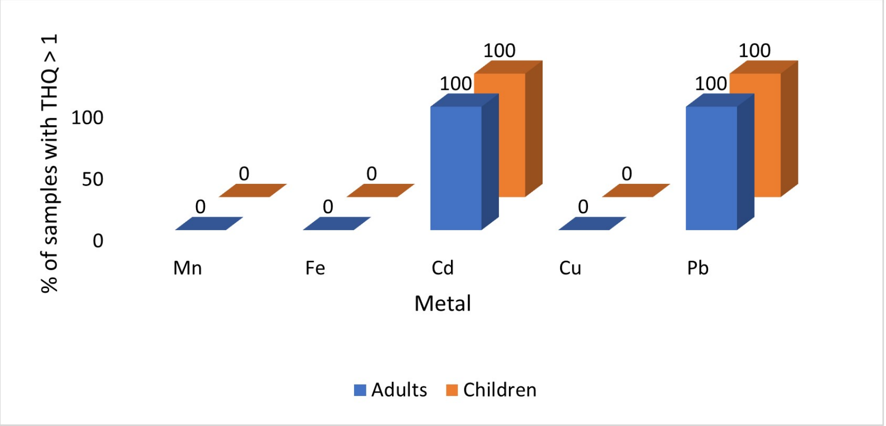

Figure 1. Percentage of samples (pork) with THQ > 1 for individual metals.

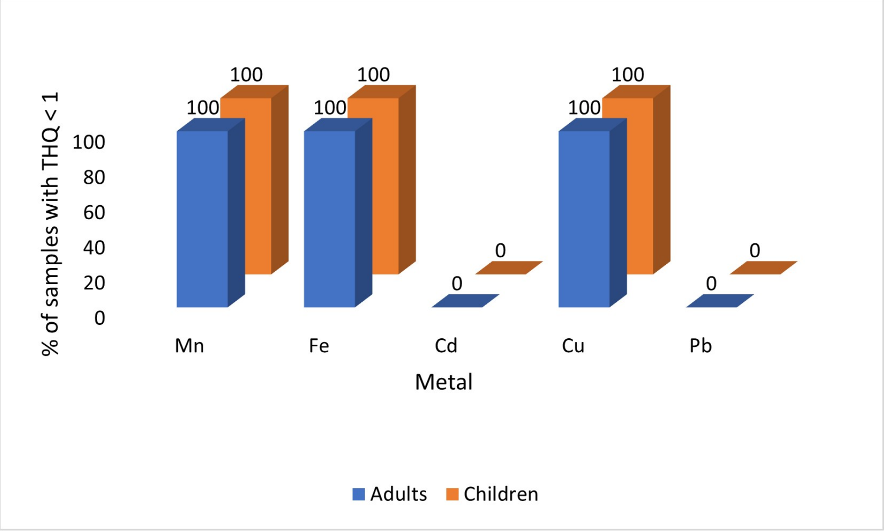

Figure 2. Percentage of samples (goat meat) with THQ < 1 for individual metals.

incremental lifetime cancer risks (ILCR) computed were within the regulatory limit for the target population except for Pb consumption in pork by children which had value higher than 10^{-4}. An ILCR > 10^{-4} is benchmark for obtaining further information whereas ILCR > 10^{-3} indicates a considerable elevated risk and should be considered a high priority as a public health issue [48].

7. Conclusion

Results obtained from this study indicated no significant difference in mean values of heavy metals between pork and goat meat samples analyzed. In addition, the average concentrations of Pb measured in the roasted pork and goat meats were significantly higher than other metals and also exceeded the international regulatory limits. The findings in this study align with numerous studies from Uganda reporting elevated Pb levels. Similar findings across the globe highlight the need for regulatory agencies to implement stringent measures to curb the increasing Pb concentration in meat sold in Uganda, aiming to minimize the risk of lead poisoning and associated human health risks. Compared to adults, children's HI values were significantly higher. Therefore, children in the research area are more susceptible to non-carcinogenic conditions. This study contributes to the foundational research needed for establishing standards for heavy metal concentrations in meat products in Uganda.

Authors' Contributions

IOS was responsible for the conceptualization, study design, supervision, data analysis, and manuscript drafting. BN handled the sample preparation and paper writing. AAA and OPA were involved in the data analysis, writing, and editing of the manuscript. JOA also contributed to the paper's editing and supervision. All authors read and gave their approval to the manuscript's final draft.

Availability of Data and Material

This article contains all the data generated and evaluated.

Declarations

All authors have read, understood, and have complied as applicable with the statement on "Ethical Responsibilities of Authors" as found in the Instructions for Authors.

Conflicts of Interest

The authors declare no conflicts of interest.

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