UNITED NATIONS UNIVERSITY
Fisheries Training Programme

unuftp.is Final Project 2016

THE QUALITY AND SHELF LIFE OF ATLANTIC MACKEREL (*Scomber scombrus*) AS INFLUENCED BY SMOKING TECHNOLOGY, PACKAGING MATERIAL AND STORAGE TEMPERATURE

Eunice Konadu Asamoah
Department of Marine and Fisheries Sciences
P.O. Box LG 99. University of Ghana, Legon, Accra, Ghana
ekonadutwum@yahoo.com

Supervisors:

Sigurjon Arason: sigurjon@matis.is
Magnea Karlsdottir: magneag@matis.is
María Guðjónsdóttir: mariagu@hi.is
Matis
Vinlandsleid 12, 113 Reykjavik, Iceland

ABSTRACT

Whole and filleted Atlantic mackerel were hot smoked using Cabin and Bradley kilns. The smoked products were then air and vacuum-packed and stored at 0 – 4 °C and 15 – 20 °C for up to 35 days. The changes in physicochemical (pH, colour, water activity, salt and water content and total volatile base nitrogen, TVB-N), microbiological and sensory quality were studied over the storage period. Vacuum-packed smoked mackerel stored at refrigerated temperatures performed better during storage than those air-packed, independent of the smoking method. According to the sensory analysis, the shelf life was estimated between 7 - 10 days for air-packed smoked mackerel fillets stored at room temperature and 10 - 18 days for vacuum and air-packed whole mackerel stored at 0 – 4 ^{o}C and 15 – 20 ^{o}C. Vacuum and air-packed mackerel fillets independent of storage temperature, as well as, vacuum-packed mackerel from the two smoking methods stored at 0 – 4 ^{o}C were not rejected by the panel during the storage period.

This paper should be cited as:
Asamoa, E. 2018. *The quality and shelf life of Atlantic mackerel (*Scomber scombrus*) as influenced by smoking technology, packaging material and storage temperature.* Nations University Fisheries Training Programme, Iceland [final project]. http://www.unuftp.is/static/fellows/document/eunice16cprf.pdf

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Ghana has a vibrant fishing industry, which accounts for about 4.5% of the country's gross domestic product (MOFAD, 2016). Fish contributes 60% to the annual protein intake in the diet of Ghanaians, with an annual per capita consumption of about 28 kg, which is higher than the world average of 18 kg (Nunoo *et al.*, 2014). In addition to food security, the fisheries sector employs about 10% of the population and is estimated to generate approximately US$ 1 billion in total revenue each year (MOFAD, 2016). The fisheries sector is divided into inland (freshwater and aquaculture) and marine subsectors. The marine subsector accounts for about 85% of the total fish catches, exploiting about 347 fish species, 17 cephalopods and 25 crustacean species (Nunoo *et al.*, 2015). It comprises the small-scale (artisanal and subsistence), semi-industrial and industrial fishing fleets. The artisanal fleets consist of wooden canoes that are either motorised or not. The inshore boats are mainly wooden with an inboard engine, while the industrial vessels are generally over 25 m long, made of steel hull and has the capacity to operate in areas beyond Ghana's national jurisdiction (MOFAD, 2016). Overall, the catch from all fleets has been decreasing since 2001, while the effort has been increasing (Nunoo *et al.*, 2014).

The artisanal sector employs about 200,000 fishermen (with approximately 2 million dependents), makes up about 92% of the total fishers and accounts for 70% of total landings. As of 2013, there were about 12,847 canoes operating in 334 landing sites in 195 fishing towns across four coastal regions (Nunoo, Asiedu, Amador, Belhabib, & Pauly, 2014; MOFAD, 2016). The artisanal sector employs multiple gears like beach seine, set net, hook and line, drift gill net, and purse seine ('*ali*', '*poli*' and '*watsa*') nets. The small pelagic species i.e. sardines, anchovies and mackerels (approximately 85% of canoe catch) are exploited with the large pelagic fish, mostly tuna and demersal stocks i.e. croakers, red snapper, sea breams and red mullet.

Fish is a highly perishable commodity that begins to deteriorate immediately after catching. It requires a degree of processing to preserve it. In Ghana, hot smoking, drying, salting, frying, fermenting and various combinations of these methods are employed to process and preserve fish for consumption and storage (Nunoo *et al.*, 2015). There are currently more than 400,000 women fish processors (involved mainly in smoking, salting and drying) in Ghana (Bentil & Appiah, 2015). Hot smoking is a traditional fish preservation method that is used for both marine and freshwater fish species. It prolongs the shelf life, enhances flavour and smoked products can be used in soups and sauces (UNDP/TCDC, 2001). It is therefore not surprising that about 70 – 80 % of fish consumed in Ghana is smoked (Nunoo *et al.*, 2015). The main smoked species are sardines, anchovies, chub and horse mackerels (marine) and tilapia and catfish (freshwater). When fish is properly smoked and packaged, it can become a stable source of dietary protein and omega-3 polyunsaturated fatty acids (Odoli, 2015) which will, in turn, improve the food and nutritional security of Ghanaians.

Smoking and trading in smoked products are traditionally carried out by women in and around coastal communities and river banks in Ghana. This is done mostly at individual or household levels (small scale, <10 ovens), even though there are few medium (11 – 25 ovens) and large (>25 ovens, usually in fish processors associations or co-operative) scale operators (Gordon *et al.*, 2011; Nunoo *et al.*, 2015). The marketing systems for smoked fish is well developed, extending into neighbouring countries (e.g. Togo, Nigeria, Benin, Burkina Faso). There is also a demand for these products in the EU and USA. In Ghana, seven industrial processors (four currently active) have been certified by the Ghana Standards Authority to export smoked fish,

however, the domestic market is the most important market for smoked fish (Gordon *et al.*, 2011; Nunoo *et al.*, 2015)

There are many traditional ovens used for smoking fish in Ghana, however, the most common one is the 'Chorkor Smoker' (Figure 1). It was developed by the Food and Agriculture Organization of the United Nations (FAO) and the Food Research Institute of the Council for Scientific and Industrial Research (CSIR), Ghana, and introduced in Ghana in 1969 (UNDP/TCDC, 2001). This oven replaced traditional methods (described in UNDP/TCDC, 2001) that were deemed ineffective in terms of the volumes produced and the inefficiency in fuel use. Also, the women who used these were prone to illnesses due to smoke exposure. Finally, the traditional smoking methods were very laborious and produced poor-quality products of low market value. These problems, however, persist even after the introduction of the Chorkor smoker. Currently, there are about 120,000 Chorkor and traditional smoking kilns in operation in Ghana and it's been estimated that about 16,600 smoked fish processors and other cook stove users die annually due to smoke exposure (Okyere-Nyarko *et al.*, 2015). Furthermore, the Chorkor smoker is only moderately energy efficient and offers moderate emission gains (Okyere-Nyarko *et al.*, 2015), calling for development of improved technologies. Fish is also exposed to a direct heat source that can lead to deposition of high levels of polycyclic aromatic hydrocarbons (PAHs) in the smoked product, thus making it unsafe for human consumption (Okyere-Nyarko *et al.*, 2015).

Figure 1: The Chorkor smoker

These problems have necessitated the development of new and innovative smoking technologies. There are currently six such technologies namely the: Morrison and AWEP (modified Chorkor smokers), KOSMOS oven, KOSMOS Chorkor, Tullow oven and the FAO-

Thiaroye Technique (FTT) and a comparison of these gave the following results (Entee, 2015a, b):

- in terms of costs, the Chorkor and Morrison ovens were the cheapest (about USD 300) whiles the FTT was the most expensive (USD 1,300)
- firewood is used in all the kilns except the FTT that uses charcoal as fuel
- none of the kilns met the Energising Development (EnDev) requirement of 40% fuel or energy saving efficiency. Comparatively, though, the Morrison oven was able to save 36.7% more energy more than the Chorkor smoker
- all the kilns produced high levels of carbon monoxide (CO) and particulate matter
- apart from the FTT, all the kilns produced high levels of PAH, which could be hazardous to both the producers and consumers.

Apart from the problems with the smokers, many quality issues have also been identified throughout the fish value chain in Ghana. One of such issues is the microbial pathogenic contamination and spoilage during handling after harvesting, which is mainly due to no or poor icing of the fish (Kleter, 2004). Mackerel is usually "soft" smoked (at temperatures of about 80 ^{o}C for 1 – 2 hours) and therefore has a high water activity. This limits the shelf life of the product (usually 1 – 3 days when stored at room temperature) due to microbial activities. Sardines, on the other hand, are "dry" smoked (at temperatures of about 80 ^{o}C for about 10 – 18 hours, and sometimes days, with a shelf life of 6 – 9 months when properly stored). They may as such may be overexposed to heat thereby making them too hard, causing the fish to have a rubber-like texture (UNDP/TCDC, 2001; Entee, 2015a). These changes in quality affect the value of the fish and this can significantly affect the livelihoods of fishers, processors and the country.

The problems discussed above, therefore, call for the development of cost effective, fuel and energy efficient smokers that offer lower emission gains. Apart from ensuring fuel use efficiency, the over-reliance on mangroves as the preferred fuel (Torell *et al.*, 2015) in fish smoking also calls for research into alternative fuel sources. Sawdust and wood shavings are used as alternatives in some African countries, including Ghana (Teutscher *et al.*, 1995). In Iceland, dried sheep dung is used in traditional smoking meat and fish (McGee, 2004).

These interventions can help produce safe and good quality fish, with minimal deforestation, while at the same time impacting less on the health of fish processors. The need for improved smoking technologies has been captured under the value chain development component of the West Africa Regional Fisheries Program (WARFP), which is currently ongoing and is expected to end in 2017. The program seeks to improve fish smoking technologies that reduce the levels of PAH (to conform to international standards) in smoked fish thereby making the product safe and reducing the impacts on women fish processors. It is also hoped that this will increase the marketability of smoked fish products and contribute to the country's economic growth (The World Bank, 2011).

The UNU-FTP, Matis and their partners in Tanzania have developed a smoker/dryer cabin that ensures women spend no time in smoke filled huts, offers good nutritional value of the fish and consumes only 20% of fuel compared to traditional methods. Another innovation is the Bradley digital smoker. This is an automatic smoker that completely controls the temperature, time and smoke delivered to a product (Bradley Smoker, 2016). An adoption of these technologies in Ghana will, therefore, be of benefit to the fishing industry (both for small scale and industrial processors) and the country.

1.1 Objectives

The main objective of this study was to determine the effect of hot smoking using the smoking Cabin developed by UNU-FTP and Matís, as well as the Bradley smoker on the quality and storage life of the final products.

The specific objectives were to:

- estimate the cost and performance of the smoking cabin and compare these to the Chorkor and other smoking kilns currently used in Ghana
- evaluate the physicochemical, microbial and sensory quality of raw and smoked mackerel, both whole and filleted, stored at either refrigerated (0 – 4 ^{o}C) or room temperature conditions (15 – 20 ^{o}C) for up to 35 days
- assess the influence of air and vacuum packaging materials, in combination with the storage temperatures, on the physicochemical, microbial and sensory quality of the smoked mackerel from the two smoking kilns.

2 STATE OF THE ART

2.1 Fish smoking

Fish processing is defined as any action that substantially alters the initial product and may include heating, smoking, curing, maturing, drying, marinating, extraction or a combination of these processes (European Commission, 2004b). Smoking according to (FAO/WHO, 2012) is a process of preserving fish, or other food products, by exposing it to smoke from smoldering wood or plant materials. The process usually consists of a combination of salting, drying, heating and smoking steps in a smoking chamber. The smoke is generated from incomplete combustion of wood and this adds flavour and preservative agents into the smoked product. Smoking typically extends the shelf life of fish by:

- lowering water activity resulting in reduced microbial growth through salting and drying
- providing a physical surface barrier to the passage of microorganisms from the elevated temperatures during drying
- deposition of antimicrobial and antioxidant compounds, such as aldehydes, carboxylic acid and phenols, which delays microbial growth and rancidity development (Arason *et al.*, 2014)

Fish can be cold, hot, liquid or electrostatically smoked, with differences arising from how the smoke is delivered (Wheaton & Lawson, 1985). The difference between hot and cold smoking is that hot smoking takes place at 70-80 °C resulting in cooking of the fish (making the product ready to eat) whereas, cold smoking takes place at temperatures below 30°C, meaning that the fish is not cooked but has less nutrient degradation (Arason *et al.*, 2014). Hot smoking causes protein denaturation, which mainly affects the texture of the final products (Gill *et al.*, 1992). Hot smoking is very popular in developing countries like Ghana where there are logistical challenges in cold storage of the products. However, cold smoking is popular in developed countries where refrigeration and other logistics are not a problem and consumers want the characteristic flavour and texture of smoked fish (Akande *et al.*, 2012).

Hot smoking involves a process that uses a suitable combination of temperature and time that would kill parasites, destroy non-sporulated bacterial pathogens and injure spores of human health concern. A final drying step (that reduces water activity to 0.75 or less) can be included to further extend the shelf life of smoked products and the final material is then termed smoke-dried (FAO/WHO, 2012). Smoke-dried fish is usually preferred by artisanal fish processors since the fish can be stored without refrigeration.

In Ghana, the hot smoking process follows the general description given in Entee (2015a). The first step is thawing (for frozen fish) for 20 to 30 minutes depending on how frozen the fish is and the quantity being used. Water is usually sprinkled on the fish or the fish is exposed to air to thaw out. Pressure is often applied to separate the fish and this can affect the quality of the fish. After thawing, the fish is washed and sorted. Fresh fish processing starts at the washing step. Washing is usually done with seawater, which may contain some salt tolerant bacteria that can increase the microbial load in the fish. The fish is then put on racks to dry for at least 15 minutes. Drying is done in open air and this exposes the fish to flies and other contaminants in the air. Once dry, the fish trays are put on the smoking kiln. Smoking is usually performed in two steps: the cooking and smoking steps. The cooking step requires heat and no smoke and usually depends on how experienced the processor is at controlling this. However, the smoking time varies based on the size of the fish, species, quantity of fish, type of smoking kiln used and fuel used. At the end of this stage, the fish has the colour and texture of steamed fish products. The smoking step involves adding smoke flavour and colour to the product while at the same time gradually drying it out. The duration of this stage depends on the experience of the processor, type of smoking kiln, the type of smoking done (soft or hard smoking), the colour, size and quantity of fish and finally the consumer's preference. Most processors prefer the soft-smoked products because they have a higher processing yield and a higher market price than the hard smoked products from similar sized fish, even though such products have very limited shelf lives (Entee, 2015a). Consumers also prefer these soft or sometimes semi-dried smoked products (Essuman, 1992).

2.2 Changes in fish muscle during smoking and factors that affect the quality attributes of smoked fish

Smoking affects the quality of fish in numerous ways, but this depends largely on the quality of the raw material used. A good quality raw material will yield a good quality smoked product that ensures a steady market demand and profits for the processor (Cardinal *et al.*, 2001). Smoking has been known to affect the weight, texture, colour, flavour, odour and general acceptability of the finished products (Arason *et al.*, 2014). Smoking results in weight loss in the final product due to the combined effect of dehydration and the leaching of lipids from the fish muscle. This weight loss can be about 10 – 25 % depending on the origin of the raw material (whether fatty or lean fish), the final product characteristics, the smoking method and the size and shape of the fish (Arason *et al.*, 2014).

During smoking, the pH of the fish muscle decreases because of the absorption of acid from the smoke, dehydration (especially from hot smoking) and the reaction of phenols, polyphenols and carbonyl compounds with protein and protein constituents (amino acids) (Arason *et al.*, 2014). An inverse relation exists between the temperature used in the smoking and the pH in fish muscle i.e. the higher the temperature, the lower the pH and vice versa (Espe *et al.*, 2002). Thus, Espe *et al.* (2002) showed that fish smoked electrostatically had the least decrease in pH as compared to the other methods of smoking.

The salt content of fish muscle during the brining step leads to changes in the protein structure of the muscle. Fish muscles swell at lower salt concentration whereas at a higher salt concentration (9 – 10 %) they may shrink due to dehydration and this might result in changes in the water holding capacity, texture and microstructure of the fish muscle (Offer & Knight, 1988; Thorarinsdottir *et al.*, 2004). A minimum salt content of 3 % has been recommended in smoked mackerel to prevent the growth of food poisoning organisms, like *Clostridium botulinum*, while keeping the salty taste at a pleasant level (Bannerman, 1990).

The main purpose of smoking in recent times has shifted to enhancing the sensory quality of the product rather than for its preservative effects (Arason *et al.*, 2014). The colour, flavour and odour of smoked fish products are attributes that affect consumer acceptance of the product. These attributes depend mostly on the smoking method and raw material used. The characteristic colour and odour of smoked fish results from a Maillard reaction between the carbonyl amino group and caramelization of fish flesh from the smoking process and lipid oxidation (Leksono *et al.*, 2014; Arason *et al.*, 2014). The increase in temperature and dryness can enhance this reaction (Getachew, 2011). Flavour is developed from phenolic compounds (guaiacol and syringol) produced from pyrolysis of lignin (Jónsdóttir *et al.*, 2008). In Ghana, mangrove is the most preferred fuel wood used in smoking because it produces the characteristic golden brown or dark brown colour, which consumers desire (Allou, 2012).

2.3 Packaging and Shelf life of smoked fish products

Hot smoked fish products have variable shelf lives, mainly depending on the type of species, amount of salt and smoke used, degree of drying, storage temperature and packaging material (Bannerman, 1990). The choice of packaging material is very important because it can be a source of contamination and cause physical losses (like insect infestation) to the product. Hot smoked fish can be air or vacuum packed. Vacuum packing excludes oxygen and thereby delays the onset of rancidity development in fatty fish (Bannerman, 1990). However, when the product is subjected to temperature abuse during storage, there is a risk of *C. botulinum* growth, irrespective of the packaging material used (FAO/WHO, 2012). In Ghana, smoked fish is cooled at room temperature and arranged carefully in cane baskets lined with paper (usually old newspapers or empty cement bags that are mostly unhygienic and contaminates the fish). The baskets are then wrapped with nets to secure the fish. This usually results in microbial contamination and physical losses (Entee, 2015a)

2.4 Atlantic mackerel (*Scomber scombrus*)

The Atlantic mackerel (*Scomber scombrus*) (Figure 2) belongs to the family Scombridae. It is a pelagic, migratory schooling species that can be found in both temperate and cold shelf areas (Collette *et al.*, 2011). The mackerel migrates into Icelandic waters in early summer to feed and build its energy reserves. It has a protein content of 18 – 20 % and its considered a fatty fish with a seasonal variation in fat (6 – 23%) and water (56 – 74%) contents (Keay, 1979). Fresh mackerel has a rich pronounced flavour, greyish and oily colour, which turns from off-white to beige when cooked. It has a soft flaky texture and is rich in omega-3 fatty acids and is also an excellent source of selenium, niacin, and vitamins B6 and B12 (NOAA Fishwatch, 2015). The Atlantic mackerel can be hot smoked, either whole, gutted with or without the head on, or as fillets. It is recommended that fish with at least 10% fat content should be used to give a good quality product (Keay, 1979). This makes the species in Icelandic waters (with fat content between 13 to 26 %) very suitable for hot smoking (Romotowska *et al.*, 2016).

Figure 2: Atlantic mackerel (Scomber scombrus)

3 METHODOLOGY

3.1 Smoking equipment

Three smoking kilns, the open fire drum, Cabin, and Bradley (Figure 3), were used to smoke fish in the pre-trial and main study, while only the latter two were used in the main study. The open fire drum, Cabin, and Bradley represented uncontrolled, semi-controlled, and controlled smoking technologies. Both the open drum and Cabin use firewood whereas the Bradley uses electric power and smoking bisquettes as fuel. The smoking cabin is made from wood with a metal drum beneath the chamber where burning wood is the source of heat and smoke. A metal plate is placed above the pipe to diffuse the hot air and provide a more even circulation of the smoke in the smoking chamber. The fish was smoked on removable wooden frames with metal meshes. The Bradley smoker had a polished stainless steel interior and a powder epoxy steel exterior, with temperature, time and smoke controls (Bradley Smoker, 2016).

(a) ***(b)*** ***(c)***

Figure 3: Open fire drum (a), Cabin (b) and Bradley (c) kilns used in smoking Atlantic mackerel

3.2 Experimental design

The study was undertaken in two phases: a pre-trial and main experiment, as stated before. Atlantic mackerel (*Scomber scombrus*) was used for this study due to its similarity to the chub mackerel (*Scomber japonicas*) which is one of the important smoked fish species produced in Ghana. The raw material (stored at -18 ^{o}C for 4 months before processing) was provided by Síldarvinnslan hf (SVN). The experiments were carried out at Matis laboratories in Reykjavik, Iceland.

3.2.1 Pre-trial

Before undertaking the main experiment, a pre-trial was conducted, as part of the learning processes, to be able to set the parameters for the main experiment. The pre-trial was used to:

- determine the appropriate brining concentration and time
- estimate the smoking duration
- compare three different smokers i.e. open fire drum, Cabin and Bradley
- compare two different smoking fuels i.e. flakes/wood and flakes with Tað (sheep dung, commonly used in Iceland for smoking meat and fish) and decide what to use in the main experiment.

Frozen mackerel was thawed at room temperature for 17 hours, after which they were filleted and washed in water of 4 ^{o}C. Fillets were either immersed in 8 or 12 % brine solutions (ratio of 1:2 fish to brine) for up to 90 minutes at 5 ^{o}C. Samples were taken at 30, 60 and 90 minutes of brining to determine the salt content in the muscle. After brining, the samples were placed on racks to drain overnight in a cooler. The samples were then smoked after preheating the smoking kilns for about 30 minutes. The sensory and physicochemical quality of smoked fish was evaluated.

3.2.2 Main experiment

The flow chart (Figure 4) shows how the main study was conducted. Frozen mackerel was thawed at room temperature for 17 hours, after which they were gutted and washed in water of 4 ^{o}C. The samples were then divided into two groups, whole gutted and filleted and immersed in an 8% brine concentration (determined in the pre-trial) for 60 and 45 minutes respectively. After brining, the samples were placed on racks to drain overnight in a cooler. Temperature loggers (iButton, iButtonLink Technology LLC, Whitewater, WI, U.S.A.) were placed inside the muscle of tagged fish to monitor the temperature at 1 minute intervals during the smoking process. The samples were then smoked after preheating the smoking kilns for about 30 minutes.

The smoking racks were removed at the end of smoking and the fish samples were dried in a convection oven at 50 ^{o}C for 2 and 3 hours for the fillet and whole mackerel, respectively. The fish were then allowed to cool completely before packaging. The fishes were then packed in clear plastic bags (air packaging) or vacuum bags and stored at either 0 – 4 ^{o}C or 15 – 20 ^{o}C for up to 35 days. The sensory, physicochemical and microbial quality was then evaluated over the storage period for the following groups:

- smoked fillets (F)
    - FAC = Cabin smoked, air-packed and refrigerated
    - FVC = Cabin smoked, vacuum-packed and refrigerated
    - FBVC = Bradley smoked, vacuum-packed and refrigerated
    - FAR = Cabin smoked, air-packed and stored at room temperature
    - FVR = Cabin vacuum room
- whole smoked (W)
    - WAC = Cabin smoked, air-packed and refrigerated
    - WVC = Cabin smoked, vacuum-packed and refrigerated
    - WBVC = Bradley smoked, vacuum-packed and refrigerated
    - WAR = Cabin smoked, air-packed and stored at room temperature
    - WVR = Cabin smoked, vacuum-packed and stored at room temperature

3.2.3 Sampling

Sensory, physicochemical and microbial analyses were performed on the samples as shown in Table 1. Each group was sampled in duplicate (n = 2).

Table 1: Sampling overview

Raw material	**Treatment**		**Packaging**	**Storage temperature**	**Sampling days (2 sample replicates per sampling)**								**Analytical methods (days 0 - 35)**
					0	5	7	10	15	18	25	35	
	Raw material		-	-	x								2
Mackerel Whole	Hot smoking	Cabin	Air	0-4°C		x		x		x			6
				15-20 °C		x	x	x					6
			Vacuum	0-4°C		x			x		x	x	8
				15-20 °C		x		x		x			6
		Bradley	Vacuum	0-4°C		x			x		x	x	8
Mackerel fillet	Hot smoking	Cabin	Air	0-4°C		x		x		x			6
				15-20 °C		x	x	x					6
			Vacuum	0-4°C		x			x		x	x	8
				15-20 °C		x		x		x			6
		Bradley	Vacuum	0-4°C		x			x		x	x	8
Total					**2**	**20**	**4**	**12**	**8**	**8**	**8**	**8**	**70**

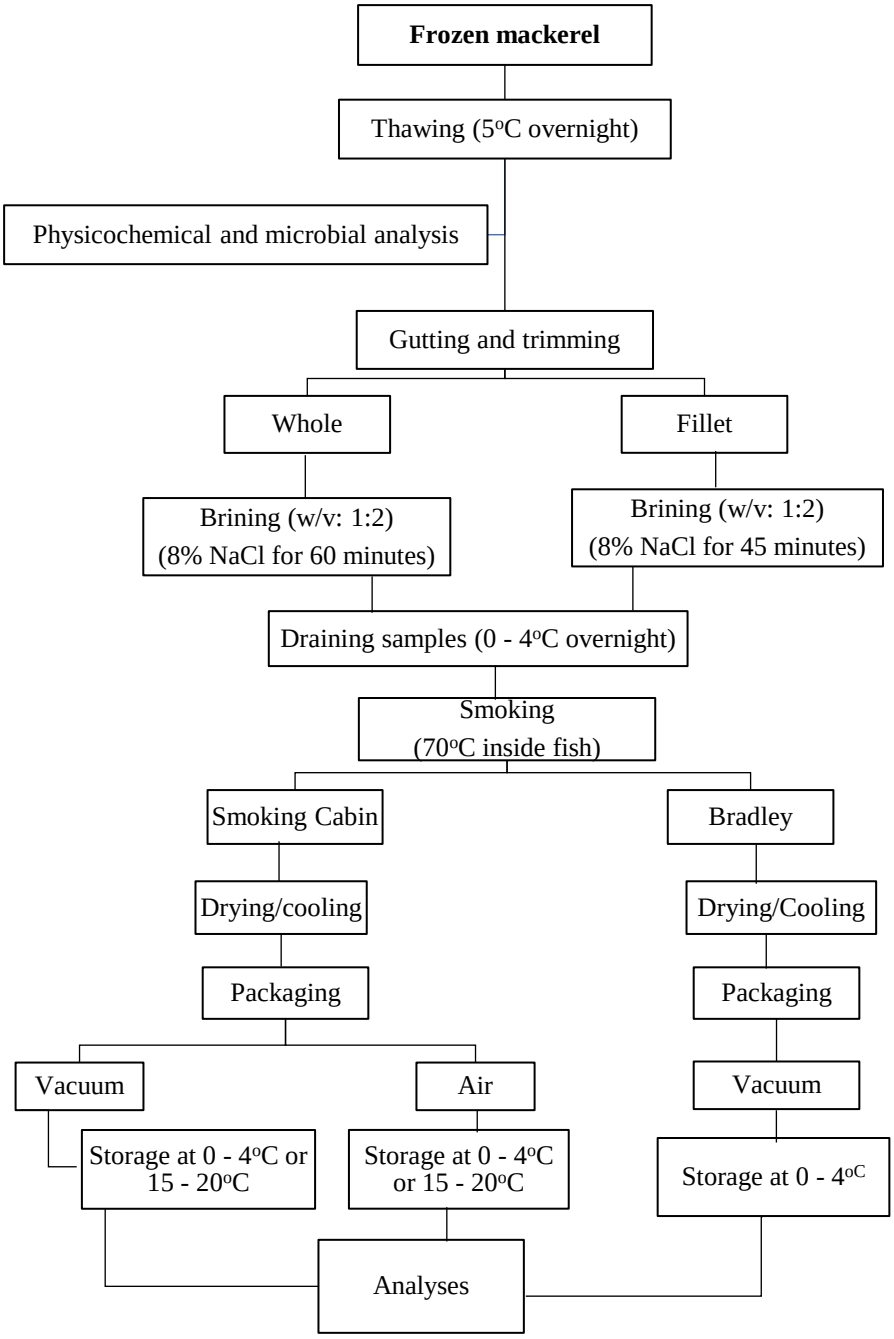


Figure 4: Experimental design for processing smoked mackerel

3.3 Analytic methods

Data were analysed based on the smoking kiln used, packaging materials, and storage temperatures.

3.3.1 Performance of smoking kilns

The performance of the smoking kilns was assessed, in terms of the temperature distribution within the kiln, amounts of fuel material consumed, the specific fuel consumption rate (kg fuel consumed per kg of fish smoked) and total time spent smoking. iButton temperature loggers were placed in both smokers to monitor the temperature at 1-minute intervals.

3.3.2 Physical analyses

Water activity measurements

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

Colour measurements

A Minolta CR-300 chromameter (Minolta Camera Co., Ltd; Osaka, Japan) was used to measure the colour intensity of the fish muscle. The ***L****, ***a****, and ***b**** values were recorded on the CIE LAB colour scale, according to (CIE, 1976). The ***L**** variable represents lightness (***L**** = 0 for black and ***L**** = 100 for white); the *a** variable represents the red/green dimension (*a** > 0 for red and *a** < 0 for green) and the *b** variable represents the yellow/blue dimension (*b** > 0 for yellow and *b** < 0 blue) (Cardinal, et al., 2004). Measurements were made at three locations from posterior to anterior, on the muscle of the smoked fillets and the mean and standard deviation were calculated.

Yield measurements

Fish samples were weighed raw and after each processing step. The percentage weight loss at each processing step was calculated following Rørå *et al*. (1998), as well as the total yield throughout the curing and smoking process assessed in comparison with the headed/gutted and fillet weights for the whole fish and fillets, respectively.

$$\textbf{Curing loss} = 100 \times \left(\frac{\textbf{weight of gutted orfilleted fish} - \textbf{cured weight of fish}}{\textbf{weight of gutted orfilleted fish}}\right)$$

$$\textbf{Smoking loss} = 100 \times \left(\frac{\textbf{Weight of cured fish} - \textbf{weight of smoked fish}}{\textbf{weight of cured fish}}\right)$$

$$\textbf{Drying loss} = 100 \times \left(\frac{\textbf{weight of smoked fish} - \textbf{weight of dried fish}}{\textbf{weight of smoked fish}}\right)$$

$$\textbf{Total loss} = \textbf{100} \times \left(\frac{\textbf{weight of raw fish} - \textbf{weight of dried fish}}{\textbf{weight of raw fish}}\right)$$

3.3.3 Chemical analyses

Water content measurements

Water content of the fish samples was determined by the weight difference during drying of 5.0 g minced samples at 104 C ± 1 C for 4 h (ISO, 1999). Results were expressed as g water/ 100 g sample.

Salt content measurements

The salt content of the fish samples was determined, according to (AOAC, 2000). 5 g of sample was weighed and put into an extraction bottle. 200 ml of deionised water was added to the sample and shaken for 50 minutes. 20 ml of nitric acid was then added to 20 ml of the supernatant and titrated with silver nitrate. The salt content in the water phase (Z-value) for smoked mackerel was calculated as:

$$\textbf{Z} - \textbf{value} = \textbf{100} \times [\%\mathbf{S}(\%\mathbf{M} + \%\mathbf{S})]$$

where: %S is percent salt content and %M is percent water content in the final product.

pH measurements

The pH measurements were performed with a pH electrode (SE 104 – Mettler Toledo Knick, Berlin, Germany) connected to a portable pH meter (Portames 913 pH, Knick, Berlin, Germany). The electrode was inserted directly in fish muscle. The pH meter was previously calibrated with buffer solutions of pH 7.00 ± 0.01 and 4.00 ± 0.01 at 20 °C.

Total volatile basic nitrogen (TVB-N) measurements

The total volatile basic 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 collected in boric acid solution and then titrated with sulphuric acid solution. TVB-N (mg N/100 g) was then calculated as

$$\frac{\textbf{14 mg/mol x a x b x300}}{\textbf{25 mL}}$$

where: a is the ml of sulphuric acid and b is the normality of sulphuric acid (0.0340 N) and 14 is the molecular weight of nitrogen.

3.3.4 Microbial analysis

Total aerobic plate count (TPC) measurements

The microbial quality of fresh and smoked mackerel was determined using the total aerobic plate counts (TPC). 20 g of fish were aseptically weighed in stomacher bags and mixed with 180 ml of maximum recovery diluent (MRD). The mixture was homogenised for 2 minutes in a Waring laboratory blender and serially diluted up to 109 and inoculated in growth media in Petri dishes. For total plate count (TPC) analysis, 1 ml of 1/10 dilutions was transferred using a pipette to the Petri plates and melted iron agar at 45 °C was poured on the plates and the content mixed to solidify. After solidification, the plates were covered with a thin layer of iron agar then incubated at 22 °C for 48 hours. All the microbiological analyses were conducted in duplicate and data expressed as a logarithm of the number of colony-forming units (log cfu/g).

3.3.5 Sensory evaluation

A six to eight-member student sensory panel evaluated the quality and shelf life of smoked Atlantic mackerel using the Quantitative Descriptive Analysis (QDA) method as described in Stone, Bleibaum, & Thomas, (2012). An unstructured scale (left end = 0%, increasing intensity to right end = 100 %) was used to define sensory attribute vocabulary describing odour, texture and flavor (Table 2). All participants were given basic training, per the international standards (ISO, 2012E) in the detection and recognition of tastes and odours, the use of scales, and development and use of descriptors. About 5 cm portions were incised from individual whole and filleted mackerel and placed in aluminium boxes. Each box had a 3-digit number that indicated the sample group, packaging material and storage time.

Table 2: Sensory vocabulary for smoked mackerel

Sensory Attribute	Short Name	Scale	Definition
ODOUR			
Rancid	O-rancid	none || much	rancid odour
TMA	O-TMA	none || much	TMA/wet tablecloth/boiled potato odour
Spoilage	O-spoilage	none || much	other spoilage odour, describe in comment line
TEXTURE			
Soft	T-soft	none || much	softness in first bite
Juicy	T-juicy	none || much	dry: pulls liquid from mouth. juicy: gives liquid
Tender	T-tender	none || much	tenderness when chewed
FLAVOUR			
Smoky	F-smoky	none || much	smoky flavour
Salty	F-salty	none || much	salty flavour
Rancid	F-rancid	none || much	rancid flavour
Sour/acid	F-sour	none || much	sour flavour, but not spoilage sour
TMA	F-TMA	none || much	wet tablecloth taste
Spoilage	F-spoilage	none || much	other spoilage flavour, describe in comment line

3.4 Data handling and analysis

Data were analysed using Microsoft Excel 2016 (Microsoft Inc. Redmond, Wash, USA) and SPSS. One-way analysis of variance (ANOVA), Tukey's multiple comparison Test (Post-hoc), and Pearson's correlation analyses were performed on means of the variables. P values less than 0.05 were considered significant for all analyses.

4 RESULTS

4.1 Pre-trial

The salt content increased faster in fillets brined in 12 % NaCl solution, reaching 2 % in 90 minutes, as compared to fillets brined in the 8 % solution, which contained 1.5 % salt at the same time. Fillets from the 8 % (and brined for 90 minutes) solution were smoked and tasted by a student sensory panel, who deemed the product too salty. Therefore, for the main experiment, a salt concentration of 8 % and brining times of 45 and 60 minutes were selected for fillets and whole fish, respectively.

The three smoking kilns, open fire drum, Cabin and Bradley were compared to determine their performance. The open fire drum recorded the highest average temperature (92 ^{o}C) in the fish muscle and the shortest smoking time (50 minutes). The temperature was, however, difficult to control in the open fire drum and most of the fish got burnt. For this reason, only the Cabin and Bradley were used in the main study.

Finally, it was decided that only wood will be used in the main study since the combination of dung and flakes proved difficult to use. This was because even though the dung was very good at producing smoke, it did not produce enough heat for the hot smoking.

4.2 Kiln performance

The performance of the smoking kilns was assessed based on temperature distribution within the kiln, the amount of time spent smoking during smoking and the fuel consumed per kg of smoked fish. The temperature profile in the Cabin was higher at the top than at the bottom, while it was the opposite for the Bradley (Figure 5). The top of the Cabin reached a high temperature of 141.5 ^{o}C after 27 minutes, whereas it only reached 120 ^{o}C after 64 minutes at the bottom. The highest temperature in the Bradley was 106.5 ^{o}C at the bottom and 55 ^{o}C at the top, both after 210 minutes.

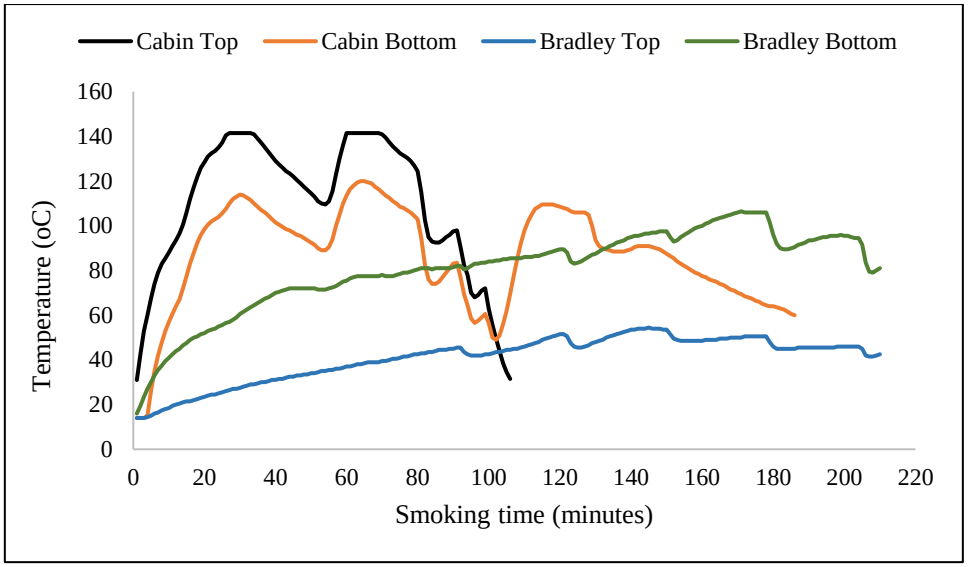


Figure 5: Temperature profile (at 1-minute interval) inside the Cabin and Bradley kilns

A comparison of the length of time used in smoking kiln was made using fish on the top and bottom shelves of the Cabin and Bradley respectively (Figure 6). The internal temperature of fish smoked in the Cabin reached 70 ^{0}C (temperature needed to to kill bacteria on the skin and in the muscle) after 23 minutes and took the shortest time of 106 minutes for all fish to cook. Fish smoked in the Bradley, on the other hand, took 210 minutes to smoke but still only reached an internal temperature of 50.5 ^{0}C after 200 minutes.

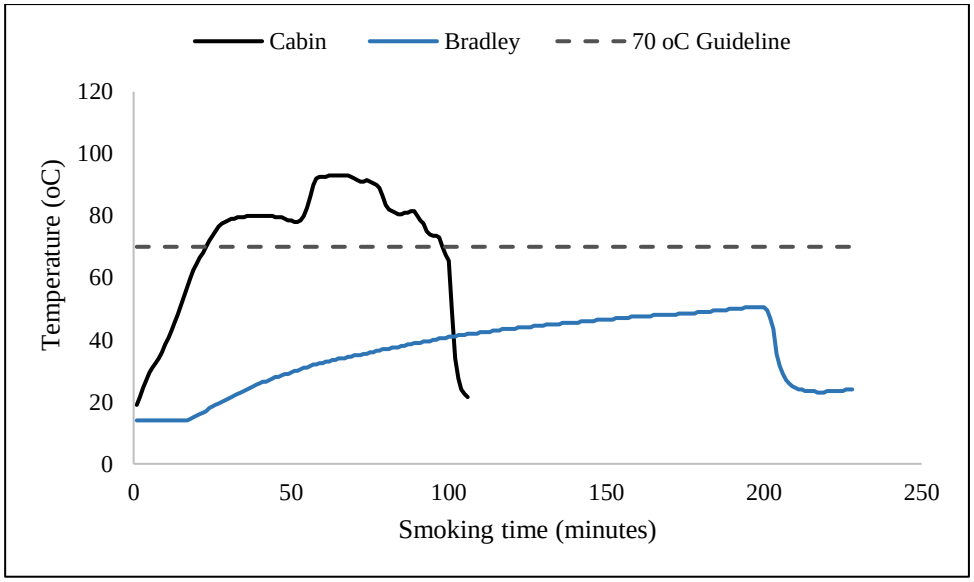


Figure 6: Temperature profile (at 1-minute interval) inside the muscle of whole Atlantic mackerel smoked in the Cabin and Bradley kilns

The total weight of the smoked whole mackerel was 27.2 kg and the equivalent weight of fuel consumed in smoking was 17.8 kg. The specific fuel consumption was therefore 0.65. The estimated smoking capacity of the Cabin is 120 kg of fish, but for this experiment, it was operated at 32% of that capacity.

4.3 Processing yield

The yield at each step of the smoking process is presented in Figure 7 and 8. The total yield for the whole mackerel was 78.8 % and 85.3 % for Cabin and Bradley respectively (Figure 7). The biggest processing losses were due to smoking (12.7 %) in the Cabin and curing (6.9 %) for those smoked in the Bradley. The total yield of fillets was 64.9 % and 69.0 % for Cabin and Bradley respectively (Figure 8). The highest loss in fillets (23.6 and 23.0 %) occurred during curing and subsequent draining overnight. The Bradley had a higher percentage yield than the Cabin for both the whole and the fillets.

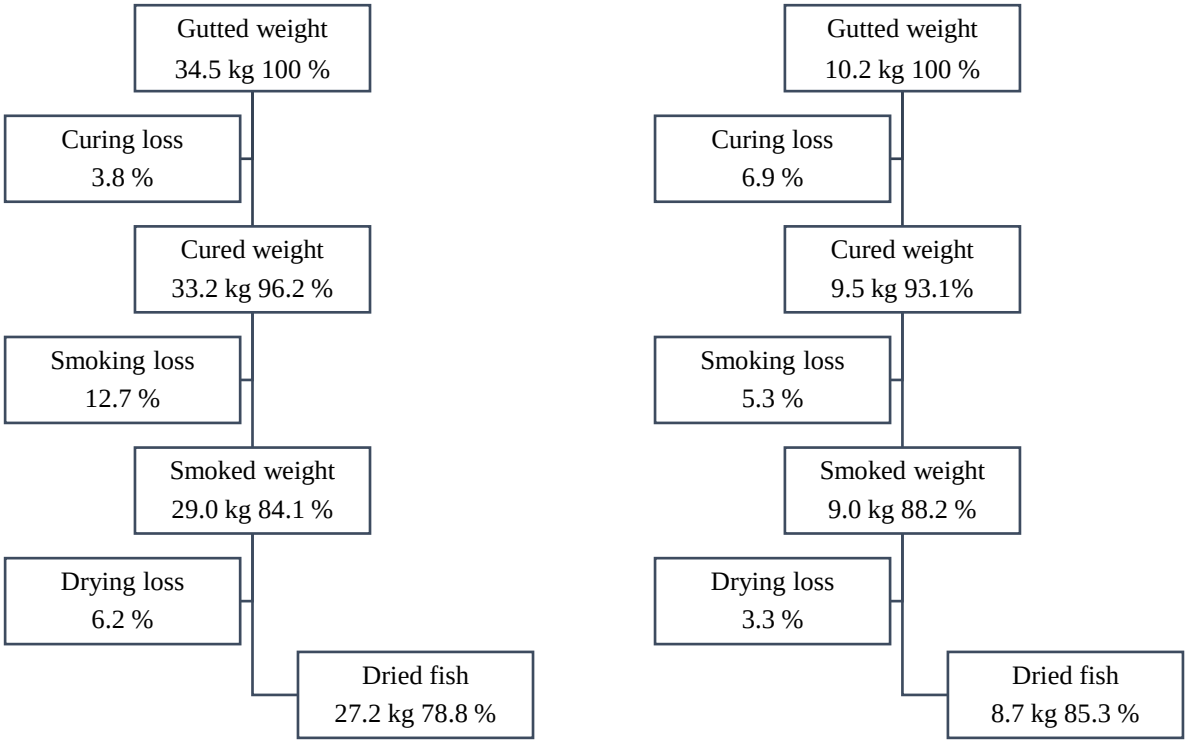
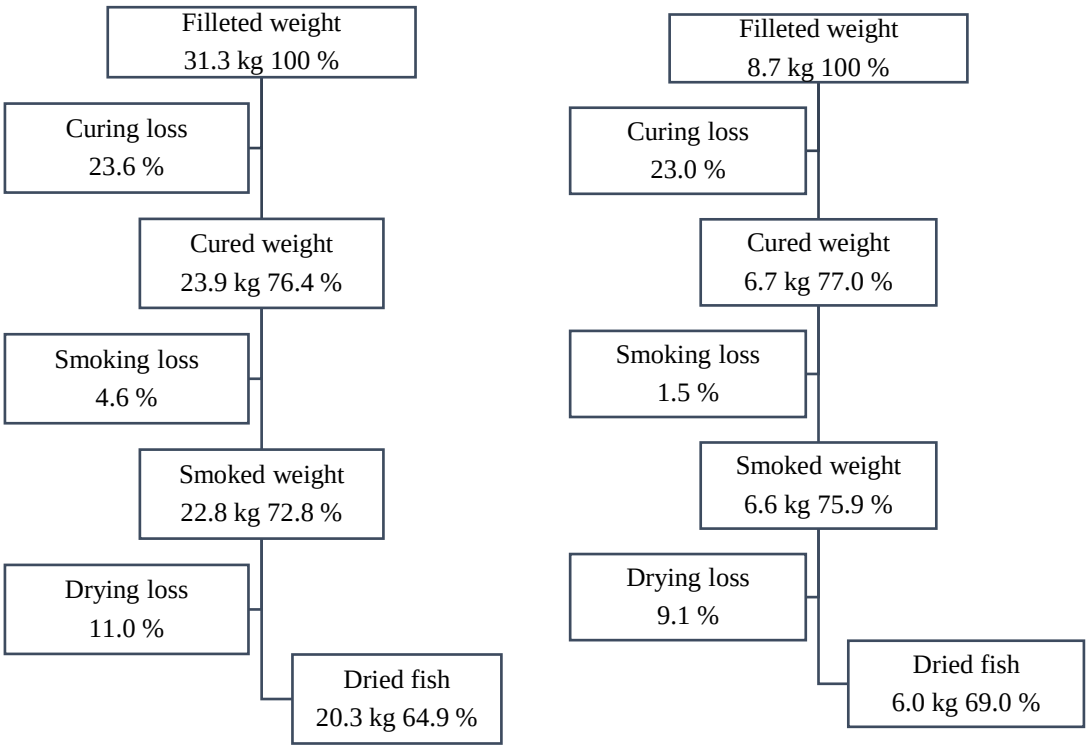


Figure 7: Processing yield and losses of whole Atlantic mackerel smoked in (a) Cabin and (b) Bradley kilns



(a) (b)

Figure 8: Processing yield and losses of filleted Atlantic mackerel smoked in (a) Cabin and (b) Bradley kilns.

4.4 Quality of smoked mackerel during storage at refrigerated and room temperature

4.4.1 Raw material quality

The raw mackerel used in the study had a mean water activity of 1.00, a water content of 59.2 ± 0.8, salt content of 0.3 ± 0.0 % and pH of 6.8 ± 0.2. The mean total volatile base nitrogen (TVBN) and total aerobic plate count were 18.4 ± 0.7 N/100g and 2.8 ± 0.3 logCFU/g respectively. The colour characteristics, lightness (L^*), redness (a^*) and yellowness (b^*) values for the raw fillets were 44.6 ± 5.9, 9.3 ±1.9 and 7.0 ± 1.4 respectively.

4.4.2 pH, water activity, salt and water content analysis

The changes in pH of the smoked mackerel during storage at the refrigerated (0 – 4 ^oC) and room (15 – 20 ^oC) temperature conditions are presented in Figure 9 and 10 for fillets and whole respectively. There was a decrease in pH of fillets compared to the raw material on day 5, indicating the effects of the smoking treatments on the pH (though this was only statistically significant in FVC, $p = 0.047$). The pH generally then increased during storage (Figure 9). A difference in the kilns was observed on day 35, where FVC was significantly higher ($p = 0.047$) than FBVC. There were, however, no statistical differences ($p > 0.05$) between packaging materials and storage temperatures during storage.

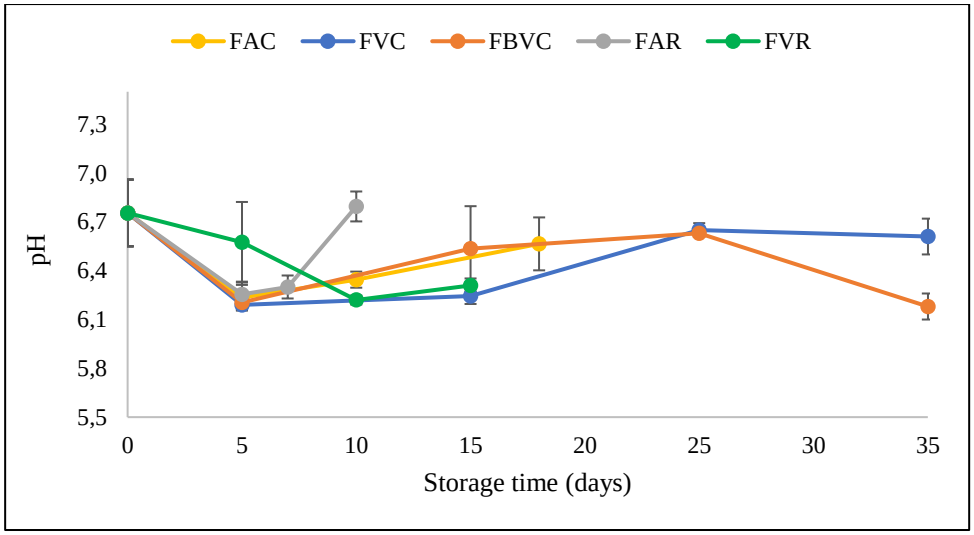


Figure 9: Changes in pH of hot smoked mackerel fillets (FAC = Cabin air-packed refrigerated; FVC = Cabin vacuum-packed refrigerated; FBVC = Bradley vacuum-packed refrigerated; FAR = Cabin air-packed room; FVR = Cabin vacuum room. Day 0 = raw mackerel)

The pH in fish muscle decreased during the smoking treatment compared to the raw material for all groups of the whole smoked mackerel (Figure 10), with WVR being significantly lower ($p = 0.004$) than the other treatments. There was also a difference between WVC and WVR ($p = 0.024$), WAC and WVR ($p = 0.034$) and WAR and WVR ($p = 0.032$) on day 5. This could be as a result of the different packaging materials and storage temperatures. pH generally increased in all groups during further storage, although the only significant difference ($p = 0.036$) was observed between WBVC and WVC on day 25.

The water activity after smoking (on day 5) ranged between 0.96 to 0.98 in all smoked fillets. This was slightly lower than that of the raw material, but did not represent a significant loss. The water activity was fairly stable during storage for all groups, with only FAC being significantly higher ($p = 0.038$) than FVR on day 18. This could be because the different packaging materials and storage temperatures.

The water activity in whole smoked mackerel ranged between 0.97 to 0.99 after smoking (on day 5), which was slightly lower than that of the raw material. There were, however, no significant decreases during the storage period for any of the groups.

The salt content in the smoked fillets (assessed on day 5) was significantly ($p = 0.001$) higher than that in the raw material (Figure 11). The salt content was about 2 % in all smoked groups, even though fillets smoked in the Cabin were slightly higher (but not significantly different) than fillets smoked in the Bradley. All smoked mackerel fillets thus had a salt content of about 3.3 % in the water phase (Z-value). There were, however, no statistically differences ($p > 0.05$) between the kilns, packaging materials or storage temperatures during the storage period.

The salt content in the whole smoked mackerel was 0.80 ± 0.06 % (Z-value = 1.3 %) and 0.65 ± 0.07 % (Z-value = 1.1 %) for fish smoked in the Cabin and Bradley, respectively (Figure 12). All smoked groups had significantly higher salt content ($p < 0.05$) than that in the raw material. A general increase was observed in the salt content during the storage period, but then this was not statistically different between the groups.

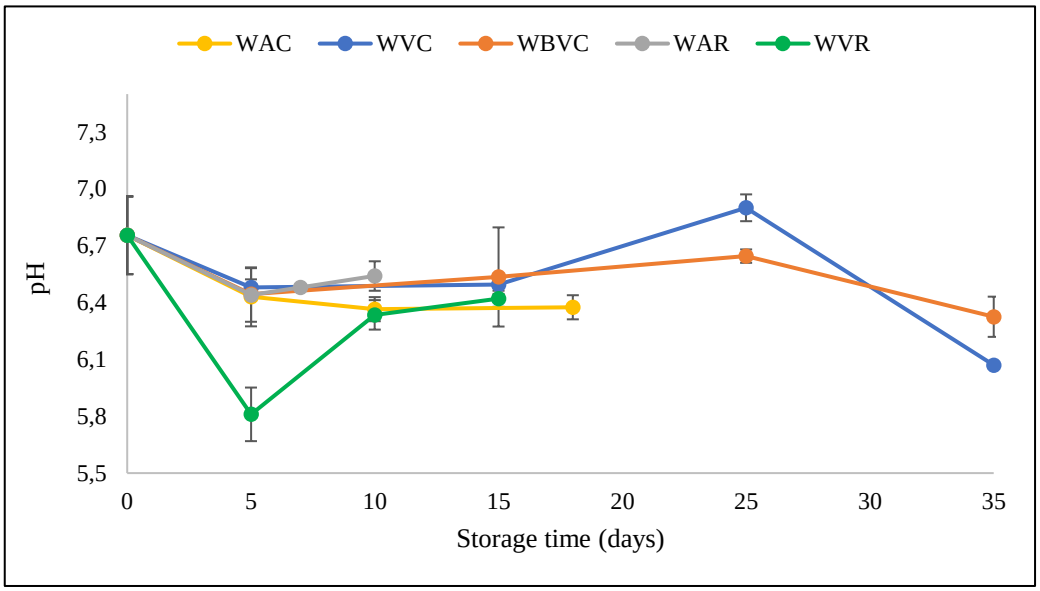


Figure 10: Changes in pH of hot smoked whole mackerel (WAC = Cabin air-packed refrigerated; WVC = Cabin vacuum-packed refrigerated; WBVC = Bradley vacuum-packed refrigerated; WAR = Cabin air-packed room; WVR = Cabin vacuum room. Day 0 = raw mackerel).

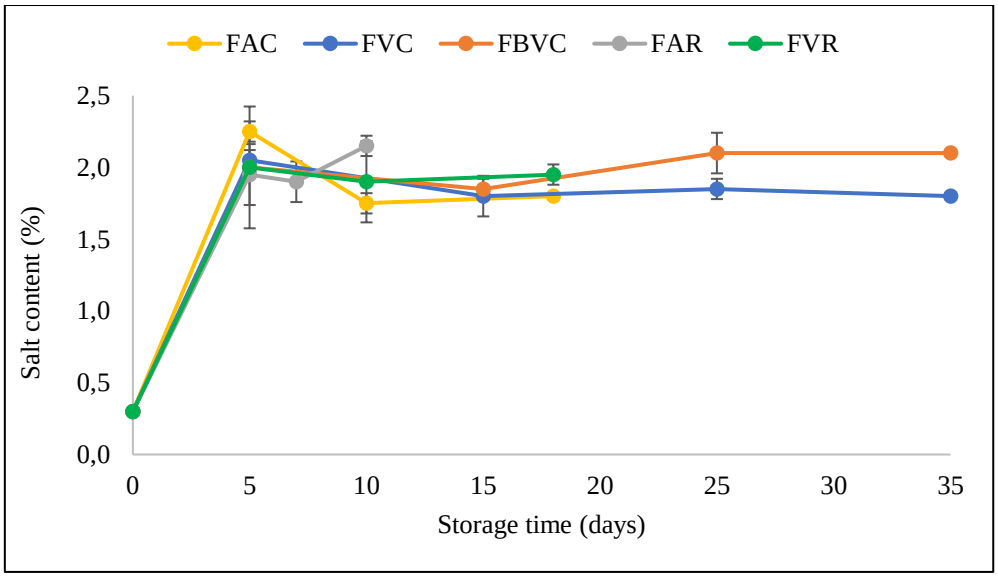


Figure 11: Changes in salt content of hot smoked mackerel fillets (FAC = Cabin air-packed refrigerated; FVC = Cabin vacuum-packed refrigerated; FBVC = Bradley vacuum-packed refrigerated; FAR = Cabin air-packed room; FVR = Cabin vacuum room. Day 0 = raw mackerel)

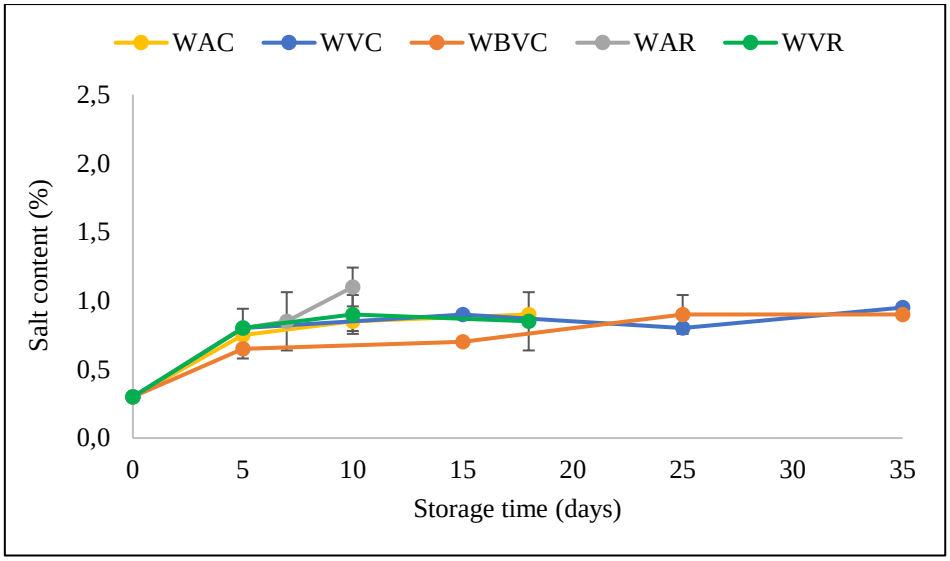


Figure 12: Changes in salt content of hot smoked whole mackerel (WAC = Cabin air-packed refrigerated; WVC = Cabin vacuum-packed refrigerated; WBVC = Bradley vacuum-packed refrigerated; WAR = Cabin air-packed room; WVR = Cabin vacuum room. Day 0 = raw mackerel).

The water content in the smoked fillets decreased compared to the raw material for all groups (Figure 13), with FBVC showing a significantly lower ($p = 0.044$) water content. There was a general increase in water content during the storage period for all groups, except for FVC, which decreased significantly ($p = 0.044$) between day 25 and 35 compared to FBVC.

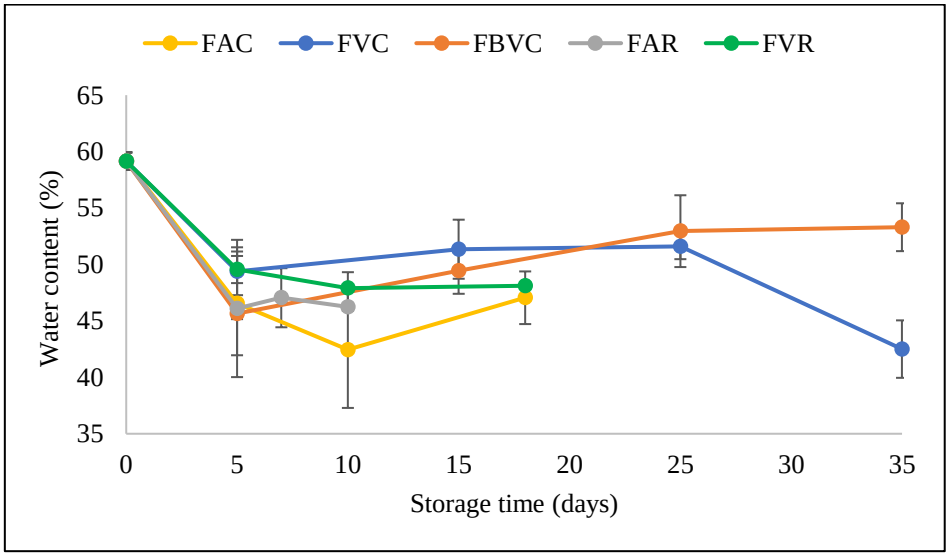


Figure 13: Changes in water content of hot smoked mackerel fillets (FAC = Cabin air-packed refrigerated; FVC = Cabin vacuum-packed refrigerated; FBVC = Bradley vacuum-packed refrigerated; FAR = Cabin air-packed room; FVR = Cabin vacuum room. Day 0 = raw mackerel)

The water content in the smoked whole mackerel decreased compared to the raw material (Figure 14), with WVR being significantly lower ($p = 0.032$) in water content than whole fish

from the other treatments. The water content generally increased during storage for WVR and WAC, while a decreasing trend was observed in WVC and WBVC up until day 25. None of the treatments showed any significant changes in water content during storage.

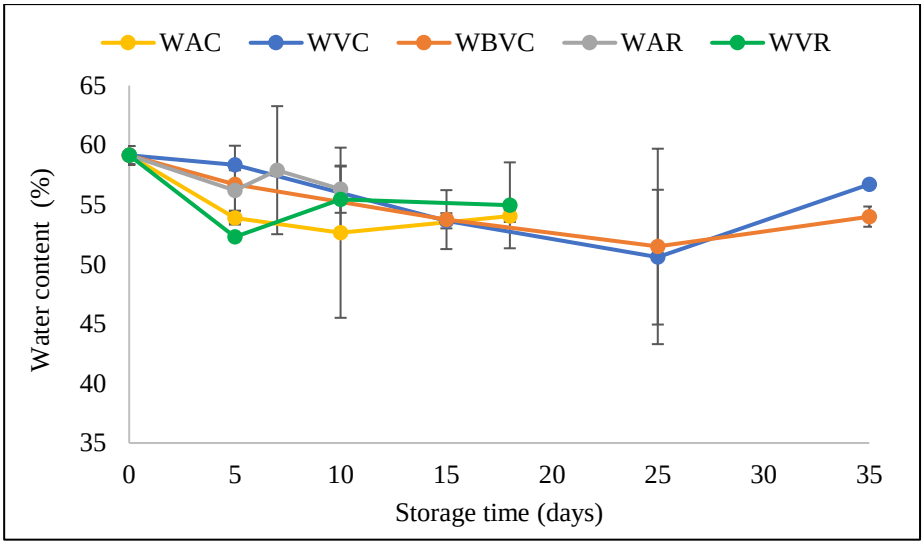


Figure 14: Changes in water content of hot smoked whole mackerel (WAC = Cabin air-packed refrigerated; WVC = Cabin vacuum-packed refrigerated; WBVC = Bradley vacuum-packed refrigerated; WAR = Cabin air-packed room; WVR = Cabin vacuum room. Day 0 = raw mackerel)

4.4.3 Colour analysis

The lightness (*L**), redness (*a**) and yellowness (*b**) characteristics of smoked mackerel fillets are presented in Figure 15. There were no significant differences between the raw material and the smoked fillets, after smoking on day 5. The *L**, however, fluctuated during storage in all groups, with FBVC being lighter than all groups, but only significantly higher ($p = 0.008$) than FVC only on day 25.

In terms of *a**, there were again no significant differences after smoking (on day 5) compared to the raw material. The *a** value decreased during storage but was only significantly different between FAC and FVR on day 18. This difference may be due to the differences in packaging material and storage temperatures.

The *b** values were not statistically different between the smoked fillets and the raw material on day 5. FBVC was however significantly higher on day 5, as compared to FVC ($p = 0.009$), FAC ($p = 0.008$), FAR ($p = 0.028$) and FVR ($p = 0.009$). This could be as a result of the difference in the kilns. *b** values increased in all groups during storage but only became statistically different ($p = 0.031$) between FBVC and FVC on day 25.

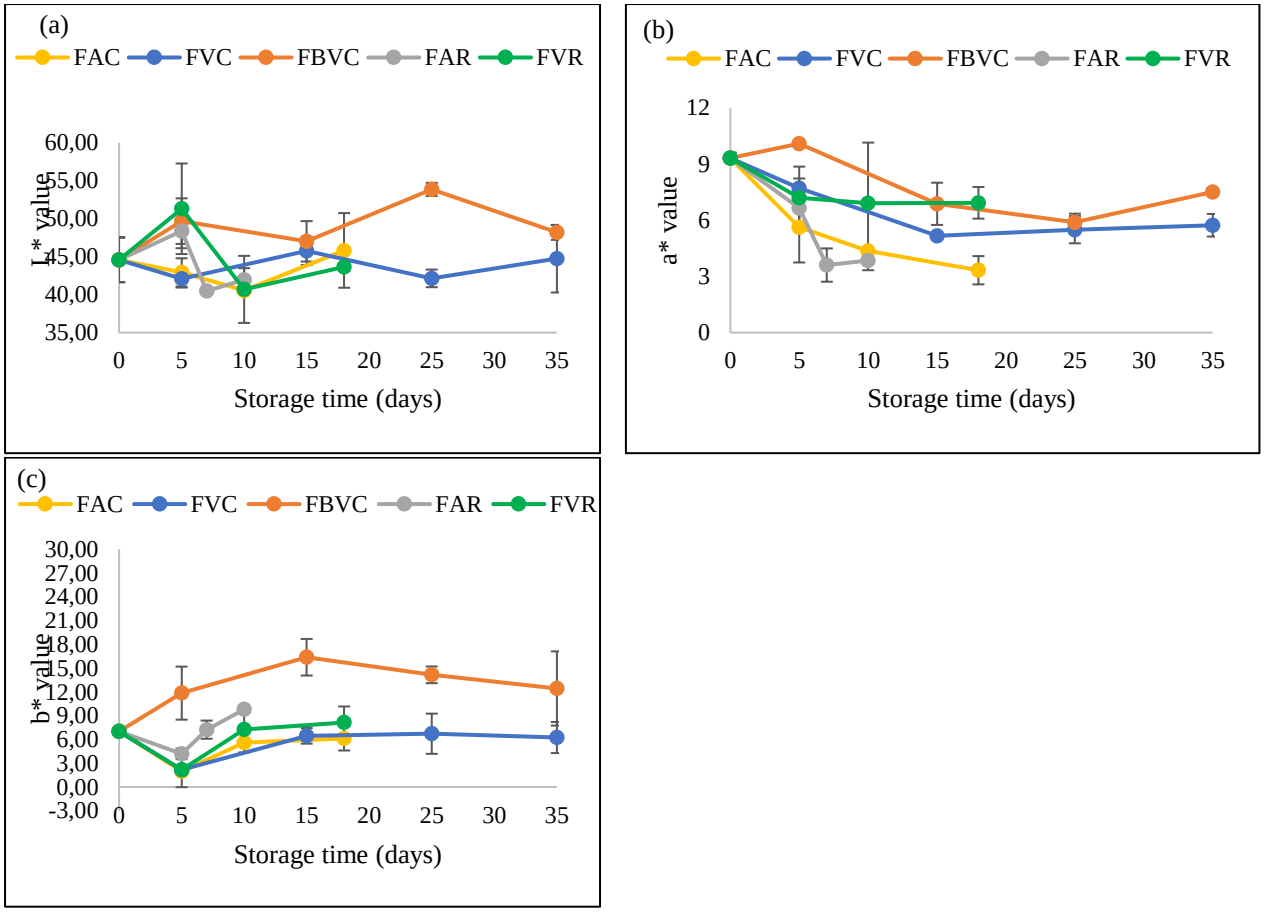


Figure 15: Changes in L* (a), a* (b), b* (c) values of hot smoked mackerel fillets (FAC = Cabin air-packed refrigerated; FVC = Cabin vacuum-packed refrigerated; FBVC = Bradley vacuum-packed refrigerated; FAR = Cabin air-packed room; FVR = Cabin vacuum room. Day 0 = raw mackerel)

4.4.4 TVBN analysis

The TVBN trends for smoked mackerel fillets during storage are presented in Figure 16. On day 5 of storage, the TVBN was significantly higher ($p < 0.05$) in all groups as compared to the raw material (Figure 17). There was an increase in TVBN during the storage period, with FAR and FVR increasing at a faster rate, while the others showed a stable, gradual increase. On day 10, FAC was significantly lower ($p = 0.037$), which could be attributed to the differences in storage temperatures. The highest TVBN was recorded in FVR on day 18 (51.15 ± 4.17 N/100g), which was significant higher ($p = 0.038$) than FAC. There were no statistical differences in TVBN formation between the two kilns.

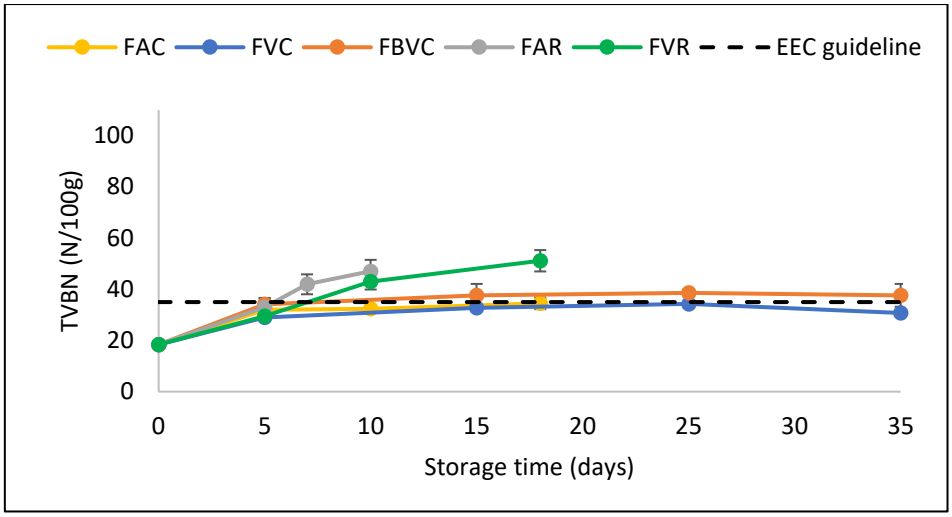


Figure 16: Changes in TVBN of hot smoked mackerel fillets (FAC = Cabin air-packed refrigerated; FVC = Cabin vacuum-packed refrigerated; FBVC = Bradley vacuum-packed refrigerated; FAR = Cabin air-packed room; FVR = Cabin vacuum room. Day 0 = raw mackerel)

Changes in TVBN for whole smoked mackerel during storage are presented in Figure 17. TVBN on Day 5 was significantly higher ($p < 0.05$) in all the smoked products than in the raw material. There was a sharp increase in TVBN for WAR and WVR after day 5 towards the end of their storage times. The highest TVBN was recorded in WAR on day 10 (88.20 ± 12.73 N/100g), which was significantly higher than WAC ($p = 0.025$) and WVR ($p = 0.039$). WVR was also significantly higher ($p = 0.027$) than WAC on day 18. WBVC, WVC and WAC showed a steadier increase during storage and didn't significantly differ from each other.

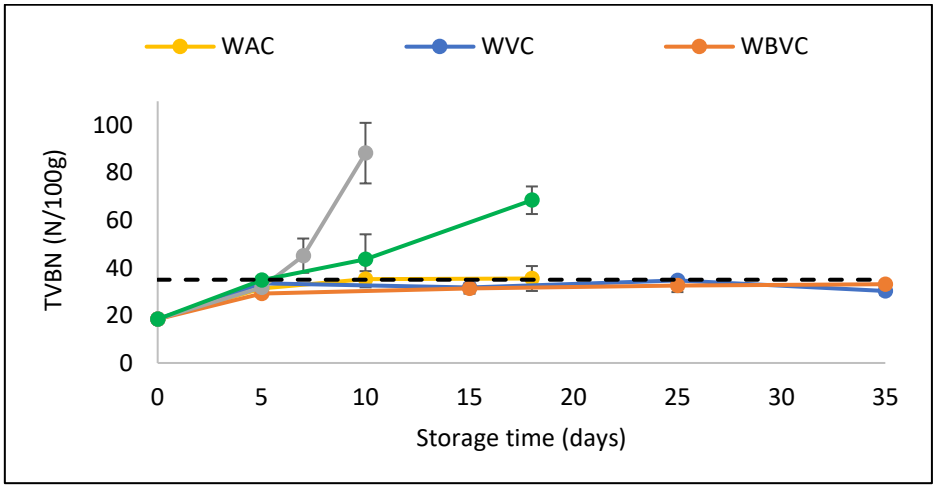


Figure 17: Changes in TVBN of hot smoked whole mackerel (WAC = Cabin air-packed refrigerated; WVC = Cabin vacuum-packed refrigerated; WBVC = Bradley vacuum-packed refrigerated; WAR = Cabin air-packed room; WVR = Cabin vacuum room. Day 0 = raw mackerel).

4.4.5 Microbiological analysis

The total aerobic plate count (TPC) were higher in all smoked fillets than the raw material, except for FBVC (Figure 17). FVC, FAC, FVR and FAR were significantly higher than the raw material ($p = 0.019$, 0.003, 0.000 and 0.000 respectively). There were also significant differences between the groups on day 5 i.e. between FBVC and FVC ($p = 0.001$); FVC and FVR ($p = 0.004$); FVC and FAR ($p = 0.000$); FAC and FVR ($p = 0.028$); and FAC and FAR ($p = 0.001$). Cabin smoked fillets had a significantly higher TPC than fillets smoked in the Bradley. Also, air and vacuum-packed fillets stored at 15 – 20 ^{o}C had a significantly higher TPC compared to those similarly packed but stored at 0 – 4 ^{o}C.

TPC increased in all groups during storage, except for FVC. On day 10, FAC was significantly lower than FVR ($p = 0.003$) and FAR ($p = 0.001$). FVR had a higher TPC on day 18 than FAC ($p = 0.007$). Finally, on day 35, FBVC was significantly higher ($p = 0.028$) than FVC. The TPC acceptance limit of 7 log CFU/g was exceeded on day 5 for FAR and reached on Day 10 for WVR (Figure 18).

The TPC in WAR was significantly higher ($p = 0.007$) than the raw material on day 5 (Figure 19). WAR was also significantly higher than WVC ($p = 0.04$), WAC ($p = 0.024$) and WBVC ($p = 0.009$) on day 5. These differences could be attributed more to the differences in packaging materials and storage temperatures. There was an increasing trend in WAR, WVR and WAC during storage. The highest TPC was recorded on day 10 as 9.1 ± 0.1 logCFU/g for WAR, which was different from WAC ($p = 0.001$) and 7.9 ± 0.3 logCFU/g for WVR, which was also higher than WAC ($p = 0.001$). Again, on day 18, WVR was higher ($p = 0.036$) than WAC. WBVC and WVC did not statistically differ during storage. The TPC acceptance limit of 7 log CFU/g was exceeded on day 5 for WAR and Day 10 for WVR.

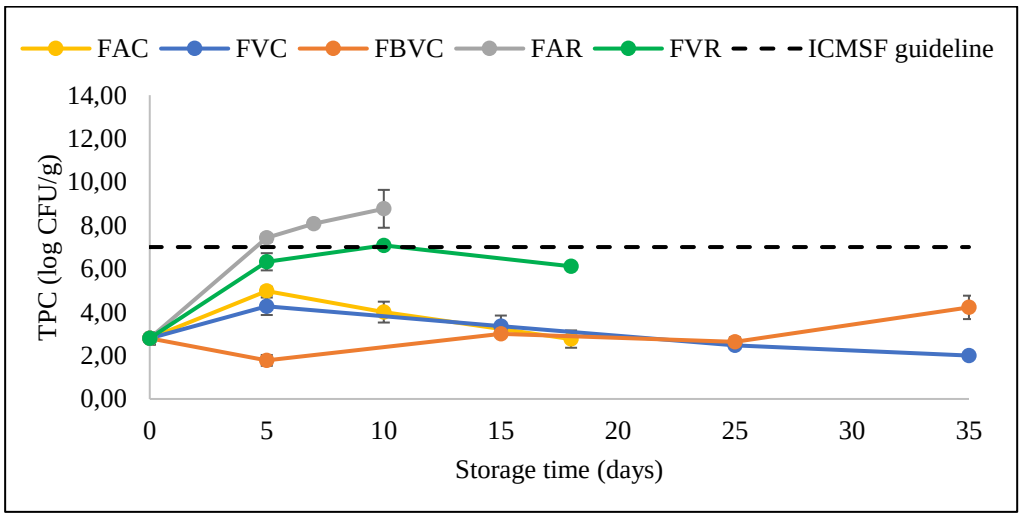


Figure 18: Changes in TPC of hot smoked mackerel fillets (FAC = Cabin air-packed refrigerated; FVC = Cabin vacuum-packed refrigerated; FBVC = Bradley vacuum-packed refrigerated; FAR = Cabin air-packed room; FVR = Cabin vacuum room. Day 0 = raw mackerel)

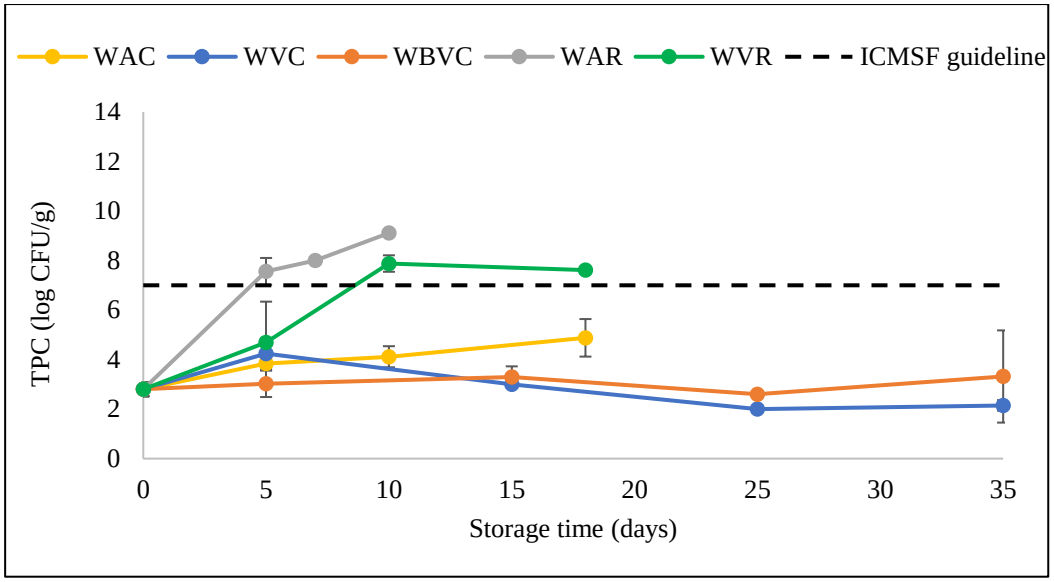


Figure 19: Changes in TPC of hot smoked whole mackerel (WAC = Cabin air-packed refrigerated; WVC = Cabin vacuum-packed refrigerated; WBVC = Bradley vacuum-packed refrigerated; WAR = Cabin air-packed room; WVR = Cabin vacuum room. Day 0 = raw mackerel)

4.4.6 Sensory evaluation

The odour, texture and flavour of smoked mackerel were evaluated over the storage time of the products. Results of positive flavour, odour and texture attributes are presented in Figures 20 and 21. In terms of flavour, whole fish and fillets smoked in the Bradley had a smokier flavour than those from the Cabin as assessed on Day 5. This flavour, however, decreased with storage. Also, the salty flavour was higher in the fillets than in the whole fish is in agreement with the higher salt concentrations measured in the chemical analysis. In terms of texture, the results indicated that the products became softer, more tender and juicier the more days they stayed in storage.

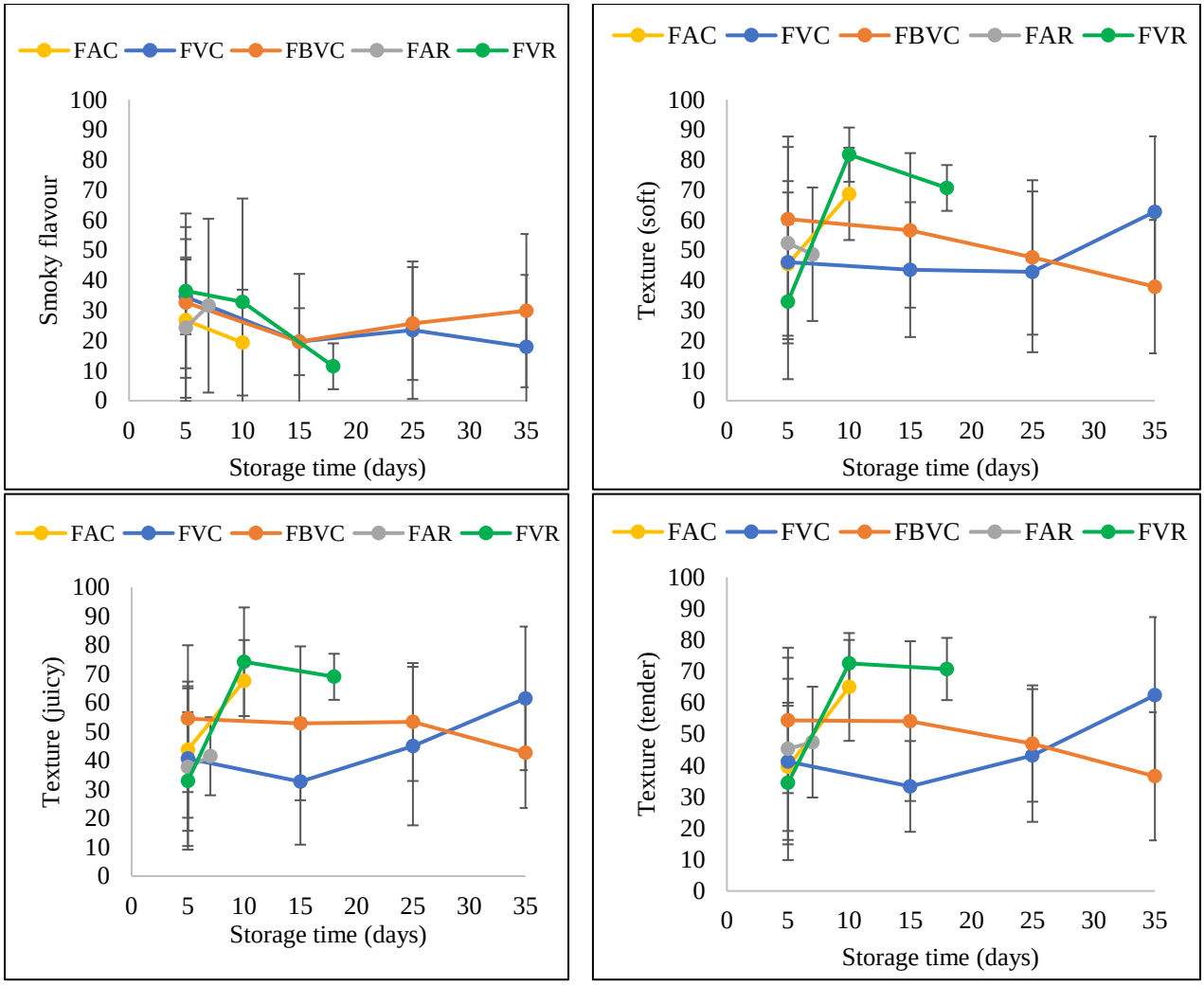


Figure 20: Changes in positive sensory flavour and texture attributes during storage of hot smoked mackerel fillets. (FAC = Cabin air-packed refrigerated; FVC = Cabin vacuum-packed refrigerated; FBVC = Bradley vacuum-packed refrigerated; FAR = Cabin air-packed room; FVR = Cabin vacuum room). Scale 0 - 100

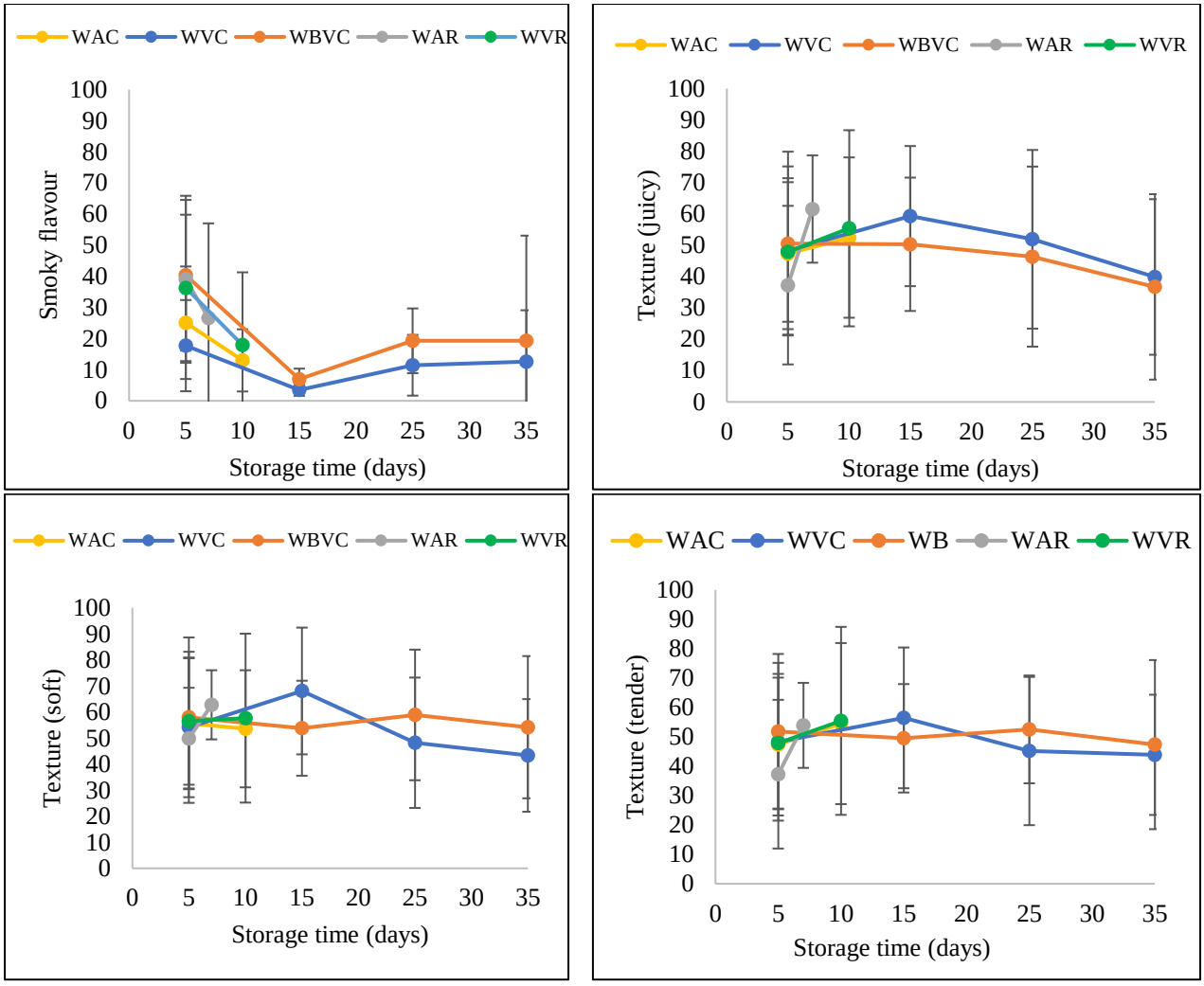


Figure 21: Changes in positive sensory flavour and texture attributes during storage of hot smoked mackerel fillets. (WAC = Cabin air-packed refrigerated; WVC = Cabin vacuum-packed refrigerated; WBVC = Bradley vacuum-packed refrigerated; WAR = Cabin air-packed room; WVR = Cabin vacuum room). Scale 0 - 100

Changes in negative odour and flavour attributes (rancid, TMA and spoilage) are presented in Figures 22 and 23 for the fillets and whole mackerel, respectively. Rancid, TMA and spoilage odours were more obvious in FAR, FVR and FAC but developed more slowly in FB and FVC (Figure 22). This led to the rejection of FAR on day 10. TMA flavour was more defined in FVR and FAC than in all the other groups.

Rancid, TMA and spoilage odours and flavours followed similar trends for whole smoked mackerel (Figure 23). WBVC and WVC had low scores of these attributes, even at day 35. WAR was rejected by the panel on day 10, whereas WVR and WAC had an increasing odour and flavour profiles and were rejected on day 18.

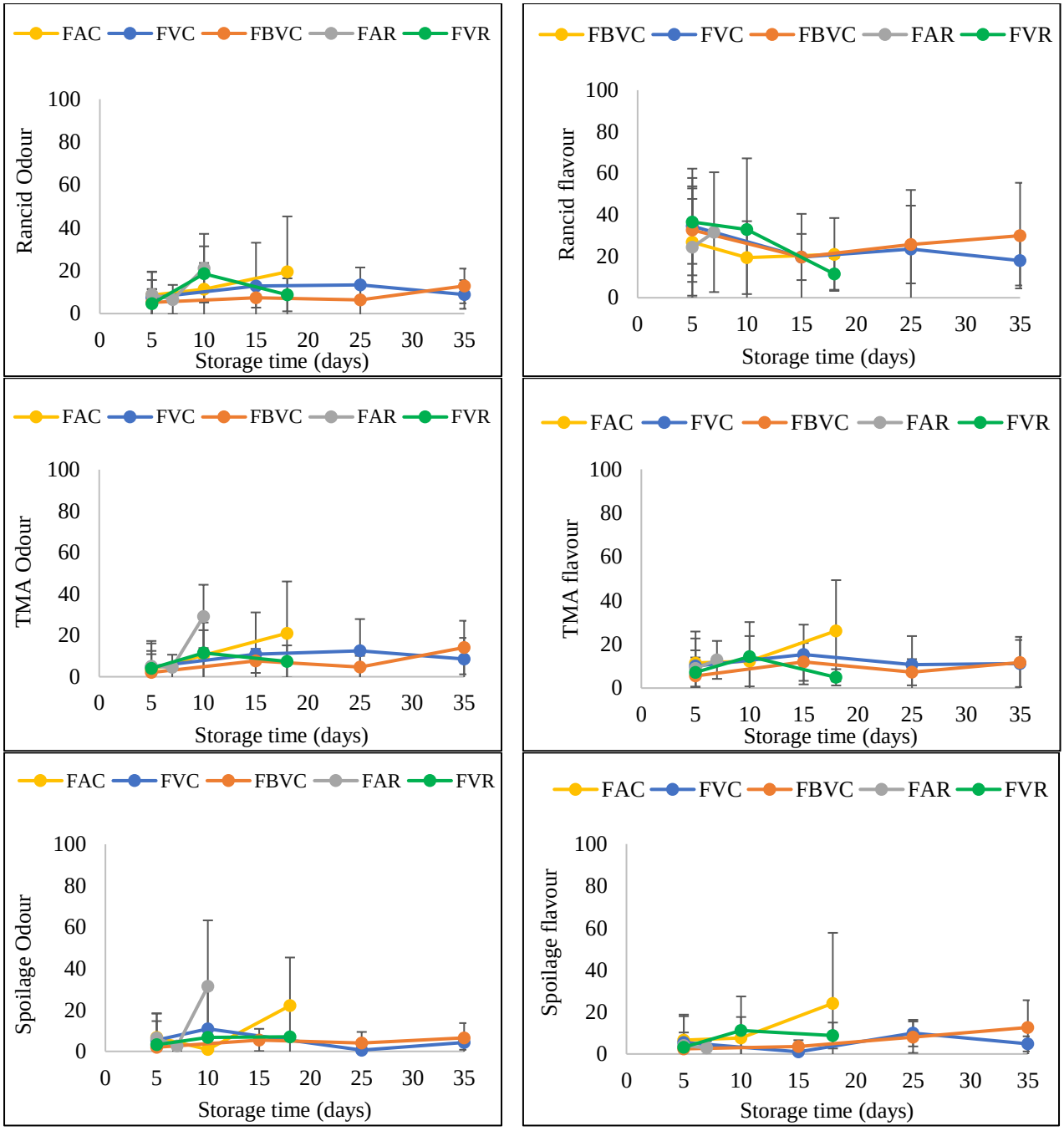


Figure 22: Changes in odour and flavour attributes during storage of hot smoked mackerel fillets. (FAC = Cabin air-packed refrigerated; FVC = Cabin vacuum-packed refrigerated; FBVC = Bradley vacuum-packed refrigerated; FAR = Cabin air-packed room; FVR = Cabin vacuum room). Scale 0 - 100

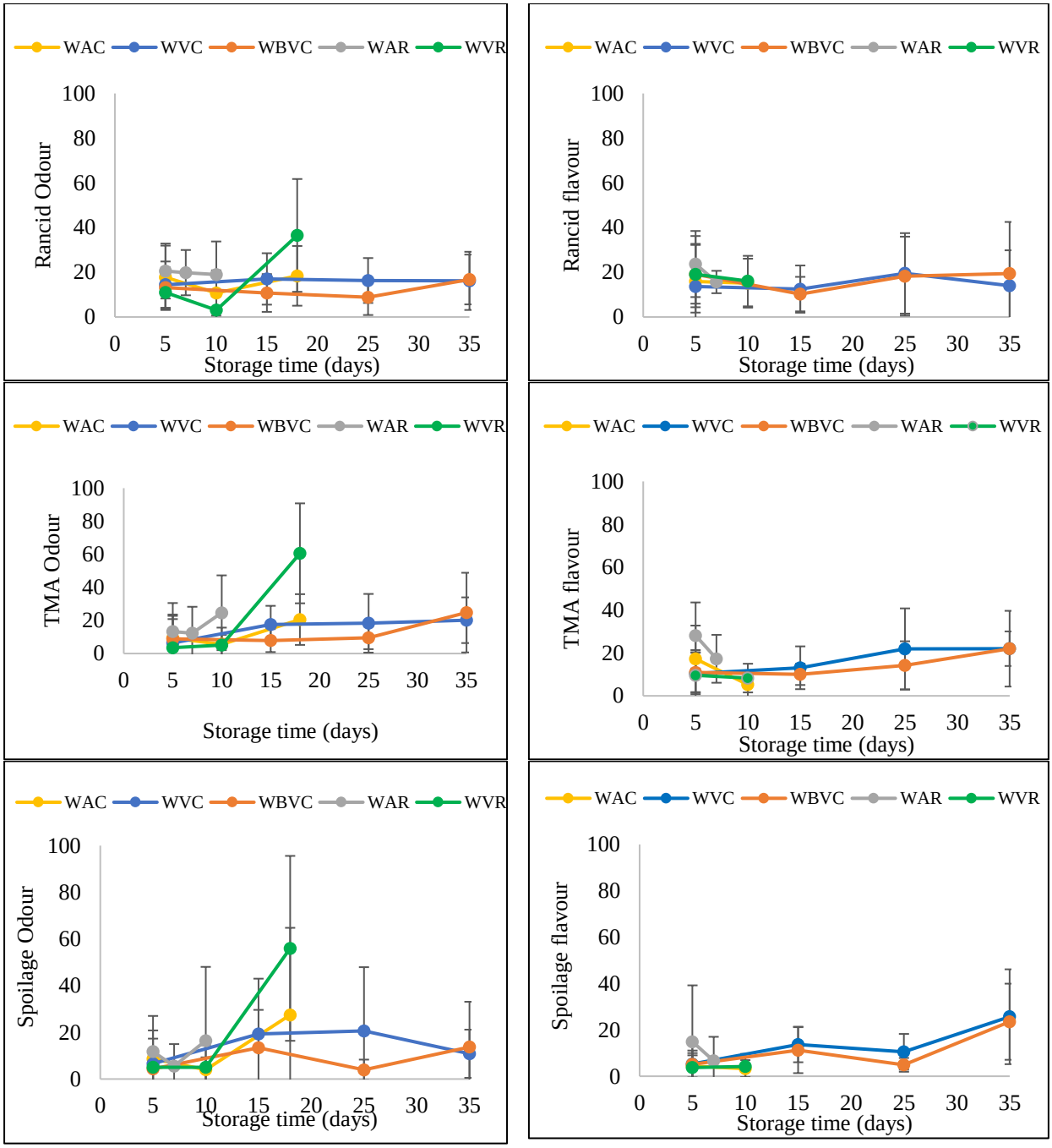


Figure 23: **Changes in odour and flavour attributes during storage of hot smoked whole mackerel. (WAC = Cabin air-packed refrigerated; WVC = Cabin vacuum-packed refrigerated; WBVC = Bradley vacuum-packed refrigerated; WAR = Cabin air-packed room; WVR = Cabin vacuum room). Scale 0 - 100**

5 DISCUSSION

The performance of a smoking kiln can be measured based on the throughput capacity (i.e. loading capacity and how fast it can dry, cook and deposit smoke on the product), fuel consumption and efficiency and quality of the final product (Hilderbrand, 1992; Entee, 2015b). In terms of throughput, the loading capacity of the Cabin was estimated at 120 kg (using all 8 racks). The time spent smoking in this experiment was 106 minutes, with an additional 180 minutes for drying, which was shorter than the times recorded by Huong (2013), Mgana (2014) and Odoli (2014), who reported overall times of 300, 390 and 360 minutes respectively. The specific fuel consumption (which is a measure of fuel efficiency) was estimated at 0.7 kg fuel per kg of smoked fish, which was higher than the 0.6 kg per kg of smoked fish obtained by Mgana (2014). The time used during smoking and the fuel efficiency reported can be explained by the ambient weather conditions in Iceland during the time of the experiments (mostly snow and rain) and the uneven temperature distribution observed in the Cabin. Mgana (2014) however suggested covering the chimney of the Cabin with a metal cap to eliminate the problem of uneven temperature distribution.

A study in Ghana on the performance of different smoking kilns gave a fuel efficiency of 0.8, 0.5 and 1.3 kg per kg of smoked fish for the Chorkor, Morrison and FTT respectively (Entee, 2015b). The same study reported a time of smoking of 312, 285 and 394 minutes for the Chorkor, Morrison and FTT respectively (Entee, 2015b). Comparing these findings to those made in the current experiment implies that given the same conditions in Ghana, the Cabin may perform better than the Chorkor and FTT kilns currently in use.

The Bradley, on the other hand, had a loading capacity of 12 kg, uneven temperature distribution (which led to core temperature of fish not reaching the threshold of 70 ^{o}C) and the smoking time was about 50 % longer than in the Cabin. These factors make the Bradley uneconomical to operate on a large scale. Also, the operational cost, since it uses electricity, might also be higher. The use of electri power might be a big deterrent to its adoption especially since electricity supply is erratic in Ghana.

The weight changes during smoking will depend on the type of raw material used, method of processing or handling, type and amount of brine used and the smoking conditions (temperature, humidity, airflow rate and drying) (Rørå *et al.*, 1998). In fatty fish like the mackerel, the final yield is almost entirely dependent on the amount of moisture that can be removed, unless it is cooked long and hot enough (above 71 ^{o}C) to melt oil from the flesh (Hilderbrand, 1992). Yield is also of high economic importance as the price of smoked fish mostly depends on the weight (Entee, 2015a). The final yield of whole smoked mackerel was 78.8 and 85.3 % for Cabin and Bradley respectively. That for fillets, on the other hand, was 64.9 and 69.0 % for Cabin and Bradley respectively. Hilderbrand, (1992) reports that yields of 75% to 80 % can be expected in products with a final water content of 60 %, and even better yields in high – fat content fish which have less initial water content to lose. This assertion agrees with results obtained for the whole mackerel, which had water content after smoking of about 56 %. Yields for fillets are however low because according to Rørå *et al.*, (1998), trimming (mostly from the removal of head and backbone), and the larger surface-to-volume ratio of fillets (leading to increased rate of dehydration) account for most of the losses in smoked fillets. This agreed with the higher draining and drying losses observed in fillets but not in whole fish.

A product meets the industrial specification of ‘‘smoked finished products’’ if its water content is less than 65% (Cardinal *et al.*, 2001). Both the smoked fillets and whole mackerel met this requirement. The pH decrease in smoked fish muscle, as compared that in the raw fish on day 5, may be due to an increase in the ionic strength of the solution inside of the cells due to the addition of salt (Goulas & Kontominas, 2005) and a reduction of water content (Turan *et al*., 2008). The pH increase during storage at room (15 – 20 ^{o}C) and refrigerated (0 – 4 ^{o}C) temperatures may be attributed to the production of volatile basic components, such as ammonia and trimethylamine by fish spoiling bacteria (Goulas & Kontominas, 2005).

The salt content in the smoked product was on average 2 % in fillets from both kilns and 0.80 % and 0.65 % in the whole fish from the Cabin and Bradley kilns, respectively. Smoke and heat produced during smoking alone are not entirely effective at preserving fish, however, the appropriate salt concentration which can reduce water activity of smoked products to 0.97 or less can retard (but not stop) bacteria growth (Hilderbrand, 1992). It has therefore been recommended that smoked fish with a salt content of 3.5 % in the water phase (Z-values) will normally attain the required water activity, even though other factors might cause variations (Hilderbrand, 1992). The smoked fillets had a Z-value of 3.3 % and water activity of 0.96 and 0.97 for Cabin and Bradley kilns, respectively. Whole smoked mackerel, however, had Z-values of 1.3 % (a_w = 0.98) and 1.1 % (a_w = 0.98) for the Cabin and Bradley smoked products, respectively. These results somewhat agree with those from Hilderbrand, (1992). A water activity of less than 0.85 is, however, necessary to make the products stable at room temperature (Hilderbrand, 1992).

Colour is an important parameter that can determine consumer acceptance of a product. Smoking technology, packing material and storage temperature had an influence on colour attributes of the final products. Smoking caused an increase in lightness (*L**), redness (*a**) and yellowness (b) of fillets smoked in the Bradley. This agrees with those results obtained by Ünal Şengör *et al.*, (2010) for smoked sturgeon and Huong (2013) for smoked mackerel. In general, the fillets smoke in Bradley were lighter, redder and yellower than those from the Cabin. The smoking kilns had an influence on *b** as shown by the significant differences in days 5 and 25. Packaging material and storage temperature influecned the *a** value more as indicated on day 18. The whole smoked mackerel had a golden-brown skin colour that is preferred by consumers in Ghana (Allou, 2012).

Seafood quality and freshness are mostly determined by the levels of total volatile basic nitrogen (TVBN). According to EEC (1995), the acceptable limit of TVBN is 35 mg N/100 g of muscle. The TVBN of the raw material was 18.4 mg N/100 g, meaning it was fit for smoking. This agrees with levels of 18 - 20 mg N/100 g reported by Malle *et al.* (1983) for fresh mackerel. After smoking, the TVBN levels almost doubled for all samples. This was in agreement with results obtained by Goulas & Kontominas (2005) for smoked mackerel (*Scomber japonicus*), and the authors attributed this initial increase to the partial dehydration of smoked samples and subsequent concentration of TVBN constituents. TVBN increased gradually for vacuum and air-packed smoked products stored at 0 – 4 ^{o}C, whereas those stored at 15 – 20 ^{o}C had a sharp increase. This increase was in agreement with Alcicek & Atar (2010), who indicated that the smoking processes influenced the TVB-N level of smoked rainbow trout and the levels increased through storage. The TVBN levels in vacuum packed fillets smoked in the Bradley surpassed the EEC (1995) limits on day 15, whereas those air and vacuum packed and stored at 15 – 20 ^{o}C exceeded the limit on day 7 and 10 respectively (similar results for whole products of similar packaging and storage temperature). Whole smoked air-packed mackerel stored at 0 – 4 ^{o}C reached the limit on day 10. Vacuum packaging can potentially

inhibit the growth of microorganisms, thus leading to their decreased deamination capacity and lower volatile compounds production (Rodrigues *et al.*, 2016). Results from this study agree with this assertion only when the samples were stored at refrigerated temperature. However, results for fillets smoked in the Bradley did not agree with this. Also, microbial and sensory analysis do not support those obtained for TVBN. TVBN is therefore only useful as an indicator of fitness for consumption rather than as an index of freshness throughout the storage of fish since it does not reflect whether spoilage is as a result of bacterial or autolytic actions (Özoğul & Özoğul, 2000; Etienne, 2005).

Raw or processed seafood are generally excellent substrates for the growth of most common bacterial agents of food-borne diseases, especially when held at improper temperatures. This can affect the shelf life of seafood. In fish, the proposed limit of acceptance for human consumption is 7 log CFU/g (ICMSF, 1986). The initial quality of the raw material used was good and fit for smoking, as indicated by the low number of bacteria (2.8 log CFU/g). The effects of processing technologies, packing materials and storage temperature were observed after smoking. Cabin-smoked, air-packed fillets and whole mackerel stored at 15 – 20 ^{o}C exceeded the limit set by ICMSF (1986) on day 5. Vacuum-packed smoked products stored at room temperature exceed the limit in fillets on day 10. There was a lag phase of bacteria in air-packed and vacuum-packed products stored at 0 – 4 ^{o}C and this could be due to cold shock on the microbes and the occurrence of antimicrobial smoke constituents (Odoli, et al., 2015). Vacuum-packed products stored at 0 – 4 ^{o}C had the lowest bacteria counts (below 7 log CFU/g throughout storage). This could be since vacuum packs exclude oxygen (thereby inhibiting microorganism development) and retain smoke constituents, which agrees with findings by (Odoli *et al.*, 2015). The importance of storage temperature was also evident from the results and this agrees with Bannerman (1990) that shelf life of the smoked product is mostly dependent on the time and temperature of storage. However, Hansen *et al.*, (1995) have suggested that in addition to total microbial counts, specific spoilage organisms (or pathogens) should be identified, as this will give a better indication of the quality of the product.

Results from the sensory evaluation of smoked mackerel agreed with some physicochemical and microbiological analysis. The vacuum-packed mackerel fillets had a smokier flavour than air-packed once. The smoked fillets had a higher salt content than that from the whole as already discussed. Although salt can prolong the shelf life of smoked products, it can also enhance oxidation of the highly unsaturated lipids which in turn can lead to the production of off – flavours and odours, protein denaturation, and textural changes (Rørå *et al.*, 1998; Aubourg & Ugliano, 2002). According to Erkan (2012), vacuum – packed hot smoked fish stored at chilled temperatures is very sensitive to deterioration and, based on sensory evaluation, has a limited shelf life ranging from 3 to 4 weeks, which is in agreement with results obtained in this study. Archer *et al.*, (2008) however explain that seafood typically becomes inedible long before the bacterial levels have increased to the extent where they would be injurious to health, and this may be the reason why air- - packed whole mackerel stored at refrigerated temperature was rejected by the panel on day 18, even though TPC was below the 7 log CFU/g limit. Also, the panel failed to reject vacuum-packed smoked mackerel fillets stored at 15 – 20 ^{o}C on day 18, when TPC had reached the 7 log CFU/g limit. It must, however, be noted that a student panel was used for this sensory evaluation and their level of training may not have been sufficient to perform this.

6 CONCLUSION

The results from this study have shown that the performance and benefits of the Cabin make it a more viable option, (than the Bradley) for introduction in Ghana. In terms of product quality, it has been established that the type of packaging material and storage temperature were especially important. Vacuum packaging was superior to air packaging, but only when stored at refrigerated temperatures. However, vacuum packing machines and accessories can be expensive but the extended shelf life of the product makes it more economical to use. The type of smoking technology used did not affect the product quality, except for the colour of fillets smoked in the Bradley being much better than those smoked in the Cabin.

The shelf life of hot smoked mackerel fillets, according to the sensory panel, was between 7 - 10 days for air-packed smoked mackerel stored at room temperature, 10 - 18 days for vacuum and air-packed whole mackerel stored at 0 – 4 ^{o}C and 15 – 20 ^{o}C. Vacuum and air-packed mackerel fillets stored at 15 – 20 ^{o}C and 0 – 4 ^{o}C respectively were not rejected on day 18. Finally, vacuum – packed mackerel from Cabin and Bradley stored at 0 – 4 ^{o}C were not rejected, as at the end of the experiment.

7 RECOMMENDATIONS

To be able to demonstrate the potential for adoption of the Cabin, a similar study should be performed in Ghana where a fair comparison can be made between the Cabin and other traditional kilns currently in operation in Ghana. A more trained sensory panel should be used in further studies.

ACKNOWLEDGEMENTS

I would like to express my sincerest gratitude to the Board of the United Nations University – Fisheries Training Programme for providing me the opportunity to undertake this training program. Special thanks to Dr. Tumi Tómasson, Mr. Þór Ásgeirsson, Mrs. Sigríður Kr. Ingvarsdóttir, and Mrs. Mary Frances Davidson for their support, guidance and endless help throughout my stay in Iceland.

I am very grateful to supervisors, Dr. Sigurjon Arason, Dr. Magnea Karlsdottir and Dr. María Guðjónsdóttir of Matis –Icelandic Food and Biotech R&D and the University of Iceland for their technical and professional guidance, comments and encouragement during this project.

I would like to give special thanks to my project partners, Mr. Benjamin Aidoo, MSc student at the University of Iceland and Mr. Osvaldo da Costa for working tirelessly with me. I am also grateful to Ms. Hildur Inga Sveinsdóttir, Dr. Paulina Romotowska and my entire sensory panel for their assistance and guidance. Many thanks to the 2016 – 2017 UNU-FTP fellows for their friendship and making our time here in Iceland memorable.

My gratitude goes to the Head and entire faculty and staff of the Department of Marine and Fisheries Sciences for their support. Special thanks also go to Prof. Elvis Nyarko for his encouragement.

Finally, I must express my very profound gratitude to my husband, Richard, sons, Jayden and Joel and my parents and siblings for providing me with unfailing support and continuous encouragement throughout this six-month period. Many thanks to my best friend Priscilla for her kind words and support. Thank you.

LIST OF REFERENCES

Akande, G. R., Ayinla, O. A., Adeyemi, R. S., Olusola, A. O., & Salaudeen, M. M. (2012). *Blueprint for smoked fish products.* Lagos: Nigerian Institute for oceanography and Marine Research.

Alcicek, Z., & Atar, H. H. (2010). The effects of salting on chemical quality of vacuum packed liquid smoked and traditional smoked rainbow trout (Oncorhyncus mykiss) fillets during chilled storage. *Journal of Animal and Veterinary Advances* 9: 2778–2783.

Allou, R. (2012). *Technology adoption and economics of small-scale fish processing in the Nzema east district of Ghana: the case of smoked fish.* Tromsø: Universitetet of Tromsø.

AOAC (2000). Salt (Chlorine as Sodium Chloride) in seafood. *The Journal of AOAC, 17th edition. 976:18.*

Arason, S., Nguyen, M. V., & Thorarinsdottir, K. A. (2014). "Preservation of fish by curing." In Boziaris I.S. eds *Seafood Processing: Technology, Quality and Safety* pp. 129-160, West Sussex: Wily Blackwell.

Archer, M., Edmonds, M., & George, M. (2008). *From Sea to plate, Seafish delivers expert knowledge, skills and support which help the UK Seafood Industry secure a sustainable and profitable future.* Seafish Research and Development.

Aubourg, S. P., & Ugliano, M. (2002). Effect of brine pre-treatment on lipid stability of frozen horse mackerel (Trachurus trachurus). *European Food Research and Technology* 215(2): 91-95.

Bannerman, A. (1990). *Hot smoking of fish.* Ministry of Africulture, Fisheries and Food Torry Reseacrh Station.

Bentil, N. L., & Appiah, S. (2015, December 13). *Association of fish processors, traders inaugurated.* [December 2016] <http://www.graphic.com.gh/news/general-news/association-of-fish-processors-traders-inaugurated.html>

Bligh, E., & Dyer, W. (1959). A rapid method of total lipid extraction and purification. *Can. J. Biochem. and Physiol*. 37(8): 911-917.

Bradley Smoker. (2016). *Add some Bradley to your adventure. Bradley takes outdoor cuisine to a whole new level*. [December 2016] <https://www.bradleysmoker.com>

Cardinal, M., Gunnlaugsdottir, H., Bjoernevik, M., Ouisse, A., Vallet, J., & Leroi, F. (2004). Sensory characteristics of cold-smoked Atlantic salmon (Salmo salar) from European market and relationships with chemical, physical and microbiological measurements. *Food Research International* 37(2): 181–193.

Cardinal, M., Knockaert, C., Torrissen, O., Sigurgisladottir, S., Mørkøre, T., Thomassen, M., & Vallet, J. L. (2001). Relation of smoking parameters to the yield, colour and

sensory quality of smoked Atlantic salmon (Salmo salar) . *Food Research International* 34(6) : 537-550 .

CIE (1976). *Colorimetry.* Vienna, Austria: Bureau Central de la CIE, Publ. No. 15.

Collette, B., Boustany, A., Carpenter, K. E., Di Natale, A., Fox, W., Graves, J., . . . Oxenford, H. (2011). *Scomber scombrus.* The IUCN Red List of Threatened Species 2011: e.T170354A6764313 [December 2016] <http://www.iucnredlist.org/details/170354/0>

Dalgaard, P. (2002). *Modelling and prediction the shelf-life of seafood.* In Bremner, H.A. eds *Safety and quality issues in fish processing* pp. 191-219 Woodhead Publishing Ltd.

EEC (1995). *Total volatile basic nitrogen (TVB-N) limit values for certain categories of fishery products and specifying the analysis methods to be used.* Commission Decision 95/149/EEC of 8 March 1995. Official Journal of European Communities.

Entee, S. (2015a). *Post-Harvest Process Characterization Studies and Needs Assessment Report on Fish Smoking and Salting of Fish.* Narragansett, RI: The USAID/Ghana Sustainable Fisheries Management Project (SFMP). Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and SNV Netherlands Development Organization. GH2014_ACT006_SNV.

Entee, S. (2015b). *Post-harvest processing stove performance report.* Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and SNV Netherlands Development Organization. Narragansett, RI: The USAID/Ghana Sustainable Fisheries Management Project (SFMP). GH2014_ACT015_SNV.

Erkan, N. (2012). The Effect of Thyme and Garlic Oil on the Preservation of Vacuum-Packaged Hot Smoked Rainbow Trout (Oncorhynchus mykiss). *Food and Bioprocess Technology* 5(4): 1246-1254.

Espe, M., Nortvedt, R., Lie, Ø., & Hafsteinsson, H. (2002). Atlantic salmon (Salmo salar) as raw material for the smoking industry. II: Effect of different smoking methods on losses of nutrients and on the oxidation of lipids. *Food Chemistry* 77: 41-46.

Essuman, K. M. (1992). *Fermented fish in Africa: A study on processing, marketing and consumption* (Vol. 399). Rome: Food and Agriculture Organisation of the United Nations.

Etienne, M. (2005). *Volatile amines as criteria for chemical quality assessment.* Seafoodplus Traceability pp 1-22.

European Commission. (2004b). *Regulation (EC) No 852/2004 of the European Paliament and the Council of 29 April 2004 on the hygiene of foodstuffs.* Official Journal of the European Communities, 18.

FAO/WHO. (2012). *Code of practice for fish and fishery products. Second edition.* Rome, Italy: World Health Organization; Food and Agriculture Organization of the United Nations. Food Standards Programme. Codex Alimentarius Commission.

Getachew, E. (2011). *Effect of hot smoking on the quality and shelf stability of Nile tilapia (Oreochromis niloticus) fillets.* Doctoral dissertation. Addis Ababa Institute of Technology (AAiT).

Gill, T. A., Chan, J. K., Phonchareon, K. F., & Paulson, A. T. (1992). Effect of salt concentration and temperature on heat-induced aggregation and gelation of fish myosin. *Food Research International* 5: 333-341.

Gordon, A., Pulis, A., & Owusu-Adjei, E. (2011). *Smoked marine fish from the Western Region, Ghana: a value chain assessment.* Narragansett: WorldFish Center. USAID Integrated Coastal and Fisheries Governance Initiative for the Western Region, Ghana.

Goulas, A. E., & Kontominas, M. G. (2005). Effect of salting and smoking-method on the keeping quality of chub mackerel (Scomber japonicus): biochemical and sensory attributes. *Food Chemistry* 93(3): 511-520.

Guðjónsdóttir, M. (2011). *Quality changes during seafood processing as studied with NMR and NIR spectroscopy.* Norwegian University of Science and Technology, Trondheim.

Hansen, L. T., Gill, T., & Huss, H. H. (1995). Effects of salt and storage temperature on chemical, microbiological and sensory changes in cold-smoked salmon. *Food Research International* 28(2): 123-130.

Hilderbrand, K. S. (1992). *Fish smoking procedures for forced convection smokehouses.* Newport, Or: Oregon State University, Extension Sea Grant Program, Hatfield Marine Science Center.

Howgate, P. (1979). Fish, in Food Microscopy (ed, J. G. Vaughan). In Boziaris I.S. eds. *Seafood Processing Techology, Quality and Safety* pp. 148-149. United Kingdom: John Wiley and Sons, Limited.

Huong, D. T. (2013). *The effect of smoking methods on the quality of smoked mackerel.* Final Project. Reykjavik: United Nations University Fisheries Training Programme.

ICMSF (1986). *Microorganisms in Foods 2. Sampling for Microbiological Analysis: Principles and Specific Applications* (Vol. 2nd Ed.). London: Blackwell Scientific Publications.

ISO 8586. (2012E). *Sensory analysis - General guidance for the selection, training and monitoring of assessors.* Geneva, Switzerland: The International Organization for Standards.

Jónsdóttir, R., Ólafsdóttir, G., Chanie, E., & Haugen, J. E. (2008). Volatile compounds suitable for rapid detection as quality indicators of cold smoked salmon (Salmo salar). *Food Chemistry* 109(1): 184-195.

Keay, J. N. (1979). *Handling and processing mackerel.* Rome: Ministry of Agriculture, Fisheries and Food, Torry Research Station.

Kleter, G. A. (2004). Control and prevention of contamination and spoilage in the traditional production of smoked fish in Ghana. *Discussion paper prepared for the Tailor Made Biotechnologies project. Projectnr.: 805.71.456.01* (p. 25). Wageningen, The Netherlands : RIKILT - Institute of Food Safety.

Leksono, T., Suprayitno, E., & Hardoko, H. P. (2014). Profile of traditional smoking striped catfish (Pangasius hypophthalmus Sauvage 1878) and firewood used in province of riau, Indonesia. *Journal of Biodiversity and Environmental Sciences* 5(1):562-572.

Lemon, D. W. (1975). Protein measurement with the Folin-Phenol reagents. *Journal of Biological Chemistry* 193:265 - 275.

Leroi, F., & Joffraud, J. J. (2000). Salt and Smoking Simultaneously affect chemical and sensory quality of cold-smoked salmon during 5 C storagepredicted using factorial design. *Journal of Food Protection* 63:1222-1227.

Malle, P., & Poumeyrol, M. (1989). A new chemical criterion for the quality control of fish: trimethylamine/total volatile basic nitrogen (%). *Journal of Food Protection* 52:419 – 423.

Malle, P., Nowogrocki, G., & Tailliez, R. (1983). Corrélation entre l'indice d'altération et l'azote basique volatil total pour divers poissons marins. *Sciences des Aliments* 3: 311 -322.

McGee, H. (2004). *Wood Smoke and Charred Wood. On Food and Cooking. The Science and Lore of the Kitchen (Revised ed.)* (Vols. ISBN 0-684-80001-2). Scribner.

Mgana, H. F. (2014). *Quality assessment of hot smoked Capelin (Mallotus villosus) and Redfish (Sebastes mentella).* Final Project. Reykjavik: United Nations University Fisheries Training Programme.

MOFAD (2016). *Fisheries management plan of Ghana. A national Policy for the management of the marine fisheries sector.* Accra: MOFAD.

NOAA Fishwatch (2015). *Atlantic Mackerel (Scomber scombrus).* NOAA FishWatch. U.U. seafood facts [December 2016] <http://www.fishwatch.gov/profiles/atlantic-mackerel>

Nunoo, F. K., Asiedu, B., Amador, K., Belhabib, D., & Pauly, D. (2014). Reconstruction of marine fisheries catches for Ghana, 1950-2010. *Working Paper Series.*, 26.

Nunoo, F. K., Asiedu, B., Kombat, E. O., & Samey, B. (2015). *Sardinella and other small pelagics value and supply chain of the fishery sector, Ghana.* Narragansett, USA: The USAID/Ghana Sustainable Fisheries Management Project (SFMP). RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and Netherlands Development Organisation. GH2014_ACT044_SNV.

Odoli, R. N. (2014). *Comparing quality and storage life of hot smoked mackerel and herring using two different smoking kilns.* Final project. Reykjavik: United Nations University Fisheries Training Programme.

Odoli, C. O. (2015). *Drying and smoking of capelin (Mallotus villosus) and sardine (Sardinella gibbosa)–the influence on physicochemical properties and consumers acceptance.* PhD Dissertation. Reykjavik: University of Iceland.

Odoli, C. O., Van Nguyen, M., Sveinsdottir, K., Jonsson, A., Tomasson, T., Thorkelsson, G., & Arason, S. (2015). In uence of smoking and packaging methods on lipid stability and microbial quality of Capelin (Mallotus villosus) and Sardine (Sardinella gibossa). *Food Science & Nutrition* 3(5): 404-414.

Offer, G., & Knight, P. (1988). "The structural basis of water holding in meat." In Lawrie, R. eds. *Developments in meat science* pp. 63-243. London, UK: Elsevier.

Okyere-Nyarko, A. A., Aziebor, E., & Robinson, J. (2015). *Namhowfo, mangroves and woodlots: a more complete approach to reducing deforestation in Ghana.* Netherlands: SNV Netherlands Development Organisation [September 2016] <http://www.snv.org/public/cms/sites/default/files/explore/download/case_study_-_mangroves_and_woodlots.pdf>

Özoğul, F., & Özoğul, Y. (2000). Comparision of methods used for determination of total volatile basic nitrogen (TVB-N) in rainbow trout (Oncorhynchus mykiss). *Turkish Journal of Zoology* 24(1): 113-120.

Rørå, A., Kvåle, A., Mørkøre, T., Rørvik, K.-A., Hallbjoørn, S., Thomassen, S., & Magny, S. (1998). Process yield, colour and sensory quality of smoked Atlantic salmon (Salmo salar) in relation to raw material characteristics. *Food Research International* 31 (8): 601-609.

Rezaei, M., Hosseini, S. F., Langrudi, H. E., Safari, R., & Hosseini, S. V. (2008). Effect of delayed icing on quality changes of iced rainbow trout (Onchorynchus mykiss). *Food Chemistry* 106: 1161-1165.

Rodrigues, B. L., da Silveira Alvares, T., Sampaio, G. S., Cabral, C. C., Araujo, J. V., Franco, R. M., . . . Junior, C. A. (2016). Influence of vacuum and modified atmosphere packaging in combination with UV-C radiation on the shelf life of rainbow trout (Oncorhynchus mykiss) fillets. *Food Control* 60: 596-605.

Romotowska, P. E., Gudjónsdóttir, M., Kristinsdóttir, T. B., Karlsdóttir, M. G., Arason, S., Jónsson, A., & Kristinsson, H. G. (2016). Effect of brining and frozen storage on physicochemical properties of well-fed Atlantic mackerel (Scomber scombrus) intended for hot smoking and canning. *LWT-Food Science and Technology* 72: 199-205.

Stone, H., Bleibaum, R., & Thomas, H. A. (2012). *Sensory evaluation practices.* Academic Press.

Teutscher, F., Tall, A., & Jallow, A. M. (1995). *Workshop on seeking improvements in fish technology in West Africa.* Pointe-Noire, Congo: IDAF.

The World Bank (2011). *Project appraisal document on a proposed credit in an amount of SDR 31.1 million (US$50.3 million equivalent) and a proposed grant from the Global*

Environment Facility Trust Fund in an amount equal to US$3.5 million to the Republic of Ghana for the Ghana . Washinton DC: Report No. 57898-GH. The World Bank Group.

Thorarinsdottir, K. A., Arason, S., Bogason, S. G., & Kristbergsson, K. (2004). The effects of various salt concentrations during brine curing of cod (Gadus morhua). *International Journal of Food Science and Technology* 39: 79 - 89.

Torell, E., Owusu, A., & Okyere Nyarko, A. (2015). *USAID/Ghana Sustainable Fisheries Management Project (SFMP), Ghana Fisheries Gender Analysis, 2015,*. Narragansett, RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island.

Turan, H., Sönmezm, G., Çelik, Y., Yalçin, M., & Kaya, Y. (2008). The effects of hot smoking on the chemical composition and shelf life of Mediterranean mussel (Mytilus galloprovincialis L. 1819) under chilled storage. *Journal of Food Processing and Preservation* 32(6): 912-922.

UNDP/TCDC. (2001). *Sharing innovative experiences. Vol. 5, Examples of successful initiatives in agriculture and rural development in the South. Chapter 3.* [September 2016] <http://tcdc2.undp.org/GSSDAcademy/SIE/Docs/Vol5/improved.pdf>

Ünal Şengör, G. F., Alakavuk, D. Ü., Tosun, Ş. Y., & Ulusoy, Ş. (2010). The chemical and sensory quality of smoked sturgeon (Huso huso): A case study. *Journal of Aquatic Food Product Technology* 19(3-4): 310-317.

Wheaton, F. W., & Lawson, T. B. (1985). Other preservation methods. In Wheaton F.W., and Lawson, T.B. eds. *Processing Aquatic Food Products* (pp. 273 - 328). New York: John Wiley & Sons.