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Original Article

Potential human health risks of mercury-contaminated cassavas – Preliminary studies

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ABSTRACT — The inevitable use of mercury (Hg) and the regular release of its waste into the ecosystem through artisanal and small-scale gold mining (ASGM) activities particularly, in developing countries such as Ghana require constant monitoring and evaluation of Hg contamination and its potential toxicities particularly, in samples such as food. This study evaluated the potential human health risks associated with total mercury (THg) and methylmercury (MeHg) levels of mercury-contaminated cassavas from farms in selected ASGM communities around Obuasi, Ghana. The THg and MeHg levels were evaluated using the direct Hg analyser, MA-3000 while the human health risk assessment was done using the USEPA risk assessment model. The estimated average daily intake for ingestion ($eAvDI_{(ing)}$) (mg/kgbw/day) and the hazard quotient (HQ) for THg levels of the samples were above the USEPA reference values of 3 x 10^{-4} and 1, respectively. This means that residents ingest more Hg through consumption of cassava, hence long-term repeated exposures to the cassavas may be associated with detrimental human health effects in future. MeHg levels may not cause any human health effects due to $eAvDI_{(ing)}$ and HQ below 1 x 10^{-4} and 1, respectively. However, constant releases of mercury waste and subsequent bioaccumulation along the food chain can cause MeHg levels to increase with time above the USEPA acceptable daily intake. Such levels may be detrimental to human health. Therefore, there is the need for regular and strict monitoring of ASGM activities within the studied communities and other communities involved in ASGM to protect human health and preserve ecosystem integrity.

Key words: Cassava, Total mercury, Methylmercury, Hazard quotient, Human health risk

INTRODUCTION

Anthropogenic activities have resulted in the release of many contaminants into the environment (Eze *et al*., 2018; Anyanwu *et al*., 2020) which have diverse detrimental effects on human health and the ecosystem at large. These contaminants such as polycyclic aromatic hydrocarbons, polychlorinated biphenyls, heavy metals, etc (Moreno and Lanusse, 2017; Thompson and Darwish, 2019) have serious negative effects on food safety and quality

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(Oppong *et al*., 2018; Thompson and Darwish, 2019) and subsequently affect human health through their bioaccumulation in the food chain. This has necessitated several studies on human health risk assessment which involves assessing the nature and the short-term and/or long-term potential adverse effects of environmental contaminants on humans (Onyedikachi *et al*., 2018; USEPA, 2021).

Mercury (Hg) is considered one of the potent environmental contaminants due to its widespread emissions and toxicity (Pirrone *et al*., 2010; Rice *et al*., 2014). It is very toxic in any chemical form i.e., elemental, organic or inorganic and its toxic effects include nephrotoxicity, cardiotoxicity, hepatotoxicity, neurotoxicity, gastrointestinal disorders, haematological effects, etc (Bernhoft, 2012; Ou *et al*., 2014). Despite the numerous studies on its toxicities, it is still being used in artisanal and small-scale gold mining (ASGM) sector in Ghana for gold purification (Addai-Arhin *et al*., 2021). Many studies in Ghana have assessed the risk of Hg to humans through food sourced from farms in ASGM communities. Bortey-Sam *et al*. (2015) evaluated the human health risks associated with plantains and cassavas from farms in some ASGM communities around the Tarkwa Municipality. Bedu-Addo *et al*. (2018) also assessed the potential human health risks associated with cassavas, plantains, and corn as consuming crops in some host mining communities around Obuasi. Amonoo-Neizer *et al*. (1995) estimated the Hg levels in plantains and cassavas in some ASGM communities around Obuasi. Other studies including Bentum *et al*., (2017) and Oppong *et al*. (2018) also assessed the human health risks upon exposure to okra and sugar cane in some communities in the Central and the Ashanti regions of Ghana, respectively.

Globally, food consumption has been the major cause of Hg poisoning. For example, the Minamata disease in the mid-1950s occurred through long-term repeated exposures to methylmercury (MeHg)-contaminated fishes from the Minamata Bay (Broussard *et al*., 2002; Hachiya, 2006; Yorifuji and Tsuda, 2014). Another example is the Iraq Hg poisoning in the early 1970s which also occurred through consumption of bread contaminated with MeHg (Broussard *et al*., 2002). These studies suggest that food sourced from Hg-contaminated environments potentially exposes humans to the diverse detrimental health effects or toxicities such as those indicated above. These toxicities are usually non-carcinogenic and may occur after several years upon long-term repeated exposures to Hg. However, despite these known toxicities, the continuous education on Hg contamination and the associated detrimental health effects, Hg is continuously used in ASGM activities particularly, in developing countries such as Ghana, basically due to economic reasons. The continuous use of Hg in ASGM operations and the incessant release of Hg waste into the environment, has necessitated continuous monitoring of Hg levels and evaluation of the potential human health hazards that may be associated with Hg contamination particularly, contamination of food crops.

Cassavas are root crops which are staple diet for many Ghanaians. Through absorption from the soil, cassava sourced from farms located near ASGM facilities in ASGM communities may be heavily contaminated with Hg. Long-term repeated exposures to Hg-contaminated cassavas through ingestion leads to long-term potential health risks to residents. Therefore, this study evaluated the potential human health risks upon long-term repeated exposures (through ingestion) to THg and MeHg levels of Hg-contaminated cassavas from selected farms in ASGM communities namely Tweapease, Nyamebekyere, and Ahansonyewodea around Obuasi, Ghana.

MATERIALS AND METHODS

Study area

Obuasi, the capital of Obuasi municipal is located at the southern part of Ashanti Region (Fig. 1). It has been a gold mining hub in Ghana for several decades (Addai-Arhin *et al*., 2021). As a result, many rural communities including Tweapease, Nyamebekyere, and Ahansonyewodea have been involved in ASGM activities for several years. Obuasi, located at latitude 5.35°N; 5.65°N, has a very mountainous landscape with a land mass of 162.4 km^2 (Akoto *et al*., 2018; Bedu-Addo *et al*., 2018). It has savanna climate with average annual rainfall of 1450 mm, average annual temperature of 25.5°C, and average relative humidity around 80% in wet seasons (Akoto *et al*., 2018; Bedu-Addo *et al*., 2018). Obuasi has about 63 urban communities (Bedu-Addo *et al*., 2018) and surrounded by several rural communities including Tweapease, Nyamebekyere, and Ahansonyewodea (Addai-Arhin *et al*., 2021). ASGM and farming are the major economic activities of most of the surrounding rural communities around Obuasi.

Sampling

Sampling was carried out in late August 2019. A total of nine (9) farms and three (3) ASGM facilities with three (3) farms and one (1) ASGM facility from each selected community were used in this study. The selection of the farms was based on their proximity to the ASGM facilities. Cassavas were randomly sampled from five (5) different sampling locations in each farm at 15–20 cm below the topsoil using a new stainless-steel machete (40 cm length x 7 cm width) from Crocodile Machete Ltd, Tema,

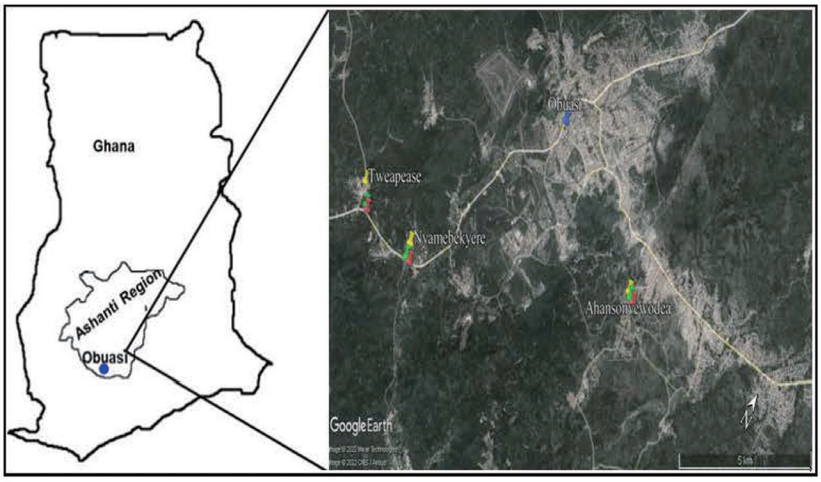

Fig. 1. Map of the study area. Key: Yellow pins = ASGM Communities, Green pins = Selected Farms/Sampling sites, and Red pins = ASGM Facilities or Sites.

Ghana. Five (5) cassava samples were obtained from each farm, and these corresponded to 45 samples from the nine (9) farms used in this study. This resulted in a total of 90 cassava samples including the peels from the farms at Tweapease, Nyamebekyere, and Ahansonyewodea.

Sample preparation

The cassava samples were peeled and washed. The edible parts and the peels were cut into pieces and dried at room temperature for three weeks. The dried samples were ground using a porcelain mortar and pestle and sifted using a sieve of mesh size 120 µm. The samples from each farm were combined and resifted. About 1 kg of each combined sample was prepared. A total of 18 combined samples including the peels were obtained. The peels were also used as samples because they are used as feed for animals such as goats, sheep, and cattle, hence form an important part of the ecosystem in this study. The 18 combined samples were sifted for the third time using a sieve of mesh size 150 µm to obtain finer particles.

Chemicals and standard solutions

All chemicals used were of analytical grade and purchased from FUJIFILM Wako Pure Chemical Industries, Osaka, Japan. For THg analysis, calibration standard solutions of concentrations 10 ppb, 100 ppb and 1 ppm Hg^{2+} in 5% (v/v) nitric acid solution were prepared from 10 ppm Hg^{2+} standard stock solution using serial dilution method. For MeHg, a 10 ppb CH_3HgCl in 5% (v/v) nitric acid solution was prepared from a 100 ppb CH_3HgCl standard stock solution using the same method.

Analysis of THg and MeHg contents of samples

THg content

Approximately 30 mg of each sample was weighed into sample boats in triplicates and put in a direct Hg analyser, MA-3000 (Nippon Instruments Corporation, Tokyo, Japan) for THg content analysis after obtaining suitable low and high calibration curves using the calibration standard solutions of 10 ppb, 100 ppb, and 1 ppm of Hg^{2+}.

MeHg content

The method was adopted from (Maggi *et al*., 2009) but was modified to optimize the samples under consideration. Approximately 0.5 g of each sample was weighed into a 50 mL corning tube. About 10 mL of 48% (w/w) Hydrogen bromide (HBr) solution was added to the sample. The mixture was shaken for 5 min at 250 rpm using horizontal recipro shaker SR-2s (Taitec, Nagoya, Japan) and centrifuged at 2400 rpm for 10 min using high-speed cooling centrifuge, Kubota 7000 (Kubota Corporation, Japan). The supernatant was decanted, and 20 mL toluene (99.5%-w/w) was added to the residue. The resultant mixture was shaken and centrifuged at 250 and 2400 rpm, respectively for 20 min. The toluene extract containing MeHg was decanted into another 50 mL corning tube and 6 mL of 1% (w/v) aqueous L-cysteine solution (98%-w/w) containing 1.25% (w/v) of anhydrous sodium sulphate and 0.775% (w/v) of anhydrous sodium acetate was added. The resultant solution was shaken and centrifuged for 20 min as above. Approximately 100 µL of the L-cysteine-MeHg solution was analysed using the direct Hg analyser, MA-3000 for MeHg content analysis after obtaining a suit-

able calibration curve using the calibration standard solution of 10 ppb CH_3HgCl. The Hg levels in the extracted samples were taken as the corresponding MeHg levels.

Quality control

Instrumental analysis was done in triplicate for each sample with a triplicate determination for each instrumental analysis. A blank analysis after triplicate determination of each 3 samples was also carried out. Recovery analysis was carried out by spiking some of the samples. About 2 g of some samples were spiked with 0.7 µg of 100 ppb Hg^{2+} and 2 ng of 10 ppb CH_3HgCl standard solutions for THg and MeHg recovery analysis, respectively. For reliability of the method used and accuracy of the results, two certified reference materials (CRM), NMIJ 7302-a (National Metrology Institute, Japan) for only THg and ERM-CC580 (Institute of Reference Materials and Measurements, Belgium) for both THg and MeHg were used.

Bioaccumulation factor

The bioaccumulation factor (BAF) was evaluated using equation 1. The BAF was used to determine the bioaccumulation of Hg in cassavas (both the edible and the peels). This was a first step in assessing the human health risks associated with the Hg-contaminated cassavas because the amount of Hg transferred from the plant to humans through the food chain depends on the amount accumulated by the plant.

$$BAF = \frac{\text{THg or MeHg Content in Edible parts or Peels}}{\text{THg or MeHg Content in Soil}} \qquad \text{equation 1}$$

Human health risk assessment

Human health risk assessment was carried out using the United States Environmental Protection Agency (USEPA) human health risk assessment model. This involved evaluation of the estimated average daily intake for ingestion ($eAvDI_{ing}$) of cassavas, and hazard quotients (HQ) for both adults and children using equations 2 and 3:

$$eAvDI_{(ing)} = \frac{MC \times IR \times ED \times EF}{AvBW \times AvT} \qquad \text{equation 2}$$

$$HQ = \frac{eAvDI_{(ing)}}{R_fD} \qquad \text{equation 3}$$

Where:

$eAvDI_{(ing)}$ = estimated average daily intake for ingestion (mg/kgbw/day) (USEPA, 2004), MC = mean concentration of the contaminant (Hg), IR = ingestion rate for cassava obtained as 0.60 kg for adults and 0.40 kg for children per day (Bortey-Sam *et al*., 2015), ED = exposure duration (years) = 30 and 10 years for adults and children, respectively, EF = exposure frequency (days/year) = 365, AvBW = average body weight (kg) = 70 and 35 kg for adults and children, respectively, AvT = averaging time (days) = ED x 365 for non-carcinogens (USEPA, 2004), HQ = hazard quotient, and R_fD = oral reference dose or acceptable daily intake of mercury given as 3×10^{-4} and 1×10^{-4} mg/kgbw/day for THg and MeHg, respectively (USEPA, 2004).

Statistical and data analysis

Results were statistically analysed using statistical software IBM SPSS statistics version 26 (IBM Corporations, New York, USA) and Microsoft Office Excel 2013 (Microsoft Corporations, USA). Descriptive statistics were used to obtain the mean THg and MeHg contents as well as the percentage methylation of the samples. Paired sample t-test (2-tailed) at 95% confidence interval was used to evaluate the statistical difference ($p \leq 0.05$) in BAF and methylation ratio among the samples. Non-parametric test through the Wilcoxon signed rant test and the sign test was also used as post hoc test to confirm the accuracy and certainty of the statistical differences in BAF among samples from the study areas. The BAF values were presented in bar graphs with error bars representing standard deviation (SD) from the mean. The study area map was obtained using Surfer Golden Software version 15 (Colorado, USA) and google earth pro with 2022 images from Maxar Technologies and CNES/Airbus.

RESULTS AND DISCUSSION

Hg content of samples

The THg and MeHg contents (µg/kg) are shown in Table 1. Farms from Tweapease had the highest THg and MeHg contents while those from Ahansonyewodea had the lowest for both the edible parts and the peels of cassavas. Differences in available soil Hg and the total metal content of the soil probably accounted for the differences in both THg and MeHg contents of cassava samples across the study areas. Differences in available soil Hg are in turn influenced by natural soil characteristics such as pH, soil organic matter (SOM), cation exchange capacity, etc (Wilson *et al*., 2014; Khan *et al*., 2015). The differences in total metal content of the soil are also influenced by differences in anthropogenic activities such as fertilizer application and the amount of Hg waste discharged into the environment or the ecosystems. Averagely, the THg and the MeHg contents of the peels were about 3 and 2.4-folds higher than those of the edible parts, respectively. This resulted from the direct contact of the peels with the soil (Addai-Arhin *et al*., 2021) which

Table 1. Hg content (µg/kg) of the edible and peels parts of cassava samples.

		Hg Content (µg/kg)					
		THg			MeHg		
Study Area	Part	Min	Max	Mean ± SD	Min	Max	Mean ± SD
Tweapease	Edible	320.9	345.4	331.2 ± 8.7	0.30	0.97	0.94 ± 0.07
	Peels	978.3	990.9	984.3 ± 5.0	2.90	3.01	2.96 ± 0.05
	Soil	3535.5	3880.3	3684.0 ± 126.3	3.19	3.48	3.33 ± 0.13
Nyamebekyere	Edible	236.3	248.1	242.6 ± 4.0	0.63	0.72	0.69 ± 0.04
	Peels	627.4	668.0	648.1 ± 15.6	1.00	1.81	1.41 ± 0.28
	Soil	2013.7	2045.0	2029.0 ± 11.0	2.63	2.99	2.77 ± 0.17
Ahansonyewodea	Edible	100.0	130.3	114.7 ± 9.8	0.55	0.60	0.57 ± 0.02
	Peels	305.6	370.3	338.4 ± 19.5	1.02	1.30	1.19 ± 0.1
	Soil	1294.8	1387.1	1335.0 ± 27.5	2.21	2.51	2.38 ± 0.13

Note:
Number of Determinations (n) = 9
Hg content values of soils were adopted from Addai-Arhin *et al*. (2021).

Table 2. Ratio of MeHg to THg.

	Methylation ratio (%)					
	Edible parts			Peels		
	Min	Max	Mean ± SD	Min	Max	Mean ± SD
Tweapease	0.25	0.30	0.28 ± 0.02	0.29	0.31	0.30 ± 0.01[b]
Nyamebekyere	0.26	0.29	0.28 ± 0.01	0.15	0.27	0.22 ± 0.04[b]
Ahansonyewodea	0.43	0.58	0.50 ± 0.05[a]	0.30	0.42	0.35 ± 0.05[b]

Note:
Number of Determinations (n) = 9

$$\% \text{ Methylation} = \frac{\text{MeHg Content}}{\text{THg Content}} \times 100$$

[a] shows the statistically significant difference ($p \leq 0.05$) in methylation rate of the edible parts from Ahansonyewodea from those of Tweapease and Nyamebekyere while [b] also shows the statistically significant difference ($p \leq 0.05$) among the peels across the study areas.

serves as a major sink for the contaminant (Masindi and Muedi, 2018).

The extremely lower MeHg content probably resulted from the low methylation rate (Table 2) of the ecosystems. According to USEPA (1997), MeHg levels in terrestrial ecosystems range from 1–3% due to low methylation rate. The methylation rate is also probably influenced by soil characteristic such as available soil Hg, pH, SOM, cation exchange capacity, and the availability of microbial methylators. Low SOM levels lead to insufficient carbon substrate for microbial activities. This reduces the concentration of microbial methylators leading to reduced methylation of available soil Hg (Su *et al*., 2021). Additionally, soil pH above 7 or within the basic region does not favour the solubility, mobility and availability of Hg in soil solution and its subsequent availability to plants (Yu *et al*., 2018). Therefore, it is possible these factors were not favourable for Hg methylation, hence the low MeHg levels. Although the methylation ratio of cassava samples in this study is lower than the 1–3% range by USEPA (1997) but confirms the extremely lower methylation rate of terrestrial ecosystems. The low methylation ratio, therefore, meant that the cassava samples used in this study chiefly contained inorganic Hg (about 99.6% on average) of which a greater percentage existed in insoluble or bound forms, hence was unavailable for methylation.

The statistically significant difference ($p \leq 0.05$) in methylation ratio of cassava samples across the study areas (Table 2) was probably due to the differences in soil characteristics and the amount of available soil Hg. The THg levels of cassava samples in this study are above the 4.00 µg/kg obtained by Bortey-Sam *et al*. (2015) in a similar study at Tarkwa, Ghana. Differences in Hg levels probably resulted from differences in anthropogenic activities such as ASGM and fertilizer application. Moreover, THg levels of all cassava samples are above the 10 µg/kg

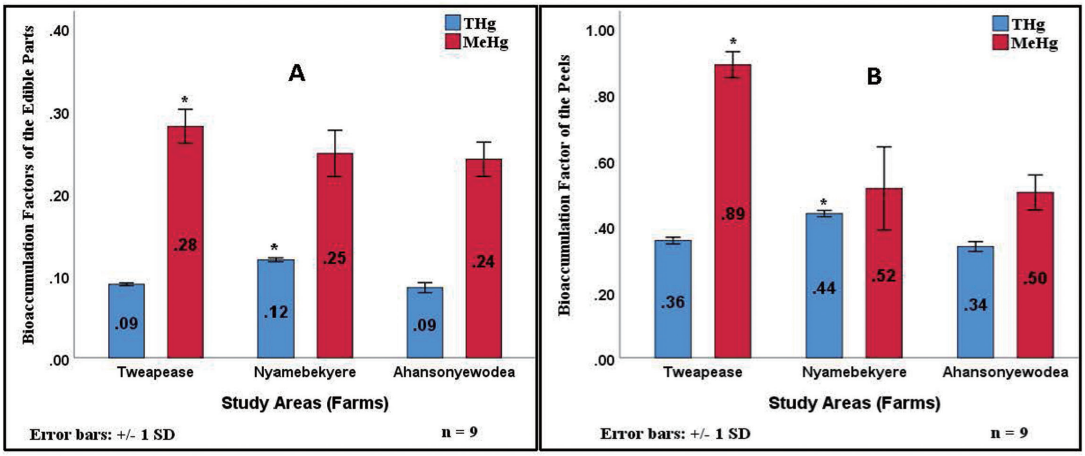

Fig. 2. Bioaccumulation factors of A = the edible parts and B = the peels of cassava samples for both THg and MeHg. * Denotes statistically significant difference ($p \leq 0.05$) in BAF of same samples of the indicated study areas from those of other study areas, n = number of replicate determinations, and error bars represent standard deviation (SD).

guideline value by the Codex Alimentarius Commission (CAC) for food (FAO/WHO, 2003). This means that all cassava samples used in this study are contaminated with Hg.

Bioaccumulation factor

The BAF is important since it helps in evaluating the toxicity of contaminants to humans through the soil – plant – human or soil – plant – animal – human food chain (UK Environment Agency, 2009). The BAF measures the level of absorption and accumulation of the contaminant from the soil by plants. BAF ≥ 1 shows higher absorption and accumulation, hence higher toxicity of the contaminant, while BAF < 1 shows the reverse (Bedu-Addo *et al*., 2018; Addai-Arhin *et al*., 2021). The BAF values are shown in Fig. 2. All BAF values were below 1 for both THg and MeHg. This meant low absorption and bioaccumulation of Hg in cassava samples (edible parts and peels) used in this study. Low bioaccumulation shows low toxicity of cassavas to humans through the food chain. The low BAF values, therefore, meant that the amount of soil Hg that was available for absorption and subsequent accumulation by the plant was low. This also meant that soil characteristics such as pH, SOM, cation exchange capacity, etc did not probably enhance Hg availability and its subsequent absorption from the soil. However, the BAF values of MeHg were higher than those of THg despite the relatively low methylation rate (Table 2) and the lower MeHg content (Table 1). The higher BAF of MeHg, therefore, was probably due to the higher bioaccumulation potential of MeHg than THg. The BAF of THg and MeHg were highest for cassava samples from Nyamebekyere and Tweapease, respectively. This resulted in statistically significant difference ($p \leq 0.05$) in BAF of THg and MeHg of cassava samples from Nyamebekyere and Tweapease, respectively as shown in Fig. 2A and B. These differences probably resulted from the differences in total metal content of the soil and the available soil Hg. Like the Hg contents, the BAF of THg and MeHg of the peels were, on average, approximately 3 and 2.4-folds higher than those of the edible parts, respectively. The higher BAF of the peels than the edible parts suggest a higher absorption and bioaccumulation potential of the peels due to their direct contact with the soil. This means the peels may have a higher potential toxicity than the edible parts.

The BAF of cassava samples in this study, although below 1 but are higher than those of plantains obtained by Addai-Arhin *et al*. (2021) in a similar study. This may be due to the nature of cassava as a root crop. Its root crop nature enhances the absorption and accumulation of contaminants from the soil due to a large surface area of the roots as stated by Natasha *et al*. (2020). This also suggests that in a more heavily Hg-contaminated soils such as Odumase (Addai-Arhin *et al*., 2021), cassavas can potentially absorb and accumulate higher Hg levels and become more toxic if the factors indicated above are slightly favourable.

Human health risk assessment

The $eAvDI_{(ing)}$ and HQ values are shown in Table 3. The $eAvDI_{(ing)}$ for THg of the edible parts of cassava samples across the study areas are above the USEPA accept-

Table 3. Human health assessment of the edible parts of Hg-contaminated cassavas.

		Human Health Assessment			
		THg		MeHg	
		$eAvDI_{(ing)}$ (x 10^{-3})	HQ	$eAvDI_{(ing)}$ (x 10^{-6})	HQ
Tweapease	Adults	2.84	9.46	5.00	0.050
	Children	3.79	12.62	5.34	0.054
Nyamebekyere	Adults	2.08	6.93	3.62	0.036
	Children	2.77	9.24	3.91	0.039
Ahansonyewodea	Adults	0.98	3.28	3.02	0.030
	Children	1.31	4.37	3.26	0.033

Note:
Number of Determinations (n) = 9

$$eAvDI_{(ing)} = \frac{MC \times ED \times IR \times EF}{AvBW \times AvT} \text{ and } HQ = \frac{eAvDI_{(ing)}}{RfD}$$

$R_fD_{(THg)} = 3 \times 10^{-4}$ and $R_fD_{(MeHg)} = 1 \times 10^{-4}$ mg/kgbw/day

Guideline
HQ < 1 = unlikely non-carcinogenic human health risks
HQ ≥ 1 = likely non-carcinogenic human health risks

able daily intake of 3 x 10^{-4} mg/kgbw/day. This means residents may ingest levels of Hg higher than the USEPA acceptable daily intake through consumption of cassava daily. The high $eAvDI_{(ing)}$ of THg resulted in HQ above 1. HQ ≥ 1 suggests the possibility of potential non-carcinogenic human health risks such as those indicated by Bernhoft (2012) and Ou *et al*. (2014). Therefore, the edible parts of cassavas from the selected farms may cause potential non-carcinogenic human health risks to both adults and children upon long-term repeated exposures through consumption. The higher $eAvDI_{(ing)}$ and HQ values of children than those of adults means that children may be at higher risk than adults. This is because the body mass to ingestion rate ratio is higher in children than in adults as stated by Bortey-Sam *et al*. (2015) and Addai-Arhin *et al*. (2021) in similar studies. Additionally, Patel *et al*. (2019) indicated that the rapid development of organs, smaller body mass per exposure dose, and the differences in pharmacokinetics of children particularly, infants compared to adults make them more sensitive or vulnerable to Hg intoxication.

Although the edible parts of all cassava samples may cause potential human health risks, those from Tweapease may cause the highest risk due to the highest $eAvDI_{(ing)}$ and HQ values. Differences in risk levels resulted from differences in anthropogenic activities particularly, ASGM activities which generate large volumes of Hg waste daily into the ecosystem. This means ASGM activities in Tweapease generate the highest volumes of Hg waste than the other study areas. The findings of this study suggest that the Hg contents of soils correlate positively with the Hg content contents of cassavas (Table 1) and their subsequent human health risks (Table 3). This means that cassavas from a more heavily contaminated soil than those used in this study particularly, Odumase (Addai-Arhin *et al*., 2021), may be associated with higher non-carcinogenic human health effects. However, since the edible parts are consumed in processed forms, the processing which involves the application of heat, may reduce Hg levels, and subsequently reduce the associated human health risks, but it should be noted that the risks of Hg to humans may not only be from exposure to the edible parts of cassavas. Residents are also indirectly at risk of any detrimental health effects that may be associated with the peels through the soil – plant – animal – human food chain as reported by Wuana and Okieimen (2011). The direct and the indirect exposures may cause higher non-carcinogenic human health risks to residents. Therefore, there is the need to evaluate the risk of Hg to animals such as sheep, goats, and cattle upon long-term repeated exposures to the peels and subsequently evaluate the risk from animals to humans through the food chain. Additionally, the effect of heat processing and processing time on the potential human health risks of Hg-contaminated cassavas is being investigated.

For MeHg, the $eAvDI_{(ing)}$ and the HQ (Table 3) are below 1 x 10^{-4} mg/kgbw/day and 1, respectively. This means long-term repeated exposures to cassavas through consumption may not be associated with any detrimental human health effects to both adults and children. However, the continuous release of Hg waste and subsequent bioaccumulation along the food chain can cause MeHg

levels to increase with time above the USEPA acceptable daily intake. Such higher levels may, therefore, be associated with human health effects.

In conclusion, the study has shown that cassava sourced from selected farms at Tweapease, Nyamebekyere, and Ahansonyewodea are contaminated with Hg, hence may be associated with potential non-carcinogenic human health risks upon long-term repeated exposures through consumption. Additionally, evaluation of Hg risks to animals through consumption of the peels and heat processing effect on Hg levels of cassavas will provide a better understanding of the risks that humans are exposed to through food consumption. Contamination of cassavas resulted primarily from ASGM activities which release large volumes of Hg daily into the environment. Therefore, constant, and strict monitoring of ASGM activities within the studied communities and other communities involved in ASGM is required to protect human health and preserve the integrity of the ecosystem.

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Conflict of interest---- The authors declare that there is no conflict of interest.

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