



FORMALIN IN IMPORTED FROZEN FISH PRODUCTS IN BAYELSA STATE, NIGERIA: EFFECTS OF HEAT TREATMENTS ON THE CONCENTRATION AND HEALTH RISK ASSESSMENT

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ABSTRACT

Fish make up an essential component of daily diets due to their nutritional composition. In this study, formalin concentration in imported fish products in Bayelsa State, Nigeria, was undertaken. The effect of household heat processing treatments on the formalin concentrations, and the potential risk associated with consumption of these fish products, were evaluated. Fish products of different species were obtained from wholesale and retail outlets, and were prepared as raw, cooked, fried and smoked samples. Formalin was extracted from the prepared fish samples using a mixture of acetone and dichloromethane, and quantified using GC-MS. The average daily intake (ADI) of formalin was used to estimate potential health risk. Results showed low concentration of formalin in the raw fish samples, while heat processing treatments (frying and boiling) significantly elevated formalin concentrations. The formalin concentrations of heat processed fish samples with respect to the raw samples followed the order: smoked < raw < boiled < fried; and raw < smoked < boiled < fried for wholesale and retail products respectively. However, all formalin concentrations were below guideline values. The ADI of formalin were below established guideline values, suggesting that the intake of formalin in fish before and after household heat processing treatments may not pose significant risk to consumers of the imported frozen fish products.

Keywords: Formalin, food safety, average daily intake, risk assessment, heat treatment.

INTRODUCTION

Fishing as an occupation is common in the riverine areas of Nigeria, where it serves as one of the major sources of income for the rural dwellers. Fish serves as

a source of important nutrients to man, including proteins, lipids and omega-3 fatty acids (Erkmen and Bozoglu, 2016; Akpe *et al.*, 2020). It is different from other animals mainly due to its high levels of docosahexaenoic, eicosapentaenoic and docosapentaenoic acids (Miklavcic *et al.*, 2011; Tesi and Iniaghe, 2020). Local fish production has remained insufficient to meet the nation's demand for fish and fisheries products, as the natural fish supplies faces numerous obstacles, one of which is low catch (Eriegha *et al.*, 2022). The total fish consumption in Nigeria is approximately 3.6 million metric tons, with local production accounting for about 1.2 million metric tons. The shortfall of about 2.4 million metric tons is thus compensated with importation of frozen fish products (Falaju, 2022). This gap made Nigeria the largest importer of frozen fish products in Africa, and this importation accounts for over ₦125 billion annually (Okojie, 2017). Since fish is a perishable item, many fish farmers preserve their products by freezing, smoking, salting, drying and pickling. Some fish marketers may also augment freezing by dipping, spraying or injecting fish products with formalin in order to artificially improve the appearance. This is often done to compensate for the unavailability of high-quality-ice at harvest centres to sustain fish in marketable condition (Jaman *et al.*, 2015).

Formalin is a solution of 37% (w/w) of formaldehyde in water. It is marketed as Formol, Lysoform, Fannoform, Morbicide acid and Superlysoform (Laly *et al.*, 2018). It is commonly used in medical laboratories as a preservative, and as a fixative in biological specimens (WHO, 2002). It is also used for limiting bacterial development in sugar factories (Jindasa *et*

al., 2022), and as a bacteriostatic agent in a variety of Italian cheese (IARC, 2004). However, in Europe, Australia and Japan, it is unapproved for use in aquaculture due to its link with cancer and tumor development (Yeh *et al.*, 2013). Although there are no indications that its use is officially banned in Nigeria, verbal warnings from the Nation's Regulatory Agency have been issued to meat and fish sellers against the use of formalin in preserving their products. There are no established safe levels of human exposures to formalin via oral ingestion; however, very low levels are specified for its presence in air. For instance, the airborne occupational exposure limit to formalin is set at 0.75 ppm in the United States, and 0.3 ppm in the European Union (NJDOH, 2016). Formalin is classified as a Group 1 carcinogen, and human exposure is reported to be associated with several health problems such as asthma, lung cancer, blindness, etc. (IARC, 2004). Toxicity studies on humans have shown that ingestion of formalin caused several effects in the central nervous system (such as behavioural disorders, headache), teratogenic and mutagenic effects, ranging from neurophysiologic to respiratory, damage and ulceration of the gastrointestinal tract, etc. (Inci *et al.*, 2013).

Formaldehyde is endogenously present in fish via enzyme-induced breakdown of trimethylamine oxide (TMAO) to equal amounts of formaldehyde and dimethylamine during post-mortem storage (Bhowmik *et al.*, 2017). The formaldehyde formed leads to toughness of fish muscles and loss of water (Otu *et al.*, 2013; Joshi *et al.*, 2015; Immaculate and Jamila, 2018). Muscle toughening and loss of water-holding ability of fish are results of a cross-linked reaction between

formaldehyde and myofibrillar protein in fish (Harard and Simpson, 2000). Endogeneously formed formaldehyde is typically present at very low levels and may not be considered a significant health concern for consumers, because the human body is able to naturally metabolize and eliminate small amounts of formaldehyde (Pontel *et al.*, 2015). However, increased quantities of formaldehyde in fish may occur, which depends on several post-harvest practices, including fish quality and dimension, storage temperature, metabolic processes, quality of fish feeds, aging and deterioration of fish flesh, etc. (Jinadasa *et al.*, 2022). The upper permissible limit of naturally occurring formaldehyde in different fish species is set at 4 mg kg⁻¹ for marine and fresh water fish, and 100 mg kg⁻¹ for all frozen stored marine products (FSSAI, 2022). Endogenous formaldehyde may thus, exhibit potential carcinogenic characteristics at increased levels (Pontel *et al.*, 2015).

There are few studies quantifying formalin levels in imported food products in Nigeria, including frozen meat (Otu *et al.*, 2013) and fish samples (Akpe *et al.*, 2020; Aniobi *et al.*, 2022). In this study, a comparative analysis on the formalin level in imported fish products obtained from wholesale and retail outlets in Bayelsa State, Nigeria, was carried out. This comparison was done basically because most of the consumers of these products, especially in small towns and villages, purchase fish products from retail outlets, and the condition of exposure during sales of the products differ. Additionally, the effect of different household heat processing treatments (cooking, frying and smoking) on the formalin content in the fish, and the potential risk arising from the

consumption of formalin in these fish products, was carried out.

MATERIALS AND METHODS

Reagents

Formalin standard was obtained from Accu Standard (New Haven, CT, USA). Dichloromethane (DCM) was HPLC grade, and obtained from Sigma-Aldrich, St. Louis, MA, USA.

Sample Collection and Preparation

Five different species of marine fish available in the market at the time of sampling, including the Atlantic horse mackerel (*Trachurus trachurus*), Mackerel (*Scomber scombrus*), Mellusa (*Merluccius spp.*), Rockfish (*Sebastes entomelas*) and Sardine (*Chupea pilchardus*) and one fresh water fish species - Tilapia (*Oreochromis niloticus*) from different countries of origin, were obtained from wholesale and retail outlets in Yenagoa metropolis, Bayelsa State, Nigeria. The wholesale products included Tilapia, Atlantic horse mackerel, Mackerel, Mellusa and Rockfish; while the retail products obtained from market places were Sardine, Atlantic horse mackerel, Mellusa, Rockfish and Mackerel. Collected fish samples were kept in plastic bags and stored in ice immediately after purchase. In the laboratory, samples were rinsed with water. Following household heat processing treatments of fish prior to consumption, the fish samples (n=3) were prepared as raw, cooked (dipped in boiling water for about 10 minutes), smoked (roasting the fish in smoky dry wood with little/ no flame for at least 12 hours), and fried (dipped in hot vegetable oil for about 10 minutes). After subjecting the fish samples to the above-mentioned processes, upon cooling, fish bones were removed, after which they were pulverized to reduce

their sizes using an electric blender. They were then packed in well-labeled aluminium foils and stored in a refrigerator at -4 °C.

Extraction, Clean-up and Quantification of Formalin

A 10 g of pulverized fish sample was weighed into a beaker, this was followed by the addition of 10 mL of a mixture of acetone and dichloromethane (1:1). The resulting mixture was swirled to mix properly and covered with aluminium foil to prevent evaporation of the extraction solvent, and allowed to stand for 12 hrs. Clean-up and concentration of the extract was done in a 5 cm length sodium sulphate-packed column. The filtrate was then collected in a 2 ml vial bottle prior to quantification (EPA, 2017). The formalin concentration in the fish samples was analyzed using Agilent 6890 with 5973 MSD GC-MS (Agilent Technologies, Wellinto, DE, USA). The GC had a 30 m length DB-5 capillary column with 0.32 mm internal diameter and 0.25 m film thickness (J & W Scientific, Folsom, CA). The mobile phase was ultrapure helium gas with linear velocity of 1 ml min⁻¹. The splitless mode was adopted for injection of 2.0 µl of sample extract. The initial column temperature was fixed at 85 °C with 3 mins

held on time. This was subsequently stepped up to 200 °C at 35 °C min⁻¹, and finally stepped up from 200 °C to 300 °C at 5 °C min⁻¹. The injector, quadrupole and mass detector source were programmed at 250 °C, 150 °C and 230 °C, respectively.

Quality Control Measures

Recovery study was used for assessing the efficiency of the extraction method. The results of the recovery studies were in the range of 80.7–96.4% with RSD for replicate analyses ($n=3$) <6%. The limits of quantification (LOQs) and detection (LODs) were evaluated based on the background noise from the blank sample analysis. The LOQ and LOD are the concentrations of the formalin that gave a signal-to-noise ratio of 10 and 3 respectively.

Health Risk Assessment

The daily intake of formalin in fish is influenced by the concentration of formalin in the fish and the average fish intake rate. Additionally, the body weight of humans consuming the fish can also affect the tolerance of formalin. The average daily intake (ADI) takes these factors into account (Chamannejadian *et al.*, 2013). It was evaluated using the expression as shown in equation (1) below:

$$ADI = \frac{\text{Concentration of formalin (mg/kg)} \times \text{consumption rate of fish (kg/day)}}{\text{Body weight (kg)}} \quad (1)$$

Where ADI is expressed in units of mg kg⁻¹ body weight day⁻¹. A consumption rate of 36.4 g of fish per day in Nigeria, and an average weight of 60 kg adult and 15 kg children (Worldfish, 2023) were assumed for the estimation of dietary exposure to formalin.

Statistical Analysis

Analysis of variance (ANOVA) was used to determine if there was a significant variation in formalin concentrations within and among the different species and heat processing technique applied at 0.05 level of significance. SPSS version 19.0 software (SPSS Inc., USA) was used to perform statistical analyses.

The results of concentration of formalin in fish samples from both wholesale and retail outlets are shown in Table 1. The formalin concentrations ranged from 0.006 to 0.032 mg kg⁻¹ in both wholesale and retail products respectively. Significant differences ($p>0.05$) existed in

same kind obtained from wholesale and retail outlets, and also across the different species from both sales outlets. However, there was no significant ($p<0.05$) difference in the average formalin concentrations from the two different outlets.

Table 1: Concentration of formalin in raw fish samples

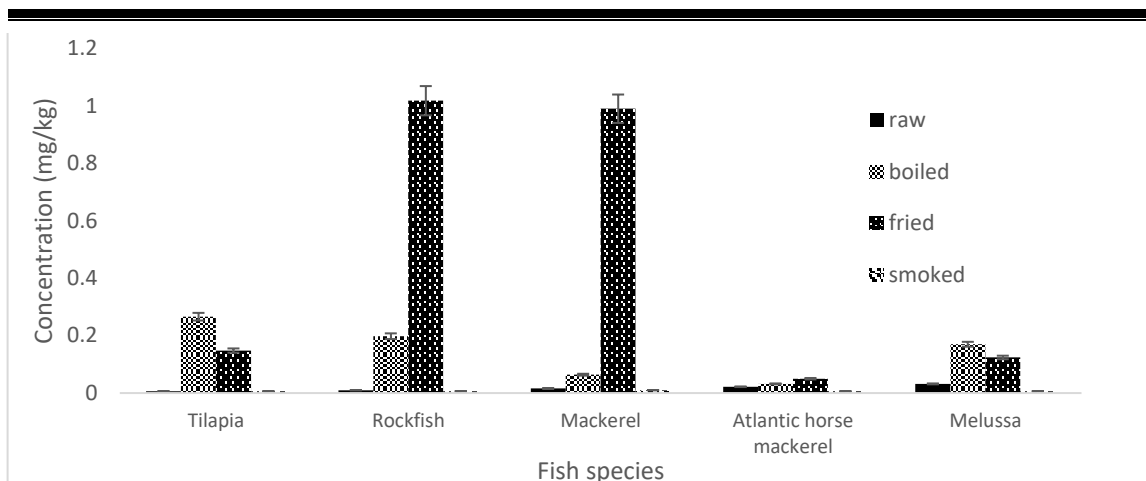
Fish species (n=3)	Concentration of formalin (mg kg ⁻¹)	
	Wholesale	Retail
Atlantic horse mackerel	0.022±0.003 ^a	0.032±0.020 ^c
Mackerel	0.016±0.001 ^b	0.010±0.001 ^d
Mellusa	0.032±0.005 ^c	0.006±0.002 ^d
Tilapia	0.006±0.002 ^d	NA
Rockfish	0.010±0.001 ^d	0.010±0.002 ^d
Sardine	NA	0.016±0.005 ^b
Mean±SD	0.017±0.010 ^b	0.015±0.010 ^b
Permissible limits	100*, 20**, 6.5-293***	

Mean values with different superscripts indicate significant difference at $p<0.05$; where NA - not available; *FSSAI (2022); **WHO (2002); ***EFSA (2014).

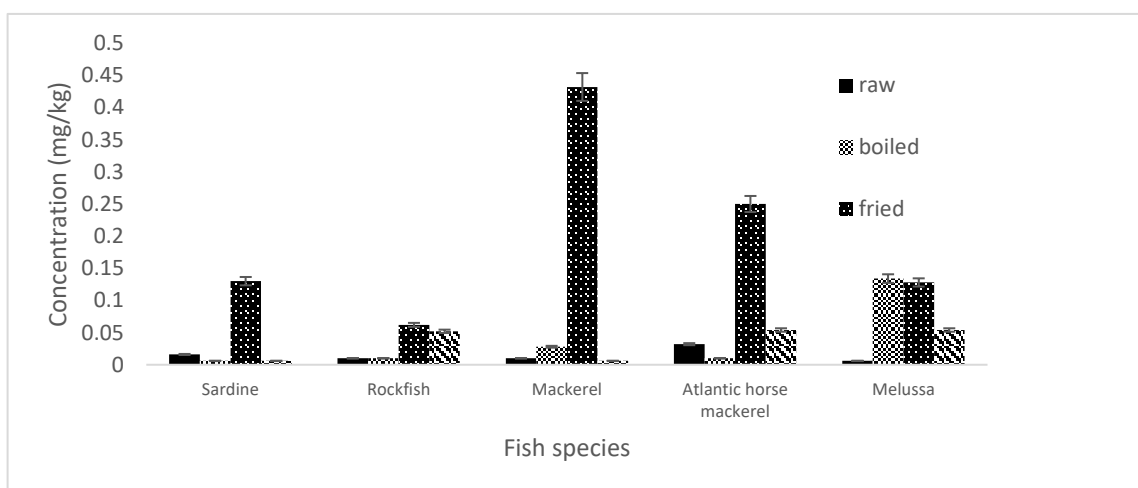
The average concentrations of formalin in heat-processed fish samples ranged as followed: boiled (0.006-0.266 mg kg⁻¹), fried (0.050-1.018 mg kg⁻¹), and smoked (0.006-0.054 mg kg⁻¹). The effect of heat processing treatments on the average formalin concentrations with respect to the raw fish samples followed the order: smoked < raw < boiled < fried in wholesale products; and raw < smoked < boiled < fried in retail products. Smoking was observed to significantly ($p>0.05$) lower formalin concentrations in all fish

samples obtained from wholesale outlets, and in 20% in fish products from retail outlets. However, frying significantly ($p>0.05$) increased formalin concentrations by over 10 orders of magnitude in Mackerel (from both sales outlets) and Rockfish (from wholesale outlet). Boiling was also seen to significantly ($p>0.05$) increase formalin concentrations in all fish samples from wholesale outlet, and in Sardine and Atlantic horse mackerel from retail outlets (Figures 1 a and b).

Formalin in Imported Frozen Fish Products in Bayelsa State, Nigeria: Effects of Heat Treatments on the Concentration and Health Risk Assessment



a.



b.

Figure 1: Effect of heat processing techniques on formalin concentrations in (a) wholesale imported fish products and (b) retail imported fish products

The contents in Table 2 compared the results of the present study on concentrations of formalin in selected fish samples from both wholesale and retail outlets in Bayelsa State, Nigeria with similar studies from within and outside Nigeria. The concentrations of formalin in

fish samples of this study were low when compared with those reported for Enugu markets, but comparable to those available in Calabar metropolis, Kumasi area of Ghana, Temale metropolis in Ghana and in fish products available in Malaysia.

Table 2: Comparison of the formalin concentrations in fish obtained in this study with literature

Location	Fish form	Concentration of formalin (mg kg ⁻¹)	Reference
Calabar, Nigeria	Raw	0.006-0.054 1.42 - 2.20	Akpe <i>et al.</i> , 2020
Enugu, Nigeria	Raw	80 - 146	Aniobi <i>et al.</i> , 2022
Ghana	Raw	0.17-3.71	Asare-Donkur <i>et al.</i> , 2018
Dhaka	Raw	9.40 - 19.23	Bhowmik <i>et al.</i> , 2017
Dhaka	Raw	5.1 - 39.6	Bhowmik <i>et al.</i> , 2016
	Cooked	0.67 - 2.29	
	Boiled	0.57 - 1.66	
Bangladesh	Raw	5.80 - 21.8	Hoque <i>et al.</i> , 2016
	Cooked	0.98 - 5.93	
Bangladesh	Raw	0.43 - 6.92	Hoque <i>et al.</i> , 2018
Nepal	Raw	0.39 - 2.33	Joshi <i>et al.</i> , 2015
Bangladesh	Raw	3.9 - 13.4	Hossain <i>et al.</i> , 2008
Dar es Saalam	Raw	3.91-16.1	Manyanga <i>et al.</i> , 2022
Malaysia	Raw	0.38 - 15.7	Noordiana <i>et al.</i> , 2011
Thailand	Raw	0.434 - 0.932	Senthong <i>et al.</i> , 2021
Malaysia	Raw	2.08-2.95	Siti <i>et al.</i> , 2013
Yenagoa, Nigeria	Raw	0.006 - 0.032	Present study
	Boiled	0.006 - 0.266	Present study
	Fried	0.050 - 1.018	Present study
	Smoked	0.006 - 0.034	Present study

The average daily intakes (ADI) or oral reference dose of a chemical is an estimate of a daily exposure to the human population that is likely to be without an appreciable risk of deleterious effects during a lifetime. The ADI of formalin in the studied fish products are shown in Table 3. For children scenario, the values ranged from 1.45×10^{-5} to 7.76×10^{-5} , 1.45×10^{-5} to

4.80×10^{-4} , 1.21×10^{-4} to 1.04×10^{-3} , and 1.45×10^{-5} to 1.31×10^{-4} mg kg⁻¹ bw day⁻¹ for raw, boiled, fried and smoked fish samples respectively. For adult exposure scenario, the ADI values ranged from 3.60×10^{-6} to 1.94×10^{-5} , 3.60×10^{-6} to 1.20×10^{-4} , 3.03×10^{-6} to 6.17×10^{-4} , and 3.60×10^{-6} to 3.28×10^{-5} mg kg⁻¹ bw day⁻¹ for raw, boiled, fried and smoked fish samples respectively.

Table 3: Average daily intake of formalin in fish

Exposure group	Point of purchase	Fish type	Average daily intake (mg kg ⁻¹ bw day ⁻¹)			
			Raw	Boiled	Fried	Smoked
Children	Wholesale	Tilapia	1.45x10 ⁻⁵	6.45x10 ⁻⁴	3.59x10 ⁻⁴	1.45x10 ⁻⁵
		Rockfish	2.42x10 ⁻⁵	4.80x10 ⁻⁴	2.47x10 ⁻³	2.42x10 ⁻⁵
		Mackerel	3.88x10 ⁻⁵	1.55x10 ⁻⁴	2.40x10 ⁻³	1.45x10 ⁻⁵
		Atlantic horse	5.33x10 ⁻⁵	7.76x10 ⁻⁵	1.21x10 ⁻⁴	1.45x10 ⁻⁵
		Melussa	7.76x10 ⁻⁵	4.12x10 ⁻⁴	3.00x10 ⁻⁴	1.45x10 ⁻⁵
	Retail	Tilapia	3.88x10 ⁻⁵	1.45x10 ⁻⁵	3.15x10 ⁻⁴	1.45x10 ⁻⁵
		Rockfish	1.45x10 ⁻⁵	3.25x10 ⁻⁴	3.10x10 ⁻⁴	1.31x10 ⁻⁴
		Mackerel	2.42x10 ⁻⁵	2.42x10 ⁻⁵	1.50x10 ⁻⁴	1.26x10 ⁻⁵
		Atlantic horse	2.42x10 ⁻⁵	6.79x10 ⁻⁵	1.04x10 ⁻³	1.45x10 ⁻⁵
		Melussa	7.76x10 ⁻⁵	2.42x10 ⁻⁵	6.06x10 ⁻⁴	1.31x10 ⁻⁴
Adults	Wholesale	Tilapia	3.64x10 ⁻⁵	1.61x10 ⁻⁴	8.97x10 ⁻⁵	3.60x10 ⁻⁶
		Rockfish	6.06x10 ⁻⁶	1.20x10 ⁻⁴	6.17x10 ⁻⁴	3.60x10 ⁻⁶
		Mackerel	9.70x10 ⁻⁶	3.88x10 ⁻⁵	6.00x10 ⁻⁵	6.06x10 ⁻⁶
		Atlantic horse	1.33x10 ⁻⁵	1.94x10 ⁻⁵	3.03x10 ⁻⁵	3.60x10 ⁻⁶
		Melussa	1.94x10 ⁻⁵	1.03x10 ⁻⁴	7.52x10 ⁻⁵	3.60x10 ⁻⁶
	Retail	Tilapia	9.70x10 ⁻⁶	3.64x10 ⁻⁶	7.88x10 ⁻⁵	3.60x10 ⁻⁶
		Rockfish	3.64x10 ⁻⁶	8.12x10 ⁻⁵	7.76x10 ⁻⁵	3.27x10 ⁻⁵
		Mackerel	6.06x10 ⁻⁶	6.06x10 ⁻⁶	3.76x10 ⁻⁵	3.15x10 ⁻⁵
		Atlantic horse	6.06x10 ⁻⁶	1.69x10 ⁻⁵	2.62x10 ⁻⁴	3.60x10 ⁻⁶
		Melussa	1.94x10 ⁻⁵	6.06x10 ⁻⁶	1.51x10 ⁻⁴	3.28x10 ⁻⁵
Maximum oral exposure dose			0.2*, 1.7**, 0.15***			

*Nordiana *et al.* (2011); **EFSA (2014); ***Zhang *et al.* (2015).

DISCUSSION

Formalin is a carcinogenic compound, and its usage is banned in many countries. However, there are reported cases of its use in fishery. The low concentration of formalin in fish samples from both wholesale and retail outlets in this study could be an indication of its endogenous presence in fish formed during postmortem storage, as a result of a breakdown of TMAO in fish by trimethylamine adolase (Yeh *et al.*, 2013; Bhowmik *et al.*, 2017). The low formalin concentrations in fish in this study can be attributed to the high reactivity of postmortem formaldehyde with free amino acids, proteins and nucleic acids, which made it difficult for formaldehyde to be released from fish

tissues (Rehbein, 1987). Additionally, low levels of formalin in fish could be attributed to the use of water for rinsing fish samples, which could remove surface-bound formalin prior to homogenization and sample preparation (Senthong *et al.*, 2021). The concentrations of formalin obtained in all studied fish samples were within the permissible upper limit for naturally occurring formaldehyde levels in frozen marine products (WHO, 2002; EFSA, 2014; FSSAI, 2022).

The low concentrations of formalin observed in fish products in this study can also be likened to the fact that all fish samples were completely frozen at the time of purchase; an indication that the products remained sufficiently frozen even during

transport from the borders to their final destinations for storage. This observation was corroborated by a previous study conducted by the World Health Organization (WHO, 2002), which demonstrated that high concentrations of formalin were formed when fish was exposed for longer periods in the environment without proper preservation. The study opined that uniced fish samples contained significantly higher formalin content compared to iced fish samples. Furthermore, Hoque *et al.* (2018) noted that increased concentration of formaldehyde was observed in imported fish due to the extra time it took along the supply chain to get to the final destination of the fish. Therefore, natural formaldehyde can accumulate during improper fish storage. The difference in formalin concentrations obtained in this study with those obtained in literature may be attributed to differences in the level of trimethylamine oxide formed upon death and during storage of fish, fish species and habitat, long storage periods prior to sale, storage temperature, moisture content, the intentional addition of formalin prior to packaging, difference in response to reaction between formaldehyde and fish protein, etc. (Bianchi *et al.*, 2007; Noordiana *et al.*, 2011, Yeh *et al.*, 2013, Wahed *et al.*, 2016).

Different heat processing methods for fish prior to consumption have been reported to alter both endogenously formed and artificially introduced formalin concentrations. According to Siti *et al.* (2013), Bhowmik *et al.* (2016) and Hoque *et al.* (2016), cooking in boiling water and frying/dipping in hot vegetable oils reduced formalin levels in fish due to solubility of formalin in water and evaporation at the boiling/frying temperature, while Hoque *et*

al. (2016) suggested that sufficient cooking was necessary to reduce the formalin levels in fish to within acceptable levels. The results of the present study however were in contrast to the above-mentioned trend for boiled and fried fish samples, as formalin concentrations were found to increase with heat processing treatments. The increasing concentration of formalin with heat processing treatments in some of the studied fish products had been explained by a sequence of reactions. According to Sikorski *et al.* (1976), endogenous formaldehyde is highly reactive towards proteins, and a substantial part will be bound to the protein's functional groups in fish muscles, thereby forming cross-links among peptide chains via covalent bonding. The highly reactive formaldehyde can also bind with lysine and arginine residues in peptides, which form unstable methylol adducts on thiol and amino groups. Additionally, Schiff base on a lysine residue is able to form stable cross-links with amino acid residues, thereby limiting the evaporation of formaldehyde (Metz *et al.*, 2006). The formaldehyde-protein adduct complexes formed could then be stimulated by heat processes, thereby increasing the amount of formaldehyde released by cooking methods (Vandemoortele *et al.*, 2017). This process was also corroborated by Mason *et al.* (2004) who suggested that under harsh conditions such as steam distillation with acids, formaldehyde levels were expectedly high, since the amount of formaldehyde released was a sum of both the free and reversibly-bound formaldehyde.

This observation on heat treatment processes on increased level of formalin is especially important from the point of view of food safety, since fish species are usually

subjected to various household heat treatment processes such as cooking, frying and smoking before consumption. Despite the observed increasing concentration due to some heat treatment processes, especially frying, the concentration of formalin in all studied fish samples were still below the WHO estimated upper limit concentration for naturally formed formalin in fish flesh (WHO, 2002), and the European Food Safety Authority established naturally occurring levels of formaldehyde in fish (EFSA, 2014; Etienne, 2015). The computed ADI values of formalin obtained in this study were lower than the US EPA (Noordiana *et al.*, 2011), the World Health Organization (Zhang *et al.*, 2015) and the European Food Safety Authority (EFSA, 2014) maximum oral reference dose for formaldehyde. This suggested that consumption of formalin in fish found in both raw and heat-treated (cooked, fried and smoked) samples may pose no significant risk to consumers of the products. Similar but slightly higher ADI values were previously reported for fresh and cooked fish species in Bangladesh (Hoque *et al.*, 2016), Malaysia (Siti *et al.*, 2016), and Kumasi area of Ghana (Asare-Donkur *et al.*, 2018).

CONCLUSION

In this study, an insight into the concentration of formalin in imported fish products, the effect of the common household heat treatment processing on its concentration, and the potential health risk associated with consumption of formalin-contaminated fish, were presented. Although formalin is a carcinogen with no established safe exposure limit when ingested orally, endogenously formed formalin in fish has established permissible

limits, above which it becomes a potential human carcinogen. The quantified formalin in all studied fish products in this study were within the established permissible limit for endogenously formed formaldehyde in fish, thereby posing no public health concern arising from consumption of the fish products. Similarly, the calculated average daily intake levels of formalin in all studied fish samples were lower than established limits set by the World health Organization and the United States Environmental Protection Agency.

RECOMMENDATION

Since the studied species of fish were all imported and preserved via freezing, the results therefore suggest the non-use of formalin in preserving these products. However, with the study area being a riverine region, there are lots of individuals engaged in the fishing occupation, and a market survey indicates that local fish products are usually not preserved by freezing prior to sale, but are usually sold in the fresh and uniced form. It is therefore recommended that further investigations on the potential use of formalin as a preservative for fish be carried out on locally produced fish in Nigeria.

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