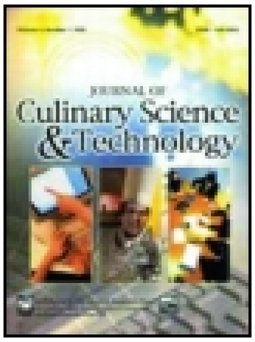

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Amino acid, vitamin and mineral profiles of smoked fish as affected by smoking methods and fish types

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ABSTRACT

This study was carried out to evaluate the amino acid, vitamin and mineral profile of smoked fish as affected by smoking methods and fish types. Forty samples of five types of fresh fish (*Guinean barracuda, Spotted tilapia, Bonga shad, Nigerian tongue sole* and *Silver catfish*) were purposively collected from 20 processing centres in Lagos State. The samples were divided into two batches, with each batch smoked using traditional drum and modern kiln methods. The contents of the smoked fish products (amino acids, vitamins and minerals) were determined. Results showed that the amino acid concentrations in g/100 g crude protein (cp) of lysine, arginine and leucine were in the ranged 7.47–7.83, 6.27–6.54 and 7.32–7.68, respectively, for drum-smoked fish, while those of the non-essential amino acids, glutamic acid, aspartic acid, and glycine were in the range 14.19– 14.52, 9.62–9.81 and 7.01–7.42, respectively. Similar results were obtained from kiln-smoked fish samples although with slightly higher values than in drum-smoked fish samples. In conclusion, it was found from this study that smoking method has no significant effect on the amino acid composition of smoked fish samples, but fish types had. Moreover, smoking method had a significant effect on vitamin contents; this might be due to the temperature of smoking as some of the vitamins investigated are heat labile. Thus, the high amino acid contents in smoked fish could supplement the corresponding deficiency in plant protein diets, especially in developing countries. Therefore, the proteins in a mixed diet could be utilized optimally for a healthy body constitution, especially among children and other vulnerable groups.

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Amino acids; vitamins; minerals; drum smoking; convective smoking

Introduction

Fish is an important dietary component of people all around the world and represents a relatively cheap and accessible source of high-quality protein for poorer households (Adeyeye, 2016; Ikutegbe & Sikoki, 2014). In West Africa, fish

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has been reported to provide 40%–70% of the protein intake of the population (Béné & Heck, 2005; Ikutegbe & Sikoki, 2014), and it is a critical source of dietary protein that is not readily available in the carbohydrate-based staple foods of the population. In Nigeria, fish has an edge over meat because it is cheaper and relatively more abundant (Eyo, 2001).

Research over the past few decades has shown that the nutrients and minerals in fish, and particularly the omega 3 fatty acids found in pelagic fish, are heart-friendly and can improve brain development and reproduction. This has highlighted the role for fish in the functionality of the human body (Aremu, Namo, Salau, Agbo, & Ibrahim, 2013; Fawole, Ogundiran, Ayandiran, & Olagunju, 2007; Fellows & Hampton, 1992).

Fish are consumed in several forms – fresh, dried, frozen, fermented, smoked or brined depending on consumer preference in many parts of the world, but smoked fish is the most common one in Nigeria and in many parts of Africa, especially due to its taste (Adeyeye, 2016). In a study by Mafimisebi (2012), it was discovered that the majority of the Nigerian people had a preference for fresh fish; however, limitations such as the low keeping quality of the fish after harvesting and the tendency of fish to spoil quickly make this very difficult. Smoking of fish has been found to enhance keeping quality, which extends the shelf-life of smoked fish (Adeyeye, 2016; Mafimisebi, 2012).

Fish is a food that is very often processed by different methods. Among the processed fish, smoked and dried fish are traditional products, which play important roles in the diet of a large section of the world's population (Adeyeye, 2016; Olley, Doe, & Heruwaty, 1988). Yanar (2007) reported that the acceptance of smoked fish in developed countries is based primarily on the sensory characteristics it imparts to the product. In Europe, about 15% of the total quantity of fish for human consumption is smoked prior to release to the market (Stołyhwo and Sikorski, 2005). The smoking process was basically used in the past for preservative purposes, although the changes in colour, odour, flavour and texture, which were produced in foods by this process, were also seen as desirable (Adeyeye, 2016).

The quality of smoked fish is affected by raw material (Adeyeye, 2016; Cardinal et al., 2001; Rora et al., 1998), salting method, brining concentration (Alcicek and Atar, 2010; Goulas and Kontominas, 2005; Sigurgisladottir, Sigurdardottir, Ingvars dottir, Torrissen, & Hafsteinsson, 2001), condition of processing (Duffes, 1999), composition of smoke (Kenneth and Hilderbrand, 1992; Stołyhwo and Sikorski, 2005), smoking method (Cardinal, Cornet, Sérot, & Baron, 2006), smoke agents (Siskos, Zotos, Melidou, & Tsikritzi, 2007) and storage conditions.

Fish provides a good source of high-quality protein and contains many vitamins and minerals (Al-Jedah, Ali, & Robinson, 1999). It may be classed as either whitefish, oily or shellfish. Whitefish, such as haddock and seer, contain very little fat (usually less than 1%), whereas oily fish, such as sardines, contain between 10% and 25% fat (Eyo, 2001). Fish is a rich source of lysine suitable for supplementing a high-carbohydrate diet. It is a good source of thiamin, riboflavin, vitamins A and D, phosphorous, calcium and iron. It is high in polyunsaturated fatty acids, which are important in lowering blood cholesterol level (Al-Jedah et al., 1999).

One of the greatest problems affecting the fishing industry all over the world is fish spoilage. In high ambient temperatures of the tropics, fresh fish have the tendency to spoil within 12–20 h (Clucas, 1981). An attempt has been made to reduce fish spoilage to the minimum through improved preservation techniques. During harvest times, fish is usually available in excess of demand. This leads to lower market price and fish spoilage, but if storage facilities are provided, the surplus of the harvest could be stored and distributed during the off-season. Preservation and processing methods explore ways by which spoilage is stopped or slowed down, to give the product a longer shelf life (Olokor, Ihuahi, Omojowo, Falayi, & Adelowo, 2007).

Food-processing methods have been found to affect food composition as well as losses in nutrients in processed foods. The nature of foods as well as the effect of the processing methods on the food to be processed should be taken into consideration in the cause of food processing.

Therefore, the objective of this study was to evaluate the amino acid, vitamin and mineral profiles of smoked fish as affected by smoking methods and fish types.

Materials and methods

Materials

Fish used

Forty samples from each type of fresh fish were obtained from 20 different fishing communities/processing centres in Badagry and Epe Local Government Areas of Lagos State, Nigeria. The fresh fish samples were divided into two batches, the first batch was smoked with a traditional drum oven and the second batch was immediately smoked with a convective kiln at the Fishery Hatchery Unit, Federal University of Agriculture, Abeokuta, Nigeria.

Methods

Traditional fish smoking process

Traditional drum-smoked fish samples (Figure 1) were prepared by the method of Ahmed, Dodo, Bouba, Clement, & Dzudie (2011). Fish samples were cleaned with water. The fish were then skewed and salted. The skewed

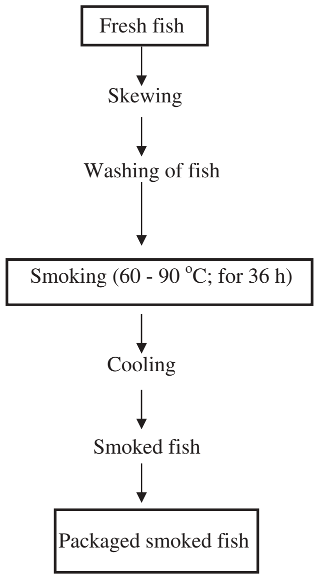

Figure 1. Traditional drum-smoking steps of smoked fish.

and salted fish samples were smoked at 60°C–90°C. Smoking was carried out for 36 h until the fish samples were fully dried.

Convective fish smoking process

Smoked fish was prepared following the method (Figure 2) as described by Crapo (2011). Fish were carefully cleaned with distilled water to remove slime and blood. The fish were eviscerated, leaving the skin on the fish. The fish were cut into uniform pieces (fillet) so that no parts will get overheated.

The fish were smoked at 80°C internal temperature (with a thermometer) for 18 h. The kiln temperature was adjusted as needed throughout this smoking period to maintain the 80°C temperature. Hands, utensils and work surfaces were cleaned when transferring fish.

Amino acid composition

The amino acid composition of the samples was analysed by digesting the samples for 24 h at 110°C in an oven with 5 mL of 6 N HCl in sealed glass tubes. An aliquot of the hydrolysate was taken and 0.4 mL AABA (alpha amino butyric acid (50 µmol mL^{-1})) was added to it as the internal standard. Then, 100 mL of distilled water was added to the aliquot. This aliquot was then filtered using Whatman filter paper, followed by a syringe filter. Sulphur amino acid, methionine and cystine were oxidized with 2 mL per formic acid prior to hydrolysis with 6 N HCl. The tryptophan content was not determined. All samples were derivatized with an AQC reagent and borate buffer

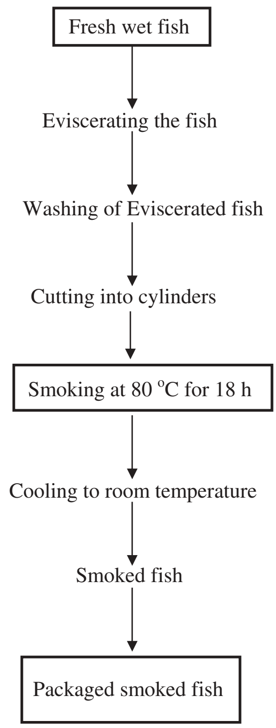

Figure 2. Convective kiln smoking of fish (Crapo, 2011).

before being separated using high-performance liquid chromatography (HPLC) using eluent A (AccQ Taq TM concentrate, Waters) and eluent B (Acetonitrile 60%, Sigma).

The HPLC with the Waters brand system consisted of the following items: a multi-fluorescence detector Waters 2475 (excitation at 250 nm and emission at 395 nm), a Waters 717 auto-sampler and a Waters binary 1525 HPLC pump and bus satin model. The column size was 3.9 × 150 mm. The eluent flowed at the rate of 1 mL min^{-1}. A standard calibration mixture was prepared from a commercial amino acid mixture (Standard H, Pierce Chemical, Rockford) and from the individual amino acid (Sigma).

The chemical scores calculated from the essential amino acid concentrations of samples were compared with the essential amino acid pattern for whole eggs, whereas amino acid scores were calculated using the 1985 FAO/WHO/UNU (FAO/WHO, 1990)-suggested pattern of amino acid requirements for preschool children (2–5 years old). Chemical score or amino acid score actually is the ratio of a gram of the essential amino acid in a test sample to the same amount of the corresponding amino acid in a reference (e.g., whole-egg protein or FAO/WHO/UNU (1985), 1990-suggested pattern) multiplied by 100.

Vitamins analysis

Vitamin A and E determination was carried out by AOAC (2005a, 2005b). For this purpose, the experimental planning used for extraction consists of saponification of flesh of fish by organic solvent, separation from matrix and then quantification by liquid chromatography. Chromatographic conditions for vitamin A were: isocratic system, injection volume, 20 µL; eluent A (980 hexane, 20 mL isopropanol); flow rate, 1 mL/min; fluorescence detector, excitation at 325 nm, emission at 480 nm and column (Maxsil 5 Silica 125*4.00 mm). The same conditions are used for vitamin E, but the eluent A used was (970 hexane; 30 mL 1, 4 dioxane), whereas the excitation is at 293 nm and the emission is at 326 nm.

Mineral content analysis

This was determined using atomic absorption spectrometry and a flame photometer (AOAC, 2005a). The fish samples were first taken into solution using metal ash. The solution of the element (sodium, potassium, lithium and calcium) was sprayed into a flame photometer, which measures the intensity of the light produced by the transition of electrons of the element to higher energy levels. The intensity of radiation was measured and the concentration of the metal was quantitatively determined. Other elements were determined using atomic absorption spectrometry.

Data analysis

All data are means of triplicate data ± standard deviation. The data obtained were subjected to statistical analysis using IBM SPSS version 21.0 software. One-way ANOVA was performed on data using Duncan's Multiple Range Test ($p < 0.05$) to study the difference between means.

Results and discussion

Amino acid concentrations of traditional drum-smoked and kiln-smoked fish samples

The amino acid composition of drum-smoked fish samples is presented in Table 1. It was observed that among the essential amino acids, lysine, arginine and leucine were the most abundant in all the smoked fish samples. In *G. barracuda, S. tilapia, Bonga shad, N. tongue sole* and *Silver catfish*, the values of lysine, arginine and leucine ranged between 7.47 and 7.83 g/100 g crude protein (cp), 6.27 and 6.54 g/100 g cp and 7.32 and 7.68 g/100 g cp, respectively. Among the non-essential amino acids, glutamic acid, aspartic acid and glycine were the most abundant amino acids in all the drum-smoked fish samples and make up to

Table 1. Amino acid profile (g/100 g crude protein) of traditional drum-smoked fish samples.

Components	*G. barracuda*	*S. tilapia*	*Bonga shad*	*N. tongue sole*	*Silver catfish*
Essential amino acids					
Lysine (Lys)	7.72 ± 0.03^{f}	7.63 ± 0.04^{f}	7.47 ± 0.04^{f}	7.83 ± 0.03^{f}	7.58 ± 0.03^{f}
Histidine (His)	2.71 ± 0.00^{b}	2.46 ± 0.03^{b}	2.92 ± 0.01^{b}	2.72 ± 0.01^{b}	2.69 ± 0.01^{b}
Arginine (Arg)	6.39 ± 0.02^{e}	6.27 ± 0.02^{e}	6.54 ± 0.01^{e}	6.48 ± 0.02^{e}	6.37 ± 0.01^{e}
Threonine (Thr)	4.69 ± 0.01^{d}	4.58 ± 0.01^{d}	4.70 ± 0.02^{d}	4.80 ± 0.02^{d}	4.71 ± 0.01^{d}
Valine (Val)	4.81 ± 0.00^{d}	4.96 ± 0.00^{d}	4.85 ± 0.01^{d}	4.77 ± 0.00^{d}	4.93 ± 0.00^{d}
Methionine (Met)	2.49 ± 0.00^{b}	2.62 ± 0.00^{b}	2.53 ± 0.00^{b}	2.71 ± 0.00^{b}	2.64 ± 0.00^{b}
Isoleucine (Ile)	3.80 ± 0.00^{c}	3.76 ± 0.03^{c}	3.49 ± 0.01^{c}	3.51 ± 0.01^{c}	3.80 ± 0.01^{c}
Leucine (Leu)	7.32 ± 0.01^{f}	7.41 ± 0.01^{f}	7.68 ± 0.01^{f}	7.54 ± 0.01^{f}	7.46 ± 0.01^{f}
Phenylalanine (Phe)	4.05 ± 0.01^{d}	4.60 ± 0.02^{d}	4.47 ± 0.01^{d}	4.62 ± 0.02^{d}	4.33 ± 0.01^{d}
Non-essential amino acids					
Aspartic acid (Asp)	9.68 ± 0.03^{g}	9.81 ± 0.03^{g}	9.59 ± 0.01^{g}	9.70 ± 0.03^{g}	9.62 ± 0.03^{g}
Serine (Ser)	4.39 ± 0.00^{d}	4.61 ± 0.01^{d}	4.43 ± 0.01^{d}	4.59 ± 0.01^{d}	4.48 ± 0.01^{d}
Glutamic acid (Glu)	14.24 ± 0.04^{h}	14.19 ± 0.02^{h}	14.43 ± 0.03^{h}	14.52 ± 0.03^{h}	14.36 ± 0.03^{h}
Proline (Pro)	4.27 ± 0.00^{d}	4.30 ± 0.00^{d}	4.42 ± 0.01^{d}	4.16 ± 0.00^{d}	4.38 ± 0.00^{d}
Glycine (Gly)	7.01 ± 0.03^{f}	7.11 ± 0.03^{f}	7.42 ± 0.03^{f}	7.39 ± 0.02^{f}	7.27 ± 0.02^{f}
Alanine (Ala)	6.23 ± 0.00^{e}	6.45 ± 0.03^{e}	6.37 ± 0.01^{e}	6.51 ± 0.01^{e}	6.48 ± 0.01^{e}
Cystine (Cys)	0.93 ± 0.00^{a}	0.90 ± 0.00^{a}	0.97 ± 0.00^{a}	0.96 ± 0.00^{a}	0.91 ± 0.00^{a}
Tyrosine (Tyr)	3.17 ± 0.00^{c}	3.42 ± 0.00^{c}	3.18 ± 0.01^{c}	3.36 ± 0.00^{c}	3.57 ± 0.00^{c}
Tryptophan (Try)	4.68 ± 0.01^{d}	4.81 ± 0.01^{d}	4.89 ± 0.01^{d}	4.73 ± 0.01^{d}	4.64 ± 0.00^{d}

Data are means of three replicates ± S.D. Data with the same superscripts in the same row are not significantly different at $p \leq 0.05$.

Table 2. Amino acid profile (g/100 g crude protein) of kiln-smoked fish samples.

Components	*G. barracuda*	*S. tilapia*	*Bonga shad*	*N. tongue sole*	*Silver catfish*
Essential amino acids					
Lysine (Lys)	7.36 ± 0.03^{f}	7.91 ± 0.04^{f}	7.63 ± 0.04^{f}	7.72 ± 0.03^{f}	7.69 ± 0.03^{f}
Histidine (His)	2.92 ± 0.00^{b}	2.77 ± 0.03^{b}	2.84 ± 0.01^{b}	2.87 ± 0.01^{b}	2.72 ± 0.01^{b}
Arginine (Arg)	6.67 ± 0.03^{e}	6.32 ± 0.01^{e}	6.71 ± 0.03^{e}	6.33 ± 0.01^{e}	6.54 ± 0.03^{e}
Threonine (Thr)	4.84 ± 0.03^{d}	4.76 ± 0.02^{d}	4.69 ± 0.01^{d}	4.91 ± 0.02^{d}	4.66 ± 0.02^{d}
Valine (Val)	4.98 ± 0.00^{d}	4.84 ± 0.00^{d}	4.92 ± 0.01^{d}	4.52 ± 0.00^{d}	4.85 ± 0.02^{d}
Methionine (Met)	2.73 ± 0.03^{b}	2.53 ± 0.01^{b}	2.68 ± 0.0^{b}	2.83 ± 0.01^{b}	2.78 ± 0.01^{b}
Isoleucine (Ile)	3.95 ± 0.02^{c}	3.82 ± 0.02^{c}	3.83 ± 0.01^{c}	3.66 ± 0.01^{c}	3.91 ± 0.01^{c}
Leucine (Leu)	7.80 ± 0.03^{f}	7.59 ± 0.01^{f}	7.56 ± 0.03^{f}	7.69 ± 0.03^{f}	7.62 ± 0.01^{f}
Phenylalanine (Phe)	4.47 ± 0.00^{d}	4.81 ± 0.03^{d}	4.58 ± 0.01^{d}	4.71 ± 0.01^{d}	4.51 ± 0.01^{d}
Non-essential amino acids					
Aspartic acid (Asp)	9.84 ± 0.03^{g}	9.67 ± 0.03^{g}	9.61 ± 0.01^{g}	9.90 ± 0.02^{g}	9.87 ± 0.02^{g}
Serine (Ser)	4.71 ± 0.01^{d}	4.82 ± 0.02^{d}	4.85 ± 0.01^{d}	4.86 ± 0.01^{d}	4.63 ± 0.01^{d}
Glutamic acid (Glu)	14.93 ± 0.05^{h}	14.06 ± 0.41^{h}	14.59 ± 0.04^{h}	14.74 ± 0.03^{h}	14.54 ± 0.03^{h}
Proline (Pro)	4.68 ± 0.00^{d}	4.53 ± 0.00^{d}	4.38 ± 0.01^{d}	4.33 ± 0.00^{d}	4.60 ± 0.00^{d}
Glycine (Gly)	7.36 ± 0.03^{f}	7.26 ± 0.04^{f}	7.61 ± 0.05^{f}	7.52 ± 0.05^{f}	7.44 ± 0.03^{f}
Alanine (Ala)	6.18 ± 0.01^{e}	6.71 ± 0.03^{e}	6.28 ± 0.01^{e}	6.67 ± 0.03^{e}	6.36 ± 0.03^{e}
Cystine (Cys)	0.89 ± 0.00^{a}	0.94 ± 0.00^{a}	0.93 ± 0.00^{a}	0.99 ± 0.00^{a}	0.98 ± 0.00^{a}
Tyrosine (Tyr)	3.36 ± 0.00^{c}	3.56 ± 0.00^{c}	3.36 ± 0.01^{c}	3.41 ± 0.00^{c}	3.67 ± 0.00^{c}
Tryptophan (Try)	4.72 ± 0.02^{d}	4.63 ± 0.04^{d}	4.71 ± 0.04^{d}	4.92 ± 0.05^{d}	4.83 ± 0.05^{d}

Data are means of three replicates ± S.D. Data with the same superscripts in the same row are not significantly different at $p \leq 0.05$.

values that ranged between 14.19 and 14.52 g/100 g cp, 9.62 and 9.81 g/100 g cp and 7.01 and 7.42 g/100 g cp, respectively. Similar results were obtained from kiln-smoked fish samples in Table 2, although with slightly higher values than in drum-smoked fish samples. Several authors had reported similar observations for smoked fish and giant rat (Adeyeye & Aremu, 2010; Aremu et al., 2013; Atowa, Nwabu, & Ogiedu, 2014; Huda, Dewi, & Ahmad, 2010; Suvitha, Eswar, Anbarasu, Ramamoorthy, & Sankar, 2014; Usydus, Szlinder-Richert, & Adamczyk, 2009).

Lysine, which ranged between 7.47 and 7.83 g/100 g cp, was the most concentrated essential amino acid, followed by leucine, with range values of 7.32–7.68 g/100 g in drum-smoked fish samples to 7.56–7.80 g/100 g in kiln-smoked fish samples. Arginine ranged between 6.27 and 6.54 g/100 g cp in drum-smoked fish samples and 6.32 and 6.67 g/100 g cp in kiln-smoked fish samples. Arginine is essential for children's growth and was present in reasonable levels in this study. The lysine contents of the smoked fish samples from drum and kiln smoking were slightly above the 6.3 g/100 g content of the reference egg protein. This signifies that the smoked fish samples are good sources of quality protein, which could be used for fortification of weaning foods, especially in Africa, where diets are predominantly cereal based. Methionine is another essential amino acid, with values ranging from 2.49 to 2.71 g/100 g cp for drum-smoked fish samples and from 2.53 to 2.83 g/100 g cp for kiln-smoked fish samples. Methionine is needed for the synthesis of chlorine from lecithin and other phospholipids in the body (Adeyeye & Aremu, 2010; Aremu et al., 2013; Huda et al., 2010; Usydus et al., 2009). When the diet is low in protein, for instance in alcoholism and kwashiorkor, insufficient chlorine may be formed; this may cause accumulation of fat in the liver. Phenylalanine values ranged from 4.05 to 4.62 g/100 g cp for drum-smoked fish samples and from 4.47 to 4.81 g/100 g cp for kiln-smoked fish samples. It is the precursor of some hormones and the pigment melanin in hair, eyes and tanned skin (Aremu et al., 2013).

This study showed that smoking methods have no effect on the amino acid compositions of five types of fish studied (*G. barracuda, S. tilapia, Bonga shad, N. tongue sole* and *silver catfish*). This agreed with the findings of Asiedu, Julshamn, & Lie (1991). The results indicated that these processing methods had no effect on the amino acid composition compared with that of fresh fish.

Vitamin profile of drum-smoked and kiln-smoked fish samples

The results of the vitamin profile of drum-smoked and kiln-smoked fish samples analysed are presented in Tables 3 and 4, respectively. The ascorbic acid, thiamine, niacin, riboflavin, vitamin A and vitamin E contents for In *G. barracuda, S. tilapia, Bonga shad, N. tongue sole* and *Silver catfish* were in the range of 0.55–0.84 mg/100 g, 0.05–0.06 mg/100 g, 0.97–1.59 mg/100 g, 0.04–0.07 mg/100 g, 11.37–12.83 mg/100 g, and 0.38–0.60 mg/100 g, respectively, for drum-smoked fish samples, while for kiln-smoked fish samples they were in the range of 0.56–0.89 mg/100 g, 0.05–0.08 mg/100 g, 1.10–1.72mg/100 g, 0.05–0.08 mg/100 g, 12.27–14.06 mg/100 g, and 0.31–0.63 mg/100 g, respectively. Vitamin E is considered as a biological antioxidant (Aremu et al., 2013; Heinonen et al., 1997) and

Table 3. Vitamin profile (mg/100 g) of traditional drum-smoked fish samples.

Components	*G. barracuda*	*S. tilapia*	*Bonga shad*	N. tongue sole	Silver catfish
Ascorbic acid	0.64 ± 0.03^{c}	0.55 ± 0.06^{c}	0.80 ± 0.06^{c}	0.84 ± 0.06^{c}	0.78 ± 0.06^{c}
Thiamine	0.06 ± 0.00^{a}	0.05 ± 0.03^{a}	0.06 ± 0.01^{a}	0.05 ± 0.01^{a}	0.06 ± 0.01^{a}
Niacin	0.97 ± 0.01^{d}	1.06 ± 0.01^{d}	1.21 ± 0.01^{d}	1.33 ± 0.01^{d}	1.59 ± 0.01^{d}
Riboflavin	0.04 ± 0.00^{a}	0.05 ± 0.00^{a}	0.05 ± 0.01^{a}	0.07 ± 0.00^{a}	0.07 ± 0.00^{a}
Vitamin A	11.41 ± 0.01^{e}	11.37 ± 0.01^{e}	12.08 ± 0.01^{c}	11.74 ± 0.01^{e}	12.83 ± 0.01^{e}
Vitamin E	0.42 ± 0.00^{b}	0.38 ± 0.00^{b}	0.47 ± 0.01^{b}	0.45 ± 0.00^{b}	0.60 ± 0.00^{b}

Data are means of three replicates ± S.D. Data with the same superscripts in the same row are not significantly different at $p \leq 0.05$.

Table 4. Vitamin profile (mg/100 g) of kiln-smoked fish samples.

Components	*G. barracuda*	*S. tilapia*	*Bonga shad*	*N. tongue sole*	*Silver catfish*
Ascorbic acid	0.79 ± 0.03^{b}	0.56 ± 0.06^{b}	0.82 ± 0.06^{b}	0.89 ± 0.06^{b}	0.81 ± 0.06^{b}
Thiamine	0.08 ± 0.00^{a}	0.06 ± 0.03^{a}	0.07 ± 0.01^{a}	0.05 ± 0.01^{a}	0.08 ± 0.01^{a}
Niacin	1.38 ± 0.01^{c}	1.10 ± 0.01^{c}	1.23 ± 0.01^{c}	1.41 ± 0.01^{c}	1.72 ± 0.01^{c}
Riboflavin	0.06 ± 0.00^{a}	0.05 ± 0.00^{a}	0.05 ± 0.01^{a}	0.07 ± 0.00^{a}	0.08 ± 0.00^{a}
Vitamin A	13.93 ± 0.01^{d}	13.48 ± 0.01^{d}	12.27 ± 0.01^{d}	13.65 ± 0.01^{d}	14.06 ± 0.01^{d}
Vitamin E	0.47 ± 0.00^{a}	0.31 ± 0.00^{a}	0.54 ± 0.01^{a}	0.49 ± 0.00^{a}	0.63 ± 0.00^{a}

Data are means of three replicates ± S.D. Data with the same superscripts in the same row are not significantly different at $p \leq 0.05$.

it played a principal role in fertility. Moreover, vitamin A has an antioxidant activity, it promotes good vision and bones growth, and generally fish species are able to transform easily carotenoids into vitamin A (Aremu et al., 2013; Olson, 1983). Typical retinoids in fish are all-trans-retinol and all-trans-3, 4-dehydroretinol, which is a typical vitamin A compound (Aremu et al., 2013; Ollilainen, Heinonen, Linkola, Varo, & Koivistoinen, 1989b). There was no significant difference in the values of vitamins in the samples between smoking methods, but there was significant difference in their values from the different types of fish smoked. The values of vitamins obtained from this study were in agreement with the works of Suvitha et al. (2014), Atowa et al. (2014), Aremu et al. (2013), and Huda et al. (2010).

The presence of riboflavin, niacin, thiamine, ascorbic acid, vitamin A and vitamin E in all of the smoked fish samples indicates the nutritional value of smoked fish (Aremu et al., 2013). Riboflavin is important for body growth and the production of red blood cells; niacin helps maintain healthy skin and nerves and ensures that the digestive and nervous systems function properly; thiamine helps the body cells change carbohydrates into energy and ascorbic acid helps the body make collagen, an important protein used to make skin, cartilage, tendons, ligaments, and blood vessels and is also needed for healing wounds and for repairing and maintaining bones and teeth (Aremu et al., 2013).

Table 5. Mineral profile (mg/100 g) of traditional drum-smoked fish samples.

Components	*G. barracuda*	*S. tilapia*	*Bonga shad*	*N. tongue sole*	*Silver catfish*
Sodium (Na^+)	31.20 ± 0.02^a	40.11 ± 0.04^a	43.16 ± 0.03^a	49.50 ± 0.04^a	30.26 ± 0.02^a
Lithium (Li^+)	10.57 ± 0.01^a	11.06 ± 0.04^a	11.24 ± 0.02^a	10.61 ± 0.01^a	10.43 ± 0.02^a
Potassium (K^+)	10.31 ± 0.02^a	10.26 ± 0.041^a	10.72 ± 0.01^a	11.02 ± 0.02^a	10.09 ± 0.01^a
Calcium (Ca^{++})	62.46 ± 0.03^a	54.88 ± 0.02^a	63.51 ± 0.11^a	58.98 ± 0.03^{ab}	54.22 ± 0.04^a
Iron (Fe^{++})	12.28 ± 0.01^a	11.63 ± 0.01^a	11.23 ± 0.01^a	10.46 ± 0.01^a	12.07 ± 0.01^a
Zinc (Zn^{++})	2.62 ± 0.00^a	1.82 ± 0.00^a	1.49 ± 0.00^a	1.38 ± 0.00^a	1.68 ± 0.00^a
Magnesium (Mg^{++})	11.29 ± 0.01^a	11.04 ± 0.01^a	10.61 ± 0.01^a	11.41 ± 0.01^a	10.52 ± 0.01^a
Phosphorus (PO4—)	41.14 ± 0.01^a	32.91 ± 0.01^a	31.18 ± 0.01^a	39.43 ± 0.01^a	30.16 ± 0.01^a
Ca/P	1.52 ± 0.05^b	1.67 ± 0.06^c	2.04 ± 0.07^c	1.50 ± 0.04^b	1.80 ± 0.06^c
Ca/Mg	5.53 ± 0.10^e	4.97 ± 0.10^d	5.99 ± 0.10^e	5.17 ± 0.10^d	5.15 ± 0.10^d
Ca/K	6.06 ± 0.10^e	5.35 ± 0.10^d	5.92 ± 0.10^e	5.35 ± 0.10^d	5.37 ± 0.10^d

Data are means of three replicates ± S.D. Data with the same superscripts in the same row are not significantly different at $p \leq 0.05$.

Table 6. Mineral profile (mg/100 g) of kiln-smoked fish samples.

Components	*G. barracuda*	*S. tilapia*	*Bonga shad*	*N. tongue sole*	*Silver catfish*
Sodium (Na^+)	40.68 ± 0.03^a	49.42 ± 0.03^a	51.46 ± 0.11^a	40.28 ± 0.01^a	41.65 ± 0.02^a
Lithium (Li^+)	10.13 ± 0.01^a	10.38 ± 0.01^a	10.52 ± 0.04^a	15.04 ± 0.04^a	11.18 ± 0.03^a
Potassium (K^+)	11.01 ± 0.01^a	10.26 ± 0.03^a	10.92 ± 0.03^a	18.74 ± 0.01^a	10.28 ± 0.01^a
Calcium (Ca^{++})	52.68 ± 0.04^a	47.31 ± 0.03^a	63.56 ± 0.18^a	62.94 ± 0.06^a	64.08 ± 0.01^a
Iron (Fe^{++})	8.03 ± 0.01^a	10.06 ± 0.01^a	10.24 ± 0.01^a	10.73 ± 0.01^a	11.04 ± 0.01^a
Zinc (Zn^{++})	1.92 ± 0.00^a	1.56 ± 0.00^a	2.18 ± 0.00^a	1.67 ± 0.00^a	1.49 ± 0.00^a
Magnesium (Mg^{++})	11.07 ± 0.01^a	11.13 ± 0.01^a	11.35 ± 0.01^a	10.69 ± 0.01^a	10.36 ± 0.01^a
Phosphorus ($PO^{4—}$)	30.16 ± 0.02^a	31.28 ± 0.02^a	41.22 ± 0.02^a	37.16 ± 0.02^a	33.20 ± 0.02^a
Ca/P	1.75 ± 0.06^b	1.51 ± 0.06^b	1.54 ± 0.05^b	1.69 ± 0.06^b	1.93 ± 0.06^b
Ca/Mg	4.76 ± 0.10^d	4.25 ± 0.07^c	5.45 ± 0.10^d	5.89 ± 0.11^e	6.19 ± 0.11^e
Ca/K	4.78 ± 0.10^d	4.60 ± 0.08^c	5.82 ± 0.10^d	3.36 ± 0.07^c	6.23 ± 0.11^e

Data are means of three replicates ± S.D. Data with the same superscripts in the same row are not significantly different at $p \leq 0.05$.

Mineral profile of drum-smoked and kiln-smoked fish samples

The results of the concentrations of minerals in the drum-smoked and kiln-smoked fish samples analysed are presented in Tables 5 and 6. The concentrations (mg/100 g) of Na, Li, K and Ca for *Guinea barracuda, Spotted tilapia, bonga shad, Nigerian tongue sole* and *Silver catfish* were in the range 31.20–49.50 mg/100 g, 10.43–11.24 mg/100 g, 10.09–11.02 mg/100 g and 54.22–63.51 mg/100 g, respectively, for drum-smoked fish samples, whereas those of kiln-smoked fish samples were in the range 40.28– 51.46 mg/100 g, 10.13–15.04 mg/100 g, 10.26–18.74 mg/100 g and 47.31–64.08 mg/100 g, respectively. Concentrations (mg/100 g) of Fe, Zn, Mg and P for *Guinea barracuda, Spotted tilapia, bonga shad, Nigerian tongue sole* and *Silver catfish* ranged from 10.46 to 12.28 mg/100 g, 1.38 to 2.62 mg/100 g, 10.52 to 11.41 mg/100 g and 30.16 to 41.14 mg/100 g, respectively, for drum-smoked fish samples, while those of kiln-smoked fish samples ranged from 8.03 to 11.04 mg/100 g, 1.49 to 2.18 mg/100 g, 10.36 to 11.35 mg/100 g and 30.16 to 41.22 mg/100 g, respectively.

The ratios of Ca/P, Ca/Mg and Ca/K for *Guinea barracuda, Spotted tilapia, bonga shad, Nigerian tongue sole* and *Silver catfish* ranged from 1.50 to 1.80, 4.97 to 5.99 and 5.35 to 6.06, respectively, for drum-smoked fish samples, while those of kiln-smoked fish samples ranged from 1.51 to 1.93, 4.25 to 6.19 and 3.36 to 6.23, respectively. The values of mineral elements obtained from this study were in agreement with the works of Adeyeye (2016), Suvitha et al. (2014), Atowa et al. (2014) and Aremu et al. (2013).

It is clear from the results of this study that smoked fish is a good source of macro and micro mineral elements and may contribute to the health, growth and development of human beings. The ratios of the mineral compositions further indicated the nutritional values of the fish, as reported by Watts (2010), who posited that nutritional interrelationship is much more important than knowing the mineral concentration alone. Mineral ratios are often more important in determining nutritional deficiencies and excesses; it is predictive of future metabolic dysfunctions or hidden metabolic dysfunction. The moderately high Ca/P ratio observed in all the smoked fish samples from drum-smoked and kiln-smoked fish is of nutritional benefit, particularly for children and the elderly, who need higher intakes of calcium and phosphorus for bone formation and maintenance. Food is considered 'good' if the ratio of calcium to phosphorus is more than one and 'poor' if the ratio is less than 0.5, whereas a Ca/P ratio greater than two helps increase the absorption of calcium in the small intestine (Aremu et al., 2013; Nieman, Butterworth, & Nieman, 1992). The Ca/K ratio is usually called the thyroid ratio because calcium and potassium play a vital role in regulating thyroid activity, and the ratio in this study is around the range (5–7) needed to maintain the regulation of thyroid activity in good balance (Aremu et al., 2013; ARL, 2012). Ca/Mg ratios in the smoked fish from drum-smoked and kiln-smoked fish samples are within the range that enhances mental and emotional stability, whereas ratios beyond 16 or less than 2 are associated with mental and emotional disturbances (Adeyeye & Aremu, 2010; Aremu et al., 2013; ARL, 2012).

The relatively small amounts of zinc content recorded in smoked fish from drum-smoked and kiln-smoked fish samples are not surprising since zinc is a trace mineral and is needed only in small amounts by our bodies, but has many important functions (Aremu et al., 2013). It is needed for the body's defensive (immune) system to properly work; plays a role in cell division, cell growth, wound healing and the breakdown of carbohydrates and is also needed for the senses of smell and taste (Aremu et al., 2013).

Conclusion

In conclusion, from this study it is seen that smoking method has no significant effect on the amino acid composition of smoked fish samples, but fish types did. Moreover, smoking method had a significant effect on vitamin contents; this might be due to the temperature of smoking as some of the vitamins investigated are heat labile. Furthermore, the study showed that the smoked fish products could serve as significant sources of essential amino acids, in terms of both quantity and quality. The products' composition of essential amino acids was comparable to the standard egg protein. Limiting amino acids, such as lysine, methionine and cystine, expressed as g per 100 g of protein, in the smoked fish occurred at levels similar to those in the standard protein (FAO/WHO, 1991). The fish products also contain substantial amounts of vitamins and minerals.

The smoked fish products are good sources of lysine, which is severely restricted in cereals, the most important staple food in the world, especially in Africa and other developing countries. Thus, the sulphur-containing essential amino acids in smoked fish products could supplement the corresponding deficiency in plant proteins. Therefore, the proteins in a mixed diet could be utilized optimally for a healthy body constitution, especially among children and other vulnerable groups.

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