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Cancer and Non-cancer Risks Associated With Heavy Metal Exposures from Street Foods: Evaluation of Roasted Meats in an Urban Setting

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Abstract Street foods (SF) are important in meeting energy and nutrient requirements for urban populations because of their convenience and low-cost. In contrast, SF represents a major public health risk due to chemical contamination especially with heavy metals. The study aimed at quantifying the levels of heavy metals (HM); lead (Pb), arsenic (As), cadmium (Cd), Chromium (Cr), copper (Cu), zinc (Zn) and iron (Fe) in street roasted and vended meats (SRVM); estimating daily HM intake; determining the cancer and non-cancer risks associated with HM exposure using probabilistic risk assessment models. Twelve samples of each SRVM (pork, beef, goat and chicken) were randomly purchased on the streets of Kampala and their HM content measured. The cancer and non-cancer risks were estimated using incremental lifetime cancer risk and target hazard quotient (THQ), respectively. Lead, Cd and As content was above maximum limits according to EFSA and WHO, while Cr, Cu, Zn and Fe were below prescribed limits. The daily intake of Pb measured in beef and pork was higher than the recommended tolerable daily intake (TDI) for both children and adults while that of Cd, As, Cu, Zn and Fe was <TDI. The probability of an adult developing cancer as a result of consuming SRVM over a 70-year lifetime was greater than US EPA management level of $1x10^{-4}$ for all the meats. THQ showed potential risk for humans due to the intake of Pb in pork and beef, and As in chicken with respect to children. THQ values also presented Pb, Cd and As as dominant contaminants. The combined non-carcinogenic effect of all metals considered in the study expressed as hazard index (HI) was >1, with values for children higher than those for adults. Regular consumption of SRVM in Kampala is a health risk with respect to Pb, Cd and As.

Keywords: *cancer, risk, heavy metal, street food, roasted-meat*

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1. Introduction

Street foods (SF) are foods and beverages prepared and or sold by vendors and hawkers in streets and other public places for immediate consumption or consumption at a later time without further processing [1]. These foods are consumed worldwide by an estimated 2.5 billion people per day due to low cost and convenience [2]. They account for 70% of the energy intake in African cities. In Uganda, roasted meat (RM) of beef, goat, pork, and chicken is popular SF. Meat plays an important part in a healthy balanced diet because of its high nutrient density. It is an important source of protein of high biological value and whose amino acid composition can complement that of cereal and other vegetable proteins [3]. It is also a very rich and convenient source of other nutrients including vitamins and microelements. However, street meats may contain substantial amounts of toxic metals resulting from mode of preparation and exposure to polluted environment.

Food safety is a major public health concern and its demand by consumers worldwide has stimulated research regarding the risk associated with consumption of foodstuffs contaminated by heavy metals (HM) [4]. Heavy metals are ubiquitous in the environment as a result of natural and human activities, and are among the major contaminants of food materials [5]. Due to their non-biodegradability and toxicity at low concentration, HM-intake through the food chain is a problem receiving increasing attention [6]. In particular, the general handling of street roasted and vended meats (SRVM) poses a safety threat because they are prepared and sold in open and dusty environment with high levels of contamination from various sources. Presence of HM has previously been reported in SF in Ghana [7]. Metals such as chromium (Cr), copper (Cu), iron (Fe) and zinc (Zn) play important biochemical roles in the life processes of many organisms, and their presence in trace amounts is essential. However, beyond certain threshold, these metals can have damaging effects on human beings. In contrast, some HM have no known beneficial role in human metabolism and are considered dangerous even at very low levels of exposure. This includes, arsenic, cadmium, and lead which are widely distributed persistent environmental contaminants and poisons that are toxic, carcinogenic, mutagenic and teratogenic, hence of public health significance [8].

Information about HM concentrations in foodstuffs and their dietary intake is very important for assessing their risk to human health. Levels of toxic metal ions in common foodstuffs have been quantified and in some cases the results statistically extended to generate target hazard quotients (THQ) for individual and combinations of metals [9]. However, there are limited studies evaluating SRVM in urban settings in developing countries. A number of biological samples from Uganda contain substantial amounts of environmental contaminants [10]. Therefore, the objectives of this study were to: (1) quantify levels of Pb, As, Cd, Cr, Cu, Zn and Fe in SRVM of pork, beef, goat, and chicken; (2) estimate daily HM intake through consumption of these meats; (3) determine the cancer and non-cancer risks associated with the HM intake using probabilistic risk assessment models.

2. Materials and Methods

2.1. Sample Collection

Twelve samples of each of the SRVM of beef, goat, pork and chicken were randomly obtained in Kampala city. All samples were stored in clean polyethylene bags according to type and freighted to the Directorate of Government Analytical Laboratories (DGAL) chemistry laboratory for preparation and analysis. Samples were chopped and blended in a domestic blender to ensure homogeneity. They were then packed separately and frozen overnight prior to analysis.

2.2. Determination of Heavy Metals

Level of Heavy metals was determined on a Shimadzu (AA-6300) Electro-thermal Graphite Furnace Atomic Absorption Spectrophotometer (GF-AAS) equipped with High-speed Deuterium (BGC-D2) and Self-Reversal Method Background Correction (BGC-SR) along with an ASC-6100 auto-sampler (Shimadzu Corporation, Japan) using a modification of the method described previously by Ogwok et al. [10]. Samples (*ca.* 5g) were weighed and dried in an oven at 105°C until constant weight was attained. To each dried sample, was added magnesium nitrate solution (15% w/v) followed by charring on a hot plate to ensure carbonization. It was then ashed in a muffle furnace at 450°C to obtain white ash. The ash was dissolved in nitric acid, HNO_3 (15% w/v) with warming to ensure total dissolution and the mixture filtered through an acid washed filter paper into a 50ml volumetric flask. The resulting solution was diluted to the mark of the flask with deionized water. These solutions were analyzed for Pb, Cd, As, Cr, Cu, Zn and Fe and the concentrations blank corrected. Standard solutions of the metals were also prepared at 5 different concentrations and the absorbance (A) determined. A calibration curve was in each case automatically generated. The calibration curves were linear within the concentration range, with regression coefficients (R^2) > 99%. From the above calibration curves, the unknown concentrations of the seven analytes in the different samples were determined. Heavy metals were determined at wave lengths (λ) 283.3, 228.8, 193.7, 357.9, 324.8, 213.9 and 248.3 nm for Pb, Cd, As, Cr, Cu, Zn and Fe, respectively.

2.3 Estimation of Daily Heavy Metal Intake

The health risk posed to consumers was determined by the specific dietary intake of each contaminant and compared with toxicologically acceptable levels. The daily intake of HM from the consumption of SRVM was estimated using equation 1 [11]:

$$\text{Estimateddaily intake of metal(EDI)} = \left(\text{C X IR}\right)/\text{BWa} \quad (1)$$

where C, IR and BWa represent the HM concentrations in meat ($mgkg^{-1}$), ingestion rate for meat and average body weight, respectively. The average adult and child body weight was considered to be 60.7 and 20.5 kg, respectively [12,13].

2.4. Health Risk Assessment

Risk assessment was done based on the mean concentrations of carcinogenic and non-carcinogenic metals determined in the meat samples using United States Environment Protection Agency (US EPA) human health risk assessment models [6]. It was assumed that the ingested dose is equal to the adsorbed contaminant dose and that cooking has no effect on the toxicity of HM in SRVM [11].

2.4.1. Cancer Risks

Potential cancer risks associated with exposure to a measured dose of chemical contaminant can be estimated using the incremental lifetime cancer risk (ILCR). The latter is the incremental probability of an individual developing any type of cancer over a lifetime due to a 24 hour/day carcinogenic exposure to a given daily dose of a chemical for 70 years [14]. One in a million (1×10^{-6}) cancer risk means that if a million people are exposed, one additional cancer case would be expected. The US EPA cancer risk considered *de minimus* or acceptable for regulatory purposes is within the range of $1 \text{ X } 10^{-6}$ to 1×10^{-4} [15]. Incremental lifetime cancer risk is obtained using the Cancer Slope Factor (CSF), which is the risk produced by a lifetime average dose of 1 $mgkg^{-1}$ $BWday^{-1}$ and is contaminant specific [16]. It was worked out for As, Cd and Pb using respective slope factors of 1.5, 6.3 and 0.0085 $(mgkg^{-1}day^{-1})^{-1}$ in equation 2.

$$\text{ILCR} = \text{CDI X CSF} \quad (2)$$

CDI (chronic daily intake of chemical, $mgkg^{-1}BWday^{-1}$) represents the lifetime average daily dose of exposure to the chemical. The CDI value was calculated on the basis of equation 3:

$$\text{CDI} = \left(\text{EDI X EFr X EDtot}\right)/\text{AT} \quad (3)$$

where EDI is estimated daily intake of metal via consumption of SRVM; EFr is exposure frequency (365 days/year); EDtot is the exposure duration 58.65 years, average lifetime for Uganda; AT is the period of exposure for non-carcinogenic effects (equal to EFr X EDtot), and 70 year life time for carcinogenic effects (i.e., 70 years X 365 days/year) [16]. Cancer risk estimates for exposures ≤35 years introduce significant uncertainty. The total cancer risk as a result of exposure to multiple contaminants due to consumption of a particular type of meat was assumed to be the sum of the individual metal incremental risks (∑ ILCR, n=1 to n).

2.4.2. Non-cancer Risks

Non-cancer risks are assumed to exhibit a threshold below which no adverse effects are expected to be observed. As such, non-carcinogenic health hazards are evaluated by the target hazard quotient (THQ) using Eq. (4) [16]:

$$THQ = CDI / RfD \qquad (4)$$

where CDI is the exposure dose obtained from Eq. (3) and RfD is the oral reference dose of the contaminant. The oral reference dose (mg/kg/day) is an estimation of the maximum permissible risk on human population through daily exposure, taking into consideration a sensitive group during a lifetime [15]. The RfD values for Pb, Cd, Cr, As, Zn, Cu and Fe are $4.0x10^{-3}$, $1.0x10^{-3}$, $1.5x10^{0}$, $3.0x10^{-4}$, $3.0x10^{-1}$, $4.0x10^{-2}$ and $7.0x10^{-1}$ ($mgkg^{-1}day^{-1}$) respectively [5,10].

Exposure to multiple contaminants results in additive and or interactive effects. Therefore, to evaluate the potential risk to human health through more than one HM, the chronic hazard index (HI) is obtained as the sum of all hazard ratios (THQ) calculated for individual contaminants for a particular exposure pathway [6]. It is assumed that the magnitude of the effect is proportional to the sum of the multiple metal exposures and that similar working mechanisms linearly affect a target organ [17]. The calculated HI is compared to a benchmark; the population is assumed to be safe when HI < 1 and in a level of concern when 1< HI < 5 [10]. THQ is not a measure of risk but indicates a level of concern and while THQ values are additive, they are not multiplicative hence a level of THQ = 20 is larger but not tenfold that at THQ = 2 [9].

2.5. Statistical Analysis

Data was analyzed using SPSS statistical package (SPSS Inc., Chicago, IL, USA). Analysis of variance, ANOVA, was performed to compare levels of heavy metals between the different meats. Difference between means was obtained using the least significance difference (LSD) at $p < 0.05$.

3. Results and Discussion

3.1. Heavy Metal Concentration

3.1.1. Concentration of Toxic elements

Fresh chicken, pork, beef and goat meat procured for preparing street foods had very low concentration (0.006 to 0.054 mg/kg) of Pb (Table 1). After roasting, lead content of street roasted and vended meats (SRVM) increased to a range of 0.146 to 2.290 mg/kg. Roasted chicken had the highest relative increment in lead amounts by more than 212 times (0.006 to 1.271 mg/kg). A similar trend was observed for the case of pork at 65, beef at 37 and goat meat at 7 times. In spite of the notable increment in Pb concentrations in SRVM, levels in chicken, pork and beef (1.271 to 2.290 mg/kg) were not statistically different ($p > 0.05$) but higher than that in goat meat (0.146 mg/kg). The concentration of Cd in fresh meats was very low (not detected to 0.001mg/kg) but increased substantially (0.063 to 0.248 mg/kg) after preparation. Cadmium was not detected in fresh meat except in pork (0.001 mg/kg). The amount of Cd accumulated more than 100 times in SRVM. Levels of Cd in SRVM of pork, goat and chicken were not significantly different ($p>0.05$) but higher than that of beef (Table 1). Level of As in fresh meat was 0.006 mg/kg for beef, 0.004 mg/kg for pork, and 0.001mk/kg for both goat meat and chicken. Arsenic concentration in SRVM was between 0.030 and 0.122 mg/kg. The increment in As concentration during handling and preparation was between 7.5 to 122 times. The As values (0.030 to 0.077mg/kg) were not significantly different in goat, beef and pork. Roasted chicken presented the highest As value of 0.122mg/kg.

Table 1. Concentration of heavy metals (mg/kg) in fresh and street roasted and vended meats (mean ± SD)

Meat	Lead	Cadmium	Arsenic
Fresh pork	0.035^{c}±0.130	0.001	0.004^{c} ±0.001
Fresh beef	0.054^{c} ±0.010	< 0.001	0.006^{c} ±0.001
Fresh goat	0.022^{c} ±0.023	< 0.001	0.001^{c} ±0.000
Fresh chicken	0.006^{c} ±0.001	< 0.001	0.001^{c} ±0.000
Street roasted and vended pork	2.290^{a} ±1.410	0.100^{a} ±0.089	0.030^{b}±0.010
Street roasted and vended beef	1.987^{a} ±0.280	0.063^{b} ±0.021	0.077^{b} ±0.053
Street roasted and vended goat	0.146^{b}±0.011	0.248^{a} ±0.135	0.042^{b} ±0.041
Street roasted and vended chicken	1.271^{a} ±0.890	0.191^{a} ±0.060	0.122^{a}±0.075
Maximum Limit [18,19]	0.1	0.05	0.01

Means within each column bearing similar superscripts are not significantly different at p =0.05.

Based on the results of this study, Pb and As are present in all fresh meats used for preparation of street foods while Cd was detected only in pork. However, Cd may still be present in the other fresh meats but in concentrations below detection limit. Detected metals in fresh muscle meats are indicative of prior contamination from the environment and metal based animal feeds. In contrast, the concentration of Pb and Cd in SRVM were above the maximum limits according to EFSA [18]. The maximum limit for Pb and Cd in muscle meat of all types is 0.1 and 0.05 mg/kg wet weight, respectively. Arsenic levels in all SRVM analyzed exceeded the permissible limit of 0.01 mg/kg set by WHO [19]. Roasted chicken was most contaminated with lead and arsenic, and goat meat most contaminated with Cd. The difference in the levels of contamination between different meats can be attributed to the mode of preparation, exposure to the environment, and the type of fuel (wood or charcoal) used to roast the meat. Street foods in Kampala are generally prepared and sold in open spaces nearby roads and garages where dust and fumes in the environment can easily contaminate the food. Lead is used as industrial raw material and is also deposited in the soil from use of lead based agrochemicals in commercial urban farming around Kampala city. In addition, use of leaded gasoline in Uganda was only phased out in 2006, and because Pb is non-biodegradable [20], it still persists in the environment. Cadmium like Pb, occurs in the soil and is spread in the environment due to human activity. Arsenic is naturally found in the environment and also gets into the air, water and soil by human activities. It is used in wood preservatives; in certain growth promotors, pesticides and herbicides in farming [20].

3.1.2. Concentration of Essential Trace Elements

Levels of chromium in SRVM ranged between 1.36 and 2.35 mg/kg. Permissible level of Cr in food is 0.025-0.2 mg/kg [21]. The examined meats therefore had chromium concentrations above maximum limit. The Cr content in foodstuffs is generally low in most foods (<0.1 mg/kg) [19]. However, proteinaceous foods such as meat contain levels above 0.1 mg/kg because in food, Cr occurs in the trivalent state (Cr(III)) which has strong tendency to form stable crosslink with protein molecules [22]. The amount of copper in the meats was in the range of 0.37 to1.22 mg/kg. Copper concentration was observed to be significantly higher (p < 0.05) in goat meat than in other meats but below permissible limit [18]. In general, the concentration of copper in foodstuffs is ≤ 2 mg/kg [21]. Levels of Cu below 10 mg/kg in muscle, and organs and other tissues of animals are suggestive of copper deficiency. The results of this study are similar to those obtained in an earlier study on internal organ meats of beef, goat and chicken [10]. Zinc level in SRVM was between 7.47 mg/kg and 36.06 mg/kg. This level is below WHO maximum limit (60 mg/kg) but consistent with the findings of De Smet [23] and Tidemann-Andersen et al. [24] who reported Zn content in the range of 11.8 to 29.8 mg/kg and 6 to 20 mg/kg respectively in muscle across species (pigs, ruminants, and poultry), and in goat meat and beef in eastern Uganda. Zinc concentration was however significantly (p < 0.05) higher in goat than in other meats. In general, goat meat is superior to other meats in terms of nutritional quality. Iron concentration was least in chicken (5.58 mg/kg) and highest in pork (24.55 mg/kg), beef (19.66 mg/kg) and goat (17.4 mg/kg). Iron level in this study was below the permissible range of 30 to 150 mg/kg in all meat samples [10]. Excess Fe in the body may play a role in the etiology of heart disease and type 2 diabetes. However, Fe deficiency is one of the most common nutritional deficiencies leading to severe anemia in children, women of child bearing age, and pregnant women [24].

Deficiency or excess of a trace element may cause disorders in the absorption, distribution, metabolism and elimination of other trace elements [25]. Heavy exposure to Pb and Cd may be a risk factor for the occurrence of iron deficiency anemia in humans. In addition, lead absorption from ingested food greatly depends on the levels of Cu, Fe and Zn in the diet and their deficiency enhances its absorption [26]. This suggests that SRVM contribution to HM exposure is a health hazard with respect to Pb and Cd particularly in children and regular consumers.

Table 2. Concentration of essential trace elements (mg/kg) in street roasted and vended meats (mean ± SD)

Metal	Maximum Limit [21]	Pork	Beef	Goat	Chicken
Chromium	0.025-0.2	1.35^{a}±0.81	2.35^{a}±1.12	2.34^{a}±1.98	1.80^{a}±0.37
Copper	40.0	0.37^{b}±0.13	0.37^{b}±0.27	1.22^{a}±1.18	0.73^{b}±0.43
Zinc	60.0	8.48^{b}±11.05	7.47^{b}±4.60	36.06^{a}±19.68	13.54^{b}±6.49
Iron	30-150	24.55^{a}±13.38	19.66^{a}±7.99	17.40^{a}±5.64	5.58^{b}±4.38

Means within each row bearing similar superscripts are not significantly different at p =0.05.

3.2. Estimated Daily Intake of Heavy Metals

The World Cancer Research Fund (WCRF) and American Institute for Cancer Research (AICR) recommend <50 g/day cooked weight of red meat intake in order to reduce the risk of contracting cancer [27]. However, daily SRVM consumption in this study, obtained through a formal survey of 100 adult male and female consumers of pork, beef, goat meat, and chicken in Kampala city was 120 g/person/day. Therefore, exposure to HM was worked out in terms of estimated daily intake (EDI) based on IR of 120 g and 56.7 g respectively for adults and children. The IR for children is based on the requirements for optimal nutrition for children 6 years of age [28]. The computed EDI was in each case compared with the tolerable daily intake (TDI) derived from the provisional tolerable weekly intake (PTWI) reference value established by the FAO/WHO expert committee on Food Additives. The PTWI value is 0.025, 0.007, 0.015, 1.05, 3.5, 7, and 5.6 mg kg^{-1} body weight $week^{-1}$ for Pb, Cd, As, Cr, Cu, Zn, and Fe respectively [29].

Lead contribution to the total heavy metal intake from chicken was less than the TDI for both children and adults, and was ten times lower in goat meat than other meats for both categories of consumers. However, Pb realized from beef and pork was greater than the TDI in both cases. Chronic exposure, even to small amounts of Pb can be hazardous to children especially under 6 years of age because they absorb lead more rapidly than adults [26]. Cadmium and arsenic intake was lower than the TDI in all cases. The EDI for these elements ranged between 0.17 and 0.69 µg/kg-bw/day, and 0.06 and 0.24 µg/kg-bw/day, respectively.

Chromium intake ranged between 3.734 µg/kg-bw/day and 6.45 µg/kg-bw/day for children but was ≤0.005 µg/kg-bw/day for adults. An intake of less than 200 µg chromium per day may reduce cellular responses to insulin [17]. Copper and iron daily intake was found to be <1% of TDI for these metals. On the other hand, the Joint FAO/WHO Expert Committee on Food Additives' (JECFA) tolerable daily intake of Zn is 1,000 µg/kg bw/day but the EVM safe upper limit for Zn is 4.2 mg/day (equivalent to 700 µg/kg bw/day in a 60 kg adult) for total dietary intake [30]. The maximum EDI for Zn was derived from goat meat for children and constituted 14% of the safe upper limit.

Table 3. Estimated daily intake (EDI) of heavy metals for the population of Kampala city through consumption of street roasted and vended meats (µgkg^{-1}day^{-1})

	TDI	Pork		Beef		Goat		Chicken	
		Children*	Adults**	Children	Adults	Children	Adults	Children	Adults
Lead	3.57	6.334	4.527	5.504	3.934	0.415	0.297	3.513	2.510
Cadmium	1.00	0.277	0.198	0.166	0.119	0.692	0.494	0.526	0.376
Arsenic	2.10	0.083	0.059	0.221	0.158	0.111	0.079	0.332	0.237
Chromium	150.00	3.734	0.003	6.450	0.005	6.472	0.005	4.979	0.004
Copper	500.00	1.023	0.731	1.023	0.732	3.374	2.412	2.019	1.443
Zinc	1000.00	23.454	16.764	20.661	14.768	99.737	71.288	37.450	26.768
Iron	800.00	67.902	48.534	54.377	38.867	48.126	34.399	15.433	11.031

TDI: Tolerable daily intake; * Children of 6 years of age; ** Adults of 58.65 years of age.

3.3. Human Health Risks

3.3.1. Cancer Risk

Cancer risks were computed as 2.7x10^{-3} for highest and 8.7X10^{-4} for lowest chances for goat meat and beef, respectively (Table 4). These risk values indicate that roasted goat meat consumption would result in an excess of 27 cancer cases per 10,000 people while consumption of beef would result into an excess of 87 cancer cases per 100,000 people [32]. The risk of developing cancer as a result of consuming goat meat, chicken and pork showed no significant difference ($p > 0.05$). Compared to the other two metals, Pb and As, Cd was predominant contaminant contributing 91%, 72%, 96% and 87% of the ILCR in pork, beef, goat meat and chicken, respectively. In general, EPA considers excess cancer risks that are below about 1 chance in 1,000,000 (1×10^{-6} or 1E-06) to be so small as to be negligible, and risks above 1 in 10,000 (1×10^{-4}) to be sufficiently large that some sort of remediation is desirable. An ILCR greater than one in ten thousand (ILCR > 10^{-4}) is benchmark for gathering additional information whereas 1/1000 or greater (ILCR > 10^{-3}) is moderate increased risk and should be given high priority as a public health concern [14]. Arsenic, Cd, Pb and Cr are classified by the International Agency for Research on Cancer (IARC) as being carcinogenic [8]. Chronic exposure to low doses of As, Cd and Pb could therefore result into many cancers [20]. The toxicity of chromium, on the other hand, depends on its chemical form with Cr(VI) compounds having a toxic, mutagenic and even carcinogenic nature [33]. However, Cr(III) which prevails in foodstuffs has no associated toxicity and is essential for good health in moderate intake.

Table 4. Incremental lifetime cancer risks for the adult population of Kampala city through consumption of street roasted and vended meats

	Street roasted and vended meats			
Metal	**Pork**	**Beef**	**Goat**	**Chicken**
Lead	4.51x10^{-5}	3.92 x 10^{-5}	2.95 x 10^{-6}	2.50 x 10^{-5}
Cadmium	1.00 x 10^{-3}	6.30 x 10^{-4}	2.60 x 10^{-3}	2.00 x 10^{-3}
Arsenic	7.45 x 10^{-5}	2.00 x 10^{-4}	9.94 x 10^{-5}	3.00 x 10^{-4}
∑ILCR	1.10 x 10^{-3}	8.70 x 10^{-4}	2.70 x 10^{-3}	2.30 x 10^{-3}

ILCR Incremental lifetime cancer risks.

3.3.2. Non-cancer Risk

Non cancer risk measured by target hazard quotients (THQ) was worked out for all the metals examined in this study for both adults and children (Table 5). The THQ followed the decrescent order Pb > As = Cd > Fe > Zn > Cu > Cr pork; Pb > As > Cd > Fe > Zn > Cu > Cr beef; Cd > As > Zn > Pb > Cu > Fe > Cr goat meat; As > Pb > Cd > Zn > Cu > Fe > Cr chicken. Target hazard quotient was greater than 1.0 for lead in pork and for both categories of consumers, and in beef for children. It was also greater than 1.0 for As in chicken for children. The sequence was the same for both adults and children although the latter had THQ values of 1.4 times higher in all cases. Similar observations have been reported previously by Wang et al. [17]. Children are more susceptible to the impact of pollutants than adults [34]. The non-cancer risks for each type of meat were expressed as the cumulative hazard index (HI), which is the sum of the individual metal THQ. The computed HI values for adults and children were 2.342 and 1.670, 2.456 and 1.753, 1.656 and 1.178, and 2.712 and 1.936 respectively for pork, beef, goat meat and chicken. Like the THQ, a HI > 1 represents a potential for adverse health outcomes. The contribution of individual metal THQ values to the HI was also evaluated and the results showed Pb, Cd and As to be dominant contaminants that together contributed over 90% of the HI through consumption of pork, beef and chicken, and 70% in goat meat. The potential health risk of Cr was minimal (0.1%) for both adults and children in comparison to other HM investigated, which is due to its high RfD (1.5 mgkg^{-1} day^{-1}) [17]. More attention should therefore be paid to Pb, Cd and As pollution in urban environments.

Table 5. Target hazard quotients by metal and meat type for street roasted and vended meats in Kampala city

Metal	Pork		Beef		Goat		Chicken	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Lead	1.584	1.132	1.376	0.984	0.104	0.074	0.878	0.628
Cadmium	0.277	0.198	0.166	0.119	0.692	0.494	0.526	0.376
Arsenic	0.277	0.197	0.737	0.527	0.370	0.263	1.107	0.790
Chromium	0.003	<0.001	0.004	<0.001	0.004	<0.001	0.003	<0.001
Copper	0.026	0.018	0.026	0.018	0.084	0.060	0.051	0.036
Zinc	0.078	0.056	0.069	0.049	0.333	0.238	0.125	0.090
Iron	0.097	0.069	0.078	0.056	0.069	0.049	0.022	0.016
HI =∑THQ	2.342	1.670	2.456	1.753	1.656	1.178	2.712	1.936

HI = Hazard index; THQ = target hazard quotient.

4. Conclusion

This study aimed at quantifying the levels of heavy metals in street roasted and vended meats (SRVM); estimating daily HM intake; determining the cancer and non-cancer risks associated with the HM exposure using probabilistic risk assessment models. The levels of Pb and Cd were above acceptable limits according to EFSA. Arsenic exceeded the maximum limit set by WHO. The estimated daily intake for Pb from beef and pork was above the tolerable daily intake for this metal in both children and adults. The probability of an individual developing cancer over a lifetime as a result of exposure to HM through consumption of SRVM was higher than acceptable risk levels (ILCR > 10^{-4}). Values of THQ for the individual metals showed potential health risk for humans due to the intake of lead in pork and beef, and arsenic in chicken with respect to children. In addition, hazard indices due to the combined non-cancer effects of all the metals considered in the study were >1. Target hazard quotients for children were higher than those for adults. Consumption of SRVM in Kampala is a health risk with respect to Pb, Cd and As, especially for children and should be given higher priority as a public health concern.

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