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ASSESSING LEVELS OF SELECTED HEAVY METAL CONTAMINATION AND ITS RELATED HEALTH RISKS IN MANGO (*MANGIFERA INDICA*) FRUITS FROM ROADSIDES IN SOUTH-EASTERN GHANA.

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Abstract

Fruits are rich in vitamins and minerals which form a vital part of the human diet. However, these fruits may contain toxic metals of varied range of concentrations. Heavy metal contamination of food crops such as mangoes (*Mangnifera indica*) threatens human health. An assessment was carried out on heavy metal contamination and the related health risks in mango fruits from South-eastern Ghana. Samples of mango fruits (n = 65) from selected market points within three days in the first weeks of July and August 2023 were measured for iron, manganese, copper, lead, chromium, nickel, and cobalt concentrations in relation to maximum allowable limits. Standard acid digestion method was employed for metal extraction for analysis using AA240FS Varian Atomic Absorption Spectrophotometer. The results showed that seven heavy metals were detected in all mango fruits collected from the streets and a market. The concentration levels of these heavy metals ranged from Fe (0.800-5.352) $mgkg^{-1}$, Mn (0.082-0.499) $mgkg^{-1}$, Cu (0.190-0.527) $mgkg^{-1}$, Pb (0.008-0.107) $mgkg^{-1}$, Cr (0.002-0.056) $mgkg^{-1}$, Ni (0.035-0.545) $mgkg^{-1}$ and Co (0.001-0.044) $mgkg^{-1}$. The measured concentrations of these heavy metals were lower than the permissible limits set by the World Health Organization (WHO) and the Food and Agricultural Organization (FAO). The hazard index (HI) range for adults (0.0345-0.5840) and children (0.1526-0.6948) did not exceed 1 and therefore poses no health and cancer risks to consumers. The mango fruits sold at the study locations were suitable for consumption. Despite these findings, the need for periodic biomonitoring of heavy metals in mango fruits sold in Ghana to safeguard their quality and public health is an imperative.

Keywords: Permissible levels, Heavy metals, Estimated Daily Intake, Hazard Index, Lifetime Cancer Risk, South eastern Ghana

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Introduction

Mango (*Mangifera indica*) is one of the food fruits preferred by many people all over the world (Rajan, 2021; Siric et al., 2022). Mango is mostly eaten as fresh fruits by many people, particularly, in India, China, Thailand, Indonesia, Mexico, South Africa, Ivory Coast, Senegal, and Ghana (Arnoldus & Clausen, 2019; Rajan, 2021). It is estimated to account for fifty percent of all fruits in the world (FAO, 2011; Okorley et al., 2014). The fruit contains vitamins, minerals, fibres and antioxidants, and macronutrients such as Iron (Fe), Potassium (K), Phosphorus (P), and Calcium (Ca) for human health, especially for people in Africa and Asia (Elbagermi et al., 2012; Edusei et al., 2022; Lebaka et al., 2021; Prasad et al., 2022; Rajan, 2021). Besides, mango production provides livelihoods to many populations and has become an export crop for many countries of which Ghana is not an exception (Arnoldus & Clausen, 2019).

In Ghana, mango production can be observed throughout the country. However, the highest production is in the Bono, Bono East, Central, Volta, Eastern, and Greater Accra Regions of Ghana (Arnoldus & Clausen, 2019). These authors report that the common mango varieties identified in Ghana are Keitt, Kent, and Palmer besides the local varieties. Keitt, a late variety, usually produced between April and July each year is most preferred by processors due to its large fruits. There is local demand for fresh fruits as well as processed products such as mango jams, dried fruits, flavours, and juice (Okorley et al., 2014). The low quantity and quality of mango fruits observed have been attributed to diseases that cause internal defects of the fruits and chemical contamination (Arnoldus & Clausen, 2019).

Uptake of heavy metals by mango fruits may occur through atmospheric deposition in soils and on the fruit surfaces during production, transportation, and marketing (Baird & Cann, 2012; Jassir *et al*., 2005; Lente *et al*., 2012). Atmospheric dust has been identified to be a major source of heavy metals contamination of fruits (Ezeilo *et al*., 2020). Heavy metals are elements with densities above 5 g/cm^3 which occur in nature (Baird & Cann, 2012). These metals are non-biodegradable either by natural processes such as oxidation, microbial action, and general food processing procedures and are poisonous at low concentrations to humans and other living organisms (Baird & Cann, 2012; Ezeilo *et al*., 2020). The main toxic heavy metals are mercury (Hg), lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As) (Baird & Cann, 2012). Heavy metals enter the environment through both natural mineral and anthropogenic sources such as from automobile exhaust, industrial discharges, sewage sludge, and mining (Qin *et al*., 2021). When bond to short chains of carbon atoms and sulphhydryl groups (SH), which are frequently found in human enzymes, this group of metals becomes extremely poisonous and dangerous in the form of their cations (Baird & Cann, 2012). These metals are members of the list of ten chemicals of major public health concern as classified by the World Health Organization (Nwuyi, 2020). However, some other elements such as copper (Cu), cobalt (Co), iron (Fe), manganese (Mn), and zinc (Zn) are essential micro-nutrients for human health. Health concerns about heavy metals arise due to their contamination in foods such as fruits and potential bioaccumulation in various organs of the human body over a long period (Ezeilo *et al*., 2020). High concentrations of heavy metals such as Cd, As, and Pb in foods is known to cause health risks (MWRWH, 2015; FAO/WHO, 2017).

Mango production in Ghana is characterized by the intensive application of chemicals, foliage and granular fertilizers, and manure as measures to protect the plant against bacterial blackspot, anthracnose, fruit flies, stone weevils, and other pests and diseases (Arnoldus & Clausen, 2019). Arnoldus and Clausen (2019) report that most farmers apply chemicals on their trees for as long as between eleven and thirteen times each season. Intake of fruits that may be contaminated with heavy metals poses a threat to human health. Therefore, regular biomonitoring of heavy metal accumulation in these fruits is key to ensuring food quality assurance for the population (Elbagermi *et al*., 2012). The mango fruit is mostly served in Ghana at homes, hotels, fruit joints, and restaurants as fresh-cut fruits, juice, ice cream, and yogurts (Edusei *et al*., 2022). The fruit constitutes the third most preferred fresh fruit by people in Ghana after pineapple and oranges (Edusei *et al*., 2022; Broek *et al*., 2016). Routine assessment and analysis of heavy metal contents in fruits most consumed by humans is important to ensure that their concentration levels are always within the internationally recommended permissible limits and to guarantee food quality for the population. Meanwhile, studies on heavy metal contamination and the health risks associated with the consumption of mango fruits in Ghana are limited. In Ghana, most of the assessment of heavy metals contamination in food crops have been carried out on vegetables (Lente et al., 2014, 2012; Osae et al., 2023) and not fruits such as mango which is one of the preferred fruits by "consumers". Therefore, this study assesses the levels of selected trace metals and the potential health risk that could come from the daily consumption of mango fruits in Ghana. Moreover, a risk assessment was carried out to generate quantitative data on both non-carcinogenic and carcinogenic risks associated with the daily intake of selected heavy metals through the consumption of mango fruits. The outcome of this study could provide useful information to help decision-makers to institute corrective measures or more studies to reduce contamination levels to ensure the quality of mango fruits for the protection of public health and exports.

Materials and Methods

The study area

Five main communities in Southeastern Ghana were selected for this study. Four of these communities (Agomeda, Ayikuma, Dodowa, and Adenta market) are in the Greater Accra region whereas the other community (Somanya) is in the Eastern Region of Ghana (**Figure 1**). Three sites were selected from each community for sampling at various geographical coordinates as follows; Agomeda (5°58′51.8″N; 0º00′45.4″W; 5°58′36.6″N, 0º00′34.9″W and 5°58′23.3″N, 0º00′24.1″W), Ayikuma (5°55′35.4″N, 0º02′44.1″W; 5°55′14.4″N, 0º02′12.2″W and 5°55′05.1″N, 0º03′17.4″W), Dodowa (5º53′14.3″N, 0º05′27.7″W; 5º52′42″N, 0º06′04″W and 5º52′18.2″N, 0º06′29.2″W), Somanya (6º04′41.9″N, 0º01′09.2″W; 6º04′37.7″N, 0º01′08.4″W and 6º04′19.5″N, 0º01′04.8″W) and Adenta market (5º42′19.3″N, 0º08′55.1″W). The study sites fall within three main mango-producing districts, (1) Yilo Krobo, (2) Lower Manya all in the Eastern region, and (3) Shai Osudoku in the Greater Accra region of Ghana. The four communities were chosen because these are commercial mango fruits vending centres, which are also the main mango production sites in the regions, where mango fruits are marketed in small baskets placed on table tops under sheds.

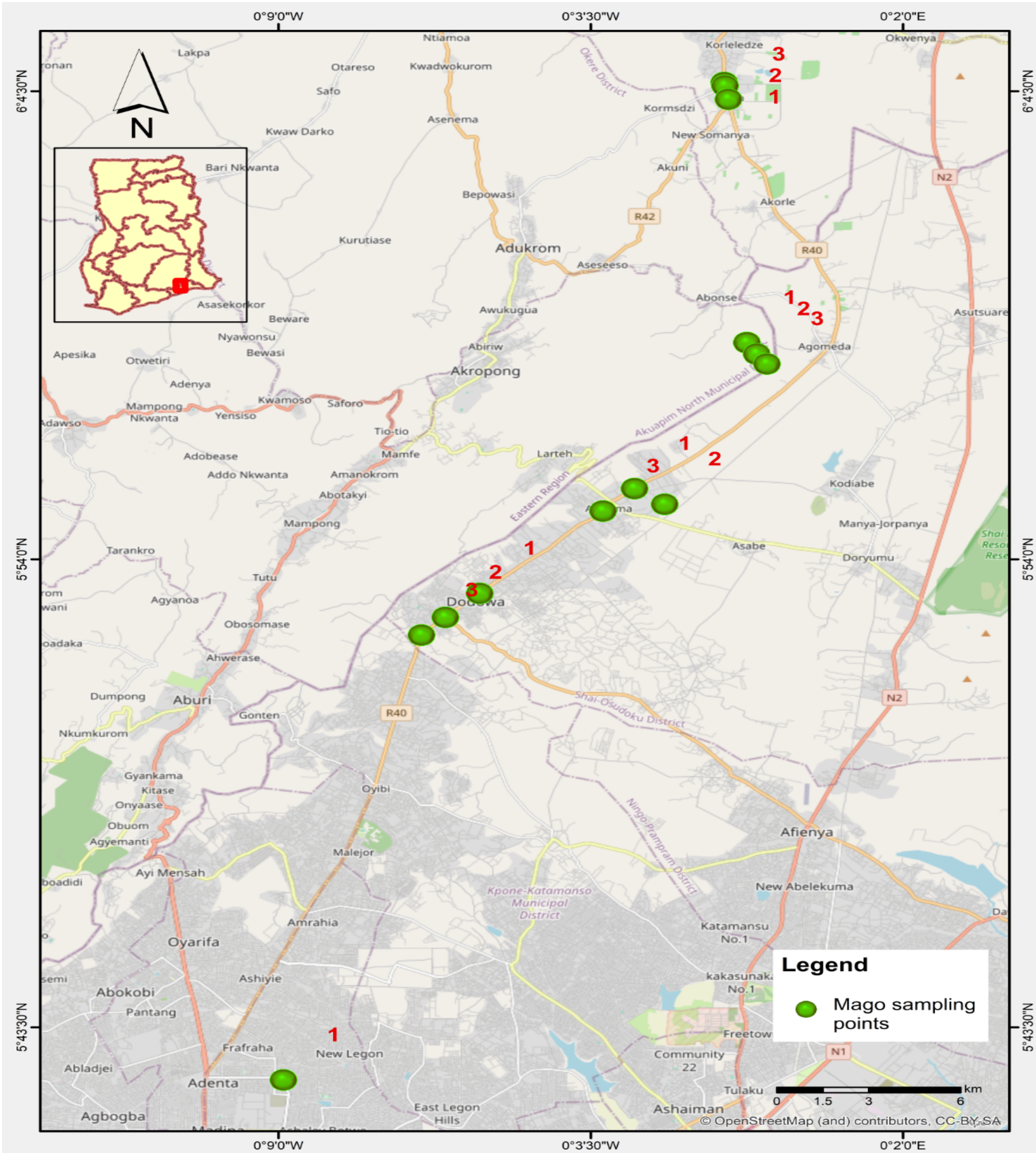

Fig. 1 A map of Southern Ghana showing locations where mango samples were taken from. This image was drawn using the ArcMap (v. 10.2.2)

Mango fruit sampling

A mixture of varieties of ready-to-eat mango (*Mangnifera indica*) fruits, including Keitt, Kent, and Palmer, which are mostly preferred by processors and consumers (Arnoldus & Clausen, 2019) were randomly sampled from each of the five study sites. A mixture of varieties was collected for analysis in order to increase the probability of sample randomization because vendors bring mango fruits from different sources. Five samples were collected from each of the thirteen sampling sites making a total of 65 samples. The samples were collected from street vendors at different locations in each community along the Accra - Somanya major road (R40) and at the Adenta market. Samples were taken during the major mango season between July and August 2023, labelled with location names and transported to the laboratory.

Laboratory analysis

The ready-to-eat mango fruit samples were first washed well with tap water followed by deionized water, sliced and placed in plastic bags. The samples were placed in a deep-freezer at -80°C and then freeze-dried for 3 days (72 hours) (Lente et al., 2012) using a Suppermodulyo Freeze Dryer at the University of Ghana Biotech Laboratory. The dried mango fruit samples were ground to powder form with a ceramic pestle and mortar. About 2.00g of powdered mango fruit sample was weighed into a 100 mL beaker and 50 mL of a ternary mixture (i.e., 500 mL HNO_3, 50 mL H_2SO_4, and 20 mL $HClO_4$) was added to each weighed sample and digested on a hot plate at a temperature of about 40°C for 30 minutes (APHA-AWWA-WEF, 2001). After the white fumes had disappeared during the digestion process, 20 mL of double deionized water was added and digested for about 10 minutes. The digestate was topped up to 50 mL with double distilled water and submitted for AAS analysis (Borowski & Schmaling, 1996). The concentration levels of each selected heavy metal including Fe, Mn, Cu, Pb, Cr, Ni, and Co were determined using the atomic absorption spectrophotometer (Model AA240FS, Varian Fast Sequential) at the Chemistry laboratories of the Ghana Atomic Energy Commission (G.A.E.C), Kwabenya-Accra, Ghana. The wavelength (nm) and the lamp current (mA) of the analytical instrument for each element were Fe (248.3 and 5), Mn (279.5 and 5), Cu (324.8 and 4), Pb (283.3 and 5), Cr (357.9 and 7), Ni (232.0 and 4), and Co (178.9 and 7).

Health risk assessment: estimation of daily intake (EDI) of heavy metals through eating mango fruits

In this study, the potential human health risk posed by heavy metals from the intake of mango fruits is assessed by comparing the measured concentration levels with the Reference doses (RfD) provided by FAO/WHO and the USEPA for fruits ingestion by humans. The EDI of selected heavy metals was calculated using mean concentrations in the mango samples and the average daily consumption of mango fruits for Ghana (FAO, 2023). The EDI of each analyzed heavy metal is estimated according to the equation (1) below and as used by the authors, Ain et al. (2023), Antoine et al. (2017), Lente *et al*. (2012) and Sharma and Prasad (2009).

$$EDI = \frac{C * Cf * IR * Ef * Ed}{BW \ X \ TAV} X \ 10^{-3} \qquad (1)$$

Where EDI is the estimated daily intake of each metal in mango fruits sampled, C stands for the concentration of metal analyzed in mango fruits, Cf represents the conversion factor of fruits into dry weight (0.085) (Asharaf et al., 2021; Elbagermi et al., 2012). IR is the average fruit consumption for Ghana given by WHO/FAO (180 kg/head/year), Ef represents exposure frequency (214 days/year), Ed is the exposure duration (70 years), BW is the average human body weight (70 kg for adults and 15 kg for children) (Osae et al., 2023) and TAV represents average time of exposure [Average time (365 days/year) X number of exposure years (70)].

Equation (1) is then simplified based on the given values for the various parameters above to give equation (2). Thus, Estimated Daily intake of heavy metals (μg/kg BW/day) = Daily mango fruit ingestion (g/day) X Concentration of heavy metals (μg/g) divided by Average Body Weight (kg)

$$EDI = \frac{C * IR}{BW} \quad (2)$$

Where C (μg/kg) stands for the level of the heavy metal found in samples, EDI (μg/kg BW/day) represents the presumed daily intake of the element in mango fruits, and BW (kg) indicates the consumer's body weight (70 kg, the mean adult weight). The wet weights were converted to dry weights using the Conversion factor of 0.085 (Asharaf et al., 2021; Elbagermi et al., 2012).

Non-carcinogenic risk assessment

Non-carcinogenic risk assessment determines the likelihood that a toxicant will have a negative health impact over a period. This assessment was conducted using hazard Quotient (HQ) and Hazard Index (HI) (Lente et al., 2012; Osae et al., 2023). The HI was estimated to determine the total risk of exposure to all the heavy metals measured through ingestion of mango fruits (Lente et al., 2012; USEPA, 1997, FAO/WHO, 2010). To estimate the HI, HQ was first calculated using the equation (3).

$$HQ = \frac{DIR}{RfD}, \quad (3)$$

HQ is a ratio of the daily intake rate (DIR) to the reference dose (RfD) or minimal risk limit (MRL) (Lente et al., 2012).

$$HI = \sum HQ \quad (4)$$

HI is the sum of all the HQs of all the heavy metals in each mango fruit sample. A HI < 1 (or 100 %) indicates that the determined exposure is unlikely to pose potential health risks, whereas a HI > 1 shows a high probability of health risks.

Carcinogenic risk assessment

A carcinogenic risk assessment conducted to estimate the cancer risk (CR) is an indication of an incremental probability of an individual to developing cancer over a lifetime, usually 70 years due to exposure to a potential carcinogen. The lifetime cancer risk (LCR) is calculated as a function of the oral carcinogenic slope factor (CSF) and the estimated daily intake (EDI) of the potential carcinogenic element according to equation (5).

$$LCR = CSF \times EDI \quad (5)$$

The acceptable risk levels for carcinogens range from 10^{-4} to 10^{-6}. LCR greater than 1×10^{-4} indicates a potential cancer risk to humans whereas values below 1×10^{-6} show no risk, and risk falling between 1×10^{-4} and 1×10^{-6} is considered an acceptable range (Ikechukwu et al., 2019; Osae et al., 2023). In this study, the individual cancer risk assessment was conducted for Cr, Ni, and Pb using cancer slope factor values, Cr (0.04 mg/kg/day), Ni (0.00084 mg/kg/day), and Pb (0.0085 mg/kg/day) adopted from Osae et al. (2023) and USEPA (1989).

Analysis of variance

'Mean ± standard error (SE)' values were computed over replicates of variables for mango samples from each sampling location using R software version 4.1.1 (R Core Team, 2021). After that, multiple comparisons of mean ±SE values of concentration of heavy metals in mango fruits between the various sampling locations were determined by fitting Tukey's HSD into ANOVA (analysis of variance) at $P \leq 5\%$ (Hirotsu, 2017). Tukey's HSD was not applied to the estimated indices or ratios for non-carcinogenic and carcinogenic details. However, tables were used to present these indices after obtaining them using the formulae in equations 1, 2, 3, and 4.

Results and Discussion

Incidence of heavy metals in sampled mango fruits

Table 1 shows the concentrations of selected heavy metals in mango fruit samples. This study only reports on heavy metals that were detected by the analytical instrument. There were significant differences ($p<0.05$) between mean values of heavy metal concentrations in mango fruits from the selected sampling locations. The highest levels of Fe (4.91±0), Mn (0.45±0), Ni (0.44±0), Cu (0.42±0), and Cr (0.06±0) $mgkg^{-1}$ were recorded in the samples from Adenta market, Pb (0.07±0.01) from Agomeda, and Co (0.03±0.01) $mgkg^{-1}$ from Ayikuma (**Table 1**). However, mangoes analyzed had lower levels of selected heavy metals than their respective maximum recommended limits (MRLs). The decreasing order of heavy metal concentrations in mango fruits was Fe>Mn>Ni>Cu>Pb>Cr>Co. Ezez and Belew, (2023) found lower mean levels of Fe (1.312±0.033 $mgkg^{-1}$), Mn (0.178±0.031 $mgkg^{-1}$), and Cu (0.127±0.007 $mgkg^{-1}$) but similar levels for Pb (0.067±0.009 $mgkg^{-1}$) in mango fruits from Southern Ethiopia compared to the levels obtained in this study. However, chromium, Cr was not detected in their study unlike the 0.06±0 $mgkg^{-1}$ detected in this study. In Uganda, Muhwezi et al. (2021) measured high mean concentration levels of Pb (0.32±0.08 $mgkg^{-1}$) and Cr (0.40±0.07 $mgkg^{-1}$) in mango fruits grown in the Kasese district. These authors observed elevated level of Pb in comparison to the MRLs by the WHO (2017). In the current study, the highest mean Pb level is 0.07±0.01, lower than the MRL standard by FAO/WHO (2011). Lente et al. (2012) attributed high Pb levels in crops to automobile emissions rather than the use of wastewater. Carcinogenic effects of lead (Pb) have been reported to include bone fractures and malfunction, cardiovascular complications, kidney dysfunction, hypertension, liver and lung diseases, nervous system disease, and immune system disease (Al-Saleh et al., 2017; El-Kady & Abdel-Wahhab, 2018; Ju et al., 2017; Krueger & Wade, 2016; Zhou et al., 2016). Siric et al. (2022) reported the concentration of Pb and Cr in mango fruits from India to be in the ranges of 0.02 - 0.15 mg/kg and 0.11 – 0.82 mg/kg, respectively, which did not exceed the safe limits. In comparison to this study, Rahim et al. (2020) measured higher concentration levels of Cr (0.081 mg/kg), Co (0.048 mg/kg), Ni (0.061 mg/kg), and Pb (0.091 mg/kg) mango fruits in Malaysia. Bioaccumulation of heavy metals may occur due to consumption of fruits contaminated with the observed metals, hence there is the need for routine testing and monitoring of heavy metals contamination in mango fruits to safeguard food quality and public health.

Table 1. Mean± standard error of concentration of selected heavy metal (mg kg^{-1} dry weight) of mango fruit (n = 65).

Selected locations (or mango market)	GPS Coordinates		Selected heavy metals in mango fruits (mg kg^{-1} dry weight)						
	Latitude (N)	Longitude (W)	Fe	Mn	Cu	Pb	Cr	Ni	Co
Adenta	5º42′19.3″	0º08′55.1″	4.91 ±0 a	0.45 ±0 *c*	0.42 ±0 *e*	0.06 ±0 *gh*	0.06 ±0 *i*	0.44 ±0 12 *k*	0.01 ±0 *l*
Agomeda	5º58′36.6″	0º00′34.9″	4.11 ±0.62 *a*	0.31 ±0.07 *cd*	0.42 ±0.06 *e*	0.07 ±0.01 *g*	0.05 ±0 *i*	0.30 ±0.12 *k*	0.00 ±0 *l*
Ayikuma	5º55′14.4″	0º02′12.2″	4.09 ±0.36 *a*	0.36 ±0.07 *cd*	0.36 ±0.02 *ef*	0.06 ±0.02 *gh*	0.03 ±0.01 *ij*	0.16 ±0.12 *k*	0.03 ±0.01 *lm*
Dodowa	5º52′42″	0º06′04″	2.32 ±0.26 *ab*	0.13 ±0.04 *d*	0.24 ±0.01 *f*	0.02 ±0.01 *h*	0.01 ±0 *j*	0.20 ±0.12 *k*	0.01 ±0 *l*
Somanya	6º04′37.7″	0º01′08.4″	1.98 ±0.82 *b*	0.14 ±0.02 *d*	0.24 ±0.02 *f*	0.01 ±0 *h*	0.01 ±0 *j*	0.21 ±0.07 *k*	0.01 ±0.01 *l*
MRL (mg/kg dry weight)			42.5	10	40	0.3	2.3	10	10

According to the ANOVA model fitted into Tukey's HSD model at $P < 0.05$, different italicized letters denote that there is a significant difference between mean values in the same column. MRL = maximum recommended limit (MRL); Values of maximum recommended limits (***MRL***) were by Tech Rep/WHO. (1993, 1989), FAO/WHO (2011) and USEPA IRIS (2011). Conversion of original wet weight values to dry weight done using a conversion factor of 0.085 (Asharaf et al., 2021; Elbagermi et al., 2012).

Health risk assessment: estimation of daily intake of heavy metals

The toxicity of heavy metals to human beings through the consumption of mango fruits will depend on factors such as consumer's age, weight, intake amount, and intake frequency (**Table 2**). Toxicity does not only depend on the concentration levels of the individual toxic metals but also the cumulative effects of all detected trace metals in the samples. Mango fruit consumption data was based on the Food and Agricultural Organization's (FAO) average fruit consumption per capita for Ghana (FAO, 2023) and the estimated number of days for which individuals consume mangoes in the study area as well as data from previous studies (Arora et al., 2008; Ashraf et al., 2021; Atta et al., 2023; Galal et al., 2021). Mango is a seasonal fruit in Ghana, which is normally eaten for about seven months in a year. It is produced in two seasons in South eastern Ghana; the major season occurs between April and August every year, whereas the minor season is between October and November annually (Arnoldus & Clausen, 2019). Hence, the estimated total number of exposure duration for the (**Table 2**). consumption of mango in the study area is 214 days/year. According to FAO/WHO (2023), the average fruit consumption per capita in Ghana is 180 kg/head/year. Therefore, the average ingestion rate (IR) of mango fruits is calculated as 0.0715 kg/person/day. Since the estimations of risks are done on the wet weight of a consumer, a conversion factor of 0.085 is applied to transform them into dry weights as in the studies of these authors (Arora et al., 2008; Ashraf et al., 2021; Atta et al., 2023; Galal et al., 2021). **Table 2** shows the calculated metal consumption levels in mango fruit samples. The EDI values in this study were in decreasing order of Fe>Cu>Co>Pb>Mn>Ni>Cr for Adults and Fe>Co>Mn>Ni>Cu>Cr>Pb for Children (**Table 2**). In a similar study carried out in Southern Ethiopia, Ezez & Belew (2023) found EDI values in order of Fe>Zn>Mn>Cu>Cd>Pb in mango samples. The estimated (EDI) values were compared with the oral reference dose (RfD) values from the USEPA IRIS (2011) and WHO/FAO (2011). All of the metal consumption levels found in this investigation fell below the crucial oral reference value (**Table 2**).

Table 2. Estimated daily intake of heavy metals from the consumption of mango fruits from South eastern Ghana for adults and children.

	Estimated daily intake (mg/kg/day)													
	Fe		Mn		Cu		Pb		Cr		Ni		Co	
Town	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Adenta	0.00508	0.0234	0.000459	0.00215	0.000429	0.00200	6.13×10^{-5}	0.000286	6.13×10^{-5}	0.000286	0.000449	0.00209	1.02×10^{-5}	4.77×10^{-5}
Agomeda	0.00419	0.0196	0.000317	0.00148	0.000429	0.00200	0.000715	0.000334	5.11×10^{-5}	0.000238	0.000306	0.00143	0.00102	0.00477
Ayikuma	0.00418	0.0195	0.000368	0.00172	0.00368	0.00172	6.13×10^{-5}	0.000286	3.06×10^{-5}	0.00143	0.000163	0.000763	3.06×10^{-5}	0.000143
Dodowa	0.00237	0.0111	0.000133	0.000619	0.000245	0.00114	2.04×10^{-5}	9.53×10^{-5}	1.02×10^{-5}	4.77×10^{-5}	0.000204	0.000953	1.02×10^{-5}	4.77×10^{-5}
Somanya	0.00202	0.00944	0.000143	0.000667	0.000245	0.00114	1.02×10^{-5}	4.77×10^{-5}	1.02×10^{-5}	4.77×10^{-5}	0.000215	0.00100	1.02×10^{-5}	4.77×10^{-5}
RfD	0.700[a,b,c]		0.014[a,b,c]		0.040[a,b,c]		0.004[a,c]		1.500[a,c]		0.020[a,c]		0.043[a,c]	

RfD values were from (a) USEPA IRIS. (2011); (b) WHO/FAO. (2011); (c) Ashraf et al. (2021).

Health risks or hazards

Human health risk assessment is the process used to examine toxicological and epidemiological data for suspected toxicants (Hughes, 2005) such as lead, cadmium, mercury, Arsenic, and chromium in order to estimate permissible exposures (Tongprung *et al*., 2024). Therefore, in human risk assessment associated with toxic metal contamination of food crops, the hazard quotient (HQ) and hazard index (HI) are confirmatory indication of whether consumption of such food crops over time poses human health risk or not. In this study, the health risk assessment predicted the extent of toxicity or risk associated with the daily consumption of mango fruits in Ghana. This involved four mean processes; (1) toxicant identification, (2) toxicant evaluation, (3) exposure evaluation, and (4) risk estimation (Hughes, 2005; Tongprung *et al*., 2024). Toxicant identification involves a review of existing literature to identify toxic elements and their adverse effects on human health. Toxicant evaluation entails the determination of toxicants, in this case, selected toxic heavy metals in mango fruits through laboratory analysis. Exposure evaluation examines exposure parameters such as maximum daily dose to determine potential health risks. Risk estimation establishes the relation between the risk on one side and toxicity and exposure on the other side. The fourth step involves estimating the daily intake of the toxicant and the hazard quotient. Hazard quotients of estimated daily intake values are compared to established reference doses (RfD) to predict the potential health risks associated with the consumption of toxicants in the case of non-carcinogens. In risk characterization of carcinogens, the risk is a function of the carcinogenic potency slope (CPS) or the cancer slope factor (CSF) and the chronic daily intake (CDI) of the toxicant (Tongprung *et al*., 2024; USEPA IRIS, 2011; Wongsasuluk *et al*., 2014).

The hazard quotient (HQ) was calculated to assess the potential health risk associated with the daily intake of mango fruits (**Table 3**). The cumulative health risks linked to each of the chosen heavy metals in the mango fruit sample are evaluated using the hazard index (HI) (Lente et al., 2012; Muhwezi et al., 2021; Osae et al., 2023). This index represents the combined risk associated with the consumption of mango fruit samples in terms of all the heavy metals detected and is calculated by adding up the hazard quotients (HQ) for each heavy metal analyzed. When the HI value is less than 1 (100 %), the predicted exposure to heavy metals will not pose any potential health risk, but when the HI is greater than 1, it indicates a high probability of health risk to consumers (Lente et al., 2012; Siric et al., 2022). The calculated HI from this study did not exceed 1 (**Table 3**). The decreasing order of HI Values for adults was Adenta (0.5840) > Agomeda (0.2571) > Ayikuma (0.1485) > Somanya (0.0877) > Dodowa (0.0345) whereas that for children was Ayikuma (0.6948) > Agomeda (0.4498) > Adenta (0.4141) >Dodowa (0.1612) > Somanya (0.1526). The highest values for both adults (0.5840) and children (0.6948) groups were obtained from the Adenta and Ayikuma sites, respectively (**Table 3**). The highest HI values for each group of humans from Adenta and Ayikuma are relatively high since the values are more than 0.5 (50%) (**Table 3**). The Adenta sampling site is located in an enclosed market surrounded by a commercial car park, a commercial bank, a police station, and a clinic. A relatively high HI (0.5840) was recorded at the Adenta market but the highest HI (0.6948) (**Table 3**) was observed at Ayikuma. The safest and lowest HI values for adults (0.0345) and children (0.1526) groups were from the Dodowa and Somanya sampling sites (**Table 3**).

Table 3. Hazard Quotient and Hazard Index for Adults (70 kg BW) and Children (15 kg BW).

Town	Fe	Mn	Cu	Pb	Cr	Ni	Co	**HI**
Adult								
Adenta	0.00726	0.0328	0.0107	0.0153	$4.08x10^{-5}$	0.0225	$2.37x10^{-4}$	**0.584**
Agomeda	0.00599	0.0226	0.0107	0.1788	$3.41x10^{-5}$	0.0153	0.0237	**0.2571**
Ayikuma	0.00597	0.0263	0.0920	0.0153	$2.04x10^{-5}$	0.0082	$7.12x10^{-4}$	**0.1485**
Dodowa	0.00339	0.0095	0.0061	0.0051	$6.80x10^{-6}$	0.0102	$2.37x10^{-4}$	**0.0345**
Somanya	0.00289	0.0102	0.0613	0.0023	$6.80x10^{-6}$	0.0108	$2.37x10^{-4}$	**0.0877**
Children								
Adenta	0.0334	0.1534	0.0500	0.0715	$1.91x10^{-4}$	0.1045	0.0011	**0.4141**
Agomeda	0.0280	0.1057	0.0500	0.0835	$1.59x10^{-4}$	0.0715	0.1109	**0.4498**
Ayikuma	0.0279	0.1229	0.4300	0.0715	$9.53x10^{-4}$	0.0382	0.0033	**0.6948**
Dodowa	0.0159	0.0442	0.0285	0.0238	$3.18x10^{-5}$	0.0477	0.0011	**0.1612**
Somanya	0.0135	0.0476	0.0285	0.0119	$3.18x10^{-5}$	0.0500	0.0011	**0.1526**

A study conducted by Siric et al. (2022) found the HI values of four heavy metals (Cr, As, Cd, and Pb) in two varieties of mango fruits for both children and adult groups from India to be less than 1. Similar findings were reported by Qureshi et al. (2016) in a study on wastewater-irrigated fruits and vegetables from Dubai, UAE. In Ghana, many human health risks studies have been carried out on heavy metal contamination in vegetables (Lente et al., 2012; Osae et al., 2023) but not many are on mango fruits. Even though the HI values obtained for this current study are lower than 1 and may not pose a potential threat to the health of consumers, the high values obtained from the Adenta market (0.5840) and Ayikuma (0.6948) sampling locations are of concern and must inform policy on heavy metal contamination in fruits and associated human health risks in Ghana. Regular consumption of fruits contaminated with toxic heavy metals over some time may lead to potential health problems such as cancer risk, neurological damage (e.g., cognitive impairment, memory loss, etc.), kidney damage and chronic kidney disease, reproductive issues (infertility, foetal development abnormalities), gastrointestinal (e.g., nausea, vomiting, diarrhoea, and abdominal pain) and cardiovascular disease (Khan et al., 2015; Siric et al., 2022; Zukowska & Biziuk, 2008). The World Health Organization (WHO) has linked reproduction disoders of women to their exposure to heavy metals such as lead, cadmium, and mercury (Apostoli & Catalani, 2011).

Carcinogenic health risks

The results of the lifetime cancer risk (LCR) of Cr, Ni, and Pb from mango fruits contamination are presented in **Table 4**. The LCR values of Cr, Ni, and Pb for both adults and children did not exceed the acceptable limits (LCR values $< 1 \times 10^{-4}$) (in Table **4**). The highest value of LCR was for Pb from the Agomeda sampling sites (**Table 4**) for adults whereas Cr was highest for children at the Ayikuma sites (**Table 4**). The increasing order of LCR values was Ni<Cr<Pb for adults while that for children was Cr<Pb<Ni. These results suggest that there is no cancer risk associated with the intake of mango fruits by both adults and children from the study area. Similar findings were observed by Ezez and Belew, (2023) in mango fruits from the southern region of Ethiopia. Exposure to heavy metals through the ingestion of mango fruits over an extended period may not be advisable due to the accumulation of negative effects on human health. Chromium (VI) compounds are known to cause lung cancer in humans (Baird & Cann, 2012), while in addition to lung cancer, nickel compounds and metallic nickel cause cancers of the nose, nasal cavity, and paranasal sinuses (IARC, 2012). Chromium, Cr contamination has many adverse effects on the human immune system. Lead exposure is noted for abnormalities in humans including arteriosclerosis and hypertension, thrombosis, atherosclerosis, and cardiac disease). Therefore, regular monitoring of heavy metal levels in mango fruits is needed.

Table 4. Lifetime Cancer Risk (LCR) from the consumption of mango fruits from South eastern Ghana for adults (70 kg BW) and children (15 kg BW).

	LCR (mg/kg/day)					
	Cr		Ni		Pb	
Town	Adults	Children	Adults	Children	Adults	Children
Adenta	2.45×10^{-6}	1.144×10^{-5}	3.772×10^{-7}	1.756×10^{-6}	5.211×10^{-7}	2.431×10^{-6}
Agomeda	2.044×10^{-6}	9.52×10^{-6}	2.570×10^{-7}	1.201×10^{-6}	6.078×10^{-6}	2.839×10^{-6}
Ayikuma	1.224×10^{-6}	5.72×10^{-5}	1.369×10^{-7}	6.409×10^{-7}	5.211×10^{-7}	2.839×10^{-6}
Dodowa	4.08×10^{-7}	1.908×10^{-6}	1.714×10^{-7}	8.005×10^{-7}	1.734×10^{-7}	8.101×10^{-7}
Somanya	4.08×10^{-7}	1.908×10^{-6}	1.806×10^{-7}	8.4×10^{-7}	8.67×10^{-8}	4.055×10^{-7}
CSF	**0.04**		**0.00084**		**0.0085**	

Sources of information are (a) USEPA. (1989); (b) Osae et al. (2023); CSF= Cancer slope factor, Acceptable risk range = 10^{-4} to 10^{-6}.

Implications for public health

Toxic heavy metal contamination of fruits undermines food quality, safety, and public health since they pose health risks to humans (Ashraf et al., 2021; Lente *et al*., 2012; Osae et al., 2023; Qin *et al*., 2021). In general, consumption of food crops contaminated with unacceptable concentrations of heavy metals according to previous reports has been associated with human health disorders (Kiani et al., 2021; MWRWH, 2015; WHO, 2017). Therefore, there is a need to regularly monitor levels of lead, nickel, chromium, and cadmium, among others, in fruits vended in Ghana. Previous studies have linked wastewater irrigation, fertilizer and pesticides application, and automobile emissions to toxic heavy metal deposition on food crops either grown or sold close to major roads and markets (Baird & Cann, 2012; Jassir *et al*. 2005; Lente *et al*., 2012; Qin *et al*., 2021). This study will provide useful information for public health and food safety policy development and implementation.

Conclusion

The concentration of selected heavy metals in mango fruits from South eastern Ghana (i.e., Adenta, Dodowa, Ayikuma, Agomeda, and Somanya) was determined analytically and the potential health risks associated with intake were estimated. The concentration levels of selected trace metals were compared to the safe limits given in the guidelines of WHO and FAO. Lower levels of Fe, Mn, Ni, Cu, Pb, Cr, and Co that were 4.91±0, 0.45±0, 0.44±0, 0.42±0, 0.07±0.01, 0.06±0 and 0.03±0.01 $mgkg^{-1}$, respectively were measured. There were significant differences ($p<0.05$) between mean values of heavy metal concentration in mango fruits from the selected sample locations. The health risk assessment showed that mango fruits sold at the study locations were fit for consumption and did not pose any potential health risk to consumers as well as cancer risk due to elevated levels of Cr, Ni, and Pb. The risk assessment indicated that both non-carcinogenic and carcinogenic health risks may not be higher for adults and children. Even though both the concentrations of the selected heavy metals in the mango samples and their hazard indices showed no potential human health risks, it is important that regular monitoring of heavy metals in mango fruits sold along busy roadsides is carried out since vehicular emissions are a major source of toxic heavy metals to the atmosphere and street foods. Such routine assessment also assures the consumer of the quality of the mango fruits by the roadside which will in turn boost the business and income of the mango fruit vendors.

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Declaration
Conflict of interest: The author declares that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the author.

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