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Concentration of heavy metals and its risk assessments on *Pseudotolithus senegalensis, Sciaenops ocellatus* and *Chloroscombrus chrysurus* smoked on different ovens

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ABSTRACT

This study sought to investigate the concentration of heavy metals and risk assessment in the fresh and smoked fish tissues (Muscles, gills and bones) of *Pseudotolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus. Pseudotolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus* were caught off the coast of Jamestown beach in Accra and treated as fresh, smoked, unwashed and washed. Smoking was done on *Ahotor, Chorkor,* and Oil drum ovens, and analyzed for heavy metals using Atomic Absorption Spectrophotometry. Fish tissues of *Pseudolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus* smoked on *Ahotor* oven respectively followed a different pattern of heavy metal concentration as Muscles > Bones > Gills; Bones > Gills > Muscles and Gills > Bones > Muscles whereas smoked fish tissues of *Pseudolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus* on Chorkor and Oil drum oven showed a similar pattern as Gills > Bones > Muscles. Studied Fish species showed higher levels of heavy metals concentration on *Ahotor* followed by Oil drum and *Chorkor* ovens. The concentration of heavy metals in *Pseudotolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus* was reduced after washing. All EDI values recorded exceeded the permissible limit but THQ and TTHQ values were <1, indicating a lower health risk hazard when smoked fish from these species is consumed.

Introduction

The quest to reduce hunger, improve nutritional quality and well-being is on the rise as its impact of hunger is touted to be great on global population [1]. The importance of this global challenge is cited in the United Nations Sustainable Development Goals (SDGs), where goal two aims to address ending hunger, achieving food security

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and improving nutrition [2]. Seafood is a rich source of iron, zinc and selenium and plays a critical role in global food security and nutrition [3]. Consequently, seafood has been reported to play significant role in socio-economic stability globally. On the global market, its import value amounted to US 148 billion in 2014 in many developing countries [4].

In Ghana, inland water bodies account for 10% of the land surface, with the largest being Volta lake (8.482 km^2) [5]. Fish and fishery products constitute a substantial portion of animal protein (50 – 80%) in Ghanaian diets [6]. The yearly per capita human consumption is estimated at 28 kg [5]. The fisheries sector plays a vital role to Ghana's economy and poverty alleviation, employing approximately 10% of labour and contributing 4.5% of the gross domestic product (GDP) [5]. To improve the fishing sector contribution there is need for astute postharvest handling practices to extend the shelf life and expand its utilization [7].

Preservation is a good approach to minimize postharvest loss of fish. Perishability could be controlled through appropriate application of processing technologies. Several preservation methods (freezing, canning, smoking, salting,) are employed to control the spoilage of seafood products. Among preservation methods, smoking is an old and traditional fish processing techniques, yet one of the widely accepted [8]. In Ghana, fish is smoked using three major types of ovens, namely, *Ahotor, Chorkor* and oil drum ovens. The latter generally consists of combustion chamber which is fitted to a Chorkor-like outer shell. The combustion chamber allows hot gases to flow up through to the fish [9]. In the Chorkor smoker oven, heat is channeled through a set of trays, thus increasing the temperature of air in the oven [10], while in the oil drum, with an open top and a perforated base is placed over a stone in which a fire is built. The fish are usually placed on galvanised wire trays hung within the drum. Generally, Smoking methods involves cold smoking (29-35°C) and hot smoking (65-120°C) [11]

Heavy metals are non-biodegradable. They play an integral role in human health, especially for biochemical and physiological functions, when consumed in the acceptable range [12]. Metals are usually assimilated into fish gills, skin surface, through ingestion of feed, ion-exchange and ingestion of solid suspended from water as contaminants [13]. These contaminants are; mercury (Hg), cadmium (Cd), Lead (Pb), Chromium (Cr), Nickel (Ni), Arsenic (As) [14]. Excessive intake and even low concentration of these contaminants hinders biological functions in the body [15].

Food safety is a major concern nowadays due to increasing demand for health and proper living. This has necessitated for intensifying research regarding the risk associated with food consumption contaminated by heavy metals from aquatic environment. Fishes are precisely known as bio-indicator to estimate extent of heavy metal contamination and potential risk for human consumption [16]. The level of health risks posed by heavy metals is reported to be determined by using different indices, including the transfer factor (TF), daily intake of metals (DIM) and health risk index (HRI) or health quotient (HQ) [17].

The aim of the present study was to investigate the effect of three commonly used smoking ovens; Ahotor, Chorkor, and Oil drum on heavy metals in three valuable fish species namely *Pseudotolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus* in Ghana. Specifically, the study focused on (1) the bioaccumulation of heavy metals concentrations in smoked *Pseudotolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus,* using the *Ahotor, Chorkor* and Oil drum smoker (2) effect of washing on the levels of heavy metal bioaccumulation and (3) assessing the degree of risk of heavy metal concentration in smoked fish from these fish species.

Methodology

Sampling; Three replicates each of raw marine fish species *Pseudotolithus senegalensis* (Cassava fish), *Sciaenops ocellatus* (Red fish) and *Chloroscombrus chrysurus* (Atlantic bumper) were purchased on each sampling occasion for a period of three months at the James Town beach which is described as one of the largest fishing communities in Accra, Ghana. Fish samples obtained were divided into three parts (fresh and smoked) and transported to the laboratory for analysis. Hot smoking method (80 °C for 3 h) was employed using the different smoking ovens namely; Ahotor, Chorkor and Oil drum oven.

Preparation of samples; Fresh or smoked fish species were washed in demineralized water to remove all foreign particles and dissected into muscle, gills and bones with a stainless-steel knife. The dissected fish parts (fresh) were separately placed into small polyethylene containers, frozen at -20°C then freeze dried in a freeze dryer (DELTA- 24 LSC) for 72 h. The freeze-dried samples and smoked fish samples were blended separately into smooth powder. The third part of smoked fish was divided into two portions and treated as washed and unwashed.

Digestion and Analysis of samples; Samples were digested using Acid Digestion Microwave (ETHOS 900, Milestone, Italy). Powdered sample (0.5 g) was weighed into 100 mL polytetraflourethylene (PTFE) Teflon bombs, previously washed with acid. Six milliliters of nitric acid (HNO_3, 65%), and 1 mL of hydrogen peroxide (H_2O_2, 30%) were added. The samples were then loaded on the microwave carousel and digested for 22 min. After digestion, the Teflon bombs mounted on the microwave carousel were cooled in a water bath to reduce internal pressure and allow the volatilized materials to re- stabilize. The digestate was diluted with distilled water to a final volume of 20 mL, which was then transferred into a test tube and assayed for Magnesium (Mg), Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu), Chromium (Cr), Cobalt (Co), Lead (Pb), Arsenic (As) and Mercury (Hg) using Atomic Absorption Spectrometer (Varian AA240FS, USA).

Risk assessment

Estimated daily intake

The estimated daily intake (EDI) is directly linked to the metal concentration, food consumption, and body weight. The following assumptions were made in this research to estimate the risk of heavy metals from fish consumption at the extreme; the ingested dose was equal to the absorbed pollutant dose [18]; cooking did not affect the pollutants [19]; the average Ghanaians' adult body weight was 75 kg [20]; According to [20], the average daily consumption of fish in Ghana is 74 g per day. Therefore, the EDI of heavy metals for adults and child was calculated as follows:

$$EDI = \frac{C\ x\ C\ cons}{Bw} \tag{1}$$

where C is the concentration of heavy metals in fish (mg/kg wet weight), C cons is the average daily consumption of fish (74 g/day Bw), and Bw represents the body weight (Adult (75 kg) Child (15kg).

Determination of hazard quotient (HQ)

$$HQ = \frac{ED}{RfD} \tag{2}$$

where HQ is the hazard quotient and RfD is the reference dose (mg kg^{-1} day^{-1}). HQ values of < 1 signify unlikely adverse health effects, while HQ values >1 indicate a likely adverse health effect.

Determination of target hazard quotient (THQ)

The THQ which is the ratio of the exposure dose to the reference dose (RfD), represents the risk of non-carcinogenic effects. If it is less than 1, the exposure level is less than the RfD. This points out the daily exposure at this level is not likely to cause conflicting effects during a person's lifetime, and vice versa. USEPA risk analysis [21] procedures were following in the dose calculations which were performed using standard assumptions from the combined. The model described by Chien *et al.* [19] was used for estimating THQ by the following equation:

$$THQ = \frac{EFr\ x\ EDtot\ x\ FIR\ x\ C}{RfDo\ x\ Bw\ x\ ATn}\ x\ 10^{-3} \tag{3}$$

Where;

EFr is the exposure frequency (350 days/year); EDtot is the exposure duration (Adult (30), child (6) years); FIR is the food ingestion rate (Adult (100), Child (200) g/day), while 10^{-3} is the unit conversion factor; C is the heavy metal concentration in fish (mg/kg wet weight); RfDo is the oral RfD (mg/kg day^{-1}); Bw is the average body weight (Adult (75 kg), child (15kg); and ATn is the average exposure time for non-carcinogens (365 days/year $\times$ number of exposure years, assuming 30 years).

Determination of total target hazard quotient (TTHQ)

In this study, the total THQ was expressed as the arithmetic sum of the individual metal THQ values according to the method of Chien *et al* [19]

$$Total\,THQ(TTHQ) = THQ(toxicant\ 1) + THQ(toxicant\ 2) + THQ(toxicant\ n) \tag{4}$$

Statistical analysis

Each analysis was conducted in triplicate, and average values were presented after variance of analysis (one-way ANOVA) using Turkey test ($p < 0.05$), perform with Minitab statistical software (Addison-Wesley, Reading, MA). The graphical work was constructed by excel 2013.

Results and Discussions

From Table SM2, the concentration of heavy metals in various parts of fresh *Pseudotolithus Senegalensis, Sciaenops ocellatus* and *Chloroscombrus chrysurus* were statistical different ($p < 0.05$) except for Pb, As, Hg and Ni which did not show any differences. The concentration of Mg ranged from 1.82 to 5.67 mg/kg in all the studied fish species with its highest concentration (5.67 mg/kg) found in the bones of *Chloroscombrus chrysurus*. Magnesium helps to produce and transport energy to the human body. It also helps to transmit nerve signals and assist in muscle relaxation [22].

Fe concentration was found in all the studied fish parts (muscles, gills, and bones) of *Sciaenops ocellatus* and *Chloroscombrus chrysurus* except muscles and bones of *Pseudotolithus senegalensis*. Fe concentration ranged from 1.82 to 9.42 mg/kg with its highest concentration (9.42 mg/kg) in the gills of *Sciaenops ocellatus*. However, Fe concentration exceeded the recommended levels by WHO [23] (Table SM1). Zn concentration ranged from 0.48 to 2.02 mg/kg in all the 3 fish species. Its highest concentration was found in the muscles of *Chloroscombrus chrysurus* which recorded a value of 2.02 mg/kg. Zn concentration was below the recommended levels by WHO [24, 23] and those obtained by Tarley *et al* [25].

Mn plays an essential role in regulating cellular energy, bone and connective tissue growth, and blood clotting. Exposure to excessive levels of Mn is associated with psychological and motor disturbances [26]. Mn accumulated in the various parts of the studied fish species ranged from 0.22 to 1.16 mg/kg. Its highest concentration (1.16 mg/kg) was found in the gills of *Sciaenops ocellatus* which exceeded the permissible limit by WHO [24] and Tarley *et al* [25]. Cu, Cr and Co were below the detection limit of 0.003, 0.001 and 0.005 respectively.

The concentration of Pb, As and Hg accumulated only in the gills of the studied fish species which respectively ranged from 0.12 to 0.08 mg/kg, 0.01 to 0.50 mg/kg and 0.26 to 0.42 mg/kg. Pb can cause fetal injury and hurt fertility. Children are extra sensitive to Pb because they absorb more lead than adults. Lead also affects enzyme activity in the blood and the transport of oxygen around our bodies. It also accumulates in our bones [27]. Hg is a known human toxicant. The primary source of contamination in people is through the consumption of fish. Hg poisoning in the adult brain is characterized by damage of discrete visual cortex areas and neuronal loss in the cerebellum granule layer [28]. Chronic exposure to inorganic As may cause several health effects, including to the gastrointestinal tract, respiratory tract, skin, liver, cardiovascular system, hematopoietic system, and the nervous system [29]. The highest concentration of Pb, As and Hg was detected in *Pseudotolithus Senegalensis* which recorded a value of 0.12, 0.80, and 0.42 mg/kg respectively. These recorded values exceeded the recommended levels by FAO [30], UNEP [31] (Table SM1). Ni accumulated in all the studied parts of *Pseudotolithus Senegalensis* and *Sciaenops Ocellatus*. However, its concentration in *Chloroscombrus chrysurus* was below the detection limit of 0.001. The concentration of Ni in the other fish species ranged from 0.44 to 7.14 mg/kg with it highest concentration in muscles (5.70 mg/kg) and gills (7.14 mg/kg) of *Pseudotolithus Senegalensis* and *Sciaenops Ocellatus* respectively. These values however exceed the permissible limit of Ni by WHO [32] (Table SM1). Table 1 shows the concentration of heavy metals in the studied fish species smoked with *Ahotor* smoker, *Chorkor* smoker and oil drum oven. The bioaccumulation of heavy metals affected using these smoking technologies were significantly different ($p < 0.05$) among the fish tissues. Mg, Fe, Zn and Mn were detected in all the fish parts namely, muscles, gills and bones, while Cu, Cr, Co, Pb and As were found in bones and or muscles of some of the fish species. Hg was detected only in the gills of *Sciaenops ocellatus,* smoked on the oil drum oven. *Pseudotolithus senegalensis, Sciaenops ocellatus* and *Chloroscombrus chrysurus* smoked on *Ahotor* oven respectively showed different pattern of heavy metal concentration in the studied fish tissues as Muscles > Bones > Gills; Bones > Gills > Muscles; and Gills > Bones > Muscles. However, similar pattern of heavy metals concentration were observed among studied fish species smoked on Chorkor and Oil drum as Gills > Bones > Muscles. Again, levels of heavy metal concentrations of the fish tissues (in muscles, gills, and bones) increased after smoking except muscles of *Pseudotolithus senegalensis* smoked on oil drum oven which showed otherwise. This is similar to studies by Igwegbe *et al* [33] who showed higher mean concentrations of heavy metals in studied smoked fish samples than in the fresh samples. The study revealed that, gills of *Sciaenops ocellatus* smoked on chorkor oven and muscles of *Pseudotolithus senegalensis* smoked on oil drum oven recorded the highest (203.41mg/kg) and lowest (11.77 mg/kg) concentration of heavy metals respectively. This also agrees with Ofori *et al* [34] who reported higher concentration of heavy metals in the gills and bones than in the muscle tissues of studied fish species. The increased concentration of heavy metals might be due to the evaporation of moisture during smoking, therefore, making the metals more concentrated.

Table 2 shows the total concentration of heavy metals in *Pseudotolithus senegalensis, Sciaenops ocellatus* and *Chloroscombrus chrysurus* smoked on *Ahotor, Chorkor* and oil drum ovens. The heavy metal concentrations of the fish species smoked on these ovens showed a significant difference ($p < 0.05$). From the study, fish species namely *Pseudotolithus senegalensis, Sciaenops ocellatus* and *Chloroscombrus chrysurus* smoked on *Ahotor, Chorkor* and oil drum respectively ranged from 0.46 to 36.94 mg/kg, 0.14 to 21.38 mg/kg and 0.14 to 29.58 mg/kg. Again, comparing the three smoking ovens, the concentration of heavy metals in *Pseudotolithus senegalensis, Sciaenops ocellatus* and *Chloroscombrus chrysurus* showed a similar pattern of *Ahotor* > oil drum > *Chorkor* oven. This is possibly due to the construction materials used for these ovens as it's contains some levels of heavy metals which leach into fish during smoking. *Ahotor* oven is built with burnt bricks, mortar from clay and wood ash, stainless steel (fat collector) and tray wire mesh [9], *Chorkor* oven is constructed with clay and clay bricks, plastered clay bricks and wooden trays [35] and Oil drum oven is made of steel oil drums and fitted with galvanized wire trays. Fe (39.94 mg/kg) and As (0.4 mg/kg) respectively recorded the highest and lowest concentration of heavy metals among the studied fish species smoked on *Ahotor, Chorkor* and Oil drum ovens.

A comparison of unwashed and washed smoked fish samples (Figures 1-3) showed that, washing reduced heavy metal levels on smoked fish samples. The concentration of metals in *Pseudotolithus senegalensis, Sciaenops ocellatus* and *Chloroscombrus chrysurus* respectively reduced after washing from a range of 0.14-12.9 mg/kg; 0.14-9.1 mg/kg; 1.14-36.94 mg/kg to a range of 0.22-5.22 mg/kg; 0.14-3.54 mg/kg; 0.22-27.70 mg/kg. Cu, As and Hg were not detected in samples of unwashed or washed smoked *Chloroscombrus chrysurus*. However, As and Hg were detected in both unwashed and washed *Pseudotolithus senegalensis, Sciaenops ocellatus* whereas concentration of Cu was only shown in unwashed *Sciaenops ocellatus*. This study agrees with Igwegbe et al [33] who reported a significant reduction of heavy metal content after washing smoked fish samples. The presence of heavy metals after washing indicates that, these metals are bonded with the fish tissues making it difficult to be removed. Also it can be attributed to smoke constituents which might react with the metals in fresh fish during the smoking process, forming water insoluble complexes that may not be readily removed by washing. However, the

Table 1
Concentrations of heavy metals in different part of fish species

Type of fish	Metals	Ahotor Smoker			Chorkor Smoker			Oil Drum Oven		
		Muscles	Gills	Bones	Muscles	Gills	Bones	Muscles	Gills	Bones
Pseudotolithus senegalensis	Mg	9.45±0.00[fgh]	10.71±0.00[bcdefg]	11.62±0.55[abcde]	10.10±0.00[defgh]	11.79±0.00[abcde]	12.39±0.02[abc]	8.36±0.00[h]	10.45±0.00[cdefg]	12.63±0.00[ab]
	Fe	41.18±0.03[i]	10.14±0.03[u]	10.02±0.03[u]	10.58±0.03[s]	130.70±0.03[b]	15.46±0.03[o]	1.32±0.01[x]	43.66±0.03[e]	22.24±0.06l
	Zn	0.52±0.06[a]	0.74±0.03[a]	0.62±0.03[a]	0.82±0.03[a]	1.74±0.03[a]	0.84±0.06[a]	0.55±0.02[a]	0.55±0.06[a]	1.14±0.03[a]
	Mn	0.18±0.03[n]	0.62±0.03[m]	0.66±0.03[i]	0.66±0.03[ij]	1.42±0.03[fg]	1.34±0.03[g]	0.46±0.03[lm]	0.46±0.03[kl]	2.08±0.06[d]
	Cu	0.26±0.03[d]	0.34±0.03[d]	0.74±0.03[d]	0.98±0.03[cd]	1.54±0.03[a]	0.20±0.06[ab]	nd	nd	0.86±0.03[bc]
	Cr	nd	nd	0.10±0.03[g]	nd	nd	nd	0.38±0.03[j]	0.38±0.03[l]	nd
	Co	nd	nd	nd	nd	nd	nd	nd	nd	nd
	Pb	nd	nd	0.22±0.03[a]	nd	nd	nd	nd	nd	nd
	Ni	nd	nd	0.68±0.06[j]	1.66±0.03[e]	3.18±0.03[g]	1.62±0.03[b]	0.70±0.03[h]	1.50±0.03[f]	2.30±0.03[c]
	As	nd	nd	nd	nd	nd	nd	nd	nd	nd
	Hg	nd	nd	nd	nd	nd	nd	nd	nd	nd
Sciaenops ocellatus	Mg	9.82±0.00[efgh]	11.90±0.00[abcd]	12.67±0.00[ab]	8.41±0.00[h]	12.39±0.00[abc]	12.74±0.00[a]	8.76±0.00[gh]	17.52±0.00[f]	12.90±0.00[a]
	Fe	39.00±0.03[w]	36.14±0.03[k]	36.14±0.03[o]	6.38±0.03[v]	181.90±0.03[a]	20.54±0.03[m]	11.22±0.03[s]	29.96±0.03[i]	15.02±0.03[q]
	Zn	0.50±0.03[a]	1.52±0.06[a]	1.90±0.03[a]	0.24±0.06[a]	1.38±0.03[a]	0.88±0.06[a]	0.30±0.03[a]	4.50±0.03[a]	1.06±0.03[a]
	Mn	0.52±0.06[kl]	1.74±0.03[e]	2.02±0.03[d]	0.50±0.03[kl]	2.62±0.03[h]	2.22±0.03[c]	nd	2.14±0.03[a]	2.46±0.06[b]
	Cu	0.52±0.03[ab]	1.26±0.03[ab]	1.18±0.25[ab]	nd	nd	nd	nd	0.48±0.03[d]	1.26±0.03[ab]
	Cr	1.22±0.03[k]	nd	0.66±0.03[i]	3.78±0.03[e]	4.44±0.66[d]	5.86±0.03[l]	4.74±0.03[b]	nd	4.56±0.06[c]
	Co	0.22±0.03[g]	nd	nd	nd	nd	nd	nd	nd	nd
	Pb	nd	0.26±0.03[t]	nd	0.07±0.03[j]	nd	nd	4.94±0.03[k]	nd	0.78±0.03[l]
	Ni	0.36±0.03[i]	0.66±0.03[h]	2.18±0.03[d]	nd	0.68±0.06[j]	nd	nd	nd	0.66±0.03[h]
	As	nd	nd	nd	nd	nd	nd	nd	0.14±0.03[c]	nd
	Hg	nd	nd	nd	nd	nd	nd	nd	0.19± 0.03[a]	nd
Chloroscombrus chrysurus	Mg	10.50±0.00[cdefg]	12.03±0.00[abcd]	12.63±0.00[ab]	10.93±1.52[abcdef]	10.29±1.85[abcd]	11.58±0.00[ab]	10.62±0.00[cdefg]	12.07±0.00[abcd]	12.86±0.00[a]
	Fe	37.94±0.03[j]	105.42±0.03[d]	41.86±0.03[h]	20.18±0.03	42.26±0.03[n]	18.62±0.03[g]	20.34±0.03[mn]	117.90±0.03[c]	42.96±0.06[f]
	Zn	1.22±0.03[a]	1.88±0.06[a]	1.50±0.03[a]	1.26±0.03[a]	1.32±0.06[a]	0.72±0.06[a]	0.66±0.03[a]	1.94±0.03[a]	2.02±0.03[a]
	Mn	0.46±0.03[lm]	1.50±0.03[f]	1.64±0.06[o]	0.60±0.06[jk]	1.30±0.03[g]	1.54±0.03[f]	0.58±0.06[jkl]	1.14±0.03[h]	1.30±0.03[g]
	Cu	1.38±0.03[ab]	1.32±0.00[ab]	0.98±0.03[d]	0.94±0.03[bc]	1.34±0.03[ab]	1.38±0.03[ab]	1.06±0.03[abc]	0.86±0.03[bc]	0.94±0.03[bc]
	Cr	0.78±0.03[h]	nd	nd	nd	1.46±0.20[g]	nd	nd	nd	nd
	Co	nd	nd	nd	nd	0.16±0.06[h]	nd	nd	nd	nd
	Pb	nd	nd	nd	nd	0.34±0.03[g]	0.12±0.06[a]	nd	nd	nd
	Ni	nd	1.26±0.03[ab]	1.18±0.03[g]	nd	nd	0.66±0.03[h]	0.34±0.02[j]	2.54±0.0[b]	0.76±0.06[h]
	As	nd	nd	nd	nd	nd	nd	nd	nd	nd
	Hg	nd	nd	nd	nd	nd	nd	nd	nd	nd

Mean values in the same column with different letters are significantly different ($p < 0.05$). nd: Non-detected

Table 2
Total concentration of heavy metals in smoked fish species on different smoking ovens

Type of Fish	Heavy Metals	Ahotor	Chorkor	Oil drum
Pseudotolithus senegalensis	Mg	9.63±0.04[a]	2.78±0.01[b]	2.56±0.02[b]
	Fe	12.90±0.03[b]	5.07±0.02[c]	9.54±0.03[b]
	Zn	0.46±0.03[c]	0.70±0.03[b]	0.78±0.03[b]
	Mn	1.14±0.03[b]	nd	nd
	Cu	nd	nd	nd
	Cr	3.26±0.03[b]	nd	nd
	Co	nd	nd	nd
	Pb	0.81±0.01[a]	1.38±0.03[b]	0.79±0.01[b]
	Ni	1.82±0.03[c]	1.74±0.03[b]	nd
	As	nd	0.14±0.03[b]	nd
	Hg	nd	0.34±0.03[b]	0.18±0.03[a]
Sciaenops Ocellatus	Mg	7.92±0.01[b]	2.60±0.02[b]	2.99±0.01[b]
	Fe	9.1±0.03[c]	3.82±0.03[b]	5.15±0.01[c]
	Zn	0.98±0.03[b]	0.56±0.06[b]	0.74±0.03[b]
	Mn	nd	nd	nd
	Cu	nd	0.23±0.01[b]	0.50±0.03[a]
	Cr	4.82±0.03[b]	nd	nd
	Co	nd	nd	nd
	Pb	0.64±0.06[a]	0.86±0.03[a]	1.62±0.03[a]
	Ni	3.20±0.28[b]	nd	2.10±0.03[c]
	As	nd	0.18±0.03[b]	0.14±0.03[b]
	Hg	3.3±0.03[a]	0.26±0.03[b]	0.30±0.03[b]
Chloroscombrus chrysurus	Mg	9.73±0.01[a]	10.91±0.01[a]	11.45±0.01[a]
	Fe	36.94±0.03[a]	21.38±0.03[a]	29.58±0.03[a]
	Zn	2.02±0.03[a]	1.63±0.02[a]	1.42±0.03[a]
	Mn	3.58±0.03[a]	1.50±0.03[a]	1.22±0.03[a]
	Cu	nd	nd	nd
	Cr	5.02±0.03[a]	5.26±0.03[a]	4.23±0.01[b]
	Co	nd	nd	nd
	Pb	1.14±0.03[a]	nd	1.66±0.03[a]
	Ni	2.52±0.11[a]	4.26±0.03[a]	3.14±0.03[b]
	As	nd	nd	nd
	Hg	nd	nd	nd

Mean values in the same column with different letters are significantly different ($p < 0.05$). nd: Non-detected

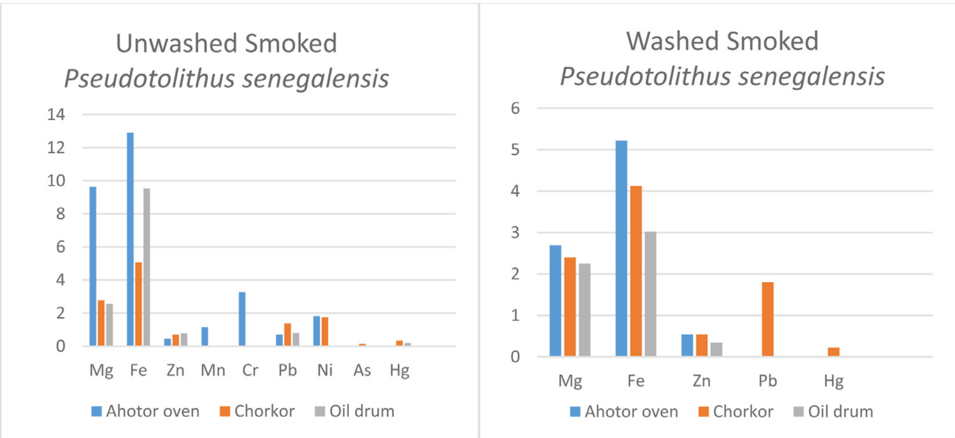

Fig. 1. Heavy metals concentration in unwashed and washed smoked fish samples on different smoking ovens

reduction or elimination of these metals after washing is because of the presence of these metals on the surface of smoked fish [33].

Human risk assessment

The current studies predicted that the local population consumes fish and therefore the Estimated Daily Intakes (EDIs), Hazard Quotient (HQ), Target Hazard Quotients (THQ) of the fishes investigated and consumed by both children and adults

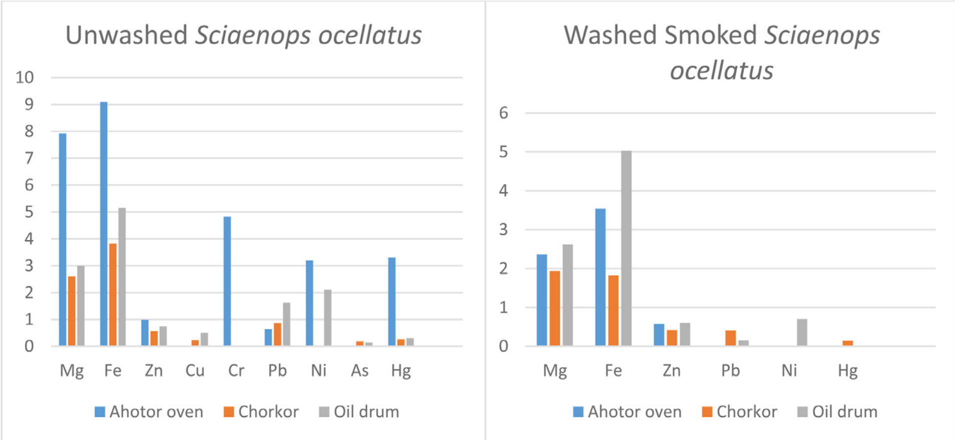

Fig. 2. Heavy metals concentration in unwashed and washed smoked fish samples on different smoking ovens

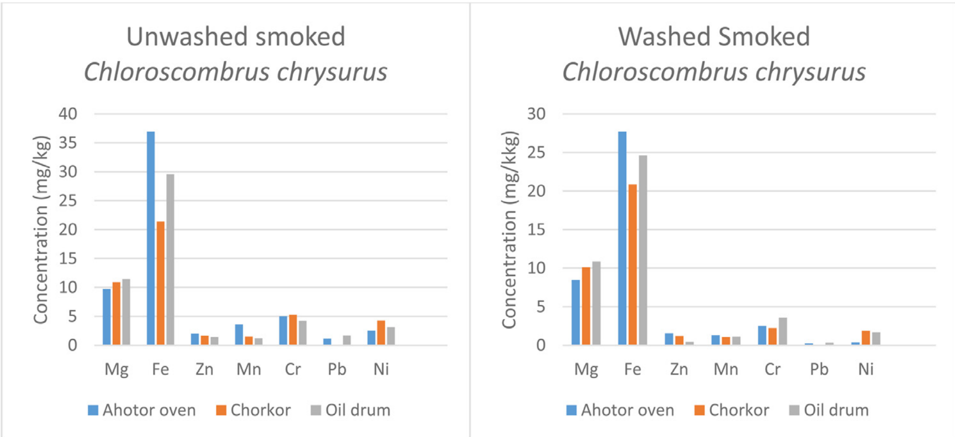

Fig. 3. Heavy metals concentration in unwashed and washed smoked fish samples on different smoking ovens

are displayed in Table 3. Apart from Zn, EDI for all the elements exceeded the permissible limit set by WHO [23, 24, 32]. The THQ value is an appropriate parameter for the risk assessment of metals associated with the consumption of contaminated fish [36]. THQ above 1 means that there is a probability of experiencing obvious adverse effects whereas a THQ below 1 means the exposed population is unlikely to have any adverse consequences [37]. The present studies showed THQ values for both child and adult of <1 for all heavy metals in the studied fish species. This implies a lower health risk hazard if these fish species are consumed. This agrees with Alipour and Banagar [38] who reported THQ values for the studied fish species to be < 1. Kortei *et al.* [39] also reported THQ values of 0.170-5.114 for fishes (*Oreochromis noliticus* and *Clarias anguillaris*) from Ankobrah and Pra basins in Ghana.

TTHQ is the summation of all THQ values. Yi *et al.*, [40] and Kortei *et al.*, [39] reported TTHQ values >1 for the studied fish species indicating potential health hazard. The results of our study (Table SM3) contrast the findings of these previous studies, as TTHQ values for both child and adult was < 1 (5.61×10^{-7}- 36.52×10^{-14}) for washed smoked *Pseudotolithus senegalensis, Sciaenops ocellatus* and Chloroscombrus chrysurus. This signifies no potential risk from the consumption of these fishes.

Conclusion

The study evaluated the concentration of Mg, Fe, Zn, Mn, Pb, As, Hg, and Ni in the muscles, gills, and bones of washed and unwashed smoked *Pseudolithus senegalensis, Sciaenops ocellatus* and *Chloroscombrus chrysurus*. The results showed an increase in heavy metal concentration after smoking. Concentration of heavy metals in fish tissues of *Pseudolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus* smoked on Ahotor oven followed a pattern of Muscles > Bones > Gills; Bones > Gills > Muscles and Gills > Bones > Muscles respectively whereas smoking of fish tissues of *Pseudolithus senegalensis, Sciaenops ocellatus*, and *Chloroscombrus chrysurus* on Chorkor and Oil drum oven followed a similar pattern of heavy metals concentration as Gills > Bones > Muscles. Washing reduced the heavy metal levels in smoked fish, and therefore

Table 3
The estimated daily intake, Hazard Quotient and Target Hazard Quotient of heavy metals in washed smoked fish samples on different smoking ovens

Type of fish	Heavy metals	Smoking Ovens	Concentrations	EDI (child)	EDI (Adult)	HQ (Child)	HQ (Adult)	THQ (child)	THQ (Adult)
Pseudotolithus senegalensis	Mg	Ahotor	2.69	6.64	2.65	16.60	6.65	2.89×10^{-3}	2.34×10^{-4}
		Chorkor	2.40	5.92	2.37	14.80	5.93	2.37×10^{-3}	1.90×10^{-4}
		Oil Drum	2.25	5.55	2.22	13.88	5.54	2.08×10^{-3}	1.68×10^{-4}
	Fe	Ahotor	5.22	12.88	5.15	42.93	17.23	1.12×10^{-2}	8.96×10^{-4}
		Chorkor	4.12	10.16	4.07	33.87	13.57	9.30×10^{-3}	5.60×10^{-4}
		Oil Drum	3.02	7.45	2.98	24.83	9.93	5.00×10^{-1}	3.00×10^{-4}
	Zn	Ahotor	0.54	1.33	0.53	0.44	0.18	1.60×10^{-2}	1.27×10^{-6}
		Chorkor	0.54	1.33	0.53	0.44	0.18	1.60×10^{-2}	1.27×10^{-6}
		Oil Drum	0.34	0.84	0.34	0.28	0.11	6.35×10^{-3}	5.15×10^{-4}
	Pb	Ahotor	nd	nd	nd	nd	nd	nd	nd
		Chorkor	1.80	4.44	1.78	444	178.00	5.33×10^{-2}	4.26×10^{-2}
		Oil Drum	nd	nd	nd	nd	nd	nd	nd
	Hg	Ahotor	nd	nd	nd	nd	nd	nd	nd
		Chorkor	0.22	0.54	0.22	54	22.00	7.92×10^{-4}	6.44×10^{-3}
		Oil Drum	0.70	1.73	0.69	173	69.00	8.08×10^{-3}	6.45×10^{-4}
	As	Ahotor	nd	nd	nd	nd	nd	nd	nd
		Chorkor	nd	nd	nd	nd	nd	nd	nd
		Oil Drum	nd	nd	nd	nd	nd	nd	nd
Sciaenops ocellatus	Mg	Ahotor	2.36	5.72	2.33	14.30	5.83	2.25×10^{-3}	1.83×10^{-4}
		Chorkor	1.94	4.79	1.91	12.00	4.78	1.55×10^{-3}	1.24×10^{-4}
		Oil Drum	2.62	6.45	2.59	16.13	6.48	2.82×10^{-3}	2.26×10^{-4}
	Fe	Ahotor	3.54	8.73	3.49	29.10	11.63	6.87×10^{-3}	5.49×10^{-4}
		Chorkor	1.82	4.49	1.80	15.00	6.00	1.82×10^{-3}	1.46×10^{-4}
		Oil Drum	5.03	12.41	4.96	41.34	16.53	1.39×10^{-2}	1.11×10^{-3}
	Zn	Ahotor	0.58	1.43	0.57	0.48	0.19	1.84×10^{-5}	1.47×10^{-3}
		Chorkor	0.42	1.04	0.41	0.35	0.14	9.7×10^{-6}	7.65×10^{-4}
		Oil Drum	0.60	1.65	0.59	0.55	0.20	2.20×10^{-5}	1.60×10^{-4}
	Pb	Ahotor	nd	nd	nd	nd	nd	nd	nd
		Chorkor	0.41	1.01	0.41	101	41.00	2.76×10^{-3}	2.24 × 104
		Oil Drum	0.15	0.37	0.15	37.00	15.00	3.7×10^{-4}	3.00×10^{-5}
	Ni	Ahotor	nd	nd	nd	nd	nd	nd	nd
		Chorkor	nd	nd	nd	nd	nd	nd	nd
		Oil Drum	0.70	1.73	1.73	3.46		1.61×10^{-4}	7.84×10^{-5}
	Hg	Ahotor	nd	nd	nd	nd	nd	nd	nd
		Chorkor	0.14	0.35	0.14	35	14.00	3.27×10^{-4}	2.61×10^{-5}
		Oil Drum	nd	nd	nd	nd	nd	nd	nd
	As	Ahotor	nd	nd	nd	nd	nd	nd	nd
		Chorkor	nd	nd	nd	nd	nd	nd	nd
		Oil Drum	nd	nd	nd	nd	nd	nd	nd
Chloroscombrus chrysurus	Mg	Ahotor	8.46	20.87	8.35	52.18	20.88	2.94×10^{-2}	2.35×10^{-3}
		Chorkor	10.09	24.89	9.96	62.23	24.90	4.19×10^{-2}	3.34×10^{-3}
		Oil Drum	10.85	26.76	10.71	66.90	26.78	4.84×10^{-2}	3.87×10^{-3}
	Fe	Ahotor	27.70	68.33	27.33	227.77	91.00	4.21×10^{-1}	3.36×10^{-3}
		Chorkor	20.84	51.41	20.56	171.37	68.53	2.38×10^{-1}	1.90×10^{-3}
		Oil Drum	24.62	60.73	24.29	202.43	80.97	3.32×10^{-1}	2.66×10^{-2}
	Zn	Ahotor	1.54	3.80	1.52	1.27	0.51	1.30×10^{-4}	1.04×10^{-2}
		Chorkor	1.17	2.89	1.15	0.96	0.38	7.51×10^{-5}	5.98×10^{-3}
		Oil Drum	0.43	1.06	0.42	0.35	0.14	1.01×10^{-5}	8.02×10^{-4}
	Mn	Ahotor	1.30	3.21	0.42	6.42	0.84	5.56×10^{-4}	1.46×10^{-4}
		Chorkor	1.06	2.61	1.05	5.22	2.10	3.69×10^{-4}	2.97×10^{-5}
		Oil Drum	1.10	2.71	1.09	5.42	2.18	3.97×10^{-4}	3.20×10^{-5}
	Cr	Ahotor	2.50	6.17	2.51	123.4	50.20	2.06×10^{-2}	1.67×10^{-3}
		Chorkor	2.22	5.48	2.19	109.60	43.80	1.62×10^{-2}	1.29×10^{-3}
		Oil Drum	3.59	8.86	3.54	177.20	70.80	4.24×10^{-2}	3.39×10^{-3}
	Pb	Ahotor	0.22	0.52	0.22	52.00	22.00	7.61×10^{-4}	6.45×10^{-5}
		Chorkor	nd	nd	nd	nd	nd	nd	nd
		Oil Drum	0.30	0.74	0.30	74.00	30.00	1.48×10^{-3}	1.20×10^{-4}
	Ni	Ahotor	0.34	0.84	0.34	1.68	0.68	3.81×10^{-5}	3.08×10^{-6}
		Chorkor	1.86	4.59	1.84	9.18	3.68	1.14×10^{-3}	9.12×10^{-5}
		Oil Drum	1.66	4.10	1.64	8.20	3.28	9.08×10^{-4}	7.26×10^{-5}
	As	Ahotor	nd	nd	nd	nd	nd	nd	nd
		Chorkor	nd	nd	nd	nd	nd	nd	nd
		Oil Drum	nd	nd	nd	nd	nd	nd	nd

consumers are encouraged to engage in such good practice to smoked fish before consumption. Assessment of EDI, THQ and TTHQ of both child and Adult revealed that, except for Zinc, all EDI values recorded in the studied fish species exceeded the permissible limit. However, THQ and TTHQ values were <1.

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Declaration of Competing Interest

The authors declare no conflict of interest or personal relationship that could have appeared to influence the work reported in this paper.

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