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Occurrence, quantities and probable human health risks of indicatory polychlorinated biphenyls in processed *Lates niloticus* (L.) products from Lake Victoria in Tanzania

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A study was conducted in Lake Victoria to assess the occurrence, levels and risks of indicator polychlorinated biphenyls (PCBs) in four processed *Lates niloticus* (L.) products (salted-sundried, trims, smoked and deep-fried). Samples extractions were done using QuEChERS method while detection and quantification of congeners was done using a GC- ECD and GC- MS. Six PCBs (CB 28, CB 52, CB 118, CB 138, CB 153 and CB 180) were detected at measurable quantities in fish products. The PCBs; CB 138, CB 153 and CB 180 dominated the loading due to their structures and high degree of chlorination. However, the mean concentration of ΣPCBs in this study were below MRL of 75 µg/kg set for fish by European Commission, implying that the fish products were safe for human consumption in regard to indicator PCBs. Similarly, indicator PCBs, CB 138, CB 153 and CB 180 were more prevalent (20 to 80%) in all fish products than other congeners. For both adults and children the cancer risks were low-to-moderate (ranging from 2.0E-04 to 3.0E-04 for adults and 2.0E-04 to 1.0E-03 for children) while the non-cancer risks were insignificant as the Hazard Indices were less than one.

Key words: Polychlorinated biphenyls (PCBs), kayabo, trims, smoked products, deep-fried products, extracting solvent.

INTRODUCTION

Polychlorinated biphenyls (PCBs) are synthetic organic compounds that are characterized by their lipophilicity (Cok et al., 2007; Bordajandi et al., 2008; Bjermo et al., 2013), persistence in the environment (due to longer half-lives), toxicity, long range atmospheric transport (LRAT) (Liu et al., 2007), accumulation in biota and increase in concentration with time at higher trophic levels (Polder et al., 2014; Ssebugere et al., 2014; Oluoch-Otiego et al., 2016). The compounds are also regarded as endocrine disruptors (EDs) (Bell, 2014) as they alter the normal

functioning of the endocrine system and are difficult to degrade in the environment (Field and Sierra- Alvarez, 2008; Frouin et al., 2013). Most are reported as potential carcinogens being responsible for breast, liver and testicular cancers. They also have negative reproductive effects such as low birth weights, small head circumferences, miscarriages, poor sperm quality and low sperm counts (Bell, 2014).

In recent years Lake Victoria fisheries sector has had an abusive history as in 1998, fish exports from Lake Victoria to the European Union were temporarily banned following observations of tainted fish, which were later proved to have been harvested using endosulfan (Henry and Kishimba, 2006). There are also unsubstantiated claims that in order to extent the shelf life of products in the markets some unfaithful fish sellers store their fish products using chemicals such as pesticides and other unknown repellents which might be potential sources of PCBs in fish products along the fish value chain from fishing to consumption. It is also suspected that some processors use transformer oils for fish frying and consumption of smoked fish products is common in the area. Both transformer oil and smoke are good sources of PCBs in the environment and environmental compartments (Wenaty et al., 2019a; Witczak, 2012).

A study carried out in Poland revealed that smoking fish increases the levels of PCBs specifically; CB 101, CB 118, CB 138, CB 153 and CB 180. The reason for this was found to be due to a decrease in co- distillation with steam and the consequence of their penetration with smoke to the fish meat tissue (Witczak and Ciereszko, 2006, 2012). There is therefore a need to investigate the impacts of smoking on fish products from Lake Victoria. Another study which was done on fried fish products revealed that deep frying reduces the levels of PCBs in fish due to the fact that; (i) deep frying process creates unique cooking conditions that accelerates drying of the fillets (ii) evaporation of water and PCBs from the fillets as a result of high temperature of the cooking oil and by transfer of PCBs to the cooking oil which itself could be acting as an extraction solvent (Witczak and Ciereszko, 2012), though the same compounds are likely to be reintroduced into fish muscles as the cooking oil is reused in subsequent fish processing. Such studies have not been undertaken in Africa and in Lake Victoria in particular thus it is necessary that a study be designed to reveal the prevalence of PCBs and how safe the fish products are. Being lipophilic in nature, high levels of PCBs could be anticipated in fish products such as fish trims that are mainly the fatty tissues of the fish mass. We could also expect high prevalence and levels of PCBs in smoked products due to the reason that the process takes place in closed system and therefore there is no room for escape of PCBs together with water vapour. PCBs are likely to stick in the walls of smoking chambers and go back to surfaces of the fish tissues being processed (Witczak, 2012).

This study therefore was designed to assess the prevalence, levels and risks of indicator PCBs in four processed *L. niloticus* products sold such as salted-sundried, fish trims, smoked fish and deep-fried. The products are mainly consumed by the low and middle income communities in the domestic and regional markets and that to our knowledge no studies regarding the prevalence, levels and risks of PCBs in such products (salted-sundried and trims) have been reported anywhere around the globe and limited studies on smoked and deep fried fish have been reported in developed nations. Studies of such kind have mainly been undertaken for fish products intended for export markets such as fish fillets. Similar studies need to be done for products that are processed for domestic and regional markets as they are consumed by the majority of the low income population and that the safety of such products in terms of chemical hazards particularly PCBs is still unknown. This study focused on only indicatory PCBs because they are known to be more persistent and bio accumulative in food chain compared to other congeners. They are therefore assumed to be a suitable representative for all PCBs.

MATERIALS AND METHODS

Description of the study area

The study was conducted at the Kirumba International Fish Market in Mwanza between April and August 2018. The Kirumba International Fish Market was purposively selected out of other markets in Lake Victoria because it is the largest fish market in the zone that collects fish products from all other regions making up the Tanzanian side of Lake Victoria. Fish folks and other processors bring their already processed fish products at the market and sell them to buyers who then deliver the products to different markets located within and outside the country, such as Uganda, DRC, Burundi, Rwanda, Zambia, Kenya and Malawi where they are used as source of protein as well as income (LVFO, 2013).

Fish samples collection and extraction

Four processed products of *L. niloticus* samples namely; salted-sundried commonly referred to as *Kayabo*, trims commonly known as *Chips*, smoked and deep fried products were collected from randomly selected fish processors and sellers at Kirumba fish Market in Mwanza between April and August 2018. A total of 120 samples (30 samples of each product) were collected for analysis.

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Fish samples extraction and clean-up for determination of indicator PCBs was effected using a quick, easy, cheap, effective, rugged and safe (QuEChERS) procedure with some modifications at the National Fish Quality Control Laboratory in Mwanza, Tanzania. Thirty grams of each sample was measured in triplicates and blended to homogenize. Thirty grams of the composite samples were transferred into 200 ml centrifuge tubes. Thereafter, 2.5 g of sodium bicarbonate ($NaHCO_3$), 60 ml of ethyl acetate and 15 g of anhydrous Na_2SO_4 were added and placed in a shaking machine to homogenize for 20 min. The supernatants were transferred into 15 ml centrifuge tubes containing 0.125 g of Primary Secondary Amine (PSA) and 0.75 g of anhydrous $MgSO_4$ (Anastassiades et al., 2003; Wenaty et al., 2019a, b). The mixture was centrifuged at 2500 rpm for 10 min and left to separate for further 5 min. The supernatants were transferred into vials ready for GC analysis.

Recoveries and analytical quality control

Recovery tests were done for six indicator PCBs of interest. Blank samples were spiked with standards and were subsequently extracted and analysed in the same way as other samples. To maintain the quality of analytical results blanks and standards were run every after five samples.

Chemical analysis

Chemical analysis was performed at the National Fish Quality Control Laboratory in Mwanza. The samples of fish collected were analysed for Polychlorinated biphenyls (Σ-7PCBs); with IUPAC numbers: CB- 28, 52, 101, 118, 138, 153 and 180. The seven indicator PCB congeners were chosen based on their persistence in food web and their tendency to increase in concentration at higher trophic levels. The studied compounds are listed in the Stockholm Convention on POPs for initial elimination and reduction in use because of their effects on environment as well as living organisms.

Gas chromatographic analysis of samples

The determination of the PCBs in the fish samples was carried out using gas chromatography (GC). A gas chromatograph (GC-2010, Shimadzu) equipped with ^{63}Ni Electron Capture Detector (ECD) and a non-polar (HP-5MS) capillary column of 30 m length × 0.25 mm i.d. × 0.25 µm film thickness was used. Nitrogen was used as both a carrier and make-up gas at a flow rate of 23.7 ml min^{-1}. The temperature programme was: initial temperature of 120°C held for 2 min, then increased at a rate of 10°C min^{-1} to 270°C held for 1 min, and at a rate of 2°C min^{-1} to the final temperature of 290°C held for 3 min. The injector and detector temperatures were 220 and 290°C, respectively. The GC was operated in a splitless mode with an injection volume of 1 µL. The standard mixture was injected in the beginning and after every five samples. Samples were injected in duplicate. The confirmation of the findings was done using gas chromatography- mass spectrometry (Shimadzu GC-MS QP 2010 Ultra equipped with a mass selective detector-MSD, fused silica capillary column Rtx-5MS of 30 m length×0.25 mm i.d×0.25 µm film and an autosampler) applying the procedures described by Mahugija et al. (2018). The GC-MS was performed in splitless injection mode and the mass spectrometer was operated in electron impact (EI) ionization and full scan mode. The calibration/working standard solutions were prepared by dissolving portions of the stock solutions in the same solvents as used for the samples. Calibration curves were prepared by running series of mixtures of standard solutions and plotting the peak areas against concentrations. Identification of the compounds involved checking the matching of the retention times and the mass spectra of the PCBs in samples to those of external reference standards that were prepared and run at the same conditions as for the samples. Quantification was carried out by linear integration of the standards and sample data based on peak areas.

Data analysis

Statistical analysis used for data analysis includes subjecting the measured PCBs data to descriptive statistics for the deduction of minimum, maximum, mean concentrations and standard deviations of the detected PCBs. Data was further subjected to SPSS, Version 16.0. Data on PCB concentration were presented as mean ± SD. One-way ANOVA was used to compare concentrations between products. In data processing, the concentrations of PCBs in samples below the limit of detection (<LOD) were treated as zero. Separation of means was done using Duncan's Multiple Range Test. Significance was declared different at $p<0.05$ for all analyses.

Risk assessment model

The estimated dose (CDI) received through consumption of fish products was calculated using Equation 1 and the cancer risk (C_R) using Equation 2, which were adopted from the Environmental Protection Agency of the United States (USEPA, 1997, 2009; Man et al., 2013).

$$CDI = \frac{C * IR * EF * ED}{BW * AT} \quad (1)$$

$$C_R = SF * CDI \quad (2)$$

For non-carcinogenic risks, the hazard quotients (HQ) of each congener PCBs measured were calculated by using Equation 3 and overall non-cancer risk using Equation 4.

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

$$HI = \Sigma HQs \quad (4)$$

Where; CDI (mg/kg-day) is the estimated chronic daily intake, C_R is the cancer risk via consumption of fish products contaminated with PCBs, C (mg/kg) is the measured concentration of indicator PCBs in fish products, IR (kg/day) is the fish consumption rate; for this study 0.37 kg/day was used (Wenaty et al., 2018), HI (mg/kg-day) is the hazard index (overall non- cancer risk via consumption of contaminated fish products, HQ (mg/kg-day) is the hazard quotient (individual compound non- cancer risk via consumption of contaminated fish products), EF is the exposure frequency, 365 days/year (USEPA, 2009), ED is the exposure duration, 60 years for adults and 12 years for children USEPA, 2009), SF is the cancer slope factor, in this study, 2 $(mg/kg\text{-}day)^{-1}$ (Ge et al., 2013) for all indicator PCBs detected. RfD is the Reference Dose (mg/kg-day), in this study, 0.02 mg/kg-day for all PCBs, BW is the hypothetical average body weight, in this study, 70 kg for adults and 29 kg for children (USEPA, 2001). AT is the averaging time, 60 years* 365 days/year= 21900 days for adults and 12 years* 365 days/year= 4380 days for children (Ge et al., 2013; USEPA, 2001).

Qualitative descriptions of lifetime cancer risks of PCBs were based on ATSDR standards as follows; very low when the estimated value is ≤10E-06, low: 10E-06<value≤10E-04, moderate:

Table 1. Results of the percentage recoveries for PCBs extraction procedure.

PCBs	Amount spiked (µg/kg)	Amount calculated (µg/kg)	Recoveries (%)
CB 28	75	69.36±0.23	92.48±0.31
CB 52	50	40.90±0.46	81.79±0.93
CB 118	200	166.87±0.46	83.44±0.23
CB 138	260	202.80±0.35	78.00±0.13
CB 153	280	209.43±0.48	74.80±0.17
CB 180	390	278.54±0.82	71.42±0.21

Table 2. Mean concentrations (µg/kg) of individual PCBs and ∑PCBs in processed fish products from Lake Victoria in Tanzania.

PCBs	Samples			
	Kayabo	Trims	Smoked products	Deep fried products
CB 28	6.08±1.95	4.92±1.38	5.20±1.58	1.75±0.35
CB 52	3.04±3.00	3.72±0.87	3.62±0.77	1.25±0.21
CB 101	ND	ND	ND	ND
CB 118	4.24±3.04	1.88±0.76	5.50±0.98	3.40±0.57
CB 138	5.43±3.58	7.13±3.48	5.81±1.86	3.00±1.84
CB 153	5.74±5.18	7.83±4.65	6.46±4.05	3.30±0.14
CB 180	3.93±3.37	6.07±5.15	4.08±2.55	3.35±0.07
∑PCBs	28.46±9.35	31.55±16.66	30.67±6.23	16.05±3.04

10E-04<value≤10E-03, high: 10E-03<value≤10E-01 and very high when the estimated value is ≥10E-01 (Man et al., 2013; Ge et al., 2013; ATSDR, 1995). For non- carcinogenic risks, hazard index (HI) greater than one was considered risky while HI less than one was considered no risk associated with consumption of fish products (Wenaty et al., 2019a, b).

RESULTS AND DISCUSSION

Recovery experiment for PCBs extraction procedure

The results for the recovery experiment are shown in Table 1. The mean percentage recoveries for PCBs extraction procedure ranged from 71.42±0.21% to 92.48±0.31% based on triplicate determinations. Studies have indicated that recoveries ranging between 70 and 120%, the extraction procedure is considered perfect (Afful et al., 2013a, b). Results herein suggest a perfect extraction method that is recommended for use in further PCBs studies, hence needing no corrections for the recoveries.

Concentrations of PCBs in *L. niloticus* fish products from Lake Victoria

Table 2 shows the concentrations (µg/kg) of individual indicator PCBs and the sum (∑PCBs) measured in processed *L. niloticus* products collected at Kirumba International Fish Market. Six indicator PCBs (CB 28, CB 52, CB 118, CB 138, CB 153 and CB 180) were detected at measurable quantities in different fish products whereas CB 101 was not detected (ND) in any of the four fish products.

The mean levels of individual indicator PCBs in different fish products were in the following ranges: 1.75±0.35 µg/kg (deep fried products) to 6.08±1.95 µg/kg (salted-sundried products) for CB 28, 1.25±0.21 µg/kg (deep fried products) to 3.72±0.87 µg/kg (trims) for CB 52, 1.88±0.76 µg/kg (trims) to 5.50±0.98 µg/kg (smoked products) for CB 118, 3.00±1.84 µg/kg (deep fried products) to 7.13±3.48 µg/kg (trims) for CB 138, 3.30±0.14 µg/kg (deep fried products) to 7.83±4.65 µg/kg (trims) for CB 153 and 3.35±0.07 µg/kg (deep fried products) to 6.07±5.15 µg/kg (trims) for CB 180.

Analysis of Variance (Mean separation by using Duncan's Multiple Range Test) showed significant differences for individual indicator PCBs between fish products with trims, smoked products and salted-sundried products having higher levels than deep fried products (Table 3). The total PCBs loading were 28.46±9.35 µg/kg (salted- sundried products), 31.55±16.66 µg/kg (trims), 30.67±6.23 µg/kg (smoked products) and 16.05±3.04 µg/kg for deep fried products.

Table 3. Analysis of Variance for the detected PCBs in processed fish products from Lake Victoria.

PCBs	Sources of variation		
	DF	F	P
CB 28	3	3.54	0.045**
CB 52	3	3.34	0.043**
CB 118	3	10.69	0.001**
CB 138	3	1.91	0.022**
CB 153	3	0.66	0.036**
CB 180	3	0.53	0.665

** Means are significantly different at 0.05 level. DF: Degree of freedom, F: F -Value and P: P –Value.

The pattern of the total PCBs loading was Deep-fried products<Salted-sundried products<Smoked products< Trims. The loading for deep fried products was significantly different (DF = 3.00, F = 1.53 and P = 0.038) from the rest of the products. The total PCBs loading for other investigated products were quite similar. Low levels of PCBs in deep fried products could be attributed to the fact that at high temperatures the cooking oil acts as an extracting solvent, thus high levels of PCBs are expected to be left with the oil (Witczak, 2009a, b).

The trims are the fatty parts of fish, thus PCBs being highly lipophilic are mainly concentrated in fatty tissues (Bjermo et al., 2013; Polder et al., 2014). For smoked products, high concentrations of PCBs could be due to the reason that there is reduced co-distillation of the components with water vapour (Witczak and Ciereszko, 2006) and removal of water from the product as the PCBs are soluble in fat and lipids. Similarly, studies have shown that smoke consist certain amounts of PCBs (Witczak, 2012) and therefore acting as sources of these persistent organochlorine compounds in foods.

For all fish products considered in this study, the PCBs loading was dominated by CB 138, CB 153 followed by CB 180. Comparable results are also reported in previous studies (Polder et al., 2014; Ssebugere et al., 2014; Oluoch- Otiego et al., 2016). The domination tendency of CB 138, CB 153 and CB 180 are also reported in other previous studies (Polder et al., 2014; Oluoch- Otiego et al., 2016). This is due to the fact that CB 138, CB 153 and CB 180 are not metabolized by certain organisms compared to the rest of congeners (Ssebugere et al., 2014). Boon et al. (1997) also reported that the rate of metabolisms of PCBs depends mainly on structure and the degree of chlorination of the molecule. Being highly chlorinated, CB 138, CB 153 and CB 180 tend to have longer half-lives, persistent to biodegradation and therefore easily detected in environmental samples. The contribution of the three congener PCBs to total loading was 53.1% for salted and sundried products, 66.7% for trims, 53.3% for smoked products and 60.1% for deep fried products.

However, the mean concentration of ΣPCBs in this study were within the limit of 75 µg/kg set for fish by European Commission (EC, 2011), implying that the fish products were safe for human consumption in regard to indicator PCBs. Furthermore the total loading as per this study are far higher than that found by Polder et al. (2014) (0.57 µg/kg) from Lake Tanganyika for fresh *Oreochromis niloticus* samples, higher than those detected by Ssebugere et al. (2014) (0.229 to 0.716 µg/kg) in fresh *L. niloticus* from the Ugandan side of Lake Victoria. This indicates that processed products have higher levels than fresh fish. It is therefore suggested that some fish processing technologies such as smoking are main sources of PCBs in food products.

Prevalence of the detected indicator PCBs in different processed *L. niloticus* fishery products

The prevalence (%) of the indicator PCBs detected in different *L. niloticus* processed products are shown in Figure 1. For the six indicator PCBs that were detected in four fish products, all were less prevalent in deep fried products being detected in only 20% of all samples considered in this study. Generally, for the rest of the products the prevalence was in the following ranges: 40 to 60% for salted- sundried fish products, 50 to 70% for trims and 40 to 80% for smoked products. The mean percentage prevalence followed this trend: Deep fried products<Salted-sundried products<Trims<Smoked products. Indicator PCBs, CB 138, CB 153 and CB 180 were more prevalent (20 to 80%) in all fish products than other congeners. This is attributed to their structures and high degree of chlorination.

Human health risk assessment

Human health risk assessment for the indicator PCBs measured in four processed fish products considered in this study was evaluated using Equations 1 to 4 and ATSDR standard for adults and children. As shown in Table 4, the cancer risks based on indicator PCBs

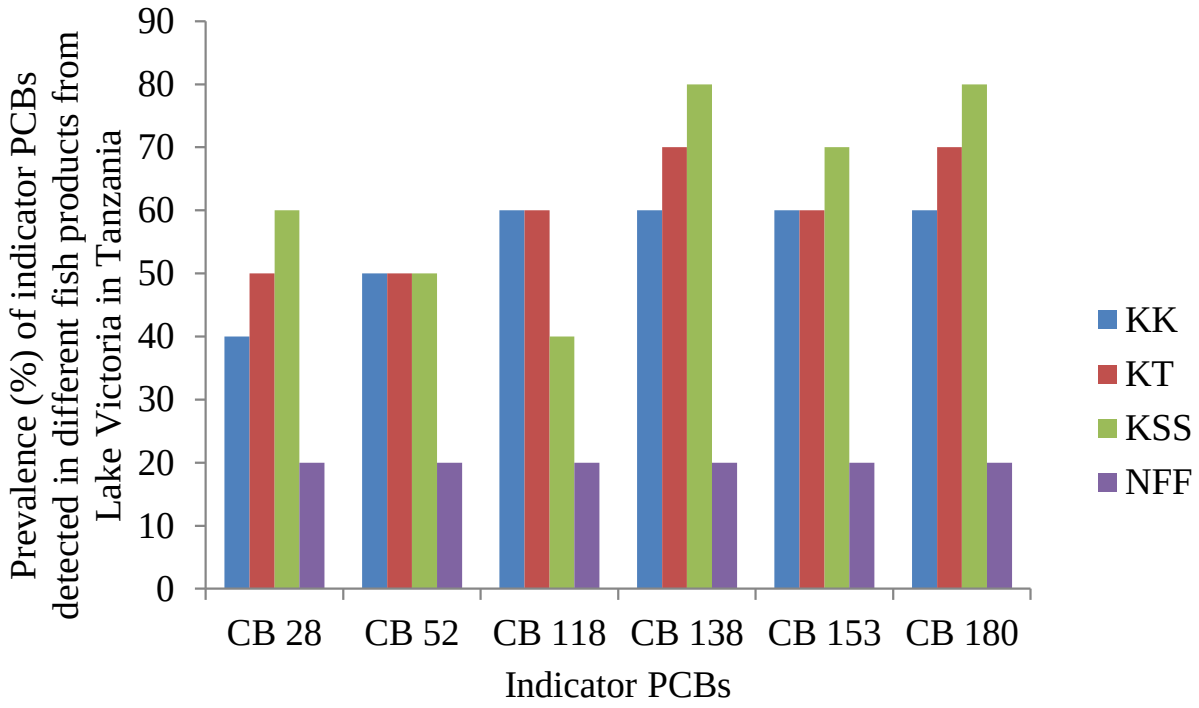

Figure 1. Prevalence (%) of indicator PCBs in fish products (KK- Kayabo, KT- Trims, KSS- Smoked products and NFF- Deep fried products).

loading for adults were in a range between 2.0E-04 and 3.0E-04 while for children were between 2.0E-04 and 1.0E-03. These values are within the range 1.0E-04≤value<1.0E-03 and classified as low to moderate risk (ATSDR, 2007; Man et al., 2013; Wenaty et al., 2019a, b). This observation suggests that there are only few cancer risks of indicator PCBs associated with consumption of *L. niloticus* products from Lake Victoria. Based on ATSDR standard, the cancer risks for PCBs in this study are between low to moderate.

Table 5 shows the hazard quotients (HQs) and hazard indices (HI) defining the non- cancer risks of indicator PCBs associated with consumption of *L. niloticus* products from Lake Victoria. The Hazard Indices (HI)(sum of Hazard Quotients (HQs)) ranged between 8.5E-03 and 1.8E-02 for adults and between 1.0E-02 and 2.0E-02 for children. In both cases, the HI values were very low (less than one). The United States Environmental Protection Agency (USEPA, 2009), recommends that HI values less than one indicates no risk. Therefore results from this study suggest that the risks associated with consumption of the analysed fish products from Lake Victoria are insignificant for both adults and children in regards to indicator PCBs (Table 4).

CONCLUSION AND RECOMMENDATIONS

This study analysed the occurrence, levels and risks of indicator PCBs in processed *L. niloticus* products from Lake Victoria in Tanzania. The levels of the detected PCBs were below the maximum recommended limits for fish and fishery products. The investigated fish products are therefore safe for human consumptions in regards to indicator PCB residues. Human health risk assessment indicated low cancer risks and insignificant non-cancer risks suggesting that the fish products do not present a health risk. However, follow up studies to assess the cooking oil and the influence of fish processing such as deep-frying and smoking on levels of indicator PCBs in fish products are hereby recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Table 4. Lifetime cancer risks for the indicator PCBs detected in processed *L. niloticus* products from Lake Victoria.

PCBs \ Samples	Kayabo		Trims		Smoked products		Deep fried products	
	AD	CHI	AD	CHI	AD	CHI	AD	CHI
	CR	CR	CR	CR	CR	CR	CR	CR
CB 28	6.4E-05	1.6E-04	5.2E-05	1.3E-04	5.5E-05	1.3E-04	1.9E-05	4.5E-05
CB 52	3.2E-05	7.8E-05	3.9E-05	9.5E-05	3.9E-05	9.5E-05	1.3E-05	3.2E-05
CB 101	ND	ND	ND	ND	ND	ND	ND	ND
CB 118	4.5E-05	1.1E-04	2.0E-05	4.8E-05	5.8E-05	1.4E-04	3.6E-05	8.7E-05
CB 138	5.7E-05	1.4E-04	7.5E-05	1.8E-04	6.1E-05	1.5E-04	3.2E-05	7.7E-05
CB 153	6.1E-05	1.5E-04	8.3E-05	2.0E-04	6.8E-05	1.7E-04	3.5E-05	8.4E-05
CB 180	4.2E-05	1.0E-04	6.4E-05	1.6E-04	4.3E-05	1.0E-04	3.5E-05	8.6E-05
∑PCBs	3.0E-04	7.3E-04	3.3E-04	1.6E-04	3.2E-04	7.8E-04	1.7E-04	4.1E-04

AD stands for adults, CHI for children, CR for lifetime cancer risk and ND for Not Determined as the concentration was <LOD.

Table 5. Non- carcinogenic risks of the indicator PCBs measured in processed *L. niloticus* products from Lake Victoria.

PCBs \ Samples	Kayabo		Trims		Smoked products		Deep fried products	
	AD	CHI	AD	CHI	AD	CHI	AD	CHI
	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ
CB 28	3.2E-03	3.9E-03	2.6E-03	3.1E-03	2.8E-03	3.3E-03	9.3E-04	1.1E-03
CB 52	1.6E-03	1.9E-03	2.0E-03	2.4E-03	2.0E-03	2.4E-03	6.6E-04	8.0E-04
CB 101	ND	ND	ND	ND	ND	ND	ND	ND
CB 118	2.2E-03	2.7E-03	9.9E-04	1.2E-03	2.9E-03	3.5E-03	1.8E-03	2.2E-03
CB 138	2.9E-03	3.5E-03	3.8E-03	4.6E-03	3.1E-03	3.7E-03	1.6E-03	1.9E-03
CB 153	3.0E-03	3.7E-03	4.1E-03	5.0E-03	3.4E-03	4.1E-03	1.7E-03	2.1E-03
CB 180	2.1E-03	2.5E-03	3.2E-03	3.9E-03	2.2E-03	2.6E-03	1.8E-03	2.1E-03
HI =∑HQs	1.5E-02	1.8E-02	1.7E-02	2.0E-02	1.6E-02	2.0E-02	8.5E-03	1.0E-02

AD stands for adults, CHI for children, HQ for hazard quotient, HI for hazard index and ND for not determined.

REFERENCES

Afful S, Awudza JAM, Osae S, Twumasi SK (2013a). Persistent Organochlorine Compounds in the Water and Sediment Samples from Lake Bosomtwe in Ghana. American Chemical Science Journal 3(4):434-448.

Afful S, Awudza JAM, Twumasi SK, Osae S (2013b). Determination of indicator polychlorinated biphenyls by gas chromatography- electron capture detector. Chemosphere 93:1556-1560.

Anastassiades M, Lehotay SJ, Stajnbaher D, Schenck FJ (2003). Fast and easy multiresidue method employing acetonitrile extraction/partitioning and "dispersive solid-phase extraction" for the determination of pesticide residues in produce. Journal of Association of Official Analytical Chemistry International 86:412-431.

Agency for Toxic Substances and Disease Registry (ATSDR) (1995). Public Health Assessment. Agency for Toxic Substances and Disease Registry, Atlanta 357 p.

Agency for Toxic Substances and Disease Registry (ATSDR) (2007). Hopewell Precision Area Contamination Hamlet of

Hopewell Junction Town of East Fishkill. New York State Department of Health Center for Environmental Health, New York 76 p.
Bell MR (2014). Endocrine-disrupting actions of PCBs on brain development and social and reproductive behaviours. Current Opinion in Pharmacology 19:134-144.
Bjermo H, Darnerud PO, Lignell S, Pearson M, Rantakokko P, Nälsén C, Enghardt-Barbieri H, Kiviranta H, Lindroos AK, Glynn A (2013). Fish intake and breastfeeding time are associated with serum concentrations of organochlorines in a Swedish population. Environment International 51:88-96.
Boon J P, Van der Meer J, Allchin CR, Law RJ, Klungsøyr J, Leonards PEG, Spliid H, Storr-Hansen E, McKenzie C, Wells DE (1997). Concentration-dependent changes of PCB patterns in fish-eating mammals: structural evidence for induction of cytochrome P450. Archives of Environmental Contamination and Toxicology 33(3):298-311.
Bordajandi LR, Abad E, González MJ (2008). Occurrence of PCBs, PCDD/Fs, PBDEs and DDTs in Spanish breast milk: Enantiomeric fraction of chiral PCBs. Chemosphere 70(4):567-575.
Cok İ, Donmez MK, Hakan-Satıroğlu M, Aydınuraz B, Henkelmann B, Kotalik J, Schramm KW (2007). Concentration of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and dioxin-like PCBs in human adipose tissue from Turkish men. Chemosphere 66(10):1955-1961.
European Commission (EC) (2011). Maximum levels of dioxins, dioxins-like PCBs and non-dioxins-like PCBs in foodstuffs. Official Journal of European Union 320:18-23.
Field JA, Sierra-Alvarez R (2008). Microbial degradation of chlorinated dioxins. Chemosphere *71*(6):1005-1018.
Frouin H, Dangerfield N, Macdonald RW, Galbraith M, Crewe N, Shaw P, Mackas D, Ross PS (2013). Partitioning and bioaccumulation of PCBs and PBDEs in marine plankton from the Strait of Georgia, British Columbia, Canada. Progress in Oceanography 115:65-75.
Ge J, Woodward LA, Li QX, Wang J (2013). Composition, distribution and risk assessment of organochlorine pesticides in soils from the Midway Atoll, North Pacific Ocean. Science of the Total Environment 452(453):421-426.
Henry L, Kishimba MA (2006). Pesticide residues in Nile tilapia (*Oreochromis niloticus*) and Nile perch (*Lates niloticus*) from Southern Lake Victoria, Tanzania, Environmental Pollution 140(2):348-354.
Lake Victoria Fisheries Organization (LVFO)(2013). Processing and Marketing of Small- Sized Pelagics in Eastern and Southern Africa. Working Papers No. 29. Published by the European Union. Jinja, Uganda 58 p.
Liu H, Yu L, Sheng G, Fu J, Peng P (2007). Severe PCDD/F and PBDD/F pollution in air around an electronic waste dismantling area in China. Environmental Science and Technology 41(16):5641-5646.
Man YB, Kand Y, Wang HS, Lau W, Li H, Sun XL, Giesy JP, Chow KL, Wong MH (2013). Cancer risk assessments of Hong Kong Soils contaminated by Polycyclic Aromatic Hydrocarbons. Journal of Hazardous Materials 261:770-776.
Oluoch-Otiego J, Oyoo-Okoti E, Kiptoo KKG, Chemoiwa EJ, Ngugi CC, Simiyu G, Omutange ES, Ngure V, Opiyo MA (2016). PCBs in fish and their cestode parasites in Lake Victoria. Environmental Monitoring and Assessment 188(483):1-14.
Polder A, Muller MB, Lyche JL, Mdegela RH, Nonga HE, Mabiki FP, Mbise TJ, Skaare JU, Sandvik M, Skjerve E, Lie E (2014). Levels and patterns of persistent organic pollutants in tilapia (*Oreochromis sp*) from four different lakes in Tanzania: Geographical differences and implications for human health. Science of the Total Environment 488(489):252-260.
Ssebugere P, Sillanpa M, Kiremire BT, Kasozi GN, Wang P, Sojinu SO, Otieno PO, Zhu N, Zhu C, Zhang H, Shang H, Ren D, Li Y, Zhang Q, Jiang G (2014). Polychlorinated biphenyls and hexachlorocyclohexanes in sediments and fish species from the Napoleon Gulf of Lake Victoria, Uganda. Science of the Total Environment 481:55-60.
US Environmental Protection Agency (1997). Exposure Factors Handbook-General Factors. Environmental Protection Agency, Washington DC. 854 p.
US Environmental Protection Agency (2001). Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Environmental Protection Agency, Washington DC. 187 p.
US Environmental Protection Agency (2009). Risk Assessment Guidance for Superfund. Human Health Evaluation Manual. Environmental Protection Agency, Washington DC. 291 p
Wenaty A, Fromberg A, Mabiki F, Chove B, Dalsgaard A, Mdegela R (2019a). Persistent Organochlorine Compounds Levels in Selected Fish Species from Lake Victoria and Associated Human Health Risks. Forestry, Agriculture and Fisheries 8(1):1-9.
Wenaty A, Fromberg A, Mabiki F, Chove B, Dalsgaard A, Mdegela R (2019b). Assessment of health risks associated with organochlorine pesticides levels in processed fish products from Lake Victoria. African Journal of Food Science 13(5):101-110.
Wenaty A, Mabiki F, Chove B, Mdegela R (2018). Fish consumers preferences, quantities of fish consumed and factors affecting fish eating habits: A case of Lake Victoria in Tanzania. International Journal of Fisheries and Aquatic Studies 6(6):247-252.
Witczak A (2009a). Effect of Heat Treatment on Organochlorine Pesticides in Selected Fish Species. Polish Journal of Food and Nutrition Sciences 59(3):231-235.
Witczak A (2009b). Effect of frying on polychlorinated biphenyls content in muscle meat of selected fish species. Polish Journal of Food and Nutritional Sciences 59:159-164.
Witczak A (2012). Influence of Smoking on Indicatory PCB Congeners Residues Levels in Fish Slices. Polish Journal of Food and Nutritional Sciences 62(1):31-39.
Witczak A, Ciereszko W (2006). Changes in total PCB content in selected fish products during hot and cold smoking. Acta Ichthyologica Et Piscatoria 36(1):11-16.
Witczak A, Ciereszko W (2012). Influence of smoking on indicatory Polychlorinated biphenyls congeners residues levels in fish slices. Polish Journal of Food and Nutrition Sciences 62(1):31-39.