Cornous Biology, Volume:1, Issue: 1, Pages: 26-34
https://doi.org/10.37446/corbio/rsa/1.1.2023.26-34

Research Article

Assessment of heavy metal concentration and their relationship in beef sold in markets

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Received: 07 January 2023 / Accepted: 28 April 2023 / Published: 30 June 2023

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This study was conducted to assess the concentration and relationship of lead, cadmium, and arsenic in the fresh muscle, kidney, and liver of cattle. Thirty samples of each of the meat parts were obtained from the Ashaiman Main, Madina, and Makola Markets within the Accra Metropolis. A GTA Graphite Tube Atomizer was used to analyze the heavy metal concentrations. Arsenic was significantly different in the liver (2.40 mg/100g), kidney (0.93 mg/100g), and muscle (0.35 mg/100g). Lead was significantly higher in the liver (1.14 mg/100g) but insignificant between the kidney (0.67 mg/100g) and muscle (0.66 mg/100g). Arsenic was significantly higher in beef from the Ashaiman Main Market (2.48 mg/100g) than in samples from Madina (0.85 mg/100g) and Makola (0.35 mg/100g) Markets. The concentration of cadmium varied across the meat parts and the three markets. The correlation between the metals in all the meat tissues was positively low to high, but the arsenic-cadmium association was negatively low (r = -0.08). Heavy metals were present in all the meat samples from the three markets, but their concentration depended on the meat parts. Generally, higher concentrations of the metals were recorded in beef from the Ashaiman compared to Madina and Makola Markets. The liver had a comparatively lower heavy metal concentration and was therefore recommended for consumption.

Key words: *heavy metals, concentration, correlation, beef, markets*

Introduction

Meat is a good and widely known source of proteins, amino acids, and vitamins (B_{12} and D). Meat proteins promote growth, repair of worn-out tissue, antibody formation, and support the overall wellbeing of the human body (Ubwa et al., 2017). However, the value of meat as food for humans is affected by its relationship with cholesterol, saturated fat, hazardous contaminants, and persistent pollutants such as heavy metals (Püssa, 2013). Heavy metals are, and because they are not easy to transfer and linger over time, they persist in nature as toxic pollutants causing serious harm to living things (Aguilera et al., 2021). According to Fan et al. (2021), metals that have a density greater than 4.5 grams per cubic centimeter are considered heavy metals. They have the potential to accumulate at low or significant concentrations throughout food value chains to make food toxic for consumption (Rowland & McKinstry, 2006; Santhi et al., 2008); hence, the presence of heavy metals in food has been a public health issue (Baykov et al., 1996) for decades. Reports elsewhere have shown the presence of heavy metals in fish, surface sediments, and grass (Muluken, 2014; Shah et al., 2014). At optimum levels, heavy metals such as chromium may assist the body in utilizing sugar, proteins, and fats (Institute of Medicine, 2007), but in excess concentrations, they have negative effects (Agency for Toxic Substances and Disease Registry, 2004). Cadmium concentrations of 5mg/kg and 10mg/kg have caused inhibition of the humoral and cellular immune responses in rats (Lafuente et al., 2004). In humans, high blood pressure and hypertension have been linked to lead exposure (Martin et al., 2006). Most heavy metals undergo chemical synthesis during industrial activities, which ultimately allows them to enter food through various environmental media (water, soil, and air via effluent sewage, landfills, and dust) and subsequently be ingested into the body through contaminated food. Several researchers (Ano et al., 2007; Amusan et al., 2003; Okoye, 1994) have reported high quantities of toxins in fish, water, soil, and plants, which serve as food or sources of food for animals. In this regard, Miranda et al. (2005) have reported elevated levels of Pb and Cd in animals raised in a contaminated region of Northern Spain, and high levels of Cu and Hg were reported in locally produced and imported mutton in Jordan (Sharif et al., 2005). In Ghana, heavy metal pollution could be on the rise due to increased industrialization and fumes from vehicles and other machinery. Meanwhile, grazing animals such as cattle mostly travel long distances to graze on plants and drink from water sources with unknown pollutant concentrations, an indication of possible meat contamination with heavy metals. In this regard, fresh meat that ends up in most Ghanaian markets may contain food-borne pathogens or heavy metals (Geck et al., 2014) because the sources and movement of meat are inadequately or not monitored at all. Though tissues play significant roles in the bodies of animals and serve as food for humans, they can bio-accumulate hazardous metals; hence, it is crucial to test for the presence and quantities of toxic substances in meat. Even though a few Ghanaian researchers have worked in this regard (Adzitey et al., 2015; Adzitey et al., 2018; Akoto et al., 2014), more information is needed, particularly in the heavily industrialized areas. Therefore, this work was designed primarily to assess the presence and evaluate the concentration and association of selected heavy metals in fresh cow meat (beef) sold in major markets within the Accra Metropolis of Ghana.

Materials and methods

Description of the study area

Beef was collected from three major markets located in Ashaiman, Madina, and Makola within the Accra Metropolitan Assembly, Ghana. Laboratory analysis was conducted at the Food Research Institute (FRI) of the Council for Scientific and Industrial Research (CSIR) in Accra. Meat from fresh muscle, kidney, and liver of cattle was obtained separately from 10 meat vendors per market, adding up to 90 samples at 30 per tissue. Each sample was analyzed in two replications to make a total of 180.

Sampling methods, sample collection, and analysis

This work was a cross-sectional study conducted in the Accra Metropolitan Assembly. The markets and neat vendors were randomly selected from the markets. From each vendor in each market, meat was obtained from all the tissues on the same day of arrival from the abattoir between 8:00 and 9:00 a.m. Greenwich Meridian Time. Meat bought from each market was packed according to the tissues (muscle, liver, and kidney) into zip-lock bags, labeled, and transported on ice in an air-tight ice chest to the Food Research Institute for analysis. Analysis for the presence and concentration of the heavy metals (lead, arsenic, and cadmium) in all meat samples commenced on arrival from the markets at room temperature (25^{o}C). The GTA 120 Graphite Tube Atomizer, 200 Series AA protocol was used according to Pequerul et al. (1993). Three grams of each meat sample were weighed on an analytical balance, digested with 5 ml of 65% concentrated nitric acid, and heated for an hour. At 30-minute intervals, 1 ml of H_2SO_4 was added until total digestion over a 3-hour period. One percent of nitric acid was added to the digestate, and the mixture was filtered into a 50-ml volumetric flask and topped up with distilled water to the 50-ml mark. The presence and concentrations of lead, arsenic, and cadmium were detected at wavelengths of 271.0, 197.2, and 228.8 nanometers, respectively.

Data Analysis

Data on the concentration of the heavy metals were analyzed with a two-way Analysis of Variance (ANOVA) using the General Linear Model in Minitab version 18, with markets and tissues as the fixed factors. Differences in means were separated with the Tukey Comparison Method at a 5% significance level. The correlation between the metals was done with Pearson Correlation Analysis. The model used was

$$Y_{ij} = \mu + M_i + T_j + ij$$

Where Y = the dependent variable; μ = the general or population mean; M = the ith observation for market; T = the jth observation for meat tissue; and ε = the random error associated with the dependent variable.

Results and discussion

Concentration of arsenic, lead, and cadmium in beef obtained from different markets

Results in Table 1 show significant variation in the concentration of the three heavy metals in beef tissues obtained from the different markets. Arsenic (As) was significantly highest in beef muscle sampled from the Ashaiman Main Market (2.48 mg/100 gm) but insignificant between the Madina (0.85 mg/100g) and Makola (0.35 mg/100g) Markets. Lead (Pb) was not significantly different in beef muscle obtained from the Ashaiman and Madina Markets but was significantly lower in muscle from the Makola Market at 0.40 mg/100g. There were significant differences in the concentration of cadmium (Cd) in muscle from the three markets at 1.04, 0.59, and 0.43 mg/100g, respectively (Table 1).

Table 1. Concentration of arsenic, lead and cadmium in beef obtained from different markets

Market	Heavy Metal		
	Arsenic (mg/100g)	Lead (mg/100g)	Cadmium (mg/100g)
Ashaiman	2.48^a	0.96^a	1.04^a
Madina	0.85^b	1.11^a	0.59^b
Makola	0.35^b	0.40^b	0.43^c
SEM	0.162	0.082	0.044
p-value	0.001	0.001	0.001

Means that carry different superscripts significantly vary; **mg:** milligram; **g:** gram; **SEM:** Standard Error of Means; **p-value:** probability value ($p < 0.05$)

Generally, toxic metal infections are a perilous health hazard due to their noxiousness and ability to accumulate or increase in the food chain (Nkansah & Ansah, 2014). Thus, their presence in any meat or food item makes them dangerous for consumption (Binkowski, 2012; Obeid et al., 2016). Even though some heavy metals such as copper, zinc, and iron in low quantities may be needed to support life processes (Fan et al., 2021), it was reported that the three heavy metals (lead, cadmium, and arsenic) discussed in the present study do not partake in any biochemical activity in animals but are toxic even at the smallest concentration (Akoto et al., 2014).

Findings of the current work reveal the presence of heavy metals in meat sold in markets within the Accra Metropolis, as was found in meat from some livestock species in Tamale (Adzitey et al., 2015; Obeid et al., 2016). However, the concentration of heavy metals in meat sold in the different markets varied. Beef bought from the Ashaiman Main Market contained significantly more arsenic compared to meat bought from the Madina and Makola Markets. Nonetheless, meat from the former market also had more arsenic than meat from the latter. Other findings (Akoto et al., 2014) proposed that an arsenic content of 0.01-0.06 mg/100g, though minute, can be detrimental to human health (Aguilera et al., 2021). This means that beef from the various markets would have more detrimental effects on consumers, but such effects would be more severe in Ashaiman than in Madina and Makola.

The 0.40–1.11 mg/100g levels of lead detected in meat collected from each of the markets in this work are similar to the 0.63–1.63 mg/kg recorded in beef and guinea fowl meat (0.4–0.70 mg/kg) in Tamale, according to Adzitey et al. (2015), but in a later investigation, no amount of lead was recorded in some meat samples (Adzitey et al., 2018). Meanwhile, higher concentrations of lead were noted in different organs of various livestock species in Obeid et al. (2016). None of the meat samples from the markets contained more than the maximum allowable level (100 g/kg) of lead per the EU standard 466/2001 (Gonzalez-Weller et al., 2006). Nonetheless, any effects from the accumulation of the element in the body, such as hematological, reproductive, renal, and neurological system disorders (Obeid et al., 2016) or other lead-related health conditions (acute and chronic poisoning or damage to the brain, bones, and thyroid gland) (Nawrot et al., 2010), are expected to be more severe in Madina, followed by Ashaiman, and then Makola. Contrary to the current data, previous authors did not find cadmium in some meat samples (Adzitey et al., 2015), though others have suggested its presence in undetectable quantities (Adzitey et al., 2018). The level of cadmium in meat obtained from each of the markets in this study was higher than the maximum allowable level of Cd (50 g/kg) as reported in Gonzlez-Weller et al. (2006). Therefore, consumption of meat from the markets would not support good human health (Obeid et al., 2016) because lung functionality (Zhao et al., 2014), kidney functionality, and reduced bone mineralization (Nkansah & Ansah, 2014) have been linked to cadmium. However, the severity of these organ disorders would be greater among consumers in Ashaiman than those in Madina and Makola if meat from the respective markets was regularly eaten.

The current findings can be linked to differences in livestock production environments (Alissa and Ferns, 2011), caused by varying natural and human activities within the various communities as well as differences in livestock management systems. For instance, more light industrial activities are carried out in Ashaiman than in Madina and Makola, which can affect the release of heavy metals into the environment for ingestion by the beef animals (cattle) and thus possibly explain the findings. Largely, differences detected in the concentrations of the metals in the current and previous works could be attributed to variation in the species, size of organs (which is a function of animals' age), feeding habits of the animals used, or the periods of accumulation (Alissa & Ferns, 2011). Also, differences in the elemental composition of meat from the markets could result from differences in the equipment and materials (water and fuel) used to slaughter animals and process meat in the different abattoirs where the meat was processed.

The concentration of the metals was highest in beef bought from the Ashaiman Main Market, apart from lead, which was highest in meat from the Madina Market. However, the metals in their entirety were lowest in meat from the Makola Market.

Concentration of arsenic, lead, and cadmium in different beef tissues

Results presented in Table 2 show that the quantity of arsenic (As) was significantly highest in the liver (2.40 mg/100g), followed by the kidney (0.93 mg/100g), and least in the muscle (0.35 mg/100g). Lead content was significantly higher in the liver (1.14 mg/100g) but insignificant between the kidney (0.67 mg/100g) and the muscle (0.66 mg/100g). Cadmium (Cd) content varied significantly among the various meat tissues, decreasing from 1.29 mg/100g in the liver to 0.58 mg/100g in the kidney to 0.20 mg/100g in the muscle (Table 2).

Table 2. Concentration of arsenic, lead and cadmium in different beef tissues

Meat Part	**Heavy Metal**		
	Arsenic (mg/100g)	**Lead (mg/100g)**	**Cadmium (mg/100g)**
Muscle	0.35^{c}	0.66^{b}	0.20^{c}
Liver	2.40^{a}	1.14^{a}	1.29^{a}
Kidney	0.93^{b}	0.67^{b}	0.58^{b}
SEM	0.162	0.0816	0.044
p-value	0.001	0.001	0.001

Means that carry different superscripts significantly vary; **mg:** milligram; **g:** gram; **SEM:** Standard Error of Means; **p-value:** probability value ($p < 0.05$)

The accumulation of heavy metals in specific organs and tissues at toxic levels can be very detrimental to the general wellbeing of organisms. In the literature, Alissa and Ferns (2011) reviewed that heavy metals can enter the human and animal bodies through food, air, water, or the skin. This could be due to environmental pollution resulting from industrialization (Okorafor & Amadiali, 2015), which predisposes livestock, especially ruminants, to pollutants as they indiscriminately ingest them from contaminated feed, water, soil, or plant materials (Bala et al., 2013). The presence of the heavy metals in the beef tissues used in this study concords with other studies elsewhere (Adzitey et al., 2015; Obeid et al., 2016) that have detected various heavy metals in meat from different livestock species and tissues or organs. The arsenic quantity of 0.35-2.40 mg/100g accordingly reported in the muscle, kidney, and liver tissues in the present study was higher than the 0.01-0.06mg/kg reported in the liver, kidney, brain, and small intestine of sheep and goats in Obuasi, according to Akoto et al. (2014), who indicated that these amounts of arsenic, though minute, can be detrimental to human health. Thus, the relatively higher amounts of arsenic recorded currently mean consumers of the meat are at higher risk if there are any effects. Due to the high toxicity of arsenic to life and the findings of the current investigation, it is suggested that meat from the muscle of cattle should be prioritized for consumption. High amounts of lead (Pb) were observed in the liver (41.34, 69.84, and 95.95 g/kg) than in the kidney (6.05, 33.90, and 28.82 g/kg) and muscle (0.62, 3.99, and 1.59 g/kg) of cattle, goats, and sheep, respectively (Obeid et al., 2016). These are against the low variations found in the current work (1.14, 0.67, and 0.66 mg/100g) respectively for cattle liver, kidney, and muscle, which are, however, similar to the levels found in beef (0.63–1.63 mg/kg) and guinea fowl meat (0.41-0.70mg/kg) in Tamale (Adzitey et al., 2015), though zero or no lead was detected in other meat samples (Adzitey et al., 2018). None of the meat tissues tested in the current work contained more than the maximum allowable level (100 g/kg) of lead per the EU standard 466/2001 (Gonzalez-Weller et al., 2006). Nonetheless, regular consumption of meat from tissues (particularly the liver) contaminated with lead over time could affect the hematological, reproductive, renal, and neurological systems of humans and animals (Obeid et al., 2016). It could also affect the brain, bones, and thyroid gland (Nawrot et al., 2010). From the current results, it can be said that beef from the muscle or kidney should be considered for consumption over meat from cattle livers if low lead intoxication is the objective.

Previous researchers did not find cadmium in meat samples (Adzitey et al., 2015; Adzitey et al., 2018). In opposition, Obeid et al. (2016) detected higher cadmium content in kidney than muscle meat in three livestock species, though the present data show significantly higher cadmium content in the liver over the kidney and least in the muscle. The findings imply that incessant eating of cattle liver could mean more accumulation of cadmium, which can affect the activities of the lungs (Zhao et al., 2014) and kidneys or reduce bone mineralization in humans (Nkansah & Ansah, 2014). Nevertheless, the lower concentration of cadmium detected in the kidney than the liver might be a natural mechanism to minimize its effect (Nkansah & Ansah, 2014) on the functionality of the kidney. Meanwhile, the higher concentrations of cadmium than the maximum allowable level of Cd (50 g/kg) (Gonzlez-Weller et al., 2006) in the various tissues could be alarming**.** Per the present data, beef from the muscle should be considered for people who have high levels of cadmium or kidney problems, while regular consumption of beef from liver tissues may not promote good health (Obeid et al., 2016) because of its high level of cadmium. Generally, the concentration of the metals was highest in the liver, followed by the kidney, and lowest in the muscle. This can be attributable to differences in the biological roles of the respective tissues or organs in the body. Therefore, meat from the liver of cattle must be least considered for consumption after muscle and kidney meat.

Correlation of arsenic, lead, and cadmium in different beef tissues

Results presented in Table 3 show the correlation between the metals in the various meat tissues. In the muscle, the correlation of arsenic with lead was moderate and significantly positive (r = 0.42).

Table 3. Correlation of arsenic, lead and cadmium in different beef tissues

Part of Meat	Heavy Metal	Arsenic (r)	Lead (r)	Cadmium (r)
Muscle	**Lead**	0.42^*	1	
	Cadmium	0.26^*	0.74^*	1
Liver	**Lead**	0.67^*	1	
	Cadmium	0.60^*	0.77^*	1
Kidney	**Lead**	0.30^*	1	
	Cadmium	-0.08	0.08	1
Pooled	**Lead**	0.52^*	1	
	Cadmium	0.59^*	0.64^*	1

r: coefficient of correlation; *: $p < 0.05$ (significant)

Meanwhile, its association with cadmium was positive and significant but low (r = 0.26) in the muscle. The association between lead and cadmium in the muscle was positive and significantly high at r = 0.74. In the liver, the relationships between arsenic and lead (r = 0.67), between arsenic and cadmium (r = 0.60) and the association of lead with cadmium were positive and significantly high (Table 2). Results for the kidney also show a significant but negative association between arsenic and cadmium (r = -0.08). The association between arsenic and lead in the kidney was positive but significantly low at r = 0.30, as was the association between lead and cadmium at r = 0.08. When all the data were pooled together, the associations among the metals were all positive and significant, but while the associations between arsenic and lead (r = 0.52) and between arsenic and cadmium (r = 0.59) were medium, those between lead and cadmium were high (r = 0.64).

Heavy metals have the ability to coexist (Fan et al., 2021), as was reported for cadmium and other heavy metals in some soils (Nriagu, 1988). Heavy metals can also coexist with microplastics (Holmes et al., 2012; Acosta-Coley et al., 2019), and such associations can affect their concentration in nature. The findings of this work reveal that an increase in quantity of either arsenic or cadmium will cause a proportionate reduction in quantity of the other element in the kidney, and vice versa. However, in any of the cases, the change will be slow. Negative and low correlations existed between arsenic and cadmium (r = -0.16), but they also related positively but lowly (r = 0.22) in the kidneys of sheep and goats accordingly (Akoto et al., 2014). However, an increase in the quantity of any of the duo in the muscle, liver, or meat in its entirety will increase the quantity of the other element simultaneously, and the reverse will happen but at a faster rate in the liver than in the entire meat and muscle. Meanwhile, Akoto et al. (2014) have found negatively low to moderate associations between arsenic and cadmium in the livers of sheep (r = -0.41) and goats (r = -0.12). The positive association between arsenic and lead in the meat shows that a change in the content of either of them would cause the content of the other to change proportionately in the same direction, irrespective of the organs or tissues. However, such quantitative changes will be more rapid in the liver than in the entire meat or kidney, and the slowest change will occur in the muscle. In a previous work, negatively low and moderate associations were respectively found between arsenic and lead contents in the kidney (r = -0.11) and liver (r = -0.37) of sheep, but positive and high (r = 0.89), though lowly positive at r = 0.19, associations were respectively noted between the kidney and liver of goats (Akoto et al., 2014). When lead content is increased in the kidney, cadmium content will also increase, but slightly, and vice versa. Akoto et al. (2014) partly found a positively high (r = 0.88) but negatively low (r = -0.19) relationship between lead and cadmium contents in the livers of sheep and goats. However, when any of the elements in the lead-cadmium association are increased or decreased in the muscle, liver, or beef in its entirety, the content of the other will also change equitably in the same direction, even though the rate of change will be higher in the liver than in the muscle and slowest in the combined tissues. This fairly agrees with the positively high (r = 0.89) but negatively low (r = -0.33) associations revealed between lead and cadmium in the livers of sheep and goats, respectively (Akoto et al., 2014). Though there may be no information readily available on the effects of the interactions between these heavy metals on life, interactive effects have been reported for other pairs of metals in previous works (Evans et al., 1970; Mills and Dalgarno, 1972). Also, a report by other researchers (Panel-Jiahui et al., 2022) revealed the effect of the coexistence of lead, zinc, and copper on the transfer of cadmium between the soil and wheat.

Conclusion

Heavy metals were present in beef sold in the markets, but the concentration of the metals could depend on their relationships and meat tissues. However, levels of the metals in beef from the markets were different, decreasing generally from the Ashaiman to Madina to the Makola Markets. Meat from the liver generally has the highest content of heavy metals and must be least considered for consumption after muscle and kidney meat due to public health concerns about heavy metals in humans.

Acknowledgment

The authors would like to thank Miss Manuela Sena and Magdalene Duah (National Service Personnel of ARI) for their support during the meat sampling, and the Laboratory Technicians of the Food Research Institute, Council for Scientific and Industrial Research, Ghana; for their contribution to the experimental analysis.

Author contributions

The research idea was conceived by Raymond L. Adjei and Theresa Nkrumah. The proposal for the work was developed by Raymond L. Adjei and Maxwell Ansong. Ethel Blessie provided technical advice for the experimental analysis. Data was collected by Raymond L. Adjei, Theresa Nkrumah and Maxwell Ansong. Francis Kurenti analysed the data. All researchers were involved in drafting the original manuscript. Ethel Blessie, Theresa Nkrumah, Maxwell Ansong did the proof reading. Raymond L. Adjei and Francis Kurenti prepared the final manuscript.

Conflict of interests

The authors declare no conflict of interests.

Ethics approval

Not applicable.

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