Effect of Smoking Technologies on Nutritional Value and Safety of *Mormyrus caschive* and *Oreochromis niloticus* in Terekeka, South Sudan

Borodi Charles Mondo[1], Peter Akoll[2] and Margaret Masette[2]
[1]School of Forestry, Environmental and Geographical Sciences, College of Agricultural and Environmental Sciences.
[2]School of Biological Sciences, College of Natural Sciences.
Makerere University, P. O. Box 7062, Kampala, Uganda.

ABSTRACT

The effect of smoking kilns on nutritional value and safety of smoked fish was determined using a total of 300 fresh *Mormyrus caschive* and *Oreochromis niloticus*. 36 fresh samples were iced and the remaining 264 samples were divided into two batches for pit and chorkor smoking. Samples were subjected to chemical analyses according to the methods of the association of official analytical chemists (2005). Microbial load was investigated using standard methods of bacmteriological analytical manual (2005). Results revealed that chorkor significantly reduced moisture content in smoked *M. caschive* (10.0±0.83%) and *O. niloticus* (15.1±0.48%) more than pit by 15.3±0.57 % and 17.3±0.42%, respectively. Thus, effective removal of water from fish is attributed to the concentration of heat associated with enclosed characteristics of chorkor kiln. Although both smoking methods concentrated crude protein, fat and ash contents, chorkor smoked fish had significantly higher nutrient concentrations than pit because of effective removal of water content from fish. In both species, the water activity in pit smoked fish increased at a rate of 1.7 times, faster than in chorkor smoked samples. Corresponding to water activity, microbial load increased at a rate of 1.7 times faster for pit smoked *M. caschive* and 1.1 times for *O. niloticus* than the samples smoked using chorkor kilns. Similarly, molds increased at a rate of 1.5 times faster for pit smoked *M. caschive* and 2.2 times for *O. niloticus* than samples smoked using chorkor. Chorkor therefore, produces better quality smoked fish in terms of nutrients and safety, hence this study recommends its adoption for artisan fisheries in South Sudan.

Keywords: Nutrition, Safety, Technologies, Microbial, Water Activity

INTRODUCTION

Fish and fishery activities contribute significantly to livelihoods through provision of nutritious food, employment and generation of revenues for local and national governments (FAO, 2016ab). It is an important and cheap source of protein to low income earners. Fish forms more than 50% of the essential animal protein and mineral intake for over 400 million people from developing countries (FAO, 2016bc).

It is estimated that over 1.7 million South Sudanese depend on fisheries for their livelihoods (FAO, 2018). The contribution and importance of small-scale fishing to household livelihoods in South Sudan increased from 6.8% to 10.2% from 2015 to 2016, indicating greater reliance on this source of income (FAO, 2018). FAO (2016a) estimated that over 10 million people in developing countries are engaged in fisheries activities mainly as fishers, processors and vendors. However, fisher folks in South Sudan are faced with high postharvest losses due to lack of proper processing and preservation techniques (CAMP, 2013). Thus, poor handling of fish catches leads to significant physical, nutritional and economic losses (FAO, 2015). Deterioration in fish quality is one of the main sources of nutritional and economic losses in South Sudan (FAO, 2018). Fisher folks reported insect infestation, animal attacks and fragmentation as the main causes of physical loss of fish and fishery products.

Processing and preservation of fresh fish are important to prevent quality, nutrient and economic losses because fish is highly susceptible to deterioration immediately after harvest. Hygienic handling of fish is important to achieve the best quality and highest possible profits.

Despite the immense contributions, fishing industry in South Sudan suffers from enormous postharvest losses which are estimated at 40% in dry season and 60% in rainy season (FAO, 2016). Fish postharvest losses have a profound adverse impact on rural fishing population whose livelihoods often depend on fisheries activities.

Lack of proper infrastructure for fish postharvest handling is a major challenge facing rural fishing communities of South Sudan. As such improved processing and preservation techniques are needed to reduce adverse effects of fish postharvest losses.

Among the traditional preservation methods such as salting, sun drying and fermentation, fish smoking is the dominant type of fish preservation technique in Terekeka State. This is due to the fact that most consumers prefer smoked fish to sun dried, wet salted and fermented fish. Besides lack of proper processing and preservation, infrastructures have made fisher folks to extensively use smoking to preserve their catches which cannot be delivered to distant markets in fresh form.

Indeed, effective and efficient smoking of fish maintain the quality and safety of smoked fish due to antioxidants and preservatives contained in the smoke (Kumolu-Johnson *et al.*, 2010; Olayemi *et al.*, 2012; Magawata and Musa, 2015). The safety and quality of smoked fish help consumers in making choices regarding various processed fish products which also influences the market price (Nunoo and Kombat, 2013; Nguvava, 2013).

Corresponding Author: Dr. Peter Pakoll
E-mail addresses: pakoll@ac.cns.mak.ug

The effect of smoking technologies, however, have not been determined in South Sudan making it hard to adopt improvement. This study therefore, assessed the effect of smoking technologies on nutritional value and safety of *Mormyrus caschive* (L) (Elephant snout in English or *Khasma al banat* in Arabic), and *Oreochromis niloticus* (L) (Nile tilapia in English or *Bulti* in Arabic) with the aim of adopting suitable kiln that maintains good quality and prolongs shelf life of smoked fish for sustainable supply of nutritious fish for the market in South Sudan.

MATERIALS AND METHODS

Study area

The study was conducted in June, 2018 in Terekeka County; Terekeka State, South Sudan. Terekeka State (Figure: 1) is located 70 km north of Juba on the western bank of the Nile. It lies between latitudes of 5˚ 23 and 879" N and longitudes 31˚ 48 and 429" E. Terekeka has tropical climate with comparatively small seasonal variations of temperatures, humidity and wind throughout the year. It receives average annual rainfall of 907 mm from the months of April to November. The area experiences dry periods between the months of December and March. The average annual temperature is 27.7 °C. It is often in the dry season when most people are actively involved in fisheries activities. However, plentiful periods of fish catch occur during the months of June to August particularly when the flood has receded.

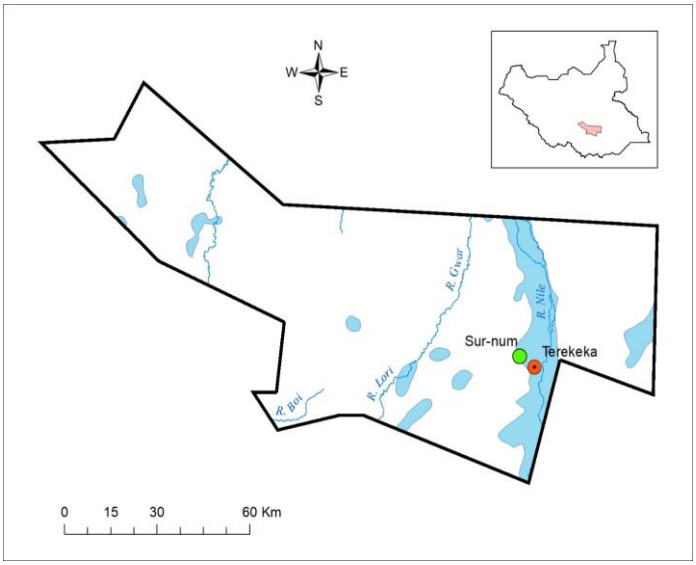

Figure 1: Map of the study area Sur-num landing site, Terekeka

Study design

The study was conducted in two phases; field smoking and laboratory analyses. Physical parameters of the two fish species under investigation were recorded in the field. The lengths and weights were reported as means ± standard deviation. Field experimental smoking of the two fish species was done by pit and chorkor technologies using completely randomized design. In the laboratory, four study parameters were determined to compare the two smoking technologies: chemical composition, PAHs concentrations, microbial load and sensory attributes

Sampling, processing and analytical procedures

A total of 300 fresh *M. caschive* and *O. niloticus* were purchased at Sur-num landing site situated about one kilometer North of Terekeka Town. Weights and lengths of the purchased fish were measured individually using calibrated weighting balance and meter rule. Full length of each fish was taken by measuring from snout to the tail. Cleaning, scaling, gutting, and washing were done at the landing site. Fresh samples were kept in cooler boxes packed with ice blocks immediately after being taken off the nets at the fishing grounds. A purposeful smoking using improved chorkor and traditional pit was conducted at Terekeka landing site.

Lokeyi women fish group chorkor was used to represent improved smoking kiln. The chorkor was measuring 2m long, 1m wide and 1m high with 3 wooden trays attached after every 30cm from base to top. The chorkor was constructed using unbaked bricks and the interior part plastered with clay soil. The top part of the chorkor was roofed with perforated flat iron sheets. It has two inlets at the base for aeration and smoke production by burning firewood. The smoking chamber has a movable door that remained closed except during monitoring periods. A traditional pit was constructed alongside improved chorkor kiln (Figure: 2).

Traditional pit

Improved chorkor

Figure 2: Traditional pit and improved chorkor kilns

The measurements for the pit were; 1m long, 0.5m wide and 0.5m high as practiced by fisher folks in the area. Four wooden planks were placed at the edges where a wire mesh sits. During fish smoking, flat iron sheet was used to cover the fish samples.

From the procured samples, 12 specimens of each fish species were ice-stored at 4ºC and transported to the laboratory where 6 specimens from each species were destined for proximate and microbial analyses respectively. The remaining 276 specimens were divided equally into two batches for pit and chorkor experimental smoking using *Acacia seyal*, the dominant tree species for smoking fish in the area. All the fish were washed to remove slime, descaled, eviscerated and rewashed thoroughly with clean water to remove blood. The fish samples were then immersed in a freshly-prepared salt solution (a mixture of 100 g salt in 10 L of clean water) for 15 minutes followed by draining for 15 minutes. Fire was set in pit and chorkor kilns to generate smoke heat by burning *Acacia seyal* wood. The pre-treated fish samples were randomly loaded on the wooden trays and wire mesh on top of chorkor and pit respectively. The desired temperature of 60º-80º C was maintained manually by a thermometer until fish were smoke dried.

During smoking, the position of fish samples in the wooden trays were changed in chorkor to attain uniformity of the products and turned upside down in pit kiln in the mid periods in order to make samples smooth and steady in texture and appearance. The smoked samples were then, cooled for 12 hr at ambient temperature and later wrapped in aluminum foil, labeled for easy identification and packed in carton boxes before transportation. The processed samples were transported to the Laboratory in Makerere University, Uganda for analyses. While in the Laboratory; specimens for microbial analysis were kept at room temperature to depict the storage conditions provided by fish vendors in South Sudan, samples for nutritional composition were stored in deep freezers.

Sample preparation for analyses

From each sample, 100 g of smoked fish muscle was removed from the edible parts, grinded to powder using blender, labeled and stored in deep freezers at -18˚C for proximate analyses. Another 100 g of fresh fish muscles from each sample were taken as control and prepared in the same way as the treatment samples.

Chemical composition, microbial and water activity determination

After homogenization of the weighed portion in each specimen, the following determinations were carried out in triplicate using standard methods for the association of official analytical chemist (AOAC, 2005); Moisture content was determined using the weight reduction method. Total crude protein was determined by digestion, distillation and titration using micro-Kjeldahl method (AOAC, 2005). Crude Fat content was determined by solvent extraction method in a Soxhlet system. Ash content was determined by incineration procedures in a muffle furnace.

Standard methods were used for identification and enumeration of microorganisms (BAM, 2005). Culture media; iron agar (IA), dextrin ampicillin agar (DAA), Aero-pseudo selective agar (APSA) and Dicloran Rose Bengal Chloramphenicol agar (DRBCA) were obtained from Oxoid limited, England. All media were prepared and sterilized according to the manufacturer's instructions. Sterility control plates of each media and diluent were made by incubating them overnight at a suitable temperature.

For water activity, a 10 g of fish muscles was aseptically removed from each fish species. The portion was placed in a round internal plate and inserted into the water activity meter device (Lab-swift-aw) for automatic reading. The water activity meter set at 20˚C, automatically read the water activity value in sample in five minutes.

From the procured fish samples, 10 g of each sample from the muscle was aseptically weighed on an electronic balance. The weighed samples were blended in a stomacher 400 (Lab. Blender, London, UK) and transferred individually into 180 mL dilution bottles (borosilicate-resistant glass with rubber stopper) containing 90 mL of sterile peptone water (0.1%) for suspension. This was done for samples of the two fish species obtained from each smoking technology and was taken as the original stock. The content was vortexed for one minute to homogenize the mixture and a dilution of 1:10 (10^{-1}) was obtained. Aseptically, 1 mL of the original stock solution was transferred into 9 mL of sterile peptone water and mixed thoroughly to give 10^{-2} dilution of the original stock and this was done for each sample. Serial dilution was carried using a sterilized micropipette from tube one to the last tube. All culture media were prepared according to the instructions of the manufacturers and sterilized using autoclave for 15 minutes at 121˚C. The prepared and sterilized culture medium was then removed and allowed to cool before it was spread into plates (petri-dishes). The plates were then allowed to solidify, after which 1 mL of the serial diluted sample of 10^{-1} and 10^{-2} dilution were inoculated on the surface of the well-dried culture medium in duplicate and gently spun to completely spread. The inoculated plates for total viable count were incubated in an inverted position for 48 hr at 35 ± 2˚Cwhile mold inoculated plates were incubated upright in dark at room temperature for 5 days at 25 ± 1˚C. After incubation, the number of colonies on a dilution plate showing between 30 and 300 colonies were counted and the number of microorganisms were determined using ISO 4833:2003 formula:

$$\mathbf{N} = \frac{\sum C}{V(n1 + 0.1n2)d}$$

Where, *N*= number of colonies per mL or gram of the sample, $\sum C$= sum of all colonies counted on the plates containing 30-300 colonies, *n1*= number of plates counted in the lower dilution, *n2*= number of plates counted in the higher dilution, *d*= value corresponding to the dilution from which the first counts were obtained and *V*= volume of inoculums used.

The total viable count and mold count were recorded as colonies formed by microorganisms in the plates inoculated with their respective culture media. The means of duplicate microbial count in colony forming units were determined and transformed to $\log_{10}$cfu/g for statistical analyses. Media and air control plates were also prepared and carried out parallel to the analysis as internal quality control.

Enumeration and identification of microorganisms

For total aerobic plate count, 1 ml of prepared dilution from each sample was spread on plates inoculated with standard iron agar (IA) in duplicates. Iron agar inoculated plates were aerobically incubated in inverted positions at 35 ± 2˚C. Colonies were counted after 48 hr of incubation using Reichert Dark field Quebec colony counter. For isolation of *aero-monas species*, 1 ml of each dilution was spread on dextrin ampicillin agar (DAA, 10 mg/L) in duplicates. Plates were then aerobically incubated in inverted positions at 35 ± 2˚C. Viable colonies were counted after 48 hrs of incubation using Quebec colony counter. For enumeration of *Pseudomonas species*, 1 ml of each dilution was spread on plates inoculated with Aero-pseudo selective agar (APSA) in duplicates. APSA inoculated plates were aerobically incubated in inverted positions at 35 ± 2˚C. Colonies were counted after 48 hrs of incubation using Quebec colony counter. For isolation of molds, a standard method of ISO 21527-1:2008 was used with minor modifications. Briefly, 1 mL of each dilution was spread on the surface of plate inoculated with Dicloran Rose Bengal Chloramphenicol agar (DRBC agar; cat. 1160) using a sterile glass rod. DRBC agar inoculated plates were incubated uprightly at 25 ± 1 ˚C. Counting of mold colonies was done after 5 days of incubation using Quebec colony counter. Colonies were recorded as colony forming units per gram (cfu/g) of fish samples. The means of duplicate microbial count in colony forming units were calculated and transformed to $\log_{10}$cfu/g for statistical analyses.

Statistical analyses

Data collected were subjected to analysis of variance (ANOVA) tests, the homogeneity of variances was tested using the Levenne test, while normality of residuals was tested using the Shapiro-Wilk test and visual inspection of quartile-normal plots. A two-way ANOVA was used to test the difference in the proximate values and microbial counts recorded in fish samples smoked using chorkor and pit with the fresh fish samples to determine the effect of smoking technologies on nutritional values and safety of smoked fish. Tukey's honest significant difference test was performed where the means of the two groups under comparison were significantly different in the normally distributed population from which the samples were drawn. Significance level at $P \leq 0.05$ was adapted.

RESULTS

The average lengths and weights of the two fish species with standard deviation regardless of sex were: 28.2±1.17 cm, 133.1±3.6 g and 23.3±1.01 cm, 126.7±1.86 g for *M. caschive* and *O. niloticus*, respectively. The two parameters which influences the smoking process showed that all samples procured were matured.

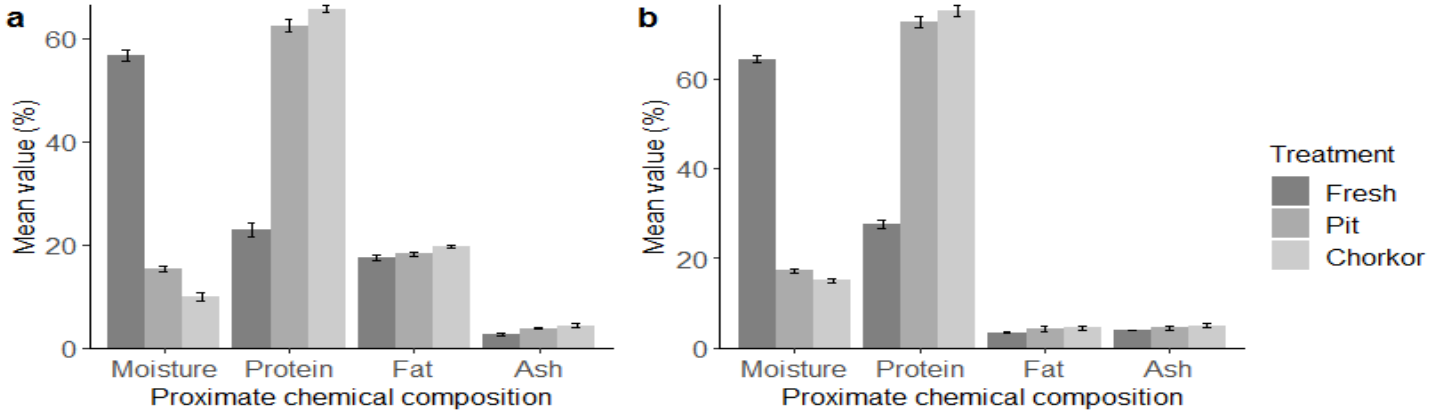

Figure 2: Proximate chemical composition of fresh, pit & chorkor smoked *M. caschive* (a) and *O. niloticus* (b)

Proximate composition of the smoked *M. caschive* and *O. niloticus*

Fresh fish generally contained significantly higher mean moisture content (Figure 2). In *M. caschive,* fresh specimens contained mean moisture content of 56.7±1.01%, which was higher than 15.3±0.57% from pit and 10.0±0.83% from chorkor smoked samples. With regard to the technologies, mean moisture in chorkor

smoked *M. caschive* (10.0±0.83%) was significantly lower than in pit smoked samples (15.3±0.57%), P<0.05. Crude protein and fat in smoked *M. caschive* were significantly higher than the fresh samples (27.6±1.07% and 17.6±0.51) for protein and fat respectively. Among the smoking technologies, chorkor smoked *M. caschive* had significantly high mean protein (65.8±0.75%), P<0.05 and crude fats (19.8±0.25%), P<0.05 than pit smoked samples (62.5±1.10%) for protein and (18.2±0.42%) for fats. Regarding minerals, significantly low amount of ash was recorded in fresh *M. caschive* (2.7±0.32%). Chorkor smoked *M. caschive* had significantly higher amount of ash (5.1±0.46%) than pit smoked fish samples (4.5±0.46%), P<0.05. Similarly, the mean moisture content in fresh *O. niloticus* (64.3 ± 0.66%) was significantly higher than pit (17.3±0.42%) and chorkor (15.1±0.48%) smoked samples. Chorkor smoked *O. niloticus* had significantly lower mean moisture content (15.1±0.48%) than pit smoked samples (17.3±0.42%), P<0.05. Smoked *O. niloticus* had significantly higher mean protein (27.6±1.07%) and crude fat (3.5±0.25%) than the fresh samples. Fish smoked using chorkor had significantly higher protein (75.20 ± 1.20%) and crude fats (4.61± 0.46%), P<0.05 than pit smoked samples (72.50± 1.26% and 4.34 ± 0.51%) respectively. Concerning ash, significantly low amount of ash was recorded in fresh *O. niloticus* (4.02 ± 0.09%). Chorkor smoked *O. niloticus* had significantly higher amount of ash (5.10 ± 0.46%) than pit smoked fish products (4.52 ± 0.46%), P<0.05. The proximate mean (moisture, protein, fat and ash contents) of chorkor and pit smoked fish were compared using Turkey multiple comparison and showed a significant difference between pit and chorkor smoked fish products (P<0.05).

Water activity and microbial load in smoked M. caschive and O. niloticus

The initial water activity in pit smoked fish samples were higher than those recorded in chorkor smoked products. Similarly, the initial total plate count was significantly higher in the fresh samples than in pit and chorkor smoked *M. caschive* and *O. niloticus* respectively (Table 1).

Table 1: Initial microbial load and water activity in smoked M. caschive and O. niloticus

Parameters Smoking types		Water activity*	Plate count**	Mold count **
M. caschive	Fresh	NA	2.71	NA
	Pit	0.62	2.12	1.65
	Chorkor	0.53	1.51	1.65
O. niloticus	Fresh	NA	4.06	NA
	Pit	0.62	2.50	1.65
	Chorkor	0.56	1.54	1.65

Values are means of duplicate determination of homogenized fish muscles;
NA= not applicable. *a_w.**log_{10}cfu/g

Chorkor smoked fish had significantly lower microbial load than pit smoked *M. caschive*and *O. niloticus,* respectively.

Water activity (a_w) determined in smoked fish during storage

Generally, water activity increased with increase in storage over the 35 days keeping time (Table 2). The average rate of increase in water activity in pit smoked fish (0.005/week) was significantly (P<0.05) higher than chorkor smoked samples (0.003/week). With regard to smoking technologies, the mean water activity recorded in pit smoked fish was significantly (P<0.05) higher than measured from chorkor specimens (Table 2).

Total plate count of smoked fish during storage at ambient temperature

An increasing trend in microbial load in the muscles of smoked fish was recorded during storage at room temperature (Table 3). Total plate count increased significantly with increase in time. In the case of technologies, pit smoked *M. caschive* had significantly higher total plate count than chorkor smoked samples in the entire storage period, P<0.05. Pit smoked *M. caschive* had significantly higher growth rate of total viable count (0.069 log_{10} cfu/g/week) than chorkor smoked fish samples (0.041 log_{10} cfu/g/week), P<0.05. Similarly, the total plate count of smoked *O. niloticus* increased with increase in storage time (Table3).

Table 2: Trend in water activity

Parameter		Water activity (a_w)	
Species	Days	Pit	Chorkor
M. caschive			
	0	0.62	0.53
	7	0.65	0.53
	14	0.69	0.55
	21	0.75	0.56
	28	0.77	0.62
	35	0.79	0.64
O. niloticus			
	0	0.62	0.56
	7	0.65	0.57
	14	0.72	0.60
	21	0.75	0.66
	28	0.78	0.70
	35	0.80	0.74

Pit smoked *O. niloticus* also had significantly higher total plate count than chorkor smoked samples, P<0.05. In regard to total viable growth rate, pit smoked *O. niloticus* had higher average growth rate (0.066 log_{10} cfu/g/week) than chorkor smoked samples (0.059 log_{10} cfu/g/week) but the difference was not statistically significant. The increase in microbial load in smoked fish during storage strongly correlated (r^2=0.94-0.98) with increase in water

activity. Regarding storage, the fourth and fifth weeks of storage showed higher water activity and microbial load than the first three weeks. Microbial loads in smoked fish samples recorded on the last week of the study (35th day of storage) were significantly higher in both *M. caschive* and *O. niloticus*.

Table 3: Trend in total plate count

Parameter	Total plate count (log_{10}cfu/g)		
Species	Days	Pit	horkor
M. caschive			
	0	2.12	1.51
	7	2.61	1.63
	14	2.76	2.16
	21	3.40	2.27
	28	4.13	2.30
	35	4.52	2.95
O. niloticus			
	0	2.50	1.54
	7	2.77	1.65
	14	2.95	2.51
	21	3.54	2.60
	28	4.20	3.13
	35	4.82	3.60

Mold count of smoked fish during storage at ambient temperature

Table 4: Trend in total plate count

Parameters	Total plate count (log_{10}cfu/g)		
Species	Days	Pit	Chorkor
M. caschive			1.51
	0	2.12	1.63
	7	2.61	2.16
	14	2.76	2.27
	21	3.40	2.30
	28	4.13	2.95
	35	4.52	
O. niloticus			1.54
	0	2.50	1.65
	7	2.77	2.51
	14	2.95	2.60
	21	3.54	3.13
	28	4.20	3.60
	35	4.82	1.51

An increasing trend in mold count in the muscles of smoked fish was recorded during storage at room temperature (Table 4). Molds increased significantly ($P<0.05$) with increase in keeping time. In regard to the technologies, pit smoked *M. caschive* had significantly ($P<0.05$) higher mold count than chorkor smoked samples during the entire storage period.

The mean growth rate of molds in pit smoked *M. caschive* (0.029 log_{10} cfu/g/week) was twice that in chorkor smoked samples (0.019 log_{10} cfu/g/week). Similarly, smoked *O. niloticus* had significantly ($P<0.05$) higher mold counts than chorkor smoked fish samples over storage time (Table 3). The mean growth rate of molds, (0.029 log_{10} cfu/g/week) was higher in pit smoked *O. niloticus* than the (0.013 log_{10} cfu/g/week) recorded in chorkor smoked samples.

DISCUSSION

Moisture content in the smoked fish generally, as expected, was found to be significantly lower than the fresh fish. Thus the ultimate aim was reduce moisture, which supports enzymatic activities, oxidation or rancidity leading to spoilage. Studies observed that high moisture content provides conducive environment for spoiling microorganisms to thrive (Akintola, 2015). Heat application during smoking breaks down the hydrogen bond resulting to free molecules which eventually evaporate on the surface of the products (Akintola, 2015). Excessive evaporation leads to decreased water activity in fish tissues (Akintola, 2015). Effective preservation method should reduce the moisture content to less than 20% depending on the purpose and the product desired (FAO, 2016). In the current study, moisture content was reduced to the levels of 10-15% and 15-17% for chorkor and pit kilns respectively. In line with previous studies, smoke drying reduced moisture content in the range of 81.49% to 84.33% in *Tilapia niloticus* and *Silurus glanis* to 14.34% and 22.67% respectively (Ahmed *et al.*, 2011). With regard to the performance of smoking technologies performance; chorkor kiln effectively reduced the moisture to 10% and 15% than 15% and 17% for pit kiln. Consistent with previous studies, chorkor technology can reduce moisture content to less than 15% (Aba and Ifannyi, 2013; Olopade *et al.*, 2013; Omodara *et al.*, 2016; Katola and Kapute, 2017; Olukayode and Paulina, 2017). The effectiveness of chorkor kiln could be explained by enclosed characteristics of the system leading to concentration of heat in this type of kiln. Lower moisture content recorded in chorkor smoked fish therefore, entails longer shelf life of fish products. While the moisture content of chorkor smoked products in the present study was below 20%, a level considered acceptable for smoked fish to inhibit both bacterial and fungal growth (Msusa *et al.*, 2017), relatively higher values recorded in pit smoked products signify susceptibility of smoked fish to microbial spoilage. Moisture content in chorkor smoked fish however, was within the 15% limit to prevent pathogenic microbial growth (Immaculate *et al.*, 2013) suggesting products with extended shelf life.

Protein, fat and mineral content

Protein, fat and mineral content (ash) were higher in smoked products than in the fresh fish samples, consistent with previous studies (Akinneye *et al.*, 2010; Ayinsa and Maalekuu, 2013; Immaculate *et al.*, 2013; Olopade *et al.*, 2013; Akinwumi, 2014; Akintola, 2015; Abraha *et al.*, 2017). Increase in protein content in the smoked fish

samples is attributed to decrease in moisture content (Kumolu-Johnson *et al*. 2010). Furthermore, increase in fat content could be attributed to loss of water holding capacity of fats that concentrated the lipids in fish tissue (Daramola *et al.,* 2007). In the case of smoking technologies, higher protein values were recorded in chorkor smoked fish than in pit, consistent with previous observations (Ahmed *et al.,* 2011; Ayinsa and Maalekuu, 2013). Increase in protein may be attributed to fish product dehydration due to sufficient smoking temperature that efficiently breaks the water holding capacity of proteins releasing water in form of vapor on the surface of fish products. Effective removal of water from smoked fish products led to protein concentration that consequently increased the protein content (Kumalo-Johnson *et al.,* 2010).

The materials (clay soil and flat iron sheet) used in the construction of chorkor led to higher heat retention that could have dehydrated the fish muscle which subsequently aggregated the proteins (Oparaku *et al.,* 2010; Olayemi *et al.,* 2012). Similarly, increase in fat content could be due to muscle dehydration caused by smoke heat that led to the concentration of lipids in smoked fish products. In regard to the kilns, higher fat content recorded in chorkor could be attributed to higher heat retention capacity of the construction materials which efficiently break down hydrogen bond in the water molecules leading to water evaporation from the fish surface.

Variation in fat content between the kilns could also be due to distribution of fat on the surface of fish which is known to change due to heat intensity during smoking (Ayinsa and Maalekuu, 2013). Higher fat content recorded in smoked fish in this study could be a good dietary attribute but may cause storage problems due to the liability of fish oils to oxidation or rancidity leading to fish spoilage (Ayinsa and Maalekuu, 2013) hence need to be handled with care.

Fresh fish samples have significantly lower ash content than the smoked fish samples. Values of ash content (minerals) recorded in the study were significantly higher, consistent with previous studies where an increase in mineral content was attributed to loss of water due to heat and salting effect (Olukayode and Paulina, 2017). Additionally, increase in ash content could be attributed to protein denaturation due to reduction in moisture and consequently loss of water holding capacity of protein in smoked fish samples (Msusa *et al.,* 2017). In relation to the smoking technologies, the study revealed significantly higher ash content in chorkor than in pit smoked fish products. This could be explained by the higher rate of water loss in chorkor smoked fish due to heat intensity that could be retained for a longer period in the system. Chorkor kiln was constructed using unbaked bricks and plastered with clay mud, such materials help in retention of heat during fish smoking hence confirming its superiority over pit kiln.

Water activity in smoked fish in storage

The initial water activity in pit smoked fish was higher than recorded in chorkor smoked products. This is attributed to inefficient smoking that could not effectively remove water due to lack of control over smoking procedures (temperature) given the openness of pit kiln. During storage, water activity increased with increase in storage time due to water absorption from atmospheric air in the storage room. The rate of increase was higher in pit than in chorkor smoked fish samples due to inefficient smoking that may not effectively remove moisture from fish tissues. The rate of absorption of moisture however, depends on the initial moisture content that was higher in pit than in chorkor smoked fish products. Effective removal of moisture to 10% and below for fatty fish e.g. *M. caschive* or 15% and below for lean fish e.g. *O. niloticus* in chorkor kiln significantly reduces the rate of increase of water absorption.

Microbial load

Considering microbial load, the study recorded higher microbial count in fresh fish than in smoked fish samples. This could be attributed to unhygienic handling of fish at the landing site and during transportation. It was observed that, the ice packs used for preserving the fresh fish melted during transportation due to temperature differences. Indeed, microorganisms increased exponentially with increase in ambient temperature. Although Aeromonas and Pseudomonas bacteria, the main fresh fish spoilers were not identified in the study, records revealed that, they are the dominant micro-flora in fresh fish (Abolagba and Igbinevbo, 2010; Pal *et al.,* 2016). With regard to storage time, low initial microbial load in smoked fish could be attributed to the potential effect of heat and smoke chemicals particularly phenols in destroying and inhibiting microorganisms in smoked fish. Indeed, the autolytic activity of most bacteria are retarded by reduction in water activity and increased smoke preservatives. In addition, salt prior to smoking, as a traditional practice could have reduced microbial load on fish but also affected the microbial growth. Studies observed that sodium chloride inhibits microbial growth in salted-smoked and salted-sundried fish (Nguvava, 2013; Odoli, 2015; Ginigaddarage *et al.,* 2018).

In regard to smoking technologies, chorkor smoked fish recorded lower microbial count than pit smoked fish, consistent with previous records (Abolagba and Igbinevbo, 2010). Low microbial load in chorkor kilns could be attributed to proper handling of fresh fish for smoking, sanitary chorkor facility, effect of smoke and heat preventing or reducing the proliferation capacity of microorganisms. In pit kiln, fish smoking is done in an open and unhygienic conditions giving the chance for microbial contaminations (Adelaja *et al.,* 2013; Adeyemi *et al.,* 2013). In relation to storage, the results revealed an increase in microbial load in smoked fish with storage

time. This is consistent with reports of Ayinsa and Maalekuu (2013) who observed quality deterioration of smoked fish during storage at ambient temperature. The deterioration was attributed to increase in microbial load associated with increase in moisture absorb from the atmosphere into fish tissues (Daniel *et al*., 2013. In the present study, increase in water activity due to reabsorbing moisture from the atmosphere during storage corresponded with the increase in microbial load.This supports the observation that microbial load correlates well with water activity during storage (Ayuba *et al*., 2013).

Indeed, dehydrated fish easily absorbs water from the atmosphere into fish tissue triggering microbial growth with subsequent increase in the load (Daramola *et al.,* 2007; Daniel *et al.,* 2013). Despite the increase in microbial load in smoked fish samples, the loads were below the maximum permissible limit recommended by WHO (1.0×10^6 and 1.0×10^4cfu/g for bacteria and fungi). Higher microbial load recorded in pit smoked fish could be attributed to insufficient water removal from the fish tissues. Nevertheless, inefficient fish smoking could not sufficiently breakdown the water holding capacity of protein in fish tissues. In addition, unhygienic handling practices and unsanitary environmental conditions of traditional pit smoking could have accelerated the microbial growth (Abolagba and Igbinevbo, 2010).

Similarly, the study recorded higher mold count in pit than in chorkor smoked fish samples and the load increased during storage at ambient temperature. This could be due to poor processing techniques employed in traditional pit technology and exposure of the products during storage (Sajib *et al.,* 2015). Findings of the present study showed that molds are capable of growing at water activity as low as 0.60. This is consistent with Daniel *et al.* (2013) who revealed that molds are the major microbes thriving in smoked and dried fish products with low water activity. However, the current findings showed that microbial loads enumerated from the initial smoked fish may be devoid of pathogenic bacteria since studies have showed that apart from molds, pathogenic microorganisms grow at water activity range of 0.75-0.99 (Odoli, 2015; Ginigaddarage *et al.,* 2018). In regard to microbial load and storage, it is imperative to say that pit smoked fish has low shelf life than chorkor smoked fish products and consumption of pit smoked fish products after 35th day of storage may result to potential health effects.

CONCLUSION AND RECOMMENDATION

This study revealed that chorkor and pit kilns concentrated the chemical components including protein, fat and minerals of fish due to reduce water content. Chemical components in chorkor were significantly concentrated than in pit smoked fish and corresponds to the extent of moisture removal. Fish smoking kilns therefore, do not necessarily change the chemical composition of fish but rather concentrates the nutrients. Regardless of the smoking kilns, fish tissues continuously absorb atmospheric moisture during storage at room temperature resulting to increase in water activity of smoked fish. The rate of moisture absorption however, depends on the initial moisture content. Therefore, effective removal of moisture to 10% and below for fatty fish e.g. *M. caschive* or 15% and below for lean fish e.g. *O. niloticus* significantly reduces the rate of increase of water absorption. With increasing water activity, the microbial load in smoked fish products also increases. Despite the increase in microbial loads, fish were safe because the loads were below the maximum permissible limit recommended by the ICMSF and WHO (6 Log_{10} cfu/g and 4 log_{10}cfu/g) for bacteria and fungi respectively. The study recommends that Fisher folks should adopt improve chorkor kilns characterized with easy control of smoking parameters and maintenance of smoked fish quality. Besides high quality, economically sustainable quantities of fish can be processed in a short time, using low firewood consumption. Therefore, uptake of improved chorkor kiln will consolidate smoked fish value chain by maintaining the quality and quantity of smoked fish products. Technologies such as chorkor smoking kiln will help fisher folks to minimize causes of climate change by reducing adverse pressure on forestry resources for firewood. This will enhance the role of fish in providing food and nutrition security in an environmentally sensitive approach in South Sudan.

ACKNOWLEDGEMENTS

This study was supported financially by Sudd and Ecology Management (NORHED Project No. 1300680) to Borodi Charles Mondo. The Department of Environmental Management, College of Agricultural and Environmental Sciences, Makerere University is thanked for hosting this research. We would like to thank Bonny Balikuddembe of Makerere University and Edgar Samuel of National Agriculture Research Organization-Kawanda for technical support.

REFRENCES

Aba, P., and Ifannyi, N. (2013). Effects of smoke- drying temperatures and time on physical and nutritional quality parameters of Tilapia (*Oreochromisniloticus*). *International Journal of Fisheries and Aquaculture,* **5:**29-34.

Abolagba, O. J., and Igbinevbo, E. E. (2010). Microbial load of fresh and smoked fish marketed in Benin metropolis, Nigeria. *Research Journal of Fisheries and Hydrobiology*, **5:** 99-104.

Abraha, B., Samuel, M., Mohammud, A., Admassu, H., and Al-haj, N. Q. M. (2017). A Comparative Study on Quality of Dried Anchovy (*Stelophorus heterolobus*) Using Open Sun Rack and Solar Tent Drying Methods. *Turkish Journal of Fisheries and Aquatic Sciences*, **17:** 1107–1115.

Adelaja, B., Adeolu, O., Jacob, O., Bolatito, I. N., and Samuel, A. (2013). Comparison of Microbial Load Associated with Smoked Fish (*Chrysichthys Nigrodi gitatus*) from Oyan Lake and Ogun Waterside in Ogun State, Nigeria. *Journal of Culinary Science and Technology*, **13:**1–6**.**

Adeyemi, O.T., Osilesi1, O.O., Onajobi, F., Adebawo, O., and Afolayan, A.J. (2013). Stability study of smoked fish, horse mackerel *(Trachurus trachurus)* by different methods and storage at room temperature. *African Journal of Biochemical Research*, **7:**98-106.

Ahmed, A., Dodo, A., and BoubaAdji, M. (2011). Influence of traditional drying and smoke drying on the quality of three fish species (*Tilapia nilotica, Silurus glanis, and Arius parkii*) from Lodgo Lake, Cameroon. *Journal of Animal and Veterinary Advances*, **10:** 301-306

Akintola, S. L. (2015). Effects of smoking and sun-drying on proximate, fatty and amino acids compositions of Southern pink shrimp (*Penaeus notialis*). *Journal of Food Science and Technology*, **52**:2646–2656.

Akinwumi, F. O. (2014). Effects of smoking and freezing on the nutritive value of African Catfish, *Clariasgariepinus* (Burchell, 1822). *Journal of Agricultural Science*, **6**: 143-149**.**

Akinneye, J. O., Amoo, I. A., and Bakare, O. O. (2010). Effect of drying methods on the chemical composition of three species of fish (*Bonga spp., Sardinella spp. and Heterotis niloticus*). *African Journal of Biotechnology*, **9:**4369–4373.

Association of official analytical Chemists. (2005). Official methods of analysis 18th edition. Association of official analytical Chemists, Washington, Arlington, Virginia, USA

Ayinsa, H. K., and Maalekuu, B. K. (2013). Effect of traditional fish processing methods on the proximate composition of red fish stored under ambient room conditions. *American Journal of Food and Nutrition*, **3**: 73-82.

Ayuba, V. O., Alhassan, M. I., and Jimmy, U. U. (2013). Assessment of the microbial load of smoked sardine (*Sardina pilchardus* , Walbaum , 1792) sold in Makurdi Markets, Original Research Article. *International Journal of Current Microbiology and Applied Sciences*, **2:**277–287.

Bacteriological Analytical Manual. (2005). United States food and drug administration for detection, enumeration and identification of individual organisms.http://www.foodinfonet.com/publicaton/fdaBAM..htm

Daniel E.O., Ugwueze, A.U., and Igbegu, H.E. (2013). Microbiological Quality and Some Heavy Metals Analysis of Smoked Fish Sold in Benin City, Edo State, Nigeria. *World Journal of Fish and Marine Sciences*, **5:** 239-243.

Daramola, J. A., Fasakin, E. A., and Adeparusi, E. O. (2007). Changes in physicochemical and sensory characteristics of smoked-dried fish species stored at ambient temperature. *African Journal of Food, Agriculture, Nutrition and Development Agriculture, Nutrition and Development*, 7(6).

Food and Agricultural Organization of the United Nations.(2015). Resilient Livelihoods for Sustainable Agriculture, Food Security and Nutrition. Country Programming Framework for Sudan Plan of Action (2015-2019)

Food and Agricultural Organization of the United Nations. (2016a). *South Sudan Resilience Strategy*, 2016-2018.

Food and Agriculture Organization of the United Nations. (2016b). The state of world fisheries and aquaculture. Controbuting to food security and nutrition for all. Rome, 200pp.

Food and Agriculture Organization of the United Nations. (2016c). How access to energy can influence food losses. Environment and Natural Resources Management; Environment, Climate change [Energy] monitoring and assessment working paper 65.

Food and Agriculture Organization of the United Nations. (2018). *World fisheries and aquaculture*.

Food and Agriculture Organization, International Fund for Agricultural Development and World Food Program. (2013). State of food insecurity in the world-the multiple dimensions of Food security. FAO, Rome, Italy, 2013.

Ginigaddarage, P. H., Surendra, I. H. W., Weththewa, W. K. S. R., and Ariyawansa, K. W. S. (2018). Microbial and chemical quality of selected dried fish varieties available in Sri Lankan market. *Sri Lanka Journal of Aquatic Science*, **23:**119–126.

Immaculate, K., Sinduja, P., Velammal, A., and Jamila P. (2013). Quality and shelf life status of salted and sun-dried fishes of Tuticorin fishing villages in different seasons. *International Food Research Journal*, ***20*:**1855-1859.

Katola, A. and Kapute, F. (2017). Nutrient composition of solar dried and traditionally smoked *Oreochromis mossambicus, International Food Research Journal*, **24:**1986–1990.

Kumolu-Johnson, C. A., Aladetohun, N. F., and Ndimele, P. E. (2010). The effects of smoking on the nutritional qualities and shelf-life of *Clarias gariepinus* (BURCHELL 1822). *African Journal of Biotechnology*, **9:**73–76.

Magawata, I., and Musa, T. (2015). Quality characteristics of three Hot-Smoked fish species using locally fabricated Smoking chorkor. *International Journal of Fisheries and Aquatic Studies*, **2:**88–92.

Msusa, N., Likongwe, J., Kapute, F., Mtethiwa, A., and Sikawa, D. (2017). Effect of processing method on proximate composition of gutted fresh Mcheni

(*Rhamphochromis species*) (Pisces : Cichlidae) from Lake Malawi. *International Food Research Journal*, ***24*:**1513–1518.

Nguvava, J.P. (2013). Effect of postharvest handling on quality and sensory attributes of sardines: A case study of Musoma district. *Master of Science Thesis*, Sokoine University of Agriculture, Morogoro, Tanzania.

Nunoo, F. K. E., and Kombat, E. O. (2013). Analysis of the Microbiological Quality of Processed *Engraulis encrasicolus* and *Sardinella aurita* Obtained from Processing Houses and Retail Markets in Accra and Tema, Ghana. *World Journal of Fish and Marine Sciences*, **5:**686–692.

Odoli, C. O. (2015). Drying and Smoking of Capelin (*Mallotusvillosus* and *Sardinellagibbosa*). The Influence on Physio-chemical properties and consumers' acceptance, *PhD Thesis*, University of Iceland.

Olayemi, F. F., Raji, A. O., and Adedayo, M. R. (2012). Microbiological quality of catfish (*Clariasgariepinus*) smoked with Nigerian Stored Products Research Institute (NSPRI) developed smoking chorkor. Special Review. *International Research Journal of Microbiology* (IRJM), **3:**426-430.

Olopade, O.A., Taiwa, I.O. and Agbato, D.A. (2013). Effect of Traditional smoking Method on Nutritive Values and Organoleptic Properties of *Sarotherodon galilaeus* and *Oreochromis niloticus*. *International Journal of Applied Agricultural and Apicultural Research.*, **9:**91–97.

Olukayode Amos, S., and Paulina, I. (2017). Assessment of Smoked Fish Quality Using Two Smoking Chorkors and Hybrid Solar Dryer on Some Commercial Fish Species in Yola, Nigeria. *Journal of Animal Research and Nutrition*, **2:**1–7.

Omodara, M.A., Olayemi, F.F., Oyewole, S,N., Ade, A.R., Olaleye, O.O., Abel, G.I. and Peters, O. (2016). The Drying Rates and Sensory Qualities of African Catfish, *Clarias gariepinus* Dried in Three NSPRI Developed Fish Chorkors. *Nigerian Journal of Fisheries and Aquaculture*, **4**:42–49.

Oparaku, N.F., Mgbenka, B.O., and Eyo, J.E. (2010). Proximate and organoleptic characteristics of sun and solar dried fish. *Animal Research International*, **7:**1169-1175.

Pal, M., Ketema, A., Anberber, M., Mulu, S., and Dutta, Y. (2016). Microbial quality of Fish and Fish Products. *Beverage and food world.*, **43**:46-49.

Sajib, A., Karmaker, S., Hassan, M., Roy S., Hoque, R., and Rahman, N. (2015). Effect of Traditional Fish Processing Methods on the Proximate and Microbial characteristics of *Laubukadadigurjori* during storage at Room Temperature. *Journal of Fisheries and Aquatic Science*, **1014:**232-243.