

## Research Article

# Postharvest Fish Processing in the Southwest Region of Cameroon and the Effect of Smoke-Drying on Quality

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Fish processing in Cameroon is mostly carried out by untrained individuals using different methods which often produce fish products of poor quality. This study was aimed at identifying the main fish processing technologies used in 5 fishing communities in Limbe Subdivision in the Southwest Region of Cameroon. A total of 120 questionnaires were administered in the study area to identify the most popular unit operation in fish processing and to evaluate its effect under controlled conditions on the quality of fish products. It was found that the main fish technology employed was smoke-drying and that most of the processors dried the *Ilisha africana* species. Smoke-drying of *Ilisha africana* was carried out under controlled conditions of temperature and time, and smoked fish samples of different colours ranging from pale brown to dark brown were obtained. Laboratory analysis of the fish samples revealed that the moisture content and microbial content of the fish decreased significantly ( $p < 0.05$ ), while protein content increased significantly ( $p < 0.05$ ) with an increase in smoking time and temperature. The optimum moisture content was achieved at temperature ranges of 61-70°C for 18 h (12.3%), 71-80°C for 12 h (10.7%), and 18 h (7.3%). The pH and microbial content of all the samples were within the recommended levels for consumption and safe storage. It was concluded that the best temperature ranges and times for smoke-drying *Ilisha africana* were 61-70°C for 18 h and 71-80°C for 12 h.

## 1. Introduction

Fisheries and aquaculture are extremely important for providing food, nutrition, and employment to millions of people worldwide. Aquatic sources account for a total of 17% of total animal-source proteins for human consumption [1]. This is because fish is the cheapest source of animal protein [2], and it contains many of the vitamins and minerals required to address some of the most severe and widespread nutritional deficiencies in lower-income countries [3]. Furthermore, fish consumption is not forbidden within some religious groups, unlike consuming dogs and pork [4]. In 2018, global fish production was estimated at 179 million tons with a first sale value

of 401 billion dollars, and of this amount, 56 million tons (88%) were used for human consumption with live, fresh, and chilled fish representing 44% of processed fish and 35% postharvest losses incurred [5].

In Cameroon, the fishing sector plays a very important role. The total volume of catch in 2013 was estimated at 78,000 tons with a 1.2% contribution to the GDP in 2009 [6]. According to Ngok et al. [7], the contribution of fishing to the creation of wealth was estimated to be over 119.4 billion FCFA with the sector creating over 200,000 jobs due to the multitude of activities that follow the catch: commercialization, handling, and transformation. Fish is the most accessible and most consumed source of protein in Cameroon [8]. This analysis can be

extended to most sub-Saharan and tropical countries because fish is cheaper compared to other animal protein sources such as bush meat, pork, chicken, and beef [9, 10].

Fish and products obtained from fishery activities constitute the most important nutritious food in the world, representing about 15-20% of all animal protein on a global basis [9, 10]. Fish processing is the chain of processes associated with fish and fish products between the time fish are caught or harvested and the time the final product is delivered to the consumer. Fish is highly susceptible to deterioration, especially without the use of preservatives or when no processing measures have been put in place [11], and therefore extremely perishable [12, 13], because of its chemical composition [14], which makes it highly prone to enzymatic and microbial action [15]. Consequently, the processing and preservation of fresh fish are of utmost importance to prevent economic losses after harvest [11].

In developing African countries, postharvest fish losses as high as 40% have been recorded which not only have a detrimental impact on the socioeconomic life of fishing communities but also significantly reduce the availability of animal protein for large segments of the population [16].

Food quality refers to the characteristics of food possesses that a consumer deems necessary to qualify the food as being in the desired state for the required purpose. Examples include physical characteristics such as size, organoleptic characteristics (smell, texture, taste, and flavour), chemical composition, microbial characteristics, and other characteristics which define the food [17]. In the food industry, the quality concept emphasizes three key factors: conformity to the product's intended purpose, safety, and satisfaction of the consumer's expectations and perceptions [18]. Processed fish quality depends on various factors, which can be grouped as raw material, pretreatment, and processing conditions [19]. The quality of fish starts to deteriorate after it is brought to the landing sites due to bacterial invasion and putrefaction, enzymatic autolysis, chemical oxidation, mechanical damage, and environmental optimization aggregating the growth of microbes [20]. There exist several methods to determine the quality and safety of fish products which can be classified into sensory and instrumental methods. As defined by Lokuruka [17], sensory evaluation of fish quality is the scientific discipline used to evoke, measure, analyze, and interpret reactions to characteristics of food as perceived through the senses of sight, smell, taste, touch, and hearing. They have the advantage of being simple, cheap, and rapid but with the disadvantage that they are subjective because they are based on the assessment by individuals of their likes and dislikes. Instrumental methods comprise physical, chemical, and microbiological methods. Chemical methods are rapid, quantitative, and reproducible. Physical methods involve the measurement of fish muscle pH, texture, or electrical properties. The techniques for assessing the quality of fish and fish products include sensory evaluation, microbial assessment, biochemical assessment, biosensor detection, toxin detection, and machine vision [21].

Fishery activities including processing have a multiplier effect on the livelihood of the processors. For example, Cameroon's National Accounts Office indicated that an investment of 2000 USD in the fishing sector generates revenue of about

12000 USD in the national economy. In addition, the postharvest fish processing subsector provides many jobs, especially to women who play an essential role in economic and social development [22]. Fish products play a crucial role in global nutrition and food security because they are cheap and highly acceptable [23]. Despite these advantages, there is, however, an information gap in the literature on local fish processing and its effect on the quality of fish and fish products. Although the results of some similar studies have been reported elsewhere in the literature, it might be erroneous to assume that the results of such studies are applicable or directly transposable to other communities because factors such as provenance, food habits, personalities, culture, climate, agricultural practices, etc. may singly or in combination with 2 more of the attributes significantly impact the results of such studies depending on the location. Hence, the need to replicate such studies in different locations so that a generalized procedure for fish processing at local levels could be established in the long run. In addition, most of the studies carried out were either limited to field surveys ([24–26]) or laboratory treatment and analysis ([27–29]), not a combination of the two, or were limited to reviews ([30–32]). In this study, we have taken a holistic approach by doing field surveys and exploiting the results therein to evaluate the effect of process parameters on the nutritional and microbiological quality of the fish as affected by the procedures used by the fish processors. This study was undertaken to evaluate postharvest technologies used by actors in the selected fishing communities and its effect on quality, to improve the already existing processing techniques, and to limit postharvest losses in the fish processing sector. We have therefore established conditions for processing that will define the quality of the smoked fish when used efficiently.

## 2. Material and Methods

In this study, a field survey was first conducted to understand all the activities in local postharvest fish processing and to evaluate the effect of the most critical unit operations along the processing chain on quality.

The study area consisted of 5 fishing communities (Downbeach, Wovia, Batoke, Isobe, and Idenau) in and around Limbe, in the southwest region of Cameroon. Figure 1 is a map of Cameroon showing the Southwest Region. Figure 2 shows the 5 fishing communities under study along the coast of Cameroon. The Southwest region of Cameroon is situated between latitudes 4.16° and 5.71° North and longitudes 8.9° and 10.06° East and covers an area of 24,571 km<sup>2</sup> (9,487 square miles) [33].

*2.1. Data Collection.* A preliminary survey was done for the identification of production sites. One hundred and twenty (120) respondents were randomly selected and interviewed for this study. Structured questionnaires (shown in Table S1), semistructured interviews, and field observations were used to assess existing fish processing techniques. The structured questionnaires targeted the processing method used by fish processors, equipment used for processing, fish species processed, time used in processing, steps involved in

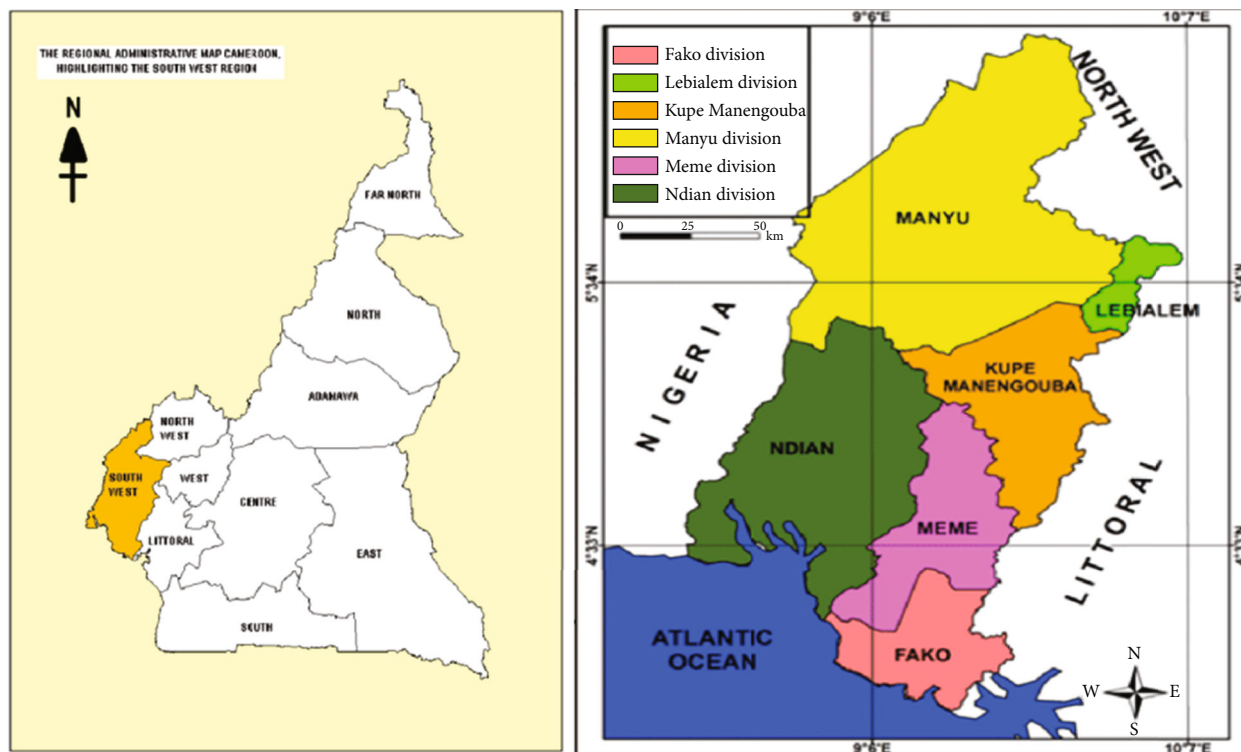


FIGURE 1: Map of Cameroon showing the Southwest Region of Cameroon [33].

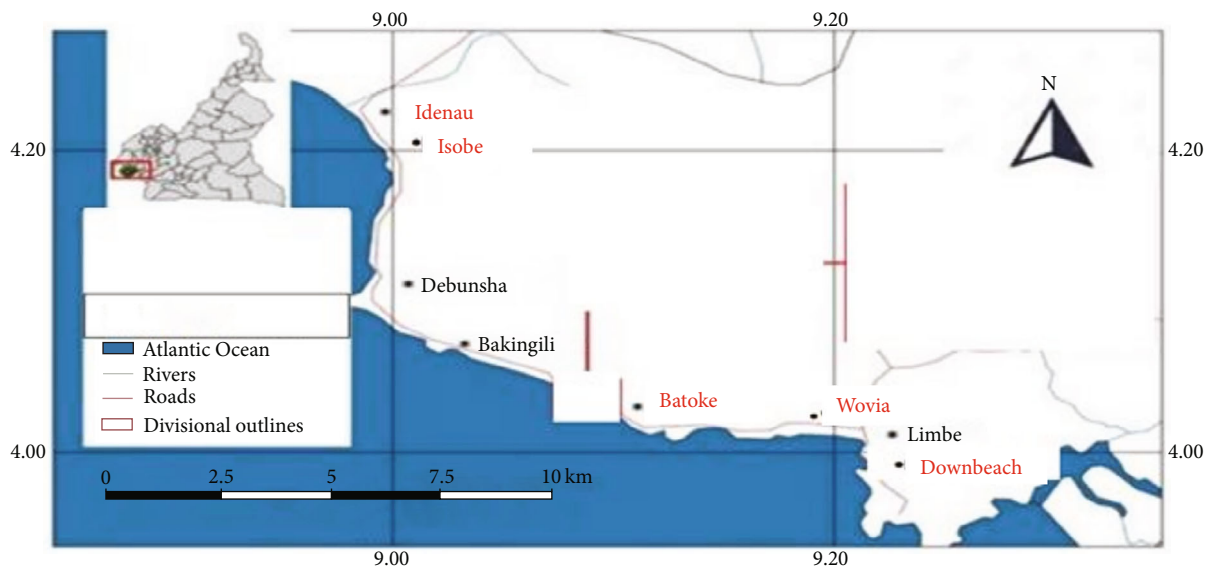


FIGURE 2: Map showing the locations of fishing communities under study.

processing, fish products obtained, problems faced after processing, and shelf life of fish products.

**2.2. Raw Materials for Fish Smoking Experiments.** Raw fish (*Ilisha africana*) were bought from fishermen in Batoke. They were weighed and their overall lengths measured, and those with a weight of  $60\text{ g} \pm 0.1\text{ g}$  and a length of  $16 \pm 0.5\text{ cm}$  were selected for smoking. *Ilisha africana* was chosen because of its high economic value.

**2.3. Smoke-Drying of Fish.** The fresh fish were manually descaled with a knife, washed with water from a regularly disinfected borehole, and smoke-dried using a Chorkor oven [34] at the Institute of Agricultural Research for Development (IRAD) in Batoke, Limbe. The oven was constructed using clay bricks plastered with a cement mixture, was rectangular with dimensions of  $160 \times 147 \times 100\text{ cm}$ , and had an opening at the front for firewood and a grill at the top for stacking fish during smoking.

Test runs were done before smoking the fish to standardize the temperature range following the quantity of wood required to attain the targeted temperature range. A smoking chamber was made by covering the fish with an aluminum bowl, and the exposed parts of the grill were covered with aluminum sheets and disinfected plantain leaves to prevent excessive loss of heat and smoke. Plantain leaves were disinfected by washing with a 6% bleach solution and then soaking in a basin of water at 100°C for 15 min. The fuel used for smoking was firewood of the wood specie *Piptadeniastrum africanum* (locally known as small leaf). Digital thermometers with probes were used to measure the smoking chamber and the internal (core) temperatures of the fish during smoke-drying.

The temperature of the smoking chamber was controlled by changing the sizes and quantity of wood used as fuel during smoking (2 logs of 15 cm diameter for temperatures ranging from 51 to 60°C, 3 logs of the same dimension from 61 to 70°C and 4 logs from 71 to 80°C). It was assumed that the temperature was constant in all areas of the smoking chamber for a given quantity of fuel used. Smoke-drying was carried out for 6, 12, and 18 h in the 3 temperature ranges following a 3 × 3 experimental design.

**2.3.1. Moisture Content Analysis.** Smoke-dried fish from each fish sample was randomly selected and finely ground using a mortar and pestle. The probe of a Tramex CME4 (China MD7822 Digital Moisture Meter) was inserted into each of the groundfish samples, and the moisture content was read and recorded as a percentage. The tests were carried out in triplicates.

**2.3.2. pH Analysis of Fish Samples.** One gram of groundfish from each of the finely ground fish samples was weighed with a WANT© electronic scale and homogenized in 10 mL of distilled water. The pH value of the solution was measured by dipping the electrodes of the pH probe of an AZ-86031 pH meter (AZ Instrument Corp.) into the solution according to the method of Pearson [35]. The tests were carried out in triplicates.

**2.3.3. Total Protein Quantification.** For total protein quantification of the fish samples, a UV-Vis Spectrophotometer (Biobase® China) designed for biochemical analysis was used.

To prepare the Biuret reagent, 60 mL of 10% NaOH was added to 100 mL of distilled water to dissolve 0.3 g of CuSO<sub>4</sub> and 1.2 g of Rochelle salt. 200 mL of water was added to the mixture. An equimolar mixture of 100 w/v of the fish sample and distilled water was made. 2.0 mg of the Biuret reagent was added to 500 µL of the protein solution previously made. The mixture was left for 60 minutes for the chromogenic reaction to be completed [36]. The absorbance measurements were then taken at 540 nm. A calibration curve of absorbance versus protein concentration was made using a reagent pack with a standard solution used for calibration. The total protein concentration of the fish samples was determined from the calibration curve.

The tests were carried out in triplicates.

**2.3.4. Microbiological Analysis.** The pour-plate method was used for counting the number of colony-forming microorganisms present in the fish samples.

10 g of groundfish samples were mixed with 100 mL of sterile distilled water. Serial dilutions were made from the stock solution, and 1 mL of the inoculum from the sample was placed at the center of sterile petri dishes with sterile pipettes.

15 mL of molten, cooled agar was poured into the petri dish containing the inoculum and mixed well. After the solidification of the agar, the plates were inverted and incubated at 37°C. The tests were carried out in duplicate.

The different analytical methods and references used for microbial counting contained in the samples are indicated in Table 1.

**2.4. Data Analysis.** The data obtained from the survey were analyzed and summarized using simple descriptive statistics. Data obtained from laboratory analysis of the nine fish samples were analyzed using one-way ANOVA to estimate the effect of smoking time and temperature range on the quality of smoked fish. The Tukey method was used to determine the HSD between means. The statistical package used was SPSS 20.0 at a confidence level of 95% ( $p < 0.05$ ).

## 3. Results and Discussion

### 3.1. Field Survey

**3.1.1. Personal Information of Respondents.** The personal information of the respondents is recorded in Figure 3. All the respondents interviewed were female with the majority (30%) aged between 36 and 45 years, 22.5% between 56 and 65 years, 20.8% between 26 and 35 years, 12.5% between 46 and 55 years, 10% between 18 and 25 years, and 4.2% above 65 years. These confirm the results obtained by Assogba et al. [25] who observed that the fish smoking activity was carried out mainly by women aged below 50 years. Most of them were conscious of the health risks associated with exposure to smoke, gases, and heat as shown in the survey. Many of them (70%) were married, while 21.7% were single. Most of the women interviewed said they carried out fish processing as an economic activity to support their families. A greater percentage of the respondents (54.2%) had a primary education; 20.8% had no education; 13.3% had a secondary education; and 11.7% had obtained a higher education. These results are similar to those by ref [43] who showed that the majority of fish processors had a primary education but different from those shown by Assogba et al. [25] who had 82.3% of illiterate processors. This difference could be because the 5 communities surveyed during this study are in the suburbs of the city of Limbe and not rural communities. The low educational level of most of the processors could negatively influence the safety of fish products due to a lack of knowledge of hygienic practices during processing [25].

**3.2. Fish Processing.** The summary of the fish processing methods, main processing equipment, fish species processed, processing time, processing steps, fish products obtained, and source of processing knowledge are presented in Table S2

TABLE 1: Flora, standards, and culture media used for microbial assays.

Microbial flora	References	Culture media
Revivable microorganisms	[37]	Plate count agar
Total coliforms	[38]	Violet red bile agar
<i>Staphylococcus aureus</i>	[39]	Chapman mannitol salt agar
<i>Pseudomonas aeruginosa</i>	[40]	Cetrimide and King B agar
<i>Salmomella</i> spp.	[41]	Citrate Simons and Hektoen agar
Yeasts and moulds	[42]	Yeast and mold agar (Oxoid®)

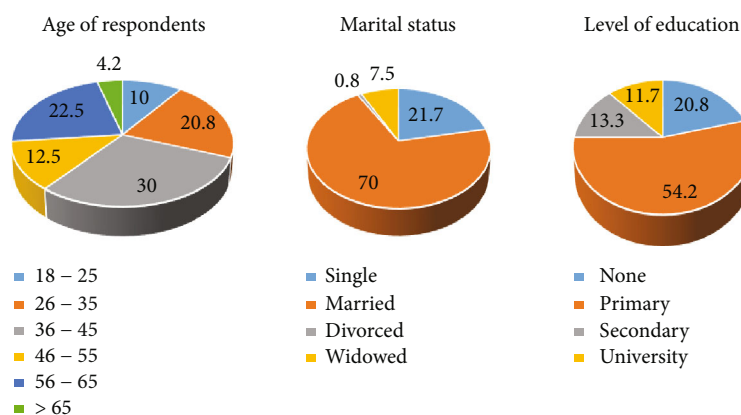


FIGURE 3: Personal information of respondents.

(Supplementary Information). This table shows the various percentages of respondents for each parameter, as explained below

**3.2.1. Fish Processing Methods.** The main fish processing method observed in the study area was the smoke-drying of fish. This method is used by 57.5% of processors for fish preservation and transformation. Sun drying was carried out by 21.7% of processors, mostly for small fish species like *Ilisha africana* (munyanya), because sun-dried *Ilisha africana* is considered a delicacy among natives of communities in the study area and their smaller sizes which make them more amenable for sun drying. Larger species and large quantities of fish cannot be effectively sun-dried due to the prolonged rainy season from March to November, humid conditions, and high temperatures characteristic of the study area which favor fish spoilage. This confirms the report by [44] which states that smoking is mostly carried out in the littoral and forest zones of Cameroon with an average humidity of 88%, while sun drying is mostly practiced in the northern regions with hot climatic conditions and lower relative humidity of 60%. 12.5% of respondents used fried fish as a processing method mainly for sale, while 5.0% of the processors combined smoke-drying and sun drying for fish processing and preservation. Few processors (3.3%) employed other methods such as grinding.

**3.2.2. Main Equipment Used for Processing.** The equipment used for fish processing varied from one community to another. For fish smoking, the suspended traditional barn

which consisted of a metal grill suspended by metal stands was mostly used (45%), while others (11.7%) used a cylindrical drum oven for fish smoking. Pots were used by 19.2% of processors for frying fish. Some processors (5.8%) constructed and used improved ovens. Sun drying of fish was done by spreading fish on surfaces such as logs of wood, large stones, or aluminum sheets (by 8.3% of processors). Other equipment such as meat grinders and sausage stuffers were used by a few processors (3.3%).

**3.2.3. Fish Species Processed.** Fifty-five percent (55%) of the processors in the study area process the following fish species: *Ethmalosa fimbriata* (bonga), *Sardinella maderensis* (strong kanda), *Ilisha Africana* (shad or munyanya), *Caranx/Chloroscombrus*, *Arius* (kwakoro), *Pseudotolithus elongatus*, *Pseudotolithus senegalensis*, *Pseudotolithus typhus*, *Galooides/Pentanemus/Polydactylus*, *Cynoglossus* spp., *Palaemon*, Juvenile *Ethmalosa/sardinilla*, *Panulirus regius*, while species caught by industrial fleets include *Pseudotolithus typhus*, *Arius*, *Pteroscion*, *Pentane-mus*, *Cynoglossus browni*, *Pseudotolithus senegalensis*, *Brachydeuterus ilisha*, *Pomadasys jubelini*, *Drepane*, *Vomer*, *Lutjanus agennes*, *Lethrinus Balistes forcipatus*, *Acanthurus*, *Chaeodon*, and *Sparus caerulostichus* [45]. Other fish species such as mackerel, barfish, and stockfish bought from cold stores were processed by 2.5% of fish processors.

**3.2.4. Processing Time.** The time used for processing fish varied according to the sizes of the fish and the processing method. For fish processed by smoking, differences in processing time were governed by the fish sizes, the type of

smoking barn used, and the demand for smoked fish. Fish species such as *Ethmalosa fimbriata* (bonga) and *Ilisha africana* (munyanya) were smoked for less than 6 h, while larger species like *Sphyraena barracuda* (kuta) and *Gadus morhua* (Atlantic cod, mukanjo) were smoked for longer periods. Thirty-seven percent (37.5%) of processors processed their fish for less than 6 h, and these consisted of those smoking fish, frying fish, and those producing fish sausages, while 30.8% of processors (smoking large species of fish) smoked for 24-48 h. Some smoke large species for less than 12 h during periods of large demand.

**3.2.5. Steps Involved in Processing.** The processing steps varied according to the processing method used. For fish smoking, the processing method varied according to the fish sizes. Among all processors smoking fish, small pelagic fish species such as *Ethmalosa fimbriata* (bonga), *Ilisha africana* (munyanya), and *Sardinella maderensis* (strong kanda) were descaled, washed, pinned, pegged, or folded and put on grills for smoking. They were neither gutted nor had the gills removed. For larger species like *Sphyraena barracuda* (kuta), the fish were scaled, gutted, gills removed, cut into chunks, and washed before smoke-drying. This is similar to what is done in Benin, where cutting is done for big size fishes, and gutting is avoided for some species because it would affect the presentation of the end product [25]. For sun-dried fish, all processors scaled, washed, and spread it out on surfaces to sun dry, while for fried fish, they were scaled, gutted, dry-salted for 30 minutes, and fried in hot vegetable oil. Sun dried and smoke-dried fish were prepared by scaling and washing, then sun drying for 6-12 h, and later smoke-drying. The sources of water used were pipe-borne, seawater, water from streams, and water from springs associated with the various fishing communities. In the case of other products such as fish sausages, the fish was dressed, washed, chopped, and ground while mixing with other ingredients, stuffing, and thermal treatment (boiling until the internal temperature reaches 72°C for 1 h).

**3.2.6. Fish Products Obtained.** A majority (60.8%) of processors produced smoke-dried fish for sale and home consumption; 15% of processors produced sun-dried and smoke-dried fish; and 7.5% produced sun-dried fish. Fried fish was produced by 13.3% of processors, and fish sausage was produced by 3.3% of processors.

**3.2.7. Source of Processing Knowledge.** Most of the processors (82.5%) acquired processing knowledge from older relatives; 13.3% learned from their friends and neighbors; and 2.5% acquired processing knowledge from schools, institutes, and organizations. A few (1.7%) learned from the Internet, and most of these were those who had obtained a higher education certificate.

### 3.3. Problems Faced by Processors

**3.3.1. Problems Faced before Processing.** Many processors (42.5%) claimed that the main problem they faced before processing is lack of fish; 37.5% complained of poor quality of fish sold to them by fishermen; 9.2% complained of prices

of the raw fish; and 10.8% complained of other problems such as lack of finances to purchase fish, fuel, and repair smoking barns. The lack of fish as reported by processors was due to a reduction in fishermen's catch as compared to previous years and during the dry season. This could be due to overexploitation and the catching of juvenile fish as noted by Thierry et al. [46]. The poor quality of raw fish sold to them was due to fishing boats not having adequate storage facilities, especially for fishing far into the sea.

**3.3.2. Problems Faced during Processing.** Thirty-eight percent (38.3%) of processors complained of insufficient fuel and energy source; 19.2% complained of the negative effect of irritation during processing; 13.3% sustained burns; 12.5% complained of heat affecting them during processing; and 16.7% mentioned other problems such as rain entering the smoking kitchens during the rainy season.

**3.3.3. Problems Faced after Processing.** The main problem faced by processors after processing was the short shelf life of their products (as indicated by 62.5% of processors). Twenty-five percent (25%) of processors had poor storage facilities for their products. Some processors had other problems such as customers paying lower prices for their products while a few processors (1.7%) complained of a reliable market for their products.

**3.4. Fish and Fish Product Properties.** The properties of fish and fish products such as shelf life of fish products, quality criteria of raw fish according to processors, quality criteria by customers, product destination, and percentages by respondents are summarized in Table S3 and explained below

**3.4.1. Shelf Life of Fish Products.** The shelf life of the fish products, according to 32.5% of the processors, was 1-2 weeks, while 29.2% of respondents had 2 days to 1 week. For smoke-dried fish products, the shelf life could be increased to more than 1 month (as claimed by 7.5% of processors) by resmoking from time to time after initial processing that prevents or limits the growth of molds and spoilage, but not without causing undesirable changes in the taste and appearance of the smoked fish product. A few processors (3.3%) refrigerate their products, and in such cases, shelf life goes above 1 month.

**3.4.2. Quality of Raw Fish according to Processors.** According to the processors, the criteria used for appreciating raw fish before purchasing are physical characteristics and include red gills (87% of processors), bright eyes (15% of processors), and firm skin (12% of processors), while 6% of the processors used all the criteria. These criteria were similar to those reported by Assogba et al. [25] and Depo et al. [47]. According to processors, they could not always purchase the fish of their choice because fishermen did not allow them the option to select the fish.

**3.4.3. Quality Criteria by Customers.** Just like the quality criteria for the appreciation of raw fish by processors, physical characteristics were also used to appreciate fish products. Thirty-eight percent (38.3%) of processors claimed the

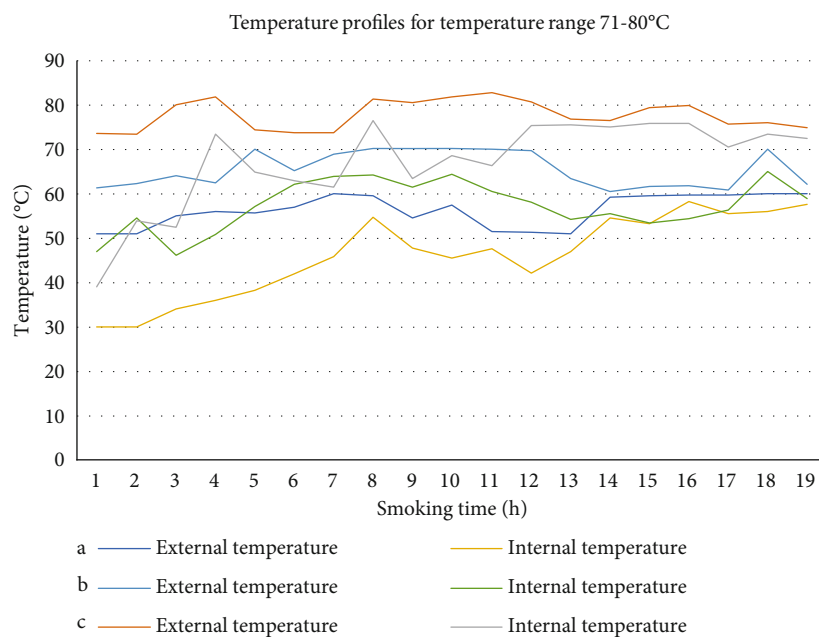


FIGURE 4: Temperature profiles for the smoking process at the various temperature ranges. (a) Temperature profiles (external and internal temperatures) for smoking in the range 51-60°C. (b) Temperature profiles (external and internal temperatures) for smoking in the range 61-70°C. (c) Temperature profiles (external and internal temperatures) for smoking in the range 71-80°C.

customers used colour to appreciate fish products, smell (14.2%), and absence of visible molds and fungi (9.2%), while 27.2% claimed customers used all the criteria for appreciation, and according to 10.8% of processors, customers used other criteria such as taste, size, and shape to appreciate the products.

**3.4.4. Fish Product Destination.** Most of the processors (60.8%) produced fish products both for sale and home consumption, while 37.5% produced only for sale and 1.7% produced only for home consumption.

From the field survey, it was observed that smoke-drying was the most popular unit operation used by most of the processors in the study area. The following sections present results on the smoke-drying of one of the most popular fish species (*Ilisha africana*) in the study area.

**3.5. Temperature Profiles for the Smoking Process.** The temperature profiles for the smoking process are shown in Figure 4. As stated by *Codex Alimentarius* [48], an appropriate time/temperature combination must be used for the complete coagulation of proteins where the internal temperature of the fish should reach 65°C in the thermal center of the product. The temperature profiles indicate that the ranges of the parameters used in the study were attainable in the smoke oven used. For each range, the internal temperature (core temperature) of the fish was lower at the beginning and slowly approached the smoking temperature of the oven with the progress of the smoking process.

### 3.6. Physicochemical Properties of Smoked Fish Samples under Controlled Conditions

**3.6.1. Fish Color.** Nine (9) fish samples smoked under different conditions of time and temperature range were obtained.

Physically, the fish smoked under different conditions and had different colour, from light brown to golden brown to dark brown (Figure 5). Colour formation in smoked fish is caused by the reaction of carbonyl compounds with fish proteins in a Maillard reaction when the product is heated [49], as well as the deposition of phenolics and the formation of excessive phenolics. Excessive deposition of phenolics, the formation of condensed phenolics, and excessive Maillard browning cause the product to have a dull, dark color with numerous specks of dark material on the surface. This takes at temperatures of 80 to 90°C [50, 51].

**3.6.2. Moisture Content.** The results displayed in Figure 6 show that for *Ilisha africana* smoked in this work, there was a drastic reduction in moisture content for all drying times and temperature ranges. Apart from samples smoked for 6 h in the temperature ranges 50-60°C and 70-80°C, there was a significant difference ( $p < 0.05$ ) in the moisture with respect to drying time and temperature range. The final moisture content of the fish reduced as expected with an increase in smoking time as well as the smoking temperature range. An increase in smoking temperature increases the quantity of heat required for smoking, while an increase in smoking time permits sufficient contact between the heat and the fish. These two activities promote water loss from the fish, resulting in a final low moisture content. In the temperature range of 51-60°C, final moisture content was greater than 19% for all drying times which represented a reduction of about 61.9% -68.2% from the moisture content range of fresh fish that is in the range of 70-80% [52]. This confirms the observation by Davies and Davies [52], which shows that moisture content reduces at a higher rate with an increase in smoking temperature and time. For the fish



FIGURE 5: Fish samples obtained after smoking experiments. (a) Sample 1 (6 h, 51–60°C). (b) Sample 2 (12 h, 51–60°C). (c) Sample 3 (18 h, 51–60°C) (d) Sample 4 (6 h, 61–70°C). (e) Sample 5 (12 h, 61–70°C). (f) Sample 6 (18 h, 61–70°C). (g) Sample 7 (6 h, 71–80°C). (h) Sample 8 (18 h, 71–80°C). (i) Sample 9 (18 h, 71–80°C).

smoked in the temperature range of 61–70°C, the final moisture content was 27, 23.7, and 12.3% for fish smoked for 6, 12, and 18 h, respectively.

For the sample smoked in the temperature range of 71–80°C, after 12 h, the moisture content reduced to 10.7% and then to 7.3% after 18 h.

As stated by Oparaku and Mbengka [53], the moisture content of fish which is favourable for storage (increased shelf life of fish) and stops mold growth should be less than 15%, while Eyo [23] reported that the moisture content must be less than 30% to ensure short-time storage of dry fish that is safe from mold and bacteria infestation. The final fish product which can be stored and transported without refrigeration should have a moisture content of 10% or less, which is necessary to control bacteria, pathogen, or fungal spoilage [54]. A higher moisture content will make the product susceptible to microbial and enzymatic spoilage. This implies that in this study, fish destined for long-term storage that will prevent mold growth and can be transported without refrigeration should be smoked in the temperature ranges

of 61–70°C for 18 h (12.3%), 71–80°C for 12 h (10.7%) and 18 h (7.3%). Destined for short-term storage, the fish should be smoked in the temperature ranges of 51–60°C for 6 h, mostly to save energy. These results corroborate well with field work where 62.5% of the respondents asserted that their fish is smoke-dried for about 6 h and this cannot be stored above a week without resmoking.

**3.6.3. pH.** Results showed that pH values ranged from 6.2 to 6.7 and that the treatment given to the fish samples had no significant effect on the pH.

pH is used to measure the extent of deterioration and is a critical factor affecting the microbial growth and spoilage of foods including fish [55, 56]. All the pH values obtained were below the 6.8–7.0 limit, which indicates fish freshness. Higher pH values favour the growth of microbes. The pH values were also within the range of smoked fish samples (6.27–6.86) reported by Huong [57] for smoked silver catfish. The results, therefore, showed that in terms of pH, the fish is of good quality.



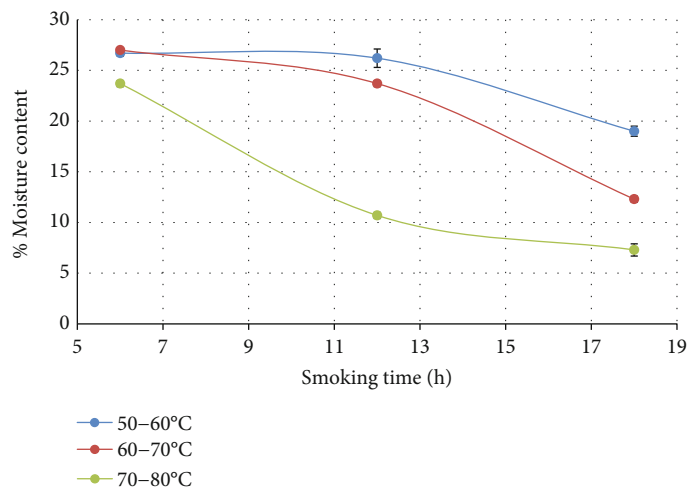


FIGURE 6: Final moisture content of *Ilisha africana* smoked at varied temperature ranges and times.

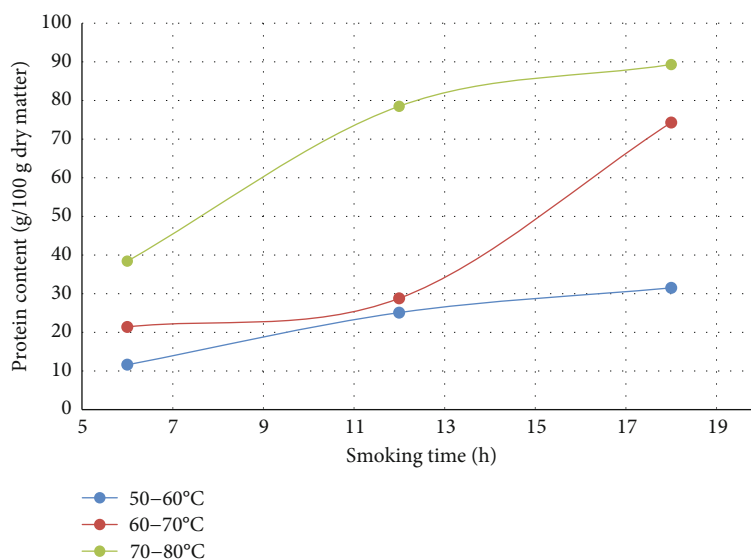


FIGURE 7: Total protein content *Ilisha africana* smoked at different temperature ranges and time.

**3.6.4. Total Protein Content.** The mean values for the total protein content of *Ilisha africana* smoked at different temperature ranges and times are recorded in Figure 7.

Figure 7 shows that total protein increased significantly ( $p < 0.05$ ) with an increase in temperature and time. For example, in the temperature range of 51-60°C, after 6 h of smoking, the protein content was 11.6 g/100 g which increased after 12 h to 25.1 g/100 g and finally to 31.5 g/100 g after 18 h.

The corresponding values in the temperature range 61-70°C, were 21.4 g/100 g, 28.8 g/100 g, and a sharp increase to 74.3 g/100 g at 6, 12, and 18 h, respectively, which were significantly higher than those in the temperature range 51-60°C. These were, however, significantly lower ( $p < 0.05$ ) than the corresponding protein values of 38.4 g/100 g, 78.5 g/100 g, and 89.3 g/100 g obtained in the temperature range of 71-80°C. The values for the protein content of fish are similar to those reported by Iko Afé et al. [58], which were 59.0% for *Scomber*

(lowest) and 84.5% for *S. barracuda* (highest) for smoked and smoke-dried fish obtained from markets in Benin. Also, the values are similar to those of Tiwo et al. [50] who reported total protein content of 86.56 g/100 g dry matter and 88.65 g/100 g dry matter for *Clarias gariepinus* and *Cyprinus carpio*, respectively, after smoking at 80°C for 7 h in an improved oven. This increase is due to the rapid loss in moisture content at higher temperatures which concentrates proteins and other proximate composition parameters [59]. An increase in total protein indicates an increase in the nutritional value of the fish [60, 61].

**3.7. Bacterial Population Detection and Enumeration.** The bacterial populations enumerated from the fish smoking experiments are recorded in Table 2.

Table 2 showed that for all the temperature ranges, the bacterial count decreased with an increase in smoking time.

TABLE 2: Bacterial count of *Ilisha africana* smoked at different temperature ranges and time.

Temperature range (°C)	Time (h)	Revivable microorganisms at 37° C ( $\times 10^4$ ) CFU/g	Total coliform count ( $\times 10^2$ ) CFU/g	Enumeration of coagulase-positive <i>Staphylococcus aureus</i> ( $\times 10$ CFU/g)	Enumeration of <i>Pseudomonas aeruginosa</i> ( $\times 10^4$ CFU/g)
51-60	6	3.1	9.1	6.0	0
	12	2.9	4.5	1.72	0
	18	2.7	0	1	0
61-70	6	3.7	1.6	1.1	9
	12	3.0	1.4	0.18	5.4
	18	2.5	0.4	0.12	0
71-80	6	3.2	1.3	2.8	2.7
	12	2.8	0.5	0.8	2.7
	18	2.3	0	0.11	0

For fish samples smoked in the temperature range of 51-60 °C, after 6 h, the revivable microorganisms, total coliform count, and *Staphylococcus aureus* were  $3.1 \times 10^3$  CFU/g,  $91 \times 10$  CFU/g, and  $6 \times 10$  CFU/g, respectively, while no bacterial colonies were detected for *Pseudomonas aeruginosa* and *Salmonella* spp. The corresponding values decreased after 12 h in the same temperature range to  $29 \times 10$  CFU/g,  $45 \times 10$  CFU/g, and  $17 \times 10^{-1}$  CFU/g for revivable microorganisms, total coliform count, and *Staphylococcus aureus*, and then to  $27 \times 10^3$  CFU/g, 0.0 CFU/g, and  $1 \times 10$  CFU/g for revivable microorganisms, total coliform count, and *Staphylococcus aureus* after 18 h of smoking.

For fish smoked in the temperature range 61-70°C, the revivable microorganisms, total coliform count, *Staphylococcus aureus*, and *Pseudomonas aeruginosa* were  $37 \times 10^3$  CFU/g,  $16 \times 10$  CFU/g,  $11 \times 10^{-1}$  CFU/g, and  $9 \times 10^4$  CFU/g after 6 h;  $3 \times 10^4$  CFU/g,  $14 \times 10$  CFU/g,  $18 \times 10^{-2}$  CFU/g, and  $54 \times 10^3$  CFU/g after 12 h; and  $25 \times$  CFU/g,  $4 \times 10$  CFU/g, and  $12 \times 10^{-2}$  CFU/g after 18 h of smoke-drying. These values represent significant decreases in all the microorganisms analysed compared to the corresponding values obtained in the temperature range 51-60 after 6, 12, and 18 h, respectively. *Pseudomonas aeruginosa* and *Salmonella* spp. were undetected at all smoking temperatures.

Similarly, for fish smoked in the temperature range of 71-80°C, a significant reduction ( $p < 0.05$ ) in the level of revivable microorganisms, total coliform count, *Staphylococcus aureus*, and *Pseudomonas aeruginosa* was observed when smoking time increased from 6 to 18 h and when compared to values of samples prepared in the temperature ranges 51-60 and 61-70°C. These results clearly indicated that the level of microorganisms in the smoked fish significantly reduced with an increase in both smoking time and temperature. *Salmonella* spp. remained undetected. *Pseudomonas aeruginosa* and *Salmonella* spp. were undetected in the samples after 18 h of smoking. Sikoki and Aminigo [62] showed that smoke-drying reduces bacterial counts which concurs with the results obtained in this work.

As observed by Akhter et al. [59], wood smoke contains pyrolygneous acid which may have a preservative effect on smoked-dried meat. Even though smoking controls the

microbial contamination in fish at adequately high temperatures, sometimes the use of high temperatures might not be sufficient to kill all the microbial contaminants such as spores [63]. This is a dormant state of the bacteria, characterized by a low metabolic rate to survive adverse conditions. When favourable conditions return, the bacterial cells can be revived [64].

Processed fish can easily be contaminated with microorganisms in nature through rough handling, improper processing, and through improper and unhygienic postprocessing handling [65]. When the bacterial loads of smoked fish exceed the acceptable limit of  $5 \times 10^5$  CFU/g, the smoked fish becomes unacceptable, and this may cause serious diseases in the human body and is also one of the contributing factors to fish spoilage [66].

The presence of coliforms in some of the fish samples indicates possible contamination of the water or as a general indicator of the sanitary condition of the culture area as well as the food processing environment [67]. This is highly plausible since fishermen display their catch after landing, on the sand at the beach during sales, and inhabitants at the seaside possess inadequate sewage treatment systems [68]. However, the values do not exceed the recommended limit of  $10^3$  CFU/g specified by the International Commission on Microbiological Specifications for Food (ICMSF) [69]. The absence of salmonella in any of the fish samples shows no contamination during processing [70].

*Pseudomonas* are among the group of fish microflora, and their spoilage activity in fish is rated among the other bacteria as high [66].

The total plate counts for all the bacteria did not exceed the range of specified microbiological limits recommended for fish and fishery products by the International Commission on Microbiological Specification for Foods [69], which recommends a maximum bacterial count of  $5 \times 10^5$  CFU/g for good quality product and did not exceed a maximum count of  $10^7$  for marginally acceptable quality products [71]. However, the initial pathogenic and spoilage microbial load indicates the potential growth of the microorganisms which determine the shelf-life, thereby necessitating processing methods such as smoking to extend the shelf-life of the fish products [72].

**3.8. Fungal Population Count.** For all the temperature ranges, the fungal population decreased with an increase in smoking time. Fish samples smoked in the temperature range of 51–60°C, had a fungal population of  $32 \times 10^2$  CFU/g,  $31 \times 10^2$  CFU/g, and  $13 \times 10^2$  CFU/g, respectively. A similar reduction in the fungal population ( $31 \times 10^2$  CFU/g,  $23 \times 10^2$  CFU/g, and  $9 \times 10^2$  CFU/g) was obtained in the temperature range 61–70°C after 6, 12, and 18 h of smoking, respectively. No fungal growth was observed in the temperature range of 71–80°C. From these results, it is seen that as processing time and temperature increased, there was a significant reduction ( $p < 0.05$ ) in the fungal population.

The values of the fungal population for fish smoked in the temperature ranges of 51–60°C and 61–70°C for 6 and 12 h are higher than the maximum limit of molds (500 CFU/g) in dried fishery products [73]. For the samples smoked at 51–60°C and 61–70°C for 18 h and all the samples smoked at 71–80°C, the values were below that limit.

The presence of fungi (molds and yeasts) in fish samples can be caused by contamination from boats in which the fish are stored between catching and sale [65] and is directly proportional to moisture content. Species of fungi observed in smoked fish samples have been attributed to partial dehydration during smoking [74]. In fact, in this work, the fungal population decreased significantly as the final moisture content reduced. The presence of yeasts and molds in fish samples can cause serious health concerns because of their mycotoxigenic potential [75].

#### 4. Conclusion

Various methods of processing fish are used in coastal regions in Cameroon, with smoke-drying being the main method. Equipment and methods used for smoke-drying of fish differ from one processor to another within each community and also depend on the fish species processed.

Smoking fish at different temperature ranges and times gives products of different quality. The moisture content and microbial content of fish decrease with an increase in smoking temperature and time, while the protein content of fish increases with an increase in smoking time and temperature. Fish smoked at a temperature range of 61–70°C for 18 h and 71–80°C for 12 h produce smoked-dried fish with moisture contents below levels favorable for fish spoilage and reduced microbial load.

#### Data Availability

The authors confirm that the data supporting the findings of this study are available within the article. Raw data that support the findings of this study are available from the corresponding author upon request.

#### Conflicts of Interest

The authors declare that they have no competing interests related to this article.

#### Supplementary Materials

S1 is a sample of the questionnaire used in the study; Table S2 is a quantitative summary of the results obtained from field questionnaires on fish processing methods; and Table S3 gives a summary of the fish and fish products which have been discussed in the manuscript. (*Supplementary Materials*)

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