Effect of smoking and chargrilling on toxic metal(loid) levels in tilapia from the Afram Arm of the Volta Lake

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\textbf{ABSTRACT}

This study assessed the effect of smoking and chargrilling on arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) levels in tilapia from cage farm and wild of the Afram Arm of Lake Volta in Ghana. Method of assessment was an Inductively Coupled Plasma - Mass Spectrometer. Culinary methods did not affect Cd levels in anyway, likewise Pb in cage fish. Wild fish Pb levels decreased significantly ($p < 0.05$) from raw (0.013 ± 0.004 mg/kg) after smoking (0.0077 ± 0.0007 mg/kg), and chargrilling (0.006 ± 0.0004 mg/kg). Raw As levels (wild: 0.0325 ± 0.0007 mg/kg, cage: 0.0478 ± 0.0009) increased significantly by smoking (wild: 0.064 ± 0.002; cage: 0.0104 ± 0.006). Smoking introduced Hg (0.005mg/kg) in wild samples. Chargrilling significantly increased As levels in cage fish (0.072 ± 0.004). These contaminants were always below the maximum permissible consumption levels. The CR of As was below the threshold (10-4) likewise THQ and HI below (1), hence consuming tilapia from study site either smoked or chargrilled is safe.

\textbf{Introduction}

Tilapia species holds a unique position amongst aquaculture fishes. Tilapia is prominent in international trade although produced in large amounts from subsistence farmers from low-income settings [1]. Nile tilapia (Oreochromis niloticus) is one of the most consumed species [2]. Tilapia consumption has increased due to its taste and nutritional benefits [3] including high contents of protein, lipids, minerals, and fat-soluble vitamins [1,4].

Tilapia’s contribution from the fisheries sector to food security is significant in Ghana as it provides about 60% of the protein requirement of the populace [5]. While increased dietary consumption improves population health [6], employment opportunities, and financial profits are created along the tilapia value chain [7]. Tilapia occupies the upper aquatic food chain like other fishes [8] and becomes closely associated with high risk of bioaccumulation of contaminants from sediments, food and water [9,10]. Concerns with such risk are increasing for the sake of consumers’ health [11,12]. Some studies show that caged fishes [13,14] and the wild counterparts [3,9] alike bioaccumulate toxic heavy metal(loid) (HMs), which could pose health risk to consumers. Generally, HMs in aquatic environments do not only bioaccumulate at trophic levels but they are non-biodegradable, and could become highly toxic [12,15–17] even at low concentrations [9,18]. HMs like As, Cd, Pb, and Hg are found to be associated with various disorders and diseases [19,20]. For example, Pb, As, and Cd could interfere with the functions of the liver, kidneys, haematopoietic, central nervous systems and others causing organs and systems failures [21–23].

Meanwhile, cooking methods are known to influence the levels of HMs in fish [24,25]. For instance, the culinary methods of smoking and grilling are able to induce contaminants, toxic compounds and environmental hazards including HMs into fish and meat cuisines [26]. These culinary methods are among centuries-old traditional processes like drying, salting, and fermentation used to cook and/or preserve fish in West Africa including Ghana [27,28]. While smoking has remained a common culinary process for centuries, emergence of fast food in the country has boosted the popularity of grilling cuisines especially for tilapia and chicken [29]. Although improved local ovens such as chorkor and oil drum stoves [30,31] are used, fuel sources could generate several chemical contaminants that could be carcinogenic and genotoxic to harm fish consumers [27].

Ghana has seen steady increases in tilapia production and consumption and currently the country is second to Egypt in Africa [7]. The phenomenon is likely supported by the strong perception among consumers that local tilapia has higher quality – more nutritious, safe, and tastes better than imported ones.
Meanwhile, some freshwater bodies including the Volta Lake is experiencing intensive fish aquaculture due to increased demand for tilapia [7], and the concurrent events of other polluting anthropogenic activities raise concerns about potential contamination of riverine fishes including tilapia [34]. Considering the limited available studies on tilapia quality especially from the many tributaries of the Volta Lake including its Afram Arm, and the possible health risk posed by grilling and smoking, this case study seeks to: 1) assess the levels of key HMs, namely, As, Cd, Hg, and Pb in fresh raw fillets (muscles) of *O. niloticus* from cage farm and wild catch; 2) assess the effect of chargrilling and smoking on the levels of HMs in cooked tilapia fillets; and 3) estimate the potential health risks consumers are exposed to. The paper ultimately contributes to literature on the heavy metal levels of riverine fresh tilapia, effect of the culinary processes of smoking and grilling on the HMs, and finally estimate the resultant health risks that contaminated tilapia pose to consumers.

**Methods and materials**

**Study Sites**

The Afram Arm is one of the rivers (tributaries) that feed the Volta Lake that collects all the drainage of the Kwahu Plateau [35]. The river is about 100 km and stretches from latitude 6° 50' 53.81" N and Longitude 0° 43' 25.49" E. The Volta Lake is part of the Volta Basin, covering approximately 400,000 km² area within six (6) West African countries with 42% allocation in Ghana, 43% in Burkina Faso and 15% in Togo, Cote d'Ivoire, Mali and Benin [36]. Locally, the lake serves the purposes of inland transportation, irrigation and fish farming [37]. It contributes about 90% of Ghana’s inland fishery production, mainly in large-scale commercial fish farms operated as cage aquaculture and also provides habitat for about 140 fish species dominated by tilapia [5,37]. In Ghana, tilapia constitutes over 80% of total aquaculture production by 86% of local fish farmers [38]. About 98% of all tilapia catches from aquaculture farms in Ghana is supplied directly to local markets [39]. Two towns, Adawso and Ekye Amanfrom (shown in Figure 1), were selected for the study. These towns are fishing communities along the Afram river and they are separated across opposite sides of the river by a distance of 3 km across the river. Transportation to and from the towns is by a ferry operated by the Volta Lake Transport Company and canoes [40]. The fisherfolk ply their fishing job across the river between the two towns. The only cage farm available at the time of the study was at Adawso, a town of the Afram Plain South District of the Eastern region, which is well known for processing smoked fish. The cage farm was similar to other aquaculture farms usually mounted on the Volta Lake – consisting of a frame made of welded galvanised pipes, floatation (plastic or metal barrels), and netting – nylon nets of various mesh sizes [41].

**Sample collection**

All fresh tilapia (*O. niloticus*) samples were collected from Ekye Amanfrom and Adawso. In all sixty (60) freshly harvested fishes were purchased on the same day: thirty (30) from the only cage farm and another separate thirty (30) from two selected local fishermen out of seven who had just returned from fishing. The tilapia samples were picked based on the available comparably sizeable range of 20.0–26 cm since fish sizes influence the levels of HM contaminants in them [25]. The separate samples (from cage farm and wild catch) were separately rinsed with deionised water onsite to eliminate plankton debris and other external adherents due to harvesting, handling, and transfer. The sample fork length (L) and weight (W) were measured using a rule with a pair of callipers and an electronic chemical balance, respectively. The scales and viscera (intestines, liver and gills) of tilapia samples were removed using clean stainless-steel scissors and forceps and rinsed with deionised water onsite. Samples of ten (10) tilapia from each environment (cage farm and wild catch) were randomly grouped into three (3), wrapped in sterile plain zipper bags and labelled as ‘raw’, ‘chargrilled’, and ‘smoked’ groups. The raw groups were kept in an ice chest containing ice blocks and dispatched within 24 hr to the Metal Contaminants Laboratory of Ghana Standard Authority (MCL – GSA) in Accra for further storage at −20°C and analyses. The remaining groups (chargrilled and smoked) were similarly packaged and temporary stored and sent to local fish processors for chargrilling and smoking.

**Chargrilling procedure**

A popular local griller was selected at Koforidua the capital of the Eastern region to chargrill samples from the cage farm and wild catch separately with no spicing. Before chargrilling, the samples were briefly brined with 10% w/v NaCl solution to mimic the usual seasoning condition for tilapia grilling. The stove was preheated to the temperature of 120 ± 10°C after testing with infrared thermometer before grilling started. A space of 15cm was maintained between the cooking grate and the heat source (burning wood charcoal). Each chargrilling lasted 30 minutes in line with local standard practice. After which, the samples were cooled, repackaged in plain sterile zipper bags, stored in an ice chest containing ice blocks, and transported within 24 h to the MCL – GSA laboratory for analysis.
Smoking procedure

One of the popular local smoked fish processor at Adawso was picked to smoke the tilapia samples using a chorkor stove with neem (*Azadirachta indica*) wood as fuel source. Tilapia samples were seasoned with 10% w/v NaCl before smoking for similar reason stated earlier. A distance of 35 cm was maintained between the cooking grate and the heat source which was operating at a temperature around 180 ± 20°C after testing with infrared thermometer. The smoking was done for about four (4) hours according to local standard practice. The samples were cooled, packaged into plain sterile zipper bags, stored in an ice chest containing ice blocks and transported within 24 h to the MCL – GSA laboratory for analysis.

Digestion and analyses of samples

The stored samples were thawed at room temperature for 1 hr. Fillets (muscles) of samples (raw, chargrilled, smoked) were separated from the bones, head, and tail. The fillets from each group were digested using the standard operating procedure according to the British Standard [42]. The As, Pb, Hg and Cd levels in samples

Figure 1. Map of the Volta Lake and its Afram Arm with the two study communities Adawso and Ekye Aman from both marked with a star.
after a microwave pressure digestion were determined using an Inductively Coupled Plasma – Mass Spectrometer (ICP-MS) (Agilent Technologies 7700 Series) at the GSA Laboratory. Determination of mercury was done by employing Cold-Vapour Atomic Absorption Spectrometry (CVAAS) after pressure digestion according to the British Standard [43]. The test solution was transferred to the reaction analysis unit, and the Hg was reduced with divalent tin (Tin (II) Chloride) and flushed into the cuvette (T cell) of the AAS instrument using a carrier gas stream (Argon gas). The absorption at 253.7 nm (mercury line) at ambient temperature was used as a measure of the mercury concentration in the cuvette. For all analyses, deionised water and reagents of analytical grade were used. Additionally, a certified reference standard (DORM4) and randomly spiked samples with an ICP-MS quality control standard and blanks were run along with the samples. The mean for each sample was obtained from triplicate runs. The recoveries made on the standards are presented in Table 1.

Data presentation and statistical analysis

Levels of As, Cd, Hg and Pb in samples were descriptively reported as mean with standard deviation (Mean ± SD) by wet weight. Statistical comparison of the means of HMs in similar samples was performed by independent samples T-test. All data were checked for homogeneity of variances and normality with Levene and Shapiro – Wilk tests, respectively [44]. One-way ANOVA was performed to inferentially compare the means of HMs in the different samples (raw, char-grilled, smoked). For the ANOVA, which reported a significant difference, a Tukey’s HSD post hoc test was performed to establish the existence of any pairwise difference. All statistical analyses were performed at a 5% (0.05) (two-tailed) significance level using IBM SPSS Statistics Version 26.

Estimation of fish health

The health status (condition factor) of fish is critical in determining the level of bioaccumulation of HMs. Hence, an estimate of the health of the sample was carried out using Equation (Eqn.) 1.

\[ K = \frac{100W}{L^3} \]  

Table 1. Certified reference materials used and their respective recoveries.

| Heavy metal(loid) | Technique | Certified value (mg/kg) | Present Work (mg/kg) | Recovery (%) |
|-------------------|-----------|-------------------------|----------------------|--------------|
| As                | ICP-MS    | 0.25 ± 0.02             | 0.23 ± 0.02          | 96.54 ± 2.5  |
| Cd                | ICP-MS    | 0.41 ± 0.03             | 0.38 ± 0.02          | 93.0 ± 4.2   |
| Pb                | ICP-MS    | 0.53 ± 0.02             | 0.57 ± 0.01          | 108.4 ± 3.6  |
| Hg                | CVAAS     | 0.37 ± 0.03             | 0.36 ± 0.02          | 91.5 ± 3.2   |

Where K is the condition factor; W is the weight of fish (g); L is the fork length of fish (cm).

Estimation of health risk

Health risk assessment is the process of quantifying and characterising the potential adverse health effects of human exposures to environmental hazards [46,47]. The Target Hazard Quotients (THQ), Hazard Index (HI), and Cancer Risk (CR) for As were estimated. The THQ for HMs consumption of fish was calculated using Eqn. 2.

\[ THQ = \frac{EF_r \times ED_{tot} \times FIR \times C}{R_tD_o \times BW_a \times AT_n} \]  

Where \( EF_r \) is Exposure Frequency; \( C \) is the level of detected metal; \( AT_n \) is the Averaging Time (365 days/year × number of exposure years), \( ED_{tot} \) the total exposure duration, \( BW_a \) the adult Body Weight; \( FIR \) is the Fish Ingestion Rate, \( R_tD_o \) is the Oral Reference Dose with details and values provided in Tables 1, 2.

In interpreting the THQ, a value < 1 indicates an exposure lower than the reference dose. A daily exposure at this level is unlikely to cause any adverse effects during a person’s lifetime, while a THQ ≥ 1 indicates possible adverse effects [48]. Additionally, the Hazard Index (HI) which is the additive effect of As, Cd, Pb and Hg combined was estimated using Eqn. 3.

\[ HI = THQ(As) + THQ(Cd) + THQ(Pb) + THQ(Hg) \]  

For HI < 1, a population is less likely to experience any health issue attributed to the HMs, while for HI ≥ 1, the population’s health may be at risk due to the ingested HMs [49].

According to the 50, As is a human carcinogen and the HM has been linked to an increased incidence of cancers among people with exposure in their environment and/or through diet. Previous studies on fishes suggest that at least 85% or more of As exists in the organic form as arsenobetaine, arsenocholine, or dimethylarsinic acid, and approximately 10% is available as inorganic toxicant [51,52]. Therefore, the lifetime Cancer Risk (CR) for As was determined using Eqn. 4 and based on the assumption that 10% of it is available in the inorganic toxic form [53].

\[ CR = \frac{EF_r \times FIR_{tot} \times C \times CSF}{BW_a \times AT_n} \]  

Table 2. Oral reference doses (mg/kg/day).

| Heavy Metal(loid) | Hg | Cd | As | Pb |
|-------------------|----|----|----|----|
| Reference dose \(R_tD_o\) | 0.00016 | 0.001 | 0.0003 | 0.004 |

Source: 54
Table 3. Parameters for health risks assessment.

| Parameters | Unit       | Value | Reference |
|------------|------------|-------|-----------|
| FIR        | kg/capita/day | 0.078 | [55]      |
| EDtot (THQ)| years      | 64.1  | [56]      |
| EDtot (CR)| years      | 70    | [[57]]    |
| BWa        | kg         | 60    | [58]      |
| AT<sub>c</sub> (THQ) | days | 23,433 | [55] |
| AT<sub>c</sub> (CR) | days | 25,550 | [55] |
| EF<sub>c</sub> | days/year | 365   | [55]      |
| R<sub>d</sub> | mg/kg/day | Table 1 | [55] |
| CSF        | mg/kg/day  | 1.50  | [59]      |

Where EF<sub>c</sub> is Exposure Frequency; C is the level of detected metal; AT<sub>c</sub> is the Averaging Time (365 days/ year × number of exposure years), ED<sub>tot</sub> the total exposure duration, BW<sub>a</sub> the adult Body Weight; FIR is the Fish Ingestion Rate, CSF is the oral Carcinogenic Slope Factor for inorganic As, and R<sub>d</sub> is the Oral Reference Dose with values and details provided in Tables 2, 3.

Limitation of the study

The findings of the study are limited to the few samples used and the limited time period including no consideration for different seasons. Muscles, viscera (intestines, liver and gills) and bones are all edible parts of tilapia fish which could be contaminated [60]; however, the current study considered analysis on only the muscles of the fish which is principally consumed by Ghanaians [3]. Also, background water and sediment levels of contaminants were not assessed, however, the raw fresh fish samples were used as control for assessing the influence of cooking methods (smoking & grilling) on heavy metal levels in cooked tilapia. Future studies will have to improve on the limitations associated with the current study in terms of expanding coverage of study sites beyond the tributary (Afram river) to others as well, while increasing sample sizes and allowing for seasonal variations (dry and wet weather seasons).

Results and discussion

Characteristics of sampled fish

The mean condition factor (K) for raw cage (2.5 ± 1.3 g/ cm<sup>3</sup>) and wild (2.7 ± 1.8 g/cm<sup>3</sup>) fish samples were statistically similar (p > 0.05) as shown Table 4. Thus, indicating a comparable health status of O. niloticus from both cage and wild environments. Also, the mean K for the fishes from the two settings was above 1 suggesting that the harvested tilapia were healthy and not under stressful conditions [61]. Comparatively, the K for this study was higher than 1.43–1.93 g/cm<sup>3</sup> reported in a similar study by [11]. The difference between the current and previous studies may be due to the variance in tilapia species (Sarotherodon melanotneron versus Oreochromis niloticus) and water bodies (river versus lagoon).

Levels of HMs in raw samples

Three HMs were detected in raw samples from the two settings in a similar order: As (0.0325 mg/kg) > Pb (0.013 mg/kg) > Cd (0.0006 mg/kg), and As (0.0477 mg/kg) > Pb (0.008 mg/kg) > Cd (0.0005 mg/kg) for wild and cage environments, respectively, as shown in Table 5. There was no significant difference in the mean levels of Cd and Pb (p = 0.05) in the samples from the two environments. However, the As levels in cage samples were significantly higher than in wild samples (p < 0.05).

BDL = Below Detection Level; Level of Detection: (As, Hg, Pb < 0.001 mg/kg & Cd < 0.0001 mg/kg) NA = No available MPL €EC ([73]European Commission, 2011), & FSAl [74] (Food Safety Authority of Ireland, 2009)

A to D values in the same column with different letters are significantly different (p < 0.05).

The levels of As in raw samples of the current study were comparable to 0.04 mg/kg found in O. niloticus from the Pra and Ankobrah basins [3] but far lower than 0.08 mg/kg detected in O. niloticus from the Barekese reservoir all in Ghana [57]. The level of As in the current study may be partly due to the runoff and leaching of insecticide, herbicide, and algaecide used

Table 5. Comparison of levels of HMs (mg/kg) detected in samples.

| Sample             | As       | Cd       | Hg       | Pb       |
|--------------------|----------|----------|----------|----------|
|                    | Mean ± SD| Mean ± SD| Mean ± SD| Mean ± SD|
| Raw Wild           | 0.0325 ± 0.0007| 0.0006 ± 0.0001| BDL      | 0.013 ± 0.004 |
| Chargrilled Wild   | 0.036 ± 0.0004| 0.0004 ± 0.0002| BDL      | 0.006 ± 0.0004 |
| Smoked Wild        | 0.064 ± 0.0002| 0.0003 ± 0.0002| 0.005 ± 0.001| 0.0077 ± 0.0007 |
| Raw Cage           | 0.0478 ± 0.0009| 0.0005 ± 0.0001| BDL      | 0.006 ± 0.0002 |
| Chargrilled Cage   | 0.072 ± 0.0004| 0.0007 ± 0.0002| BDL      | 0.011 ± 0.0001 |
| Smoked Cage        | 0.104 ± 0.0006| 0.0003 ± 0.0001| BDL      | 0.006 ± 0.0004 |
| Standard *         | NA       | 0.05     | 0.50     | 0.30     |
by farmers along the banks of the lake [34]. Also, the slightly high As levels in cage samples could be partly attributed to fish feeds supplied by the fish farmers [62]. This is because multiple sources of pollution are common with aquatic ecosystems [63].

The levels of Cd and Pb detected in this study were below the levels found in similar studies from Ankobrah and Pra basins: Cd (0.00–0.008 mg/kg) and Pb (0.03–0.42 mg/kg) [3]. Even though the levels of Hg in the current study were below detection in all raw samples (Table 5), the levels are dependent on several factors such as body size, trophic position, sex, migratory biology, foraging behaviour, and environmental conditions like temperature, salinity, pH and dissolved oxygen [64].

The low levels of HMs in raw samples in the study may have resulted from the minimal bioaccumulation of HMs by fish into the fillets [65,66]. The detection of HMs in fish fillets signals exposure to contaminated environment with potential to bioaccumulate overtime even above maximum permissible limits (MPL) [62]. However, HMs levels in the raw tilapia are low and far below the MPLs suggesting that the fish environment (cage and wild) is not loaded with the contaminants, and probably because the Afram Arm of the Volta Lake is not overly polluted, especially by anthropogenic activities. Results on Hg may support that assertion of less polluted environment because literature posits that for slightly polluted aquatic environment Hg targets fish muscle for storage [63].

**The effect of culinary methods on levels of HMs**

Wild and cage fish samples after chargrilling contained three HMs in the order of levels: charred wild fish – As (0.036 mg/kg) > Pb (0.006 mg/kg) > Cd (0.0004 mg/kg); and chargrilled cage fish – As (0.072 mg/kg) > Pb (0.011 mg/kg) > Cd (0.0007 mg/kg) (see Table 5). Similarly, the three HMs were detected in cage fish samples after smoking in the order: As (0.104 mg/kg) > Pb (0.006 mg/kg) > Cd (0.0003 mg/kg). Smoked wild fish, however, recorded the three HMs in addition to Hg in the order of magnitude: As (0.064 mg/kg) > Pb (0.0077 mg/kg) > Hg (0.005 mg/kg) > Cd (0.0003 mg/kg). The mean levels of Cd in all samples were statistically similar (p > 0.05). Likewise, the mean levels of Pb in all cooked (smoked and chargrilled) samples were statistically similar (p > 0.05) (Table 4). Thus, the culinary methods (smoking and chargrilling) did not affect the levels of Cd in the fish samples, and also the levels of Pb in cage fish. However, the levels of Pb in the raw wild fish decreased by 40.7% and 53.8% after smoking and chargrilling, respectively (Table 5). Nevertheless, there was no significant difference in the effect of smoking and chargrilling (p > 0.05) on the levels of Pb in raw wild tilapia samples.

There are contradictory assertions in literature regarding the effects of cooking methods on HMs levels in fish. The results of this study follow suit by corroborating and contradicting some findings from other studies. In a study by 24,67, and, it is reported that chargrilling lowers the levels of HMs in fish. Also, 68,report that cooking methods (including grilling) could significantly increase Cd levels but decrease Pb levels in fish. Similarly, our current study found that chargrilling reduced Pb levels, but did not affect Cd levels in wild tilapia. The effect of cooking may be partly due to difference in the fish species and culinary procedures with the associated levels of leaching of water and fat during cooking [25].

Some studies on Hg levels in fish present divergent views on the effect of cooking. According to 69, grilling did not affect Hg levels in fish sampled for their study. However, 25,70, and, found that the Hg levels increased in fish after cooking including frying, and grilling due to pre-concentration, formation of complexes with Hg species and sulphydryl groups in the tissues and/or loss of water and fat. Our study rather found that chargrilling did not affect Hg levels in the fish (either from the wild or cage). Meanwhile, smoking contributed to the detection of 0.005mg/kg Hg levels in wild fish samples. Since cage and wild samples were similarly smoked and were of similar size and weight, the source of the Hg in smoked samples is unclear. However, the detected Hg could be partly linked to water loss during the cooking leading to an increased Hg to mass ratio and also formation of complexes with Hg species and other groups [70]. Although least expected, the detected Hg in smoked samples could have originated from contamination from manipulation and processing techniques employed by the local smoker and chorkor stove used.

The level of As in fish samples was significantly influenced by the two culinary methods. Smoking significantly increased As levels in both wild and cage fish samples by about 96% and 117% (p < 0.05), respectively. Chargrilling increasing effect on As levels was comparatively low in cage fish around (50.63%) yet significant (p < 0.05). However, the variations in As level could partly be attributed to some As loss with water and volatiles including other gross constituents (such as lipids, proteins and carbohydrates) in the fish [71].

Generally, the effect of smoking on the levels of HMs was more pronounced than chargrilling. The difference in culinary effect may be due to the difference in distances between the fish being cooked on the cooking grate and fuel source (15 cm vs 35 cm), temperatures or heat source (120°C vs 180°C), and cooking durations (30 minutes vs 4 hours) employed in this study (for chargrilling vs smoking respectively). The temperature and distance could have affected the
water loss along with other constituents including some HMs during cooking. However, chargrilling may have resulted in lower water loss hence its lower HMs levels in comparison to smoking. Although HMs (Pb, Cd, and Hg) were detected in the cooked tilapia, the levels were far below the maximum permissible limit (MPL) according to EC (2006) and FSAnI (2009), thus strongly suggesting that it is safe to consume smoked and chargrilled tilapia from both the cage and wild environment within the study sites.

**Health risk estimates**

The health risk estimates for the HMs are presented in terms of target hazard quotients (THQ) (as shown in Table 6), hazard index (HI), and cancer risk (CR) (all shown in Table 7). The THQ for As was the highest in all samples due to the high As levels detected in tilapia from both cage and wild environment and both cooking methods. For instance, smoked cage tilapia had the highest THQ for As (0.45) among all cooked samples, indicating that the smoked cage fish has more non-cancerous effect from As. Also, the additive influence of health risk from all the four HMs (As, Cd, Pb and Hg) which is measured as HI generally increased in the order: smoked > chargrilled > raw. Although the HI is an indicative measure, it suggests that non-cancerous health vulnerability due to additive influence from the HMs is highest in eating smoked fish, followed by chargrilled and then raw tilapia. For the culinary treated fish, the mean HI of cage samples was significantly higher than that of wild tilapia. For our raw *O. niloticus*, the HI were far below some values (as high as 1.883) reported by 72, in a tilapia study from Malaysia. Again, our study shows low THQ and HI (< 1), similar to previous studies in Ghana [9,11,57], suggesting that eating Ghanaian tilapia is associated with comparatively low vulnerability to non-cancerous health effects from the key HMs (Cd, Pb, Hg and As). This could corroborate with the already existing general perception in Ghana that local tilapia safe [32,33].

The Cancer Risk (CR) for As in cage tilapia were also significantly higher than wild tilapia (Table 7) in the order: smoked (1.86 ×10⁻⁶) > chargrilled (1.28 ×10⁻⁶) > raw (8.55 ×10⁻⁶) and smoked (1.15 ×10⁻⁵) > chargrilled (6.36 ×10⁻⁶) > raw (5.82 ×10⁻⁶), respectively, for cage and wild fishes. Comparatively, the mean CR values from our study (5.82 ×10⁻⁶ to 1.86 ×10⁻⁵) for raw, smoked and chargrilled tilapia were lower than reported studies from Taiwan (3.4 ×10⁻⁵ to 9.3 ×10⁻⁵) [75], and Malaysia (7.3 ×10⁻⁵) [72]. Thus, our current study implies that risk of developing cancers from consuming tilapia (raw, smoked and grilled) from our study site is around 600 to 2000 people in a hundred million (100,000,000). This is an indication of a tolerable cancer risk level associated with eating fish from the study site since the CR scores are far below the threshold (10⁻⁶). For health risk assessment, a lifetime CR of 1 chance in ten thousand (10⁻⁴) or greater indicates severe risk [76] but that is far from the case in this study.

**Table 6. Target Hazard Quotient of heavy metal(loid)s in *O. niloticus*.**

| Environment | Culinary Method | THQs | Mean ± SD |
|-------------|----------------|------|-----------|
| Wild        | Raw            | Cd   | 0.0008 ± 0.0004 | |
|             |                | Pb   | 0.004 ± 0.003  | |
|             |                | Hg   | NA         | |
|             |                | As   | 0.141 ± 0.006  | |
| Grilled     |                | Cd   | 0.0005 ± 0.0002 | |
|             |                | Pb   | 0.0018 ± 0.001 | |
|             |                | Hg   | NA         | |
|             |                | As   | 0.154 ± 0.006  | |
| Smoked      |                | Cd   | 0.0005 ± 0.0002 | |
|             |                | Pb   | 0.0025 ± 0.002 | |
|             |                | Hg   | 0.043 ± 0.008  | |
|             |                | As   | 0.279 ± 0.008  | |
| Cage        | Raw            | Cd   | 0.0006 ± 0.0008 | |
|             |                | Pb   | 0.003 ± 0.001  | |
|             |                | Hg   | NA         | |
|             |                | As   | 0.207 ± 0.008  | |
| Grilled     |                | Cd   | 0.0008 ± 0.0003 | |
|             |                | Pb   | 0.0036 ± 0.0004 | |
|             |                | Hg   | NA         | |
|             |                | As   | 0.31 ± 0.02  | |
| Smoked      |                | Cd   | 0.0004 ± 0.0001 | |
|             |                | Pb   | 0.0018 ± 0.0001 | |
|             |                | Hg   | NA         | |
|             |                | As   | 0.45 ± 0.03  | |

NA = Not applicable

A to f Values within the same column with different letters are significantly different (p < 0.05)

**Table 7. Health risk estimates of consumption of *O. niloticus*.**

| Culinary Method | Environment | Hazard Index | Cancer Risk (As) |
|-----------------|-------------|--------------|-----------------|
| Raw             | Wild        | 0.146 ± 0.004 | 5.82 ×10⁻⁵ A | 2.60 ×10⁻⁷ |
|                 | Cage        | 0.210 ± 0.008 | 8.55 ×10⁻⁵ B | 3.39 ×10⁻⁷ |
| Grilled         | Wild        | 0.156 ± 0.006 | 6.36 ×10⁻⁵ A | 2.57 ×10⁻⁷ |
|                 | Cage        | 0.320 ± 0.020 | 1.28 ×10⁻⁵ B | 7.92 ×10⁻⁷ |
| Smoked          | Wild        | 0.320 ± 0.010 | 1.15 ×10⁻⁴ D | 3.43 ×10⁻⁷ |
|                 | Cage        | 0.450 ± 0.003 | 1.86 ×10⁻⁴ E | 1.07 ×10⁻⁶ |

A to f Values in the same column with different letters are significantly different (p < 0.05)

**Conclusions**

Three key HMs are found in the raw fresh tilapia (*O. niloticus*) from the Afiram Arm of Volta Lake in Ghana in the order of magnitude: As > Pb > Cd but there was no significant difference in the levels of Cd and Pb between wild and cage fishes except for As. The culinary methods – smoking and chargrilling, do not influence the levels of Cd in all cases, as well as Pb levels in cage fish samples. However, smoking and chargrilling decrease Pb levels in the wild tilapia and the cooking effect could be around 41% and 54%, respectively. The cooking methods influence is significant on As levels because smoking could increase the levels in wild fish by almost 97%, and in cage counterparts by 118%, whereas chargrilling could increase the levels in cage by nearly 51%. Also, smoking could introduce some detectable levels (0.005mg/kg) of Hg.
especially in the wild tilapia samples. The detected levels of HMs (Pb, Cd, and Hg) in raw and cooked tilapia are below the maximum permissible limits, suggesting that consuming the tilapia including raw, smoked and chargrilled could be safe. The health risk assessments further confirm that consuming the tilapia is safe since the THQ and HI are below one (<1), and the CR for As is well below the severe risk threshold (10⁻³). Smoking and chargrilling tilapia from the study site are safe for consumption because of insignificant health risks; however, further studies should extensively look at tilapia from other sources and fresh waterbodies in Ghana. Such health risk assessment studies should consider the influence of different types of fuel sources and types commonly used for smoking and grilling tilapia in Ghana. Also analyses of HMs loads in background water and sediments of the waterbodies in addition to their levels in raw and cooked tilapia viscera are warranted.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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