COMPARING QUALITY AND STORAGE LIFE OF HOT SMOKED MACKEREL AND HERRING USING TWO DIFFERENT SMOKING KILNS

Richner Naa Krokor Odoi
Ministry of Fisheries and Aquaculture Development
Fisheries Commission, P. Box GP 630, Accra, Ghana
richner.odoi@gmail.com, richnerodonkor@yahoo.com

Supervisors:

Magnea Karlsdottir: magneag@matis.is
Asbjorn Jonsson: asbjorn@matis.is
Oli Thor Hilmarsson: oli.th.hilmarsson@matis.is

ABSTRACT

Hot smoking of herring and mackeral was done using two different techiniques, an open fire drum and smoking cabin designed by MATIS. Commercial wood chips was used to enhance the smoky aroma and hard wood added to generate the glowing fire. Smoking was done between three and six hours for both open fire drum and smoking cabin respectively. After smoking, the smoked herring and mackerel were packed in clear plastic bags and stored at room temperature (23 °C) and cold temperature room (2 – 4 °C) . Physical parameters (temperature, pH, water activity) , microbial (total plate count), chemical properties (Polycyclic Aromatic Hydrocarbons (PAHs), total volatile base nitrogen (TVB-N), protein and water content) and lipid degradation including, thiobarbituric acid reactive substances (TBARS), free fatty acids (FFA), peoxide values (PV)), were analyzed on fresh brined material and smoked samples during storage, which ended on day 26. Total sum of all the positive PAHs in smoked mackeral from the cabin were in inapplicable limits. However, levels from the open fire drum was 9.7 µ/kg and the sum of the four PAHs (Benzo(a)anthranthene, Chrysene, Benzo(b)fluoranthene and Benzo(a)pyrene) were 6.9 µ/kg.

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1   INTRODUCTION

1.1   Background

Fish is important for food security, nutrition, income and employment in Ghana. Fish accounts for about 60 % of animal protein consumed in Ghana with an average per capita consumption of 23.7 kg per annum (Anon, 2011). Over 10 % of the 26 million Ghanaians depend either wholly or partly on the fishing industry, mostly the artisanal sector to derive their livelihood (MOFAD, 2013).

Ghana has a coastline of 550 km and a relatively narrow continental shelf with a total area of 24,300 km^2. The fishing industry in Ghana is based on resources from the marine and to a lesser extent, inland and aquaculture sectors. The main sources of freshwater fish include the Volta Lake, reservoirs, fish ponds and costal lagoons. Marine fishing is practiced along the four coastal regions in Western, Central, Greater Accra and Volta (Figure 1) which form the backbone of the fishing industry in Ghana. The marine fisheries can be classified into three main subsectors namely artisanal (small scale), semi-industrial (inshore) and industrial (bottom trawlers, shrimpers and tuna fisheries). The artisanal canoes and semi-industrial boats can operate 30 m depth contour while the industrial fleets are to fish beyond this zone as stated in the Fisheries Act 625, 2002.
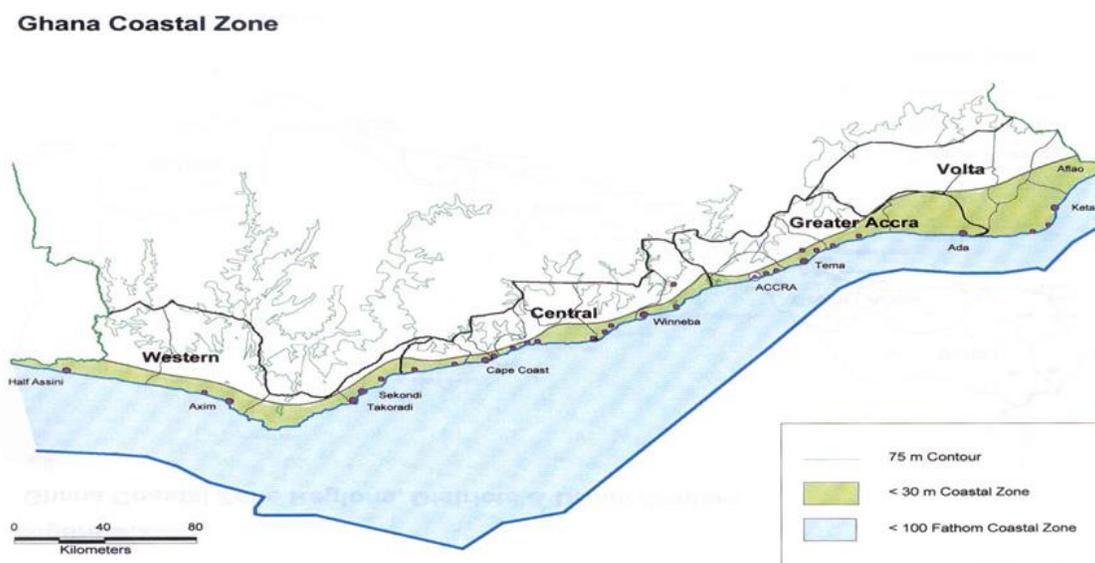
Figure 1: Coastline of Ghana indicating the fishing zones (MOFA, 2012).

Over 70 % of the annual fish production in Ghana comes from the marine fisheries. For instance, in 2013, 314,868 MT (73 %) of the total fish production (434,120 MT), was from marine waters while inland waters and aquaculture produced only 86,740 MT (22 %) and 32,512 MT (7 %) respectively. However, this annual production is still far below the annual requirements of one million metric tonnes to meet the country's fish demands and the country continues to rely on imports to make up for the deficit. The artisanal fisheries subsector is the most important with

respect to volume of landings in the marine fisheries (Figure 2). There are about 12,000 canoes operating in this sector from over 300 landing sites using several types of gear such as purse seine, beach seine, sets nets, drifting gill nets and hook and line. These gears target different fishery resources but the most exploited species include sardines, chub mackerel, anchovies and sea breams. The sector provides about 70 to 80 % of the total marine fish production annually (Armador, Bannerman, Quaatey, & Ashong, 2006).
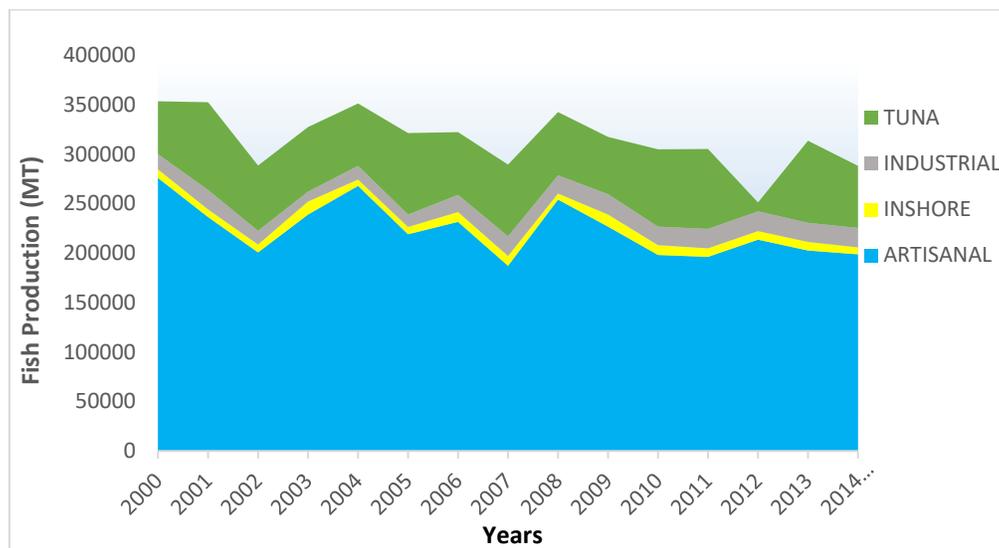
Figure 2: Fish production of catch landings in the marine industry (MOFAD, 2013).

The catch is processed in various ways including smoking, drying, salting, deep frying and fermenting or a combination of two or more of these to achieve the desired product for consumption. However, the most preferred product by an average Ghanaian is the smoked fish which is used in preparation of traditional soups and stews. Accordingly, smoking is the main method of preserving fresh fish and smoked products are available in most fish markets throughout the country. The two most important attributes influencing choice and preference for the smoked fish products in Ghana are flavour and long storage time (shelf life) of the products.

Smoking is a traditional preservation method for muscle foods and the oldest known method for preserving fish in Africa (Samey, 2013). Practically, in Ghana all species of fish available in the country can be smoked and it has been estimated that 70 to 80 % of fish catches from the domestic marine, freshwater and aquaculture are consumed in smoked form (Samey, 2013; FAO, 2010) Processing of smoked fish is done on small scale level, mostly by women, especially along the coastal regions and inland communities close to water bodies. Most of the processing takes place at the individual or household level and in some cases joint associate groups have smoking sheds where smoking is done by individual processors.

The most common method of smoking used by most fish processors in Ghana is the "Chorkor Smoker" (Figure 3) which was developed in 1969 by the Food and Agriculture Organization of the United Nations (FAO) and the Food Research Institute of the Council of Scientific and

Industrial Research (CSIR) in Ghana to replace the older traditional smoking ovens such as Adjetey and Altona, cylindrical and rectangular smoking ovens made from drums and mud (Figure 4). The Chorkor smoking kiln can be designed in three forms, with a mud base, cement base or brick base. It can also have a single or a double type smoker but the choice of smoker depends on the fish processor as well as cost and maintenance. The single chamber can take about 14 wooden frame trays during smoking and as a single pit for fuel wood while the double smoker takes about 28 wooden trays and as two point source for fuel wood. The Chorkor Smoker has constituted a major progress role than older technologies of smoking in meeting most of the previous challenges encountered from the other older traditional smoking ovens. These traditional smoking ovens had low capacity and were inefficient in fuel usage. Excessive handling of the fish during smoking contributed to high post-harvest losses. The process was unhygienic and fish processors were exposed to heat and inhalation of smoke. Although, fish processors are moving away from using these methods of smoking and are well adapted to the smoking technique using the Chorkor smoker, the cylindrical ovens are still being used in some of the coastal regions. In 2013, there was an estimated 36,000 fish smoking ovens in the coastal zone of Ghana, suggesting that including inland locations, the total number may be above 50,000. Of the total, 33 % are of the traditional drum or round type with single mesh/tray, and 67 % of the Chorkor variety (Samey, 2013).

Figure 3: Types of Chorkor smokers. To the left: A Single mud base Chorkor Smoker with stackable wooden trays; To the right: A double cement base Chorkor smoker.

Figure 4: Cylindrical drum ovens.

However, there are still some constraints of the Chorkor smoking technique that can be improved for the benefit of both processors and consumers. Examples of these constraints are uneasiness related to the inhalation of excessive smoke by fish processors, high use of fuel wood, long hours spent per fish smoking cycle, uncontrollable temperatures in the kiln during smoking and direct heat source on the products which can cause high levels of Polycyclic Aromatic Hydrocarbons (PAHs) in the smoked product making it unsafe for human consumption.

PAHs are environmental contaminants that are formed during the incomplete combustion of carbon based fuels (Suchanová *et al.,* 2008). According to the European Food safety Authority (EFSA, 2008) several PAHs have been shown to induce a number of adverse effects, which are toxic and carcinogenic. Food exposure to carcinogenic PAHs generally emanate from their contamination during processing such as roasting, smoking and charcoal grilling. Exposure to direct flame can lead to high levels of PAHs in the final food product. The choice of technology for processing is therefore very important for the final concentration of PAHs. The direct exposure of fish to smoke brings about higher concentrations of PAHs in the fish as compared to the indirect methods, where PAHs are partially eliminated by condensation in tars (Palm *et al*., 2011). The potential and toxicological effect of PAHs are strictly regulated through codes of good practice and guidelines to ensure that their presence in food are at the lowest levels possible. Codex Alimentarius, the only international body responsible for development of standards, codes of practice, guidance and recommendations published a specific code of practice in 2009 in connection with food contamination by PAHs from direct smoking and drying processes (Codex

Standards, 2009). The guidelines state some variables which can lead to the formation of PAHs from direct smoking and drying processes. These include:

a) distance between the food and heat source
b) temperature during smoking and direct drying
c) position of the food in relation to the heat source
d) duration of smoking and direct drying
e) fuel (woods and other plant materials, diesel, gases, liquid or solid waste and other fuels)
f) fat content of the food and what happens to it during processing
g) cleanliness and maintenance of equipment
h) design of the smoking chamber and the equipment used for smoke or air mixture which influences the smoke density in the smoking chamber.

In addition, the EU Regulation 1881/2006, which was recently amended as (EU) No 1327/2014 (EU regulations, 2014) regards maximum level of PAHs in traditionally smoked fish and fishery products. It requires a formal setting of rules on the content of PAH in smoked products because recent evidence has shown that lower levels of PAHs have not been achievable in some countries where smoking practices cannot be changed without changing significantly the organoleptic characteristics of the food. Subsequently, new application of good smoking technology must be adapted. Therefore, permitted limit set by the European Commission for all PAHs in smoked fish textures is 30 µg per kg, and acceptable limit of Benzo(a)pyrene, which is the carcinogenic criterion of smoke has been stated as 5 µg per kg in smoked fish.

However, the process of handling fish from catch through processing in the artisanal sector has been a challenge for decades. Efforts to sensitize fishermen on the need for hygienic handling of fish catch (raw materials) to maintain quality and prevent loss of value have not yielded much of the desired results. Once removed from their habitats, fish immediately begin to undergo a series of biological, chemical and physical changes that lead to spoilage and hence lower their quality, unless specific precautionary measures are taken during and after harvest. The degradation of the tissue is brought about both by indigenous fish enzymes and by micro-organisms which are present on the surface of the skin, on the gills and in the intestines. Although fishermen have ice holding facilities in their canoes, affordability and accessibility has been a challenge. Artisanal fishers must be given access to ice so they can ensure rapid cooling of their catches using proper fish holding tubs and avoiding exposure to direct sunlight since improper handling causes fish losses. Poor handling practices reduce the quality of the smoked products and subsequently affects their value in the markets. In Ghana, post-harvest losses are estimated to be 40% in value due to loss in quality during smoking and drying for packaging and transportation to the market (Aryee & Oduro, 2013). Moreover, the continued dependency on fuel wood as the major source of energy for smoking will only exert further pressure on the already depleted forest, especially the mangroves.

The Ministry of Fisheries and Aquaculture Development (MOFAD) in Ghana has been working in collaboration with the Food and Agriculture Organization (FAO) and Centre for Scientific and Industrial Research (CSIR) to develop new techniques of smoking kilns that can produce better quality of smoked fish products with lower fuel efficiency and also reduce the smoky emissions that pose health complications to fish processors during smoking. This strategy is partly aimed at meeting targets in the Ghana fisheries and aquaculture sector development plan 2010-2015, (Ministry of Fisheries and Aquculture, 2008) which seeks to promote value addition in the fisheries

sector and improve livelihoods in the fishing communities. The plan further outlines three opportunities to add value namely, reducing post-harvest losses, reducing handling costs and producing higher value products.

In implementing the fisheries and aquaculture sector development plan, the ongoing West Africa Regional Fisheries Programme (WARFP) aims to help Ghana to sustainably increase the net economic benefits from its fisheries and aquaculture investments. It also addresses the issue of food safety and introduces technologies to create better hygienic and safer processing facilities. The project document states the following objectives:

i.   Reduced levels of PAH in smoked fish products
ii. Provide more hygienic conditions for the production of salted/smoked-dried fish, consistent with international standards.

The UNU-FTP has also identified fish processing in artisanal fisheries as a priority area in capacity building (UNU-FTP, 2014). Hence, several fellows and PhD students have done research in this area. Over the past few years MATIS (Laboratory Icelandic Food and Biotech Research and Development, Iceland), have been developing a solar smoker/drier to reduce fuel wood consumption and produce safe and more nutritious products.

In the present project the performance and efficiency of a smoking cabin kiln designed by MATIS was evaluated. Improvements that would make it suitable for fish processing by communities in Ghana to overcome challenges faced with the current fish smoking techniques are also proposed.

Overall Objective
The main objective of this project was to study the performance of two different smoking kilns and determine the quality and storage life of the smoked products.
Specific Objectives:

- Compare the levels of PAH in the smoked products on an open fire (drum) and cabin smoking kiln designed by MATIS.
- Compare products of herring and mackerel before and after smoking from the open fire and cabin smoking kilns with respect to microbiological, chemical and physical characteristics.
- Evaluate the storage life of the smoked products of herring and mackerel stored at different temperatures (23 °C and 2 – 4 °C) by using microbiological, chemical and physical analysis.
- To estimate the amount of wood (heat energy) used during the hot smoking of fish samples in each of the smoking kilns.

2   MATERIALS AND METHODS

2.1   Species selection for the experiment

In Ghana the dominant species in both the artisanal and the inshore sectors include round and flat sardines, chub mackerel, sea breams, anchovy and burrito, which form over 70 % of the annual marine total catch. Most of these species are traditionally smoked and are available throughout the year.

Sardines can grow to about 30 cm and move in schools close to the surface in the inshore waters where they feed and spawn at the onset and during the major upwelling season. This is when major catches of herring are made generally between July and September each year (MOFAD, 2013).

Chub mackerel (*Scomber japonicas*) is also an important pelagic specie which constitutes about 20 % of the total annual inshore catch. Chub mackerel, locally called 'saman', is one of the most important specie in terms of economic value, abundance and quality. Chub mackerel fishery is also seasonal and coincides with the upwelling seasons (July and September). It is mostly 10 to 26 cm long, but can grow to 30 cm. It is fished with a purse seine net.

Atlantic mackerel (*Scomber scombrus*) and Atlantic herring (*Clupea harengus*) caught in Icelandic waters were chosen as raw materials since studies have shown that they have similar characteristics as the species in Ghana. Small Icelandic herring caught around August have fat content of about 5 to10 % which is similar to the sardines in Ghana.

Headed and gutted mackerel and herring were used for the experiment. All samples were purchased from Icelandic markets. Herring (C*lupea harengus*) and mackerel (*Scomber scrombus*) used in the study (pre-trial and the main study) were caught in August and November 2014, respectively. They were caught by purse seine off the south-east coast of Iceland, and processed by Síldarvinnslan hf. The fish were kept on-board after capture in tanks at -1.2 °C before being transported to the company where they were (headed and gutted) and packed in blocks of 22 kg each, plate frozen and stored at -25 °C. Prior to the study, the fish was transported in a refrigerated truck set at -20 to -25 °C to MATIS and stored at -25 °C until a day before the experiment when the fish was thawed in a cold room at temperatures between 2 and 4 °C.

2.2   Smoking equipment

Two types of smoking equipment were evaluated, an open fire drum kiln and a cabin smoking kiln (Figure 5). A cylindrical drum was used in this experiment to demonstrate the open fire technique used in the Chorkor smoker and cylindrical metal drum ovens in Ghana.

The smoking cabin is a new smoking kiln constructed by MATIS. The smoking cabin is made out of wood with a metal drum beneath the chamber where burning wood is the source of heat and smoke. A metal pipe connects the drum and the smoking chamber to allow the heat flow into the compartment. A metal plate is placed above the pipe to diffuse the hot air and provide a more even circulation in the smoking chamber. The fish is smoked on removable wooden frames with metal mesh.

Figure 5: The smoking equipment used in the study. To left: Open fire smoking kiln; To right: Smoking cabin designed by MATIS.

2.3   Experimental design and sampling

The experiment was done at the MATIS laboratory from January to March, 2015.

2.3.1   Pre-trial for smoking

Before conducting the main experiment, a pre-trial was done to test the performance of the smoking kilns and the brine concentration of the final smoked product which should be around 4 to 5 %. Stored fish samples were thawed and put into 15 % solution at 5 °C for 2 hours with a fish to brine ratio of 1:1. After brining, the fish samples were put on racks to drain overnight in a cooler with temperature between 1.7 to 3 °C. The smoking kiln was then prepared and heated for about 30 minutes before fish were arranged on the wire mesh trays and then put into the smoking kilns.

2.3.2   The main experiment

The design of the main experiment is presented in (Figure 6), and sample groups used are described in Table 1. Fish samples stored at -25 °C were thawed in a cold temperature room between 2 to 4 °C prior to processing. After thawing, the fish was washed thoroughly and immersed in a brine solution of about 15 % concentration at 5 °C for 2 hours in order to attain about 4 to 5 % of salt content in the fish muscle after smoking. The fish samples were then put on drying racks to allow the water to drain for about an hour and left over night in a cooler. Temperature loggers were then

placed inside the muscle of tagged fish set to measure the temperature at ten minute intervals during smoking. The fishes were arranged on metal racks for smoking.

When smoking in the drum, the fish had to be turned over at regular intervals to prevent charring and also to obtain uniformly smoked products. The fish was also covered with cardboard to retain heat. In the cabin smoker, the wire mesh trays were rotated during the smoking to improve uniformity of the products.

The amount of wood used in each of the kilns was recorded. At the end of the smoking, the racks and trays were removed from the kilns and the fish allowed to cool at room temperature before being prepared for storage. Fish samples were packed in clear plastic bags and labelled for storage at 23 °C and between 2 – 4 °C.
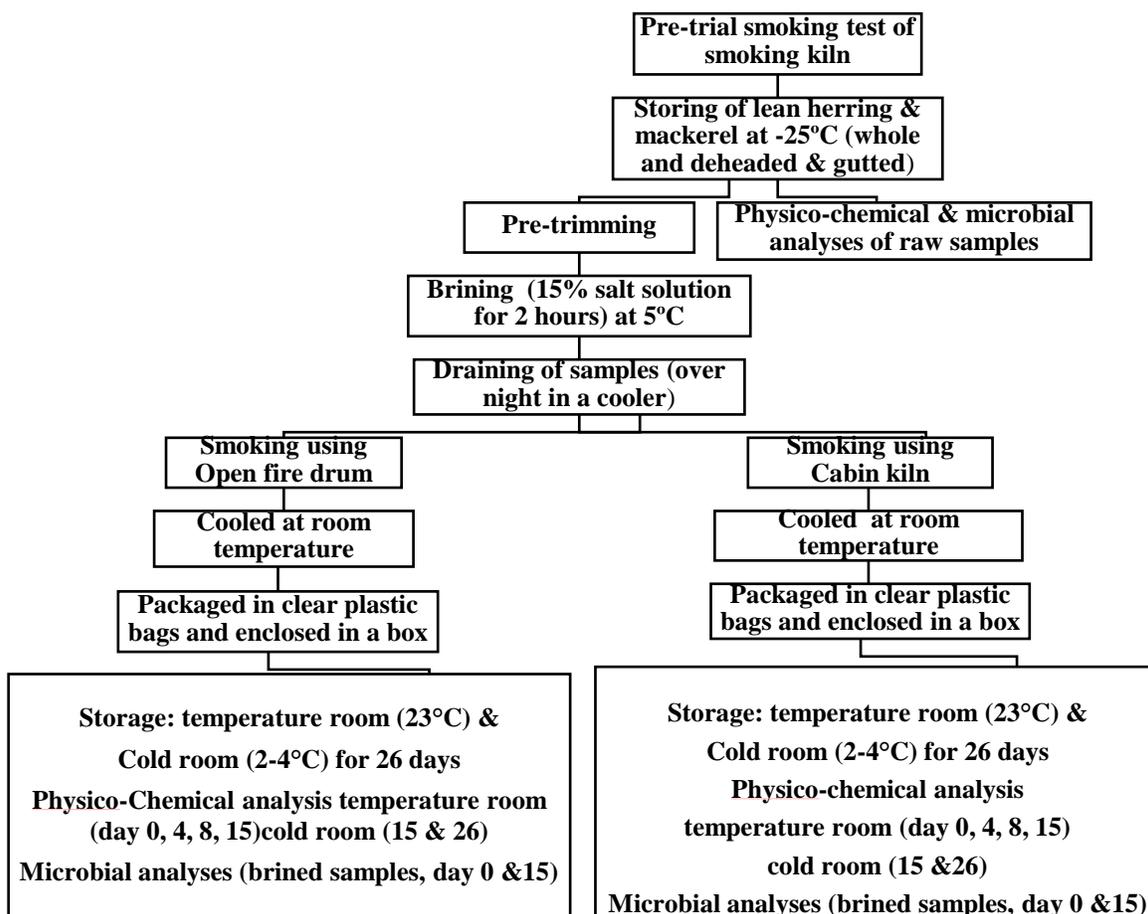
Figure 6: Experimental design of the main study for fish processing using two different smoking kilns.

2.3.3   Temperature and humidity measurements

Smoke in both kilns was produced from wood. Processing cabin kiln was divided into three stages: preliminary drying, a partial cooking or smoking and full heat smoking.
In order to retain the quality of the fish during the smoking process it is important to control the temperature inside the chamber and inside the fish muscle. Therefore, temperature loggers were placed inside the fish muscle and at five other positions within the cabin before smoking process commenced to record temperatures at ten minutes interval. Also, humidity loggers were placed both inside and outside the cabin to record the relative humidity at ten minutes interval.

The temperature inside the open fire drum was measured using a thermometer (*teste 926 thermometer* AG, Germany) and temperature loggers were placed in the fish muscle to record the temperature at ten minutes interval. Generally, temperature monitoring inside the open fire kiln was difficult to control and to accurately ascertain temperature measurements at regular intervals.

2.3.4   Sampling

Water content, protein and lipid content were measured after brining and again once the fish had cooled down after smoking. Measures of colour, pH, peroxide value (PV), free fatty acid (FFA), thiobarbituric acid reactive substances (TBARS), total plate counts (TPC), water activity (Aw) and total volatile basic nitrogen (TVB-N) were done on days (0, 4, 8 and 15) and (14 and 26) of storage at room temperature (23 °C) and cold temperature (2 – 4 °C) respectively. All analyse were performed in duplicate (n=2).

Table 1. Experimental design, sample group definition and sampling.

Species	Group	Smoking	Storage conditions	Sampling days
	FBH*	No	-	0
	SR-HO	Open fire	23 °C	0, 4, 8, 15
Herring	SC-HO	Open fire	2-4 °C	0, 14, 26
	SR-HC	Cabin	23 °C	0, 4, 8, 15
	SR- HC	Cabin	2-4 °C	0, 14, 26
	FBM*	No	-	0
	SR-MO	Open fire	23 °C	0, 4, 8, 15
Mackerel	SC-MO	Open fire	2-4 °C	0, 14, 26
	SR-MC	Cabin	23 °C	0, 4, 8, 15
	SR-MC	Cabin	2-4 °C	0, 14, 26

2.4   Evaluation methods

2.4.1   Microbiological analysis – Total plate count (TPC)

The conventional "pour-plate" method was used on Plate Count Agar. A 20 g of fish samples was aseptically weighed in stomacher bags and mixed with 180 ml of maximum recovery diluent (MRD) (0.85 % NaCl + 0.1 % peptone). They were then homogenized for 2 minutes in Waring laboratory blender and serially diluted up to 109 and inoculated in growth media in Petri dishes. For the analysis of total plate count (TPC) 1 ml of 1/10 dilutions was transferred using pipette to Petri plates and melted Iron agar at 45 °C poured on the plates and the content mixed to solidify.

After solidification the plates was covered with a thin layer of Iron agar then incubated at 22 °C for 48 hours. All the microbiological analyses were conducted in duplicate using two polled samples per replicate and data expressed as a logarithm of the number of colony-forming units (log cfu/g). Analysis were done on raw brined samples, day 0 of samples from fish stored at room temperature (23 °C) and day 15 of storage in the cold room (2 – 4 °C).

2.4.2   Proximate analysis

The proximate composition of fish was evaluated by determining the moisture, lipid and protein content in the fish samples.

The water content was calculated as the loss in weight during drying at 105 °C for 4 hours (ISO, 2005). Results were expressed as percentage of wet weight.

Protein content was determined by using the Kjeldahl method. The organic matter was digested by sulphuric acid in the presence of a catalyst. The reaction product was rendered alkaline, then the liberated ammonia was distilled and titrated with hydrochloric acids (ISO, 2005). The nitrogen content was multiplied by 6.25 to get the ratio of crude protein.

The salt content of the smoked mackerel and herring was determined by weighing 5 g of sample into and extraction bottle, 200 ml of deionised water was added and shaken using the shaker for 50 minutes. 20 ml of nitric acid was then added to 20 ml of the supernatant and titrated with silver nitrate (AOAC, 2000).

Total lipids (TL) were extracted from 25 g samples (80±1 % water) with methanol/chloroform/ 0.88 % KCl (at 1/1/0.5, v/v/v) according to the Bligh and Dyer (1959) method. The lipid content was determined gravimetrically and the results were expressed as grams lipid per 100 g wet muscle. The TL extract was further used to evaluate the amount of free fatty acids.

2.4.3   Total volatile basic nitrogen (TVB-N)

The total volatile base nitrogen (TVB-N) was determined according to the method described by Malle & Poumeyrol (1989). TVB-N was measured by steam distillation (Struer TVN distillatory, STRUERS, Copenhagen) and titration, after extracting the fish muscle with 7.5 % aqueous trichloroacetic acid solution. The distilled TVB-N was then collected in boric acid solution and titrated with sulphuric acid solution. TVB-N content was expressed as mgN/100 g of fish sample. TVB-N was then calculated as

$$\frac{14 \frac{mg}{mol} \; x \; a \; x \; b \; x 300}{25 \; mL} \; \left[\frac{mgN}{100g}\right]$$

Where a = volume of sulphuric acid (mL) b = normality of sulphuric acid (%) and 14 is the molecular weight of nitrogen.

2.4.4   PAH Analysis

Polycyclic Aromatic Hydrocarbons was measured in the Eurofins WEJ contaminant laboratory. After smoking, samples of mackerel from the open fire drum and the cabin kiln were allowed to cool and then minced and packed into special glass jars with screw closure and sent to the laboratory for analysis.

2.4.5   Free fatty acids evaluation

Free fatty acid (FFA) content were determined on the TL extract by the method from Lowry & Tinsley (1976) with modification made by (Bernardez, *et al.,* 2005). The FFA concentration was calculated as µM quantities of oleic acid based on a standard curve spanning a 2 – 22 µmol range. Results were expressed as grams FFA/100 g of total lipids.

2.4.6   Lipid oxidation measurements

Lipid hydroperoxide (PV) was determined using the ferric thiocyanate method described by Santha & Decker (1994). Total lipids were extracted from 5.0 g of samples with 10 ml ice-cold chloroform: methanol (1:1) solution, containing 500 ppm BHT to prevent further peroxidation during the extraction process. Sodium chloride (0.5 M) was added (5.0 ml) to the mixture and homogenized for 30 sec before centrifuging at 5100 rpm for 5 min (TJ-25 Centrifuge, Beckmann Coulter, USA). The chloroform layer was collected (100 µL) and completed with 900 µL chloroform: methanol solution. A total amount of 5 µL of ammonium thiocyanate (4 M) and ferrous chloride (80 mM) mixture (1:1) was finally added. The samples were incubated at room temperature for 10 minutes and read in a spectrophotometer at 500 nm (Tecan Sunrise, Austria). A standard curve was prepared using cumene hydroperoxides. The results were expressed as mmol lipid hydroperoxides per kg of wet muscle.

Thiobarbituric acid reactive substances (TBARS) were measured by modified method of Lemon (1975). A sample (5.0 g) was homogenised with 10 ml of 7.5 % trichloroacetic acid (TCA) using an Ultra-Turrax homogeniser (Kika Labortechnik, T25 basic, Germany) at 2400 rpm for 10 seconds. The homogenate was then centrifuged at 5100 *rpm* for 20 minutes at 4 °C (TS-25 centrifuge). A mixture of 0.1 mL of supernatant and 0.9 mL of 0.02 M thiobarbituricacid solution was mixed in 1.5 mL eppendorfs tubes and heated in a water bath at 95 °C for 40 minutes. The samples were cooled down on ice and 0.2 mL was placed in microplate for absorbance reading at 530 nm (Sunrise Microplate Reader, Tecan AustriaGmbH, A-5082 Grödig, Austria). A standard curve was prepared using tetraethoxypropane. The results were expressed as µmoL of malomaldehyde diethylacetal per kg of sample.

2.4.7   Water activity

An Aqua Lab water activity meter was used to measure water activity (a_w) of the fresh and smoked fish. About 2 g of samples were put into the instrument and a_w were measured automatically after starting the program. Each sample were measured in duplicate.

2.4.8   Colour measurements

The intensity of the flesh colour was measured by using a Minolta CR-300 chromameter (Minolta Camera Co., Ltd; Osaka, Japan) in Lab system with CIE Illuminant C. The instrument records the **L** (lightness), **a** (redness) and **b** (yellowness) values on CIELAB colour scale as shown in (Figure 7). Measurements were made on five positions on each fish the mean and standard deviation of the **L**, **a**, **b** values calculated.

Figure 7: LAB scale for colour.

2.4.9   Processing yield

The yield for each processing step for production of hot smoked mackerel and herrings was calculated according to the formula.

$$Yield = \frac{W_{processed}}{W_{raw}} \times 100(\%) \qquad \text{Equation (1)}$$

$$Yield = \frac{W_{brined}}{W_{raw}} \times 100(\%) \qquad \text{Equation (2)}$$

W_{smoked} is the weight of smoked fish before drying;

2.4.10 Statistical Analysis

All the chemical analyses were carried out in duplicate. Data were subjected to analysis of variance to determine significant differences in biochemical indices and lipid freshness as a function of storage days. All the statistical analyses were performed using Excel 2013. The significance level was set at 95 % ($p < 0.05$).

3   RESULTS

3.1   Physical and microbiological analysis

3.1.1   Temperature

Temperature was higher in the muscle of the fish in the open fire smoking drum than the fish smoked in the cabin (Figure 8). The highest value recorded in the fish muscle in the two smoking kilns were 81.5 °C and 60 °C respectively.
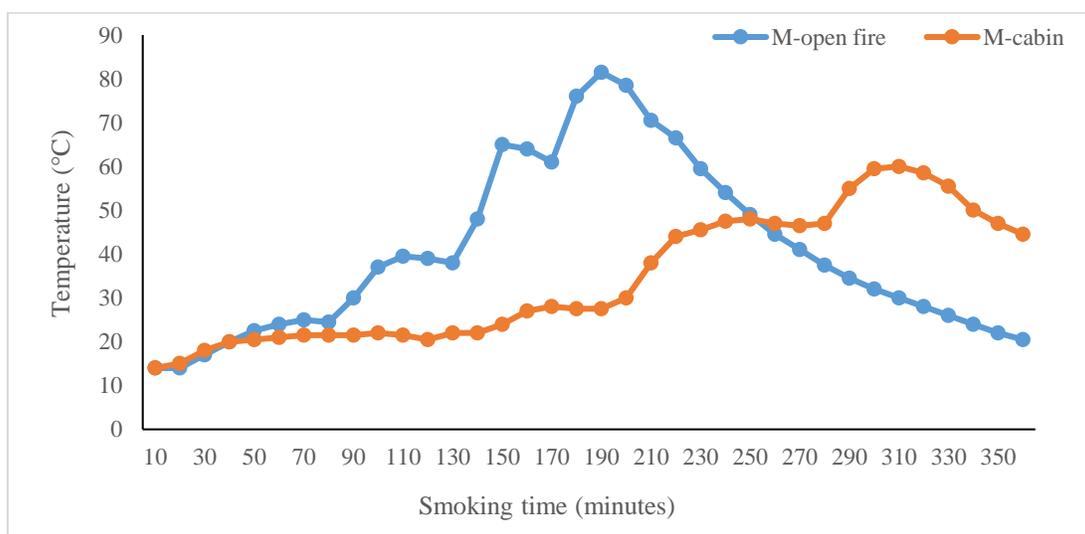
Figure 8: Temperature in the fish muscle during hot smoking in the cabin and the open fire. M-open fire: muscle of fish smoked using open fire M-cabin: muscle of fish smoked using the cabin.

Temperature measurements recorded with the loggers placed at five different positions of the smoking cabin (centre, down up, down bottom, top up and top bottom corners) is shown in (Figure 9). Average temperature was around 40 °C in all positions and temperature readings indicated that there was an even circulation of heat within the smoking cabin. The highest value of 107 °C was recorded at the centre of the smoking chamber. However, temperature readings in the open fire smoking kiln ranged from 40 °C to 127 °C.
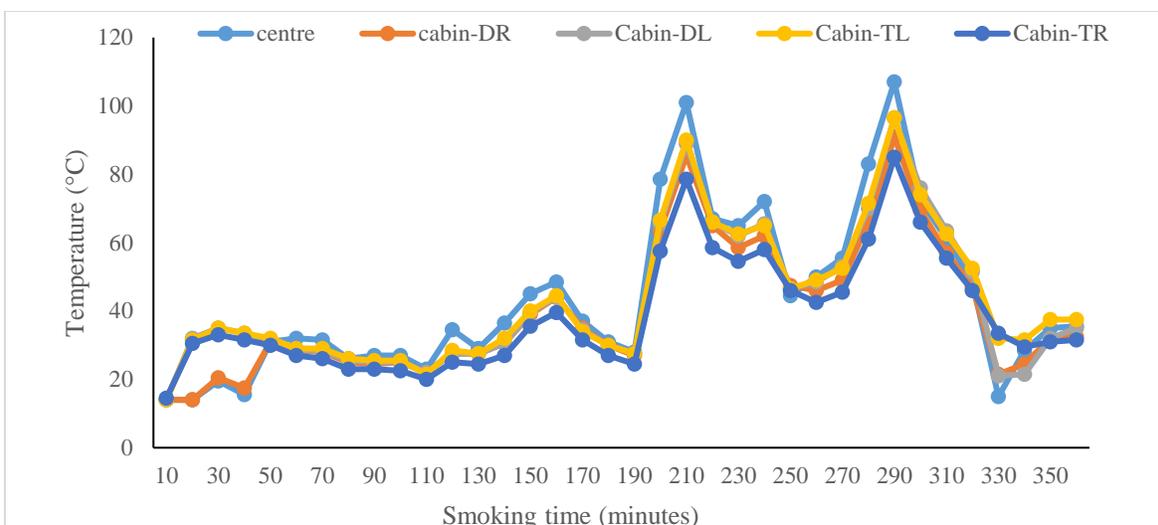
Figure 9: Temperature measurements inside the smoking cabin at different locations
DR: down up; DL: down bottom; TL: top up; TR: top bottom.

The relative humidity increased outside the cabin and ranged between 63.1 % - 90 % while in the cabin, relative humidity range from between 2.5 % - 64.69 % (Figure 10). Temperature on the smoked product was dependent on relative humidity.
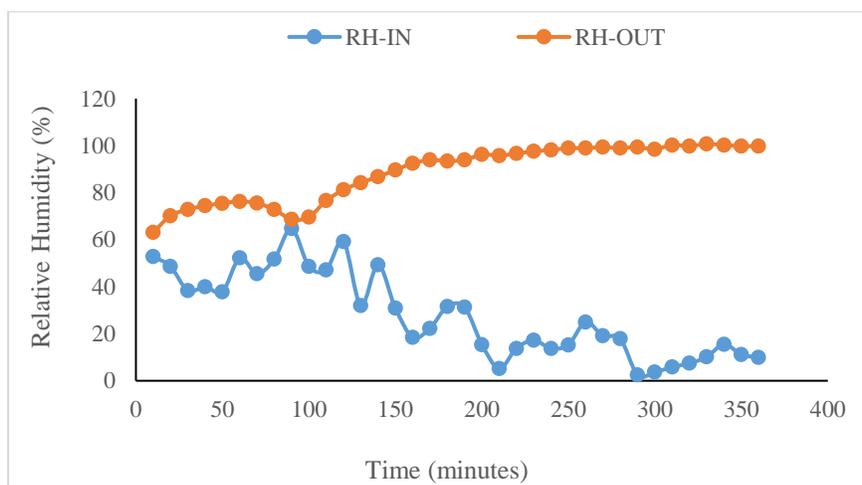
Figure 10: Relative humidity inside and outside the smoking cabin
RH-IN= relative humidity inside the cabin; RH-OUT= relative humidity outside the cabin.

3.1.2   Colour measurement

L-value measurement ranges from L=0 (black) to L=100 (white) as illustrated in (Figure 7), representing the overall lightness and darkness of the fish. Fresh brined herring recorded (L, a and b) values of 57.39 ±13.3, -0.44 ±1.56 and -5.48 ±1.66 respectively. During storage at 23 °C, smoked herring from both open fire and cabin (Figure 11A) showed an increase in lightness at (p

= 0.12). The lightness of smoked mackerel in (Figure 12B) was rather stable during storage at (p = 0.89).

In the cold storage room (2 – 4 °C), the lightness of the smoked herring from open fire was rather stable but decreased slightly in smoked herring from the cabin (Figure 12A). The lightness throughout the storage days were stable in smoked mackerel from the cabin while it decreased significantly in the smoked mackerel from the open fire (Figure 12 B).
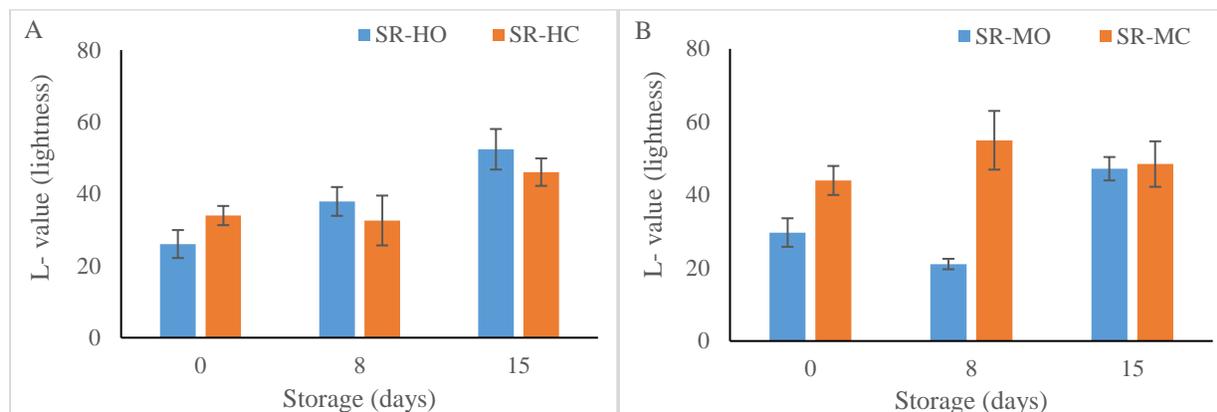
Figure 11: Lightness (L- value) of (A): smoked herring from an open fire and cabin kiln stored at 23 °C (B) smoked mackerel from open fire and cabin kiln stored at 23°C.
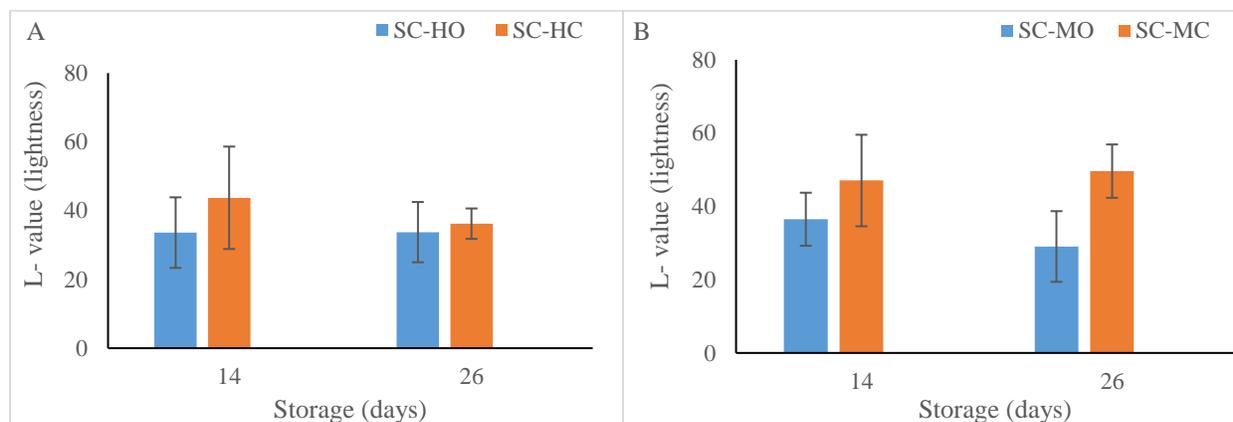
Figure 12: Lightness (L- value) of (A): smoked herring from open fire and cabin kiln stored at 2-4 °C (B) smoked mackerel from open fire and cabin kiln stored at 2 – 4 °C.

At room temperature (23 °C), the yellowness (b-value) increased from day 0 to day 8 and then decreased on day 14 for both herring and mackerel (Figure 13A and B). Similar trend was seen for both smoking kilns at ($p < 0.05$).

In the cold room (2 – 4 °C), yellowness also increased with storage time except for the mackerel from the open fire, which decreased from day 14 to 26 (Figure 14A and B). However, yellowness was more pronounced in fish smoked in the cabin. Consequently, there was no significant difference with storage time at ($p < 0.05$).
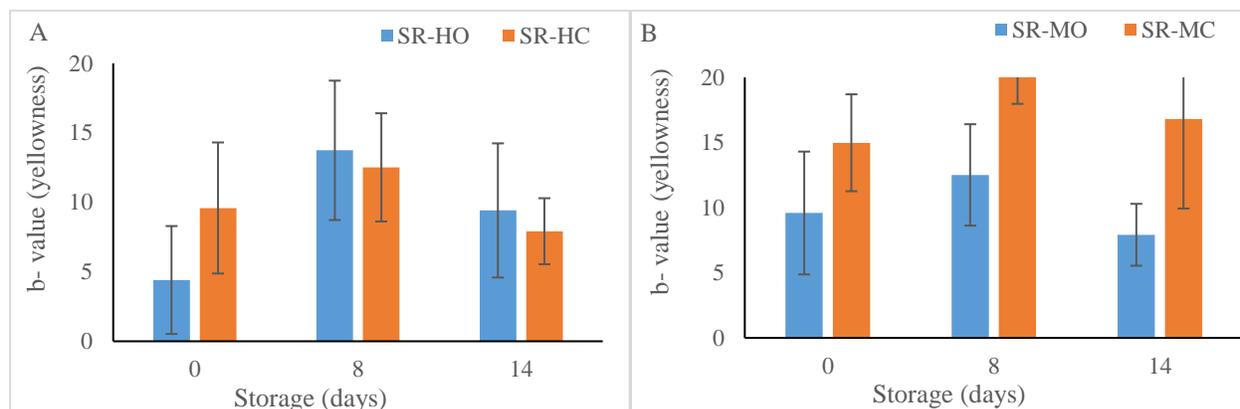
Figure 13: Yellowness (b-value) of (A): smoked herring from open fire and cabin kiln stored at 23 °C (B) smoked mackerel from open fire and cabin kiln stored at 23 °C.
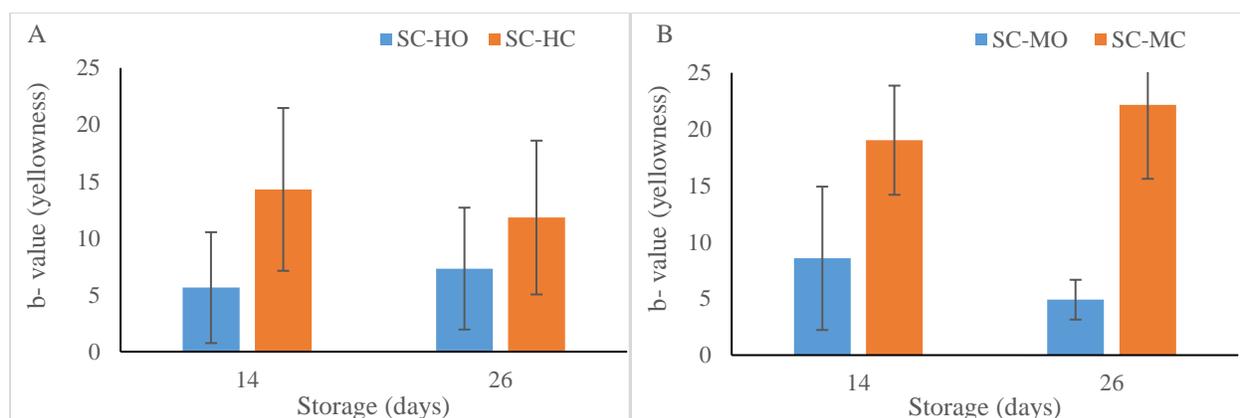
Figure 14: Yellowness (b-value) of (A): smoked herring from open fire and cabin kiln stored at 2- 4 °C; (B) smoked mackerel from open fire and cabin kiln stored at 2 – 4 °C.

At room temperature, redness (a-value) of both mackerel and herring increased from day 0 to day 8 and then decreased again on day 15. Redness was generally higher in fish smoked from the open fire (Figure 15A and B). There was no significant difference with both smoked herring and mackerel from the open fire at ($p < 0.05$).

Redness of the smoked mackerel from both open fire and cabin was stable in the cold storage room (2 – 4 °C) at p = 0.61 (Figure 16A). Throughout the storage days, mackerel smoked in the open fire showed more redness compared to smoked samples from the cabin at p = 0.02. No significant changes in redness were observed for smoked herring and mackerel samples stored at cold storage room.
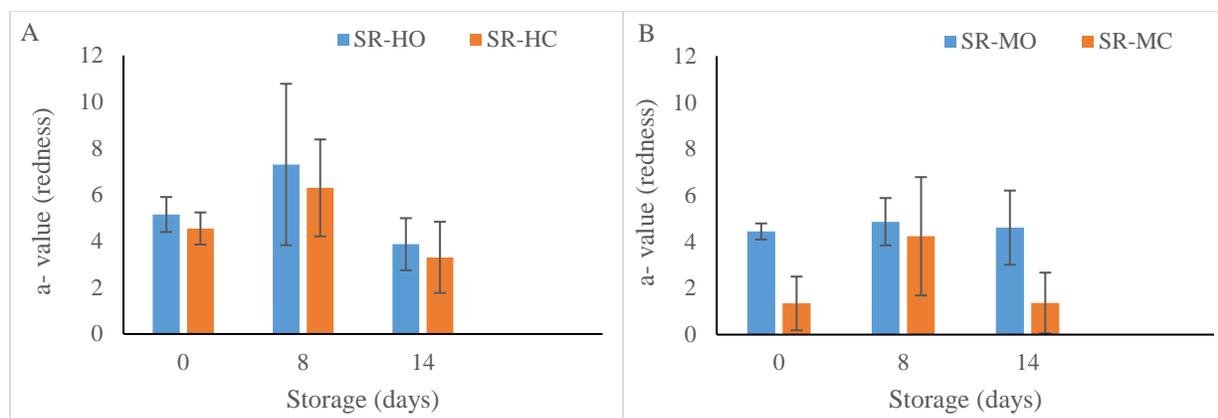
Figure 15: Redness (a-value) of (A): smoked herring from open fire and cabin kiln stored at 23 °C (B) smoked mackerel from open fire and cabin kiln stored at 23 °C.
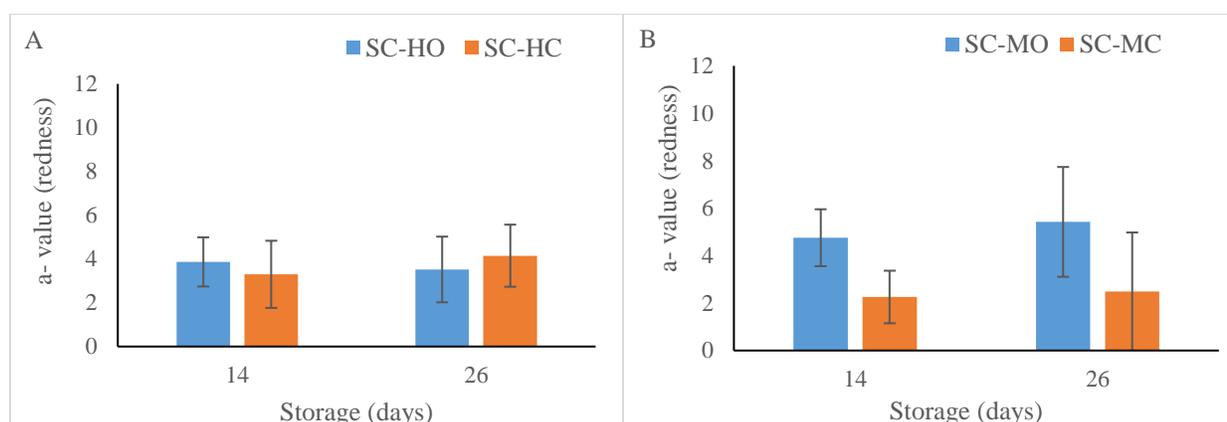
Figure 16: (A): Redness (a-value) of smoked herring from open fire and cabin kiln stored at $2 - 4$ °C (B) redness (a-value) of smoked mackerel from open fire and cabin kiln stored at $2 - 4$ °C.

3.1.3   Microbial Analysis

The initial number of bacteria on raw brined herring was < 1 (log cfu/g). After smoking, the total plate count (TPC) in herring smoked from both the open fire and cabin ranged between 1 and < 1 (log cfu/g). Mackerel smoked from the open fire and cabin also had TPC range from 1.69 to 3.11 (log cfu/g) and < 1 to 2 (log cfu/g) respectively. After two weeks of storage in the cold room, the difference was not significant between the two groups. However, mackerel smoked in the open fire had TPC which increased sharply and reached levels of 7.681 (log cfu/g) after two weeks of storage in cold room.

3.2   Chemical Analysis

The moisture, protein, TVB-N level and salt content in fresh brined herring and mackerel as well as after smoking are illustrated in Table 2. The water, protein and salt content of the fresh brined herring was 66.6 ±4 %, 17.945 ±3 % and 1.03 % respectively. Parallel values for the fresh brined mackerel were 57.4 ±4 %, 16.8 ±3 % and 1.2 % respectively. After smoking, the water content increased slightly in samples from the open fire compared to samples from the cabin. Additionally, the total volatile basic nitrogen (TVB-N) was determined to be 14.52 ±0.57 mg N/100g in brined herring. TVB-N of both herring and mackerel increased after smoking. However, TVB-N for the fresh brined mackerel was not received from the chemistry laboratory. Also, lipid content of fresh brined herring increased after smoking but rather decreased in fresh mackerel after smoking as shown in Table 2.

Table 2: Chemical analysis (moisture, protein, salt, TVB-N and lipid content) of brined raw material and smoked herring and mackerel.

Experimental groups*	Moisture (%) ±4	Protein (%) ±3	TVB-N (mg N/100g)	Salt content (%)	Lipid content (%)
*FBH	66.6	17.9	14.5	1.03	14.71
FBM	57.4	16.8		1.2	32.39
SR0.HO	53.7	-	24.3	1.6	19.27
SR0.HC	56.7	-	22.1	1.3	12.38
SR0.MO	54.0	-	23.6	1.2	20.32
SR0.MC	57.5	-	19.2	1.0	16.62

*FBH: Fresh brined herring; FBM: fresh brined mackerel; SR0.HO: Smoked herring in open fire (day 0); SR0.HC: Smoked herring in Cabin (day 0); SR0.MO: Smoked mackerel in open fire (day 0); SR0.MC: smoked mackerel in Cabin (day 0).

Consequently, TVB-N level of herring and mackerel stored at 23 °C after smoking in both open fire and cabin kiln during the storage period ranged between 22.05 - 30 mgN/100g and 19.2 - 192.3 mgN/100g respectively. Levels of TVB-N in smoked herring from open fire was rather stable from day 0 to the end of storage life on day 8. TVB-N levels in smoked mackerel from the open fire and the cabin increased gradually from day 0 to day 8, followed by a sharp increase on day 15 (Figure 17). TVB-N increased significantly with storage time in the smoked herring samples when compared with the brined raw samples before smoking. However, day 15 smoked herring samples were not measured because samples had spoilt and was not good for human consumption (Appendix 1). Conversely, during cold storage (2 – 4 °C) of smoked herring and mackerel, the TVB-N was stable from day 14 to the end of the experiment on day 26 in both the open fire and cabin kiln.

3.2.1   Water Activity

Before smoking, the water activity of the brined fresh herring and mackerel was on average of 0.986 and 0.982 respectively (Figure 18). The water activity was very stable in both herring and mackerel from both the open fire and cabin kiln during the storage period at room temperature (23 °C) and the cold room (2 – 4 °C).
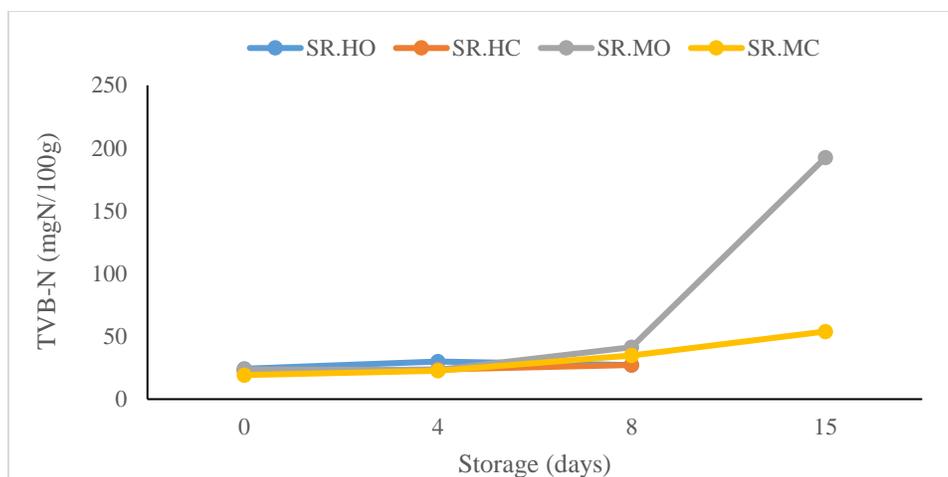
Figure 17: TVB-N (mg N/100 g) of smoked herring and mackerel stored at 23 °C. SR.HO = smoked herring from open fire; SR.HC= smoked herring from cabin; SR.MO= smoked mackerel from open fire; SR.MC= smoked mackerel from cabin.
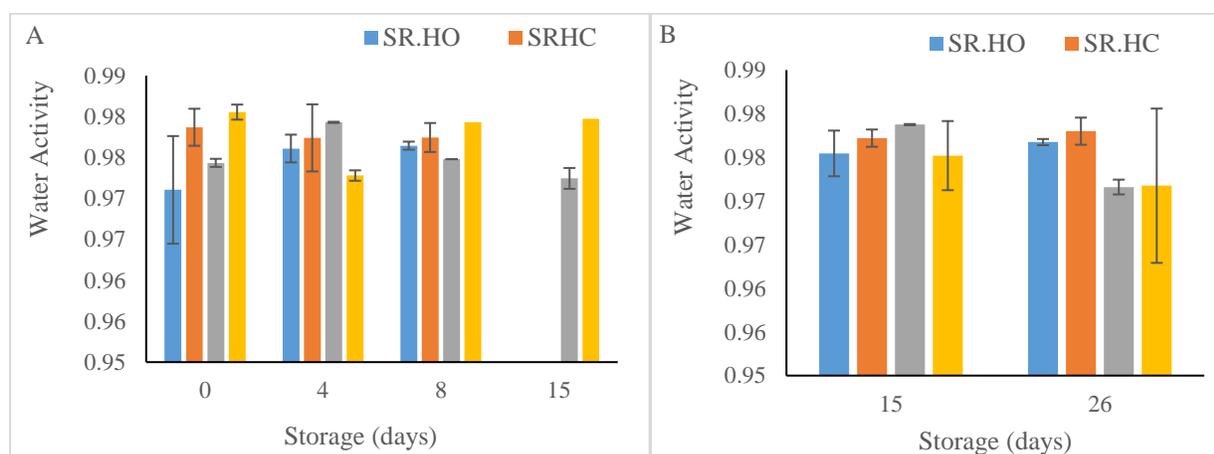
Figure 18: Water activity of herring and mackerel during the storage days. (A): samples stored at room temperature 23 °C (B): samples stored at 2 – 4 °C. SR.HO= Smoked herring using open fire, SR.HC=Smoked herring using smoking cabin, SR.MO= Smoked mackerel using open fire, SR.MC=Smoked mackerel using smoking cabin.

3.2.2 *Lipid degradation measurements*

Peroxide Values (PV)

The PV of fresh brined herring and mackerel were 0.112 µmol/g and 0.246 µmol/g respectively (Figure 19). PV generally increased after smoking in both samples stored at 23 °C and 2 – 4 °C. Levels of PV during storage at 23 °C was slightly higher in herring and mackerel smoked on the open fire compared to samples smoked in the cabin (Figure 20). During storage, smoked herring

from open fire was rather stable from day 0 to day 4 but the PV declined sharply on day 8. Moreover, the PV of smoked herring in the cabin kiln increased significantly from day 0 to day 4 followed by a sharp decrease on day 8. However, smoked herring on the open fire and cabin showed a significant difference at ($p < 0.05$). Herring and mackerel stored in the cold temperature room (2 – 4 °C) were very stable in both open fire and cabin kiln on day 14 and 26 when the shelf life ended (Figure 21). Moreover, herring for day 15 stored in the temperature room was not measured because samples were spoilt (Appendix 1).
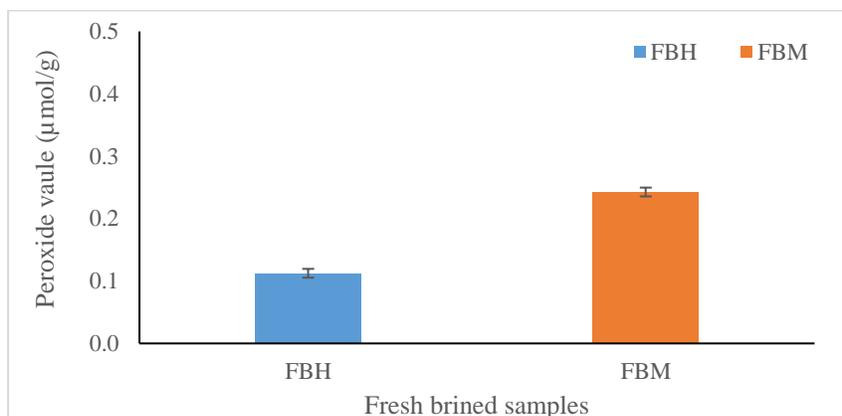
Figure 19: Peroxide value (PV: µmol/g sample) of fresh brined herring and mackerel. FBH=fresh brined herring; FBM=fresh brined mackerel.
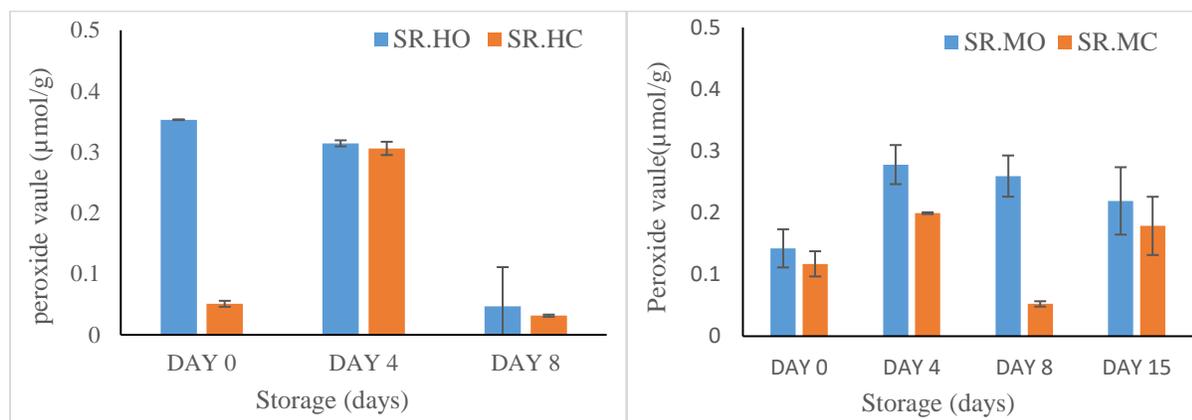
Figure 20: Peroxide values (PV: µmol/g sample) during storage of smoked herring and mackerel at temperature room (23 °C). SR.HO= Smoked herring using open fire, SR.HC=Smoked herring using smoking cabin, SR.MO= Smoked mackerel using open fire, SR.MC= Smoked mackerel using smoking cabin.
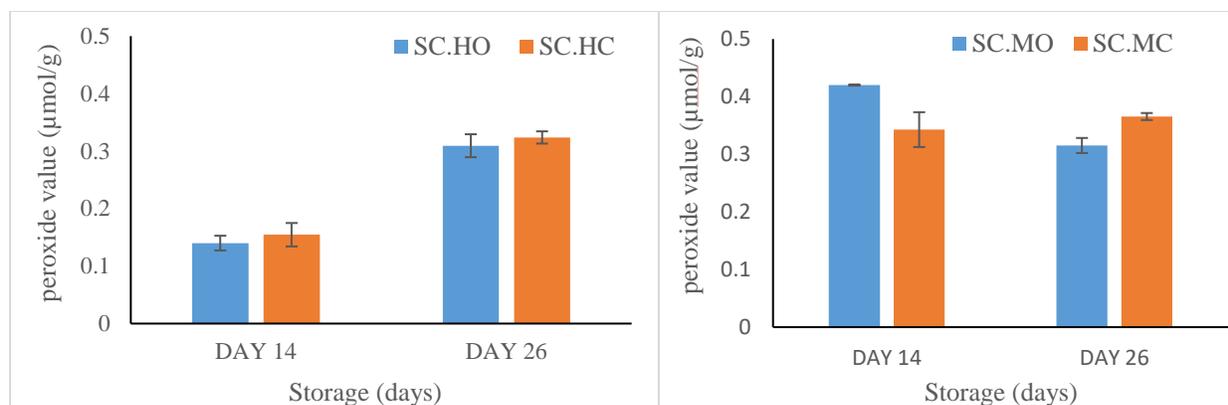
Figure 21: Peroxide values (PV: µmol/g sample) during storage of smoked herring and mackerel at cold room (2 – 4 °C). SC.HO: Smoked herring using open fire, SC.HC: Smoked herring using smoking cabin, SC.MO: Smoked mackerel using open fire, SC.MC: Smoked mackerel using smoking cabin.

3.2.3   *Thiobarbituric acid reactive substances (TBARS)*

Thiobarbituric acid reactive substances (TBARS) of fresh brined herring and mackerel was 0.041 µmol/kg and 0.084 µmol/kg respectively (Figure 22). After smoking, TBARS increased in all the experimental groups. Open fire smoked herring stored in the temperature room (23 °C) had higher TBARS compared to smoked herring from the cabin, which was rather stable from day 0 to day 8 (Figure 23). TBARS was stable in both herring and mackerel stored in the cold room (2 - 4 °C) from the open fire and cabin on day 14 and 26 (Figure 24) except the sharp increased, which was rather seen on day 26 of smoked herring from the cabin.
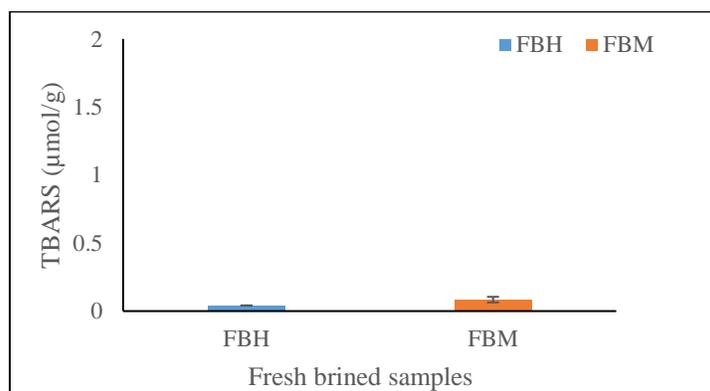
Figure 22: Thiobarbituric acid reactive substances (TBARS; µmol/g sample) of fresh brined herring and mackerel. FBH=fresh brined herring; FBM=fresh brined mackerel.
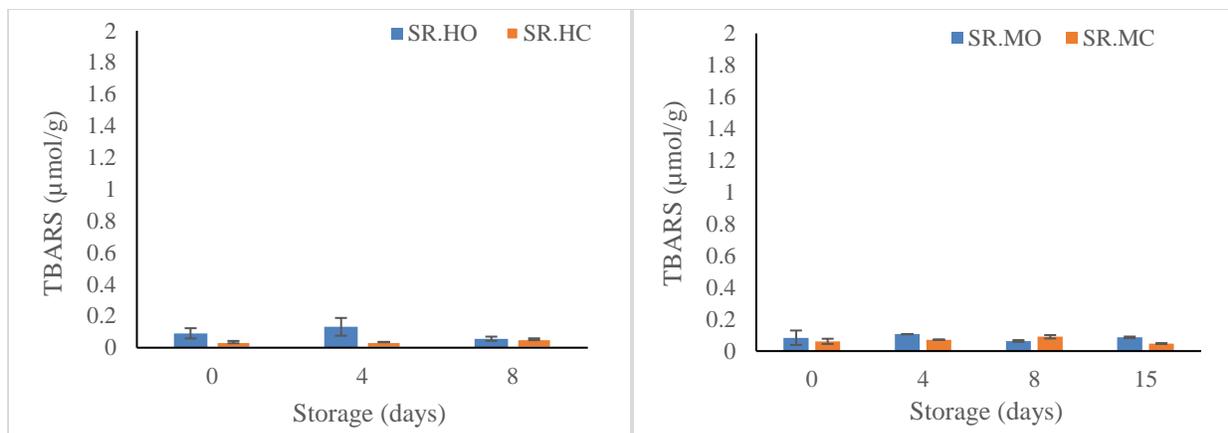
Figure 23: Thiobarbituric acid reactive substances (TBARS; µmol/g sample) during storage life of smoked herring and mackerel at temperature room (23 °C). SR.HO: Smoked herring using open fire, SR.HC: Smoked herring using smoking cabin, SR.MO: Smoked mackerel using open fire, SR.MC: Smoked mackerel using smoking cabin.
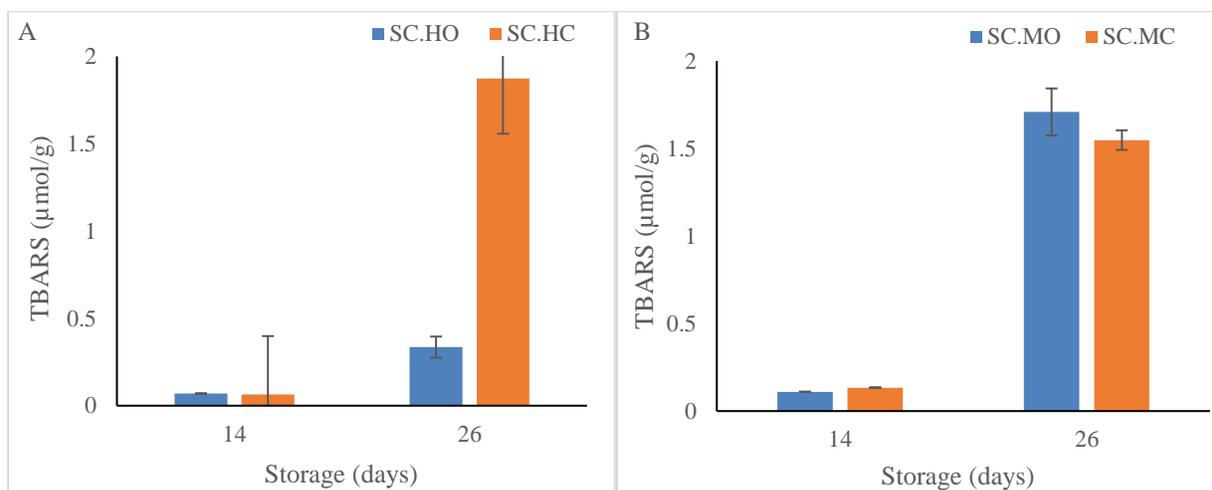
Figure 24: Thiobarbituric acid reactive substances (TBARS: µmol/g sample) during storage life of smoked herring and mackerel at cold room (2 – 4 °C). SC.HO: Smoked herring using open fire, SC.HC: Smoked herring using smoking cabin, SC.MO: Smoked mackerel using open fire, SC.MC: Smoked mackerel using smoking cabin.

3.2.4 *Free Fatty Acid (FFA)*

The free fatty acid (FFA) in the fresh brined herring and mackerel was 1.03 g FFA/100g and 0.76 g FFA/100g respectively. After smoking, the amount of FFA increased significantly at both temperatures (Figure 25 and 26).
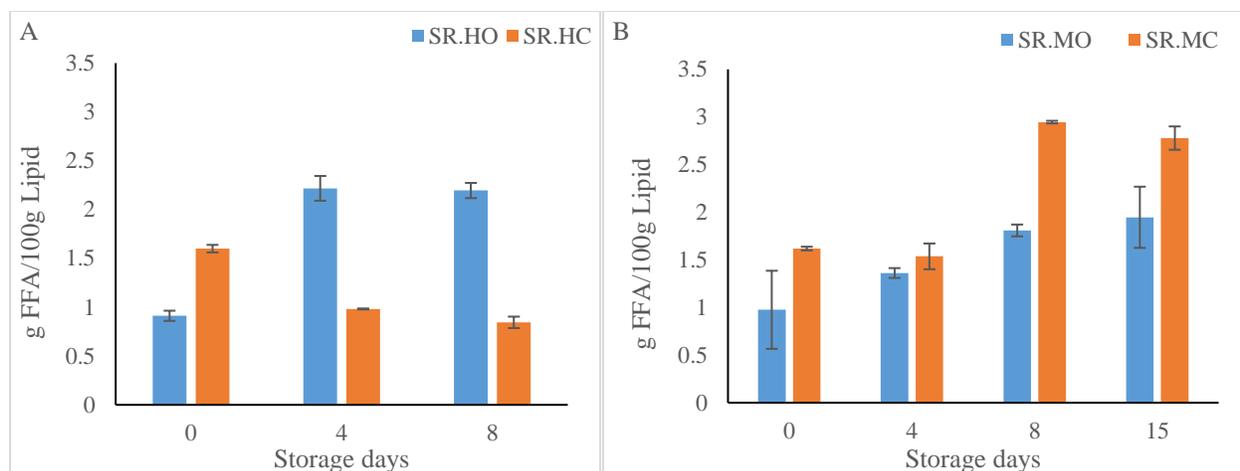
Figure 25: Changes in FFA during storage at temperature room (23 °C). (A): smoked herring from open fire and cabin (B): smoked mackerel from open fire and cabin. SR.HO: Smoked herring using open fire, SR.HC: Smoked herring using smoking cabin, SR.MO: Smoked mackerel using open fire, SR.MC: Smoked mackerel using smoking cabin.
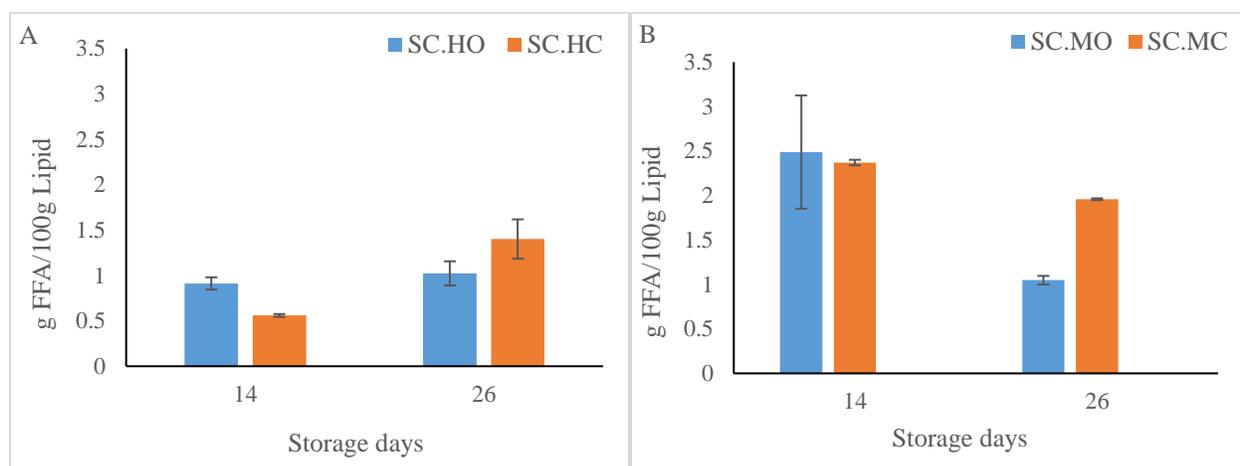
Figure 26: Changes in FFA during storage at cold room (2 – 4 °C). (A): smoked herring from open fire and cabin (B): smoked mackerel from open fire and cabin. SC.HO: Smoked herring using open fire, SC.HC: Smoked herring using smoking cabin, SC.MO: Smoked mackerel using open fire, SC.MC: Smoked mackerel using smoking cabin.

3.2.5   Lipid content

Lipid content variation of fresh brined herring and mackerel were 14.71 % and 32.39 % respectively. The variation of lipid content during storage of smoked herring and mackerel at 23 °C is as shown in (Figure 27). Lipid content decreased from day 0 to day 8 in smoked herring from the open fire stored in the temperature room (23 °C) while smoked herring from the cabin showed an increase with storage time. However, smoked herring from the open fire, which was stored in the cold room was stable in lipid content but decreased slightly in smoked herring from the cabin as illustrated in (Figure 28). The results shows that lipid content of smoked mackerel

decreased from the brined raw material after smoking but the reversed occurred with smoked herring.
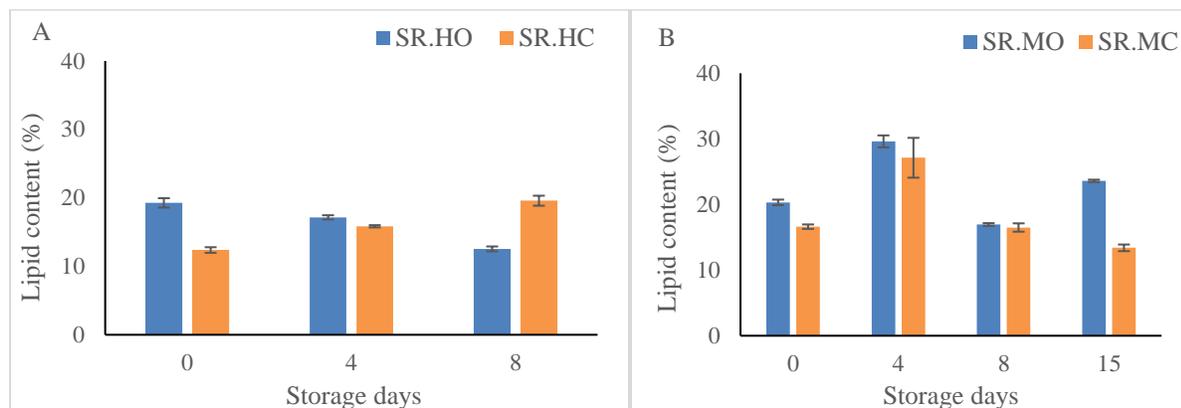
Figure 27: Lipid content variation during storage of smoked herring and mackerel at temperature room (23 °C). (A): smoked herring from open fire and cabin (B): smoked mackerel from open fire and cabin. SR.HO: Smoked herring using open fire, SR.HC: Smoked herring using smoking cabin, SR.MO: Smoked mackerel using open fire, SR.MC: Smoked mackerel using smoking cabin.
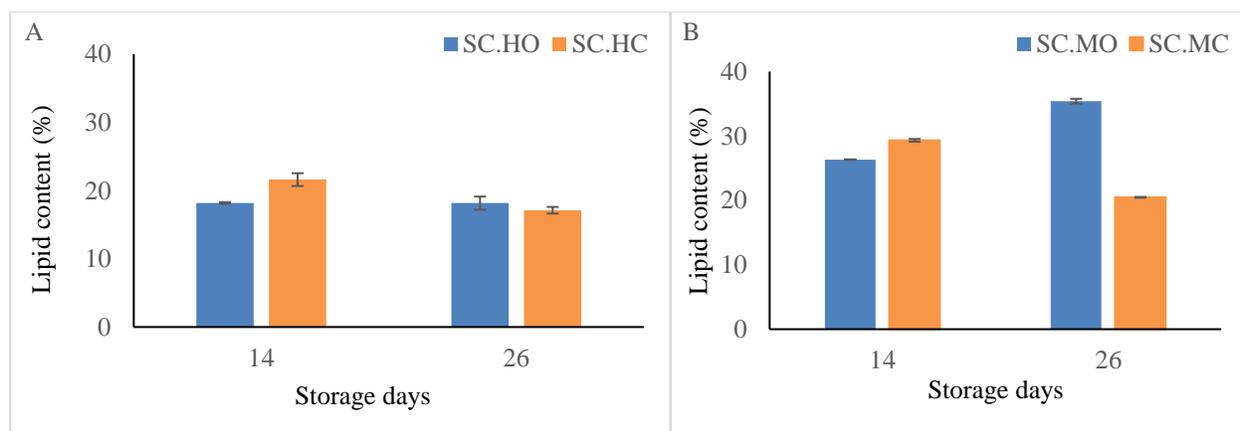
Figure 28 : Lipid content variation during storage of smoked herring and mackerel at cold room storage (2 – 4 °C). (A): smoked herring from open fire and cabin (B): smoked mackerel from open fire and cabin. SC.HO: Smoked herring using open fire, SC.HC: Smoked herring using smoking cabin, SC.MO: Smoked mackerel using open fire, SC.MC: Smoked mackerel using smoking cabin.

3.2.6   *Polycyclic Aromatic Hydrocabons (PAHs)*

Levels of PAHs in smoked mackerel from the experiment are shown in (Table 3). Benzo(a)pyrene also known as BP, which is the main indicator maker for PAHs in smoked products recorded <0.5 and 1.1 ± 0.34 in smoked mackerel from open fire and smoking cabin respectively. Moreover, the sum of the four main PAHs (Benzo(a)anthranthene, Chrysene, Benzo(b)fluoranthene and Benzo(a)pyrene) in the smoked mackerel from the open fire drum was 6.9 µg/kg but inapplicable

limits in the smoked mackerel from the cabin kiln. Finally, the sum of all positive PAHs was 9.7 µg/kg in the smoked mackerel from the open fire drum and in inapplicable limits in the smoked mackerel in the cabin kiln.

Table 3: Levels of Polycyclic Aromatic Hydrocarbons in smoked mackerel.

Types of PAHs	Level of PAHs in Open fire sample (µg/kg)	Levels of PAHs in cabin sample (µg/kg)
Benzo(a)anthranthene	2.3±0.69	< 0.5
chrysene	2.5±0.76	< 0.5
Benzo(b)fluoranthene	0.96±0.29	< 0.5
Benzo(k)fluoranthene	< 0.5	< 0.5
Benzo-(j)-fluoranthen	0.77±0.31	< 0.5
Benzo(a)pyrene	1.1±0.34	< 0.5
indenol(1,2,3-cd)pyrene	< 0.5	< 0.5
Dibenzol(a,h)pyrene	< 1	< 1
benzo(ghi)perylene	< 0.5	< 1
Dibenzo(a,l)pyrene	< 1	< 0.5
Dibenzo(a,i)pyrene	< 1	< 1
Dibenzo(a,h)anthracene	< 0.5	< 1
dibenzo(a,e)pyrene	< 1	< 1
cyclopenta(c,d)pyrene	2.1±0.83	< 1
5-Methychysene	< 1	< 1
benzo-(c)-fluorene	< 1	< 1

3.3 Yield

The yield results during the experiment for hot smoked herring and mackerel are presented in the Table 5. The process of brining and draining in the cooler for over 18 hours affected the yield of the smoked products.

Table 4: Yield of smoked herring and mackerel.

Species	Group	Weight (kg)	Brining yield (%)	Weight (kg)	Processing Yield (%)
	raw material	20.632	100	20.038	100
Herring	SR.HO	6.59		4.81	72.96
	SR.HC	14.042	97.12	10.12	72.07
	raw material	20.243	100	20.043	100
Mackerel	SR.HO	6.03		4.86	80.62
	SR.HC	14.213	99.03	10.58	74.44

SR.HO: Smoked herring using open fire, SR.HC: Smoked herring using smoking cabin, SR.MO: Smoked mackerel using open fire, SR.MC: Smoked mackerel using smoking cabin

3.4 Fuel wood Consumption

In the present study, the fuel wood consumption in the cabin was less compared to the Chorkor smoker and the open fire drum as illustrated in (Figure 29). The average kg of wood per kg of fish in the cabin and open fire was 0.13 and 0.48 respectively. However, in a similar study in Ghana by (Morrison, *et al.,* 2013) using the Chorkor smoker, the average kg wood per kg fish was 0.45. Smoking was done for about 4 - 5 hours in the cabin and the Chorkor smoker.
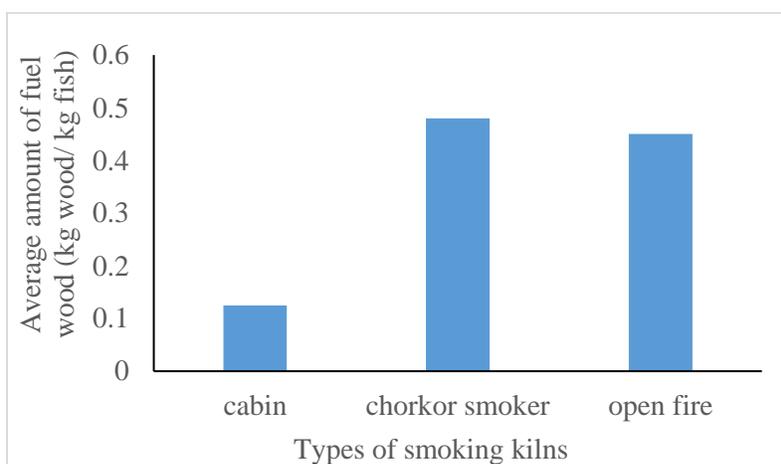
Figure 29: Types of Smoking kilns and fuel wood consumption.

4   DISCUSSION

4.1   Physico-chemical and microbial evaluation

In the present study, the water activity in smoked herring and mackerel stored at temperature room (23 °C) and cold room (2 – 4 °C) showed no significant difference during storage. However, the high water activity (0.97 on average) created suitable environment for microorganisms to multiply. When the water activity is high, bacteria predomintes in smoked samples and other biological are affected from yeast and moulds which can also occur when the water activity is less than 0.950 (Burt, 1988). Consequently, during the storage days the formation of moulds occured in samples from the temperature room (23 °C). According to (Rahman & Labuza, 2007) pathogenic bacteria cannot grow when the water activty is below 0.85 - 0.86. Therefore, to avoid rapid microbial growth, the water activity of dried fish products must be maintained below the critial value of 0.60 (Perera & Rahman, 1997).

Also, spoilage of the smoked herring and mackeral were not retarded by their exposure to storage conditions in the temperature room and cold room during the study. All experimetnal groups were affected by microbial growth, enzymatic activity and lipid oxidation at different storage days although spoilage occured more rapidly in smoked samples stored at 23 °C. Microbial rates were also affected by availability changes in both temperature and cold storage rooms. Total plate count of fresh brined herring was < 1 log cfu/g but during subsequent storage days the number of bacteria increased from 1.69 to 3.11 log cfu/g in smoked samples from the open fire. This increase may probably be due to the continuous handling of the fish during smoking. Also, smoked mackerel from the open fire drum stored in the cold room recorded high number of total plate count of 7.681 log cfu/g which showed that sample was contaminated before packaging. Hence, contamination of smoked products before packaging will increase the formation of growth of bacteria even at cold storage temperatures.

Temperature in the muscle of herring and mackerel during the smoking process was above 80 °C and 60 °C respectively. (Doe, 1998) suggested that during hot smoking, the centre of the fish should be at least 80 °C to kill bacteria on the skin and in the muscle. However, higher temperatures will maximise muscle protein denaturation and texture damage (Arason, *et al.,* 2014). During the smoking process, water was also removed from the fish muscle which caused increase in salt concerntration. The increased salt concerntarion drives the salt molecules further into the fish to regions of lower diffusion. The penetration of the salt has implications for the microbial stability of the smoked product (Arason, *et al.,* 2014). Therefore, brining can be used to prolong the shelf life of smoked products. Although 4 % brined was not achieved at 15 % concerntation in the study, the level for both herring and mackerel was enough for consumers. According to (Elizete, 2013), 5 % salt content in the final product of smoked mackerel was too high for some consumers. Other studies have shown that high levels of salt are considered undesirable and linked to hypertention (Wekell, *et al.,* 1983) and also may reduce protein quality (Burt, 1988).

Moreover, the smoking process in the present study had an effect on the yield. There was weight loss due to dehydration of the fish muscle. Howgate (1979) suggested that the weight loss due to dehydration during smoking process is about 10 – 25 %. However, the processing yield can also be affected by the size and shape of the fish as well as the physical and chemical characteristics of

the raw material (Arason, *et al.,* 2014). TVB-N results for smoked herring and mackerel during the cold storage in both the open fire and cabin kiln ranged between 23.2 mgN/100g - 25.3 mgN/100g and 24.5 mgN/100g - 27.8 mgN/100g respectively. These levels of TVB-N are well within the EU limit of 35mgN/100g. However, at room temperature storage the TVB-N levels increased with storage time.

4.2   Lipid degradation analysis on smoked products

In present study, hot smoking process affected the formation of lipid oxidation. The lipid oxidation products PV and TBARS were generally more stable in smoked samples stored in the cold storage room compared to when stored at room temperature (23 °C). Moreover, PV increased and TBARS decreased during storage for herring and mackerel when smoked both with open fire and cabin. Similar results of PV and TBARS were reported according to (Huong, 2013) for mackerel using commercial liquid smoke flavourings. The lipid oxidation, which are usually at the site of unsaturated bonds in the fatty acid chains results in a variety of compounds being formed including free radicals and hydro-peroxides. Therefore, at the onset of oxidation, PV levels will increase but eventually be oxidised to aldehydes and ketones. Increased levels of free fatty acids of stored herring and mackerel from both the open fire and smoking kiln is in agreement with similar study made by Huss and others (1995) regarding the development of free fatty acids in herring at different temperatures.

4.3   Effect of fuel wood on smoked products

Fuel wood is the main source of energy for fish smoking in Ghana. Chemicals in the wood improve flavor, increase the utilization of the fish products, promotes shelf life and deposit antioxidant compounds such as phenols which delays microbial growth and rancidity development (Leroi & Joffraud, 2000). The fuel wood preferences of most fish processors are also related to the physical characteristics of the wood and how they affect the smoked product. Although, lightness and yellowness were seen more in the smoked products from the cabin compared to the open fire, the golden brown colour preference by consumers in Ghana was not achieved. The characteristics of traditionally smoked products are to some extent dependent on the source of the smoke. A study on smoking fish with Eucalyptus wood in Zambia showed that the smoked product was golden-brown, and had a desirable texture as well as an appealing smoky aroma. There was no bitter taste when eaten, and the product market value increased (Nerquaye-Tetteh, *et al.,* 2002). Observation of smoked fish from the Volta Lake in Ghana showed that black and unattractive smoked fish were normally not due to charring but the type of fuel wood used. In another study, (Allou, 2012) reported that Leucaena fuel wood was considered by fish processors in the Nzema District of Ghana because it produced a dark brown smoked fish preferred by most consumers.

Moreover, fuel wood for commercial fish smoking was described by (Morrison, *et al.,* 2013) as the "most pervasive" threat to the sustainability of forest reserves, mangrove ecosystems, and water bodies in Ghana and much of Sub-Saharan Africa. Therefore, replacing traditional fish smoking systems with an improved technology which can use less fuel wood will thereby contribute significantly to forest depletion and also reduction of global warming and climate change. The cabin designed by Matis in the present study used less fuel wood compared to the Chorkor smoker. This technology can therefore be introduced to fish processors in Ghana.

4.4   Levels of Polycyclic Aromatic Hydrocarbons in Smoked fish

The direct exposure of fish to smoke brings about higher concentrations of PAHs in the fish as compared to the indirect method, and this was observed in the present study. Although levels of PAHs of smoked samples from the smoking cabin was inapplicable limits, the direct open fire drum technique had the total sum of the four main PAHs (Benzo(a)anthranthene, Chrysene, Benzo(b)fluoranthene and Benzo(a)pyrene) as 6.9 µg/kg and sum of all the positive PAHs as 9.7 µg/kg. Nevertheless, the PAH quantities in the open fire were below the European legal limit for smoked fish which is 5 µg/kg and the sum of all positive PAHs which is 12 µg/kg. However, the direct method of smoking using the Chorkor smoker and cylindrical oven drums in Ghana can be improved to ensure quality of the product as well as safe limits for consumers. Palm *et al.,* (2011) identified twenty types PAHs using fresh smoked fish purchased at different fish markets in Ghana and found PAH levels below the limit of detection to be 83.928 µg/kg.

5   CONCLUSION

The traditional process of smoking of fish has been used for decades and although some aspects have not changed substantially, improvement can be made in the formulation and equipment used during the process.

Microbial control can be ensured to minimize contamination of fresh fish from time of capture by maintaining good fish tubs for rapid cooling, transpotation and storage equipment, processing procedure and packaging methods. Although contamination during these processess are unavoidable, good hygienic and controlled processing technologies can limit the rate of growth and predominance of different types of microorganisms throughout the processing chain.

Results obatained in present study indicated that smoked products using the cabin developed by MATIS gives better smoked quality and also inapplicable levels of PAHs. The smoking cabin used less fuel wood, had better quality of smoked products, and less exposure to heat. Inhalation of smoke is less then in the traditional smoking method, and handling of the fish was not as laborious as smoking using the open fire drum. The technology can therefore be extended to fish processors in Ghana to reduce the challenges faced by the fish processors. However, the technology of smoking using the Cabin designed by MATIS, must be simple, easily adaptable, inexpensive and above all easy to construct and increase yields to encourage fish processors to readily accept the model in their various communities. Currently, the smoking cabin can operate between 80 -100 kg of fish but fish Processors in Ghana on average smoke about 300 kg of fish per week. Therefore, the smoking cabin can still be improved in terms of capacity and drying process to help reduce the water activity and thereby promote the shelf life of smoked products.

Also, the decision of the Codex Alimentarius Commission is very important for the activity of the smoked fish industry because it will lead to the questioning of direct methods of smoking and the need of an absolute control of processes to produce smoked fish presenting both excellent organoleptic product and assurance in terms of food safety.

Moreover, the government of Ghana and the Fisheries Commission should adopt a participatory approach to promote alternative substitute for fish processors using the direct method of smoking. Training programmes should be held for fish processors to highlight the importance of improving upon the traditional methods of smoking using the Chorkor smoker and the cylindrical drum ovens. Additionally, the health issues of fish processors (inhalation of smoke and direct heat contact during smoking) and that of the consumer concerning the risky intake of levels of PAHs should be emphasized. Awareness must be created for both fish processors and consumers concerning PAHs and how they can be controlled to inapplicable limits.

Finally, smoking can be used to prolong the shelf life of fish due to combination effects of salting, which lowers the water activity resulting in reduced microbial growth, elevated temperatures of drying and deposition of antioxidant compounds, which delays microbial growth and rancidity development.

6   RECOMMENDATIONS

Similar study should be carried out to determine the quality and storage life of smoked fish, by including time for drying and sensory analysis. On the other hand, further analysis should be carried out to determine the level of PAHs in both the smoked fish skin and muscle of the fish.

To Improve the quality of smoked fish using the chorkor smoker and other older traditional ovens, fish processors should take into account the quality of the raw material, smoking treatment, type of packaging and more especially the storage conditions. Moreover, the catching method and the use of ice for rapid cooling must be emphasized. Fishermen must therefore have quality in mind rather than quanity of landings.

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APPENDIX 1

Figure 30: smoked herring on day 15 stored in the temperature room