Research Article

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Comparison of the efficiency of improved and traditional fish smoking kilns and their effects on smoked fish quality in Ghana

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Abstract

BACKGROUND: Fish smoking is a traditional fish preservation method that is affordable, and hence employed by most artisanal fish processors in Ghana. Traditional kilns are used but are less fuel efficient and the end-product has lower quality. This study therefore sought to test and compare the efficiency and quality of smoked fish for two improved kilns, the Cabin and Abuesi gas fish smoker (AGFS), against the traditional Chorkor smoker.

RESULTS: The results showed that the AGFS and Cabin had specific fuel consumption of 0.31 $\pm$ 0.02 and 0.67 $\pm$ 0.01 g kg^{-1} of smoked fish, respectively, which were significantly lower than that of the Chorkor (6 $\pm$ 0.12 g kg^{-1} smoked fish). Again, the AGFS and Cabin had significantly higher processing rates (251.18 $\pm$ 10.65 and 156.80 $\pm$ 8.30 g min^{-1}, respectively) compared to the Chorkor (135.20 $\pm$ 5.60 g min^{-1}). Smoking improved the nutritional, microbiological and sensory quality of mackerel, with only the sensory quality being statistically different between the products from the AGFS and Cabin. The Cabin-smoked products had more traditional smoked fish attributes while the gas-smoked products had a pronounced fried appearance and taste.

CONCLUSION: The AGFS and Cabin were more efficient than the Chorkor. There were no significant differences in the nutritional and microbial quality between the AGFS and the Cabin. Cabin-smoked products, however, had the more traditional qualities of smoked fish (appearance and flavor) that the gas-smoked products lacked.

Keywords: smoking kilns; controlled cooking test; proximate composition; microbial quality; sensory evaluation

INTRODUCTION

Fish smoking and drying are ancient, traditional fish processing methods that are widely employed to preserve fish in most developing countries of the world.[1] Smoked and dried fish products have longer shelf lives and serve as the main source of fish in rural areas that are far from fishing sites.[2] In Ghana, both fresh and frozen fish are smoked and the majority of fish consumed is in the smoked form.[3,4]

Fish smoking is usually undertaken using traditional fish smoking kilns (like the metal drum and round mud kiln) and improved ones like the Chorkor, Banda and Altona, among others.[2,5] In Ghana, the most popular kiln is the Chorkor, which was developed in 1969 through the joint collaborative efforts of the Food and Agriculture Organization (FAO) and the Food Research Institute, Ghana.[6] This kiln has the advantage of being relatively more energy efficient, has greater throughput capacity, poses lower risks to processors in terms of smoke exposure and produces better quality products, compared to the other traditional kilns.[2,7]

The kilns rely on solid/biomass (firewood mainly) combustion to cook, smoke and dry the fish, and this imparts the characteristic color, odor and taste that is favored by consumers.[2,5,8] Biomass resources are readily accessible and provide a major source of renewable energy in most households in developing countries.[9] The combustion of these fuels is usually less efficient and releases a variety of incomplete combustion pollutants which affect human health and local/regional climate change significantly.[9-11] 11 Several studies in Ghana have reported the potential public health and climate implications of using the Chorkor and other traditional fish and improved smoking kilns.[3,5,7,12,13] This calls for the development and testing of new improved and efficient fish smoking kilns.

Three smoking kilns (i.e. two improved and one traditional) were therefore evaluated in the study reported here. The Abuesi

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gas fish smoker (AGFS) and the Cabin smoker, developed by GRATIS Foundation (Ghana) and UNU-FTP and Matis (Iceland), respectively, were the improved kilns. The possibility of adopting these kilns will be dependent on an assessment of their performance, costs and the quality of the smoked fish produced, relative to the Chorkor. The information obtained will be very useful for consumers and businesses that will be interested in these technologies. The aim of the study was therefore to assess the efficiency of the Cabin, Chorkor and AGFS smoking kilns and the microbial, nutritional and sensory quality of the smoked products from these kilns.

MATERIALS AND METHODS

Controlled cooking test (CCT) protocol

The CCT procedure was employed to assess the efficiency of the three smoking kilns.[7,14,15] The CCT, developed by the Global Alliance for Clean Cookstoves compares the performance of improved and traditional stoves, aiming at replacing the traditional models.[16] The CCT involves recruiting processors with relevant experience, describing the kilns, fuel and fish used, and monitoring and recording the smoking process. The performance of the kiln is then determined by estimating the specific fuel consumption, total smoking time and processing rate. The smoking experiments were carried out at the Fish Processing Facility, which belongs to the Abuesi Fish Processing Association, at Abuesi in the Western Region of Ghana.

Description of fish smoking kilns and fuel

The Chorkor, Cabin and AGFS kilns, representing uncontrolled, semi-controlled and controlled smoking technologies, respectively, have been extensively described by Asamoah *et al.*[17] The Chorkor kiln is double-chambered, constructed using cement blocks and can hold up to 15 racks. For this CCT, only one side was used. The Cabin kiln is built with fired bricks and can take up to 7 wooden racks. Lastly, the AGFS is an industrial, double-chamber fish smoking oven built from stainless steel, with 25 metal trays arranged on rails. For the Chorkor and Cabin kilns, the hardwood *Uapaca guineensis*, with a calorific value of 4126 kcal kg^{-1}, was used.[18] The estimated mean length and width was 54 cm × 11.6 cm. The moisture content of the wood (19.2%) was measured at three different locations in each wood, for 20 samples using a General Tools MMD4E moisture meter. For the AGFS kiln, the cooking and smoking steps were accomplished using LPG and sugarcane and then the dryer (which uses electricity) was employed afterward. The atmospheric temperature and humidity were measured during the testing period. The mean temperature and relative humidity were 25.7 °C and 85.7%, respectively. There was a light breeze during that time.

Experimental procedures

For the CCT, three local fish processors, each with more than 10 years of fish smoking experience, who use smoking kilns were recruited under the supervision of the researchers. Each processor tested each kiln once daily, over 3 days. Imported frozen chub mackerel (*Scomber colias*) with a mean total length of 25.2 ± 3.1 cm and weight of 225.5 ± 53.4 g was used in the smoking trials. Each processor was given 60 kg of fish per kiln (Chorkor and Cabin) per day and 60 kg of firewood per kiln per day (which was about twice the quantity of the fuel that they estimated would be enough to smoke all the fish per day). For the AFGS, 100 kg of fish was used per smoking session due to its industrial size and to avoid excessive fuel wastage. The processor was given a 30 kg LPG cylinder per smoking session. The weights of fish and wood were taken using a KERN CH50K100 electronic hanging balance (KERN & Sohn GmbH, Germany), with a maximum capacity of 50 kg and a resolution of 0.10 kg. The smoking was accomplished following Fig. 1. The fish was thawed at ambient temperature, weighed, washed and then brined in an 8% NaCl solution for 30 min. After brining, fish were arranged on the smoking racks and allowed to dry before smoking started. Smoking, cooking and drying were accomplished in the Cabin and Chorkor by adjusting the fuel used while the fan in the AGFS was turned on for about 30 min to circulate hot air, after which it was turned off and the residual heat was used for further drying. The temperature inside the fish was taken at 30 min intervals with a Thermco Precision Handheld Pt100 digital thermometer (resolution of 0.1 °C). Once the temperature inside the fish reached 70 °C, the fish were allowed to be in the kiln for an extra 30 min, before the fish were taken out and allowed to cool as described in Asamoah.[6]

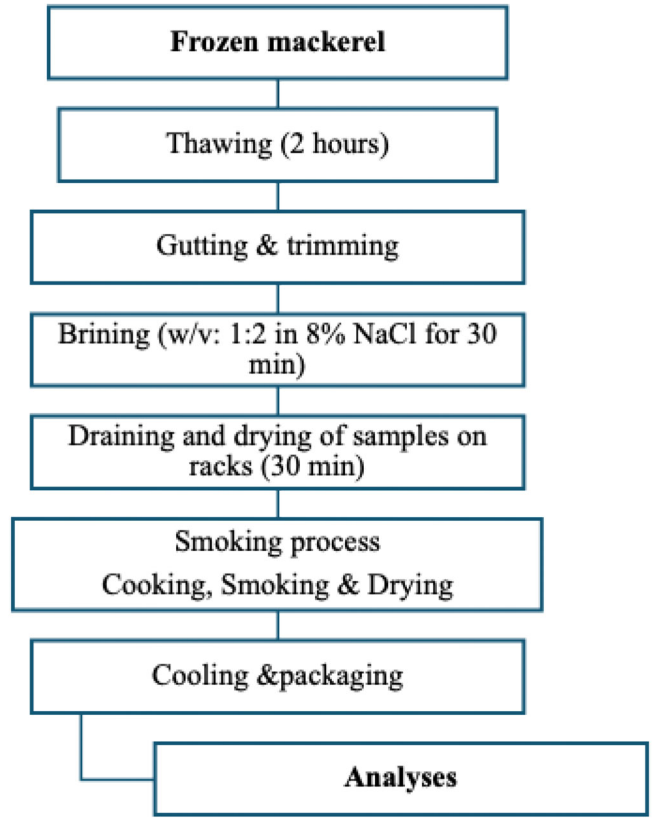

Figure 1. Overview of the fish smoking process.

Quality measurements of smoked products

Based on the results of the CCT (specific fuel consumption and processing rate), the smoked products from the Cabin and AGFS were further assessed for proximate composition, microbial quality and sensory quality. Two batches of 20 kg each of *S. colias* were smoked and tested. The mackerel was smoked whole. After smoking, the fish were cooled at ambient temperature for about an hour, after which they were packed into Ziplock bags, iced and transported to the laboratory for analysis.

Proximate composition
Samples were packed in Ziplock bags and transported to the laboratory of the Food Research Institute, Ghana for analysis. The samples were deboned, and the heads removed, after which the muscle was minced thoroughly. To assess the nutritional quality of the fish samples, the moisture, protein, fat and ash contents were analyzed using the air-oven method (AOAC 32.1.03), Kjeldahl method (AOAC 4.2.09), Soxhlet method (AOAC 4.5.01) and dry ashing method (AOAC 32.1.05), respectively.[19] The results were expressed as percentages. The pH, which measures the acidity of the product and can aid microbial spoilage, was determined following a modified AOAC method (2.8.01).[19]

Microbial analyses
The safety of the fish samples (fresh and smoked) for consumption was analyzed using the total count of aerobic mesophiles (TVC), coliforms (fecal coliforms and *Escherichia coli*), staphylococci, *Clostridium perfringens*, yeasts and molds. The rinse method was used in sample preparation and enumeration of microbial loads was done using plate count agar by the pour plate technique for TVC, coliforms, *C. perfringens*, yeasts and molds, and the spread plate technique for staphylococci.[20] An amount of 25 g of each sample (including head, skin, bones and muscle) was aseptically weighed into a sterile stomacher bag, into which 225 mL of 0.1% peptone water was added. Serial dilutions were performed on the rinse fluids and homogenized tissue samples for the various microbial count tests, as per the methods described by the International Commission for Microbiological Specifications for Foods.[21] All microbial counts were expressed as log CFU g^{-1} sample.

Sensory evaluation
A Quantitative Descriptive Analysis (QDA®) method was carried out to compare the sensory descriptive profiles of smoked mackerel from the different kilns.[22] An eleven-member panel with prior training in Quantitative Descriptive test were recruited for the test. The assessors were trained, in three sessions, to describe, assess and score sensory attributes of smoked fish i.e. the appearance, aroma, flavor, texture (in hand), mouthfeel and aftereffect of samples. For assessments and evaluations, samples of fish were taken out from the batch and cut into pieces while frozen to enable easy and uniform cuts and prevent any possible structural disintegration due to flaking. The head and tail fin portions of the samples were cut off and discarded. The body was then cut transversely into two equal parts. Each part was then split along the backbone into two symmetric halves, deboned and gutted and further divided to obtain four equal portions. The prepared samples were transferred into appropriately labelled 80 cm^3 plastic containers with lids and left out at ambient temperature to thaw to about 18 ± 2 °C before serving to the assessors. Samples were presented to the assessors, in triplicate, in a randomized balanced order using the Williams design in Compusense Cloud® (Compusense, Guelph, Ontario, Canada). Samples were served in a monadic sequential order. The assessors used Compusense Cloud® to score the intensities of the different attributes defined on a 15 cm line scale.[22] A total of 26 sensory descriptors were generated to describe the smoked mackerel.

Data and statistical analysis
Statistical analysis was performed using Microsoft Excel 2016 and XLSTAT (Addinsoft, New York, USA). The data from the CCTs were inputted into CCT 2.0 Spreadsheet software.[9] The software estimated the equivalent dry wood consumed (kg), specific fuel consumption (kg of firewood used per kg of fish smoked) and total cooking time (min) for the individual tests, based on Eqns (1)–(3):

$$\text{Equivalent dry wood consumed}(f_\text{d}) = (f_\text{i}-f_\text{f})\times(1-(1.12\times m))-1.5\times\Delta C_\text{c} \quad (1)$$

$$\text{Specific fuel consumption (SC)} = \frac{f_\text{d}}{W_\text{f}}\times 1000 \quad (2)$$

$$\text{Total smoking time } (\Delta t) = t_\text{f}-t_\text{i} \quad (3)$$

where f_i and f_f are the initial and final weights of firewood, respectively (g); m is the wood moisture content (%); ΔC_c is the weight of char remaining (g); W_f is the weight of smoked fish (g); and t_i and t_f are the start and finish times of smoking (min).[14]

The smoking yield (%) was also calculated according to[23]:

$$\text{Smoking yield} = \frac{W_\text{s}}{W_\text{r}}\times 100 \quad (4)$$

where W_s is the weight of smoked fish and W_r is the weight of raw fish.

The processing rate (g min^{-1}) was calculated as:

$$\text{Processing rate} = \frac{W_\text{s}}{\Delta t} \quad (5)$$

The cost of firewood or gas per kg of smoked fish (USD kg^{-1}) was calculated as:

$$\text{Cost of fuel} = \frac{\text{Cost of fuel used}}{W_\text{s}}$$

Analysis of variance, with stepwise comparison, was performed using Tukey's HSD test at the 5% level of significance for the proximate composition. Multivariate comparison of different variables and samples was performed using principal component analysis on means to identify sensory differences and similarities between the samples.

RESULTS
Efficiency of smoking kilns
The results from the CCT are presented in Table 1. The smoked fish yields were comparable for Chorkor and Cabin while AGFS had the lowest at 50.2%. A look at the solid fuel consumption showed that in all cases the Cabin kiln was more fuel efficient than the Chorkor kiln. The mean specific fuel consumptions of smoked fish were all statistically different ($P < 0.05$), with the Chorkor kiln consuming the most. The amount of char remaining in the Chorkor averaged 0.35 kg, which was significantly lower ($P < 0.05$) than in the Cabin, which produced 0.99 kg of char.

The total smoking times in the Cabin and AGFS were 15% and 22%, respectively, lower than that in the Chorkor. The processing rate of the Chorkor was 135.2 g min^{-1}, which was about 16% significantly lower ($P < 0.05$) than that of the Cabin, with a 156.8 g min^{-1} rate. That for AGFS was 251 g min^{-1}, which was 86% and 60% significantly higher ($P < 0.05$) than for the Chorkor and Cabin, respectively.

The cost of firewood was estimated at USD0.16 kg^{-1}. The Cabin saved about 20% fuel cost compared to the Chorkor and this was

Table 1. Comparison of efficiency of Chorkor, Cabin and AGFS kilns (mean ± SD)

Parameter	Chorkor	Cabin	AGFS
Weight of fresh fish (kg)	60.00 ± 0.00	60.00 ± 0.00	100.0 ± 0.0
Weight of smoked fish (kg)	34.57 ± 1.07	34.13 ± 0.49	50.17 ± 0.76
Yield (%)	57.61 ± 1.80^a	56.89 ± 0.80^a	50.17 ± 0.76^b
Weight of char remaining (kg)	0.35 ± 0.35^a	0.99 ± 0.16^b	-
Equivalent fuel consumed (kg)	33.20 ± 3.39^a	23.29 ± 0.46^b	15.60 ± 0.92^c
Specific fuel consumption (g kg^{-1} of smoked fish)	0.96 ± 0.12^a	0.67 ± 0.01^b	0.31 ± 0.02^c
Total smoking time (min)	256 ± 15^a	218 ± 9^b	200 ± 10^b
Processing rate (g min^{-1})	135.20 ± 5.60^a	156.80 ± 8.30^b	251.18 ± 10.65^c
Cost of fuel per kg of smoked fish (USD kg^{-1})	0.20 ± 0.12^a	0.15 ± 0.01^a	0.33 ± 0.17^b
Maximum capacity (kg)	120.0	90.0	500

Means with different superscripts (a, b, c) within a row are significantly different at $\alpha < 0.05$.

statistically significant ($P < 0.05$). The mean cost of gas used was USD14.67 and it cost USD0.31 to produce 1 kg of smoked fish, which was significantly higher ($P < 0.05$) than when using firewood. The cost of electricity used for drying the fish could, however, not be determined, and this could increase the cost.

The estimated lifespan of the Cabin and Chorkor is about 10 years, but the smoking racks may last for between 2 and 4 years. The AGFS can also last for about 15 years.

Proximate composition

The smoked products from the two improved kilns are referred to as Cabin-smoked mackerel (CSM) and gas-smoked mackerel (GSM) for the Cabin and AGFS, respectively. The mean moisture, fat, protein and ash contents of the fresh and smoked fish samples are presented in Table 2. The moisture, protein, fat and ash contents were 71.97 ± 3.10%, 24.33 ± 1.37%, 5.51 ± 5.56% and 1.41 ± 0.10% in fresh mackerel (FM). The pH in the FM was 5.98 ± 0.10. Smoking significantly decreased ($P < 0.05$) the moisture content of CSM and GSM. The protein was significantly higher ($P < 0.05$) in smoked samples as compared to FM samples. Fat, ash and pH contents showed no significant differences ($P > 0.05$) between the fresh and smoked samples. There were also no significant differences ($P > 0.05$) between the smoked samples from the two kilns, concerning the proximate composition.

Microbial composition

Fecal coliform was observed in all fresh fish samples. This decreased in CSM and GSM samples to 50% and 75%, respectively. The prevalence of *E. coli* was the same (50%) in all samples, except for CSM, which was higher (75%). *C. perfringens* decreased in the smoked mackerel to 25%, when compared to fresh samples. Yeast and mold were in all samples of FM and GSM and decreased to 75% in CSM. *S. aureus* was in 50% of FM but decreased to 25% in CSM and was absent in GSM, compared to the fresh samples.

The mean counts of microorganisms in fresh and smoked samples are presented in Table 3. FM had total mesophilic, fecal coliform, *E. coli*, *C. perfringens*, yeast and mold and *S. aureus* counts of 7.5 ± 1.0, 3.1 ± 0.9, 2.4 ± 2.0, 1.9 ± 0.8, 3.9 ± 0.4 and 1.2 ± 0.6 log CFU g^{-1}, respectively. The microbial counts decreased in all smoked samples as compared to the fresh samples, with only *C. perfringens* significantly lower in CSM and GSM. *S. aureus* was not detected in GSM samples.

Sensory analyses

The spider web plots in Fig. 2 describe the sensory attributes of smoked mackerel from the two kilns. Of the 26 sensory descriptors, 13 significantly discriminate between the two kilns ($P < 0.05$). To understand the similarities or differences between sensory attributes of the smoked products from the two kilns, a principal component analysis was carried out on the

Table 2. Proximate composition (mean ± SD) of CSM and GSM ($n = 4$)

	Mackerel		
Parameter	FM	CSM	GSM
Moisture (%)	71.97 ± 3.10^a	34.18 ± 9.68^b	32.00 ± 10.13^b
Fat (%)	5.51 ± 5.56^a	11.23 ± 2.99^a	16.06 ± 7.04^a
Protein (%)	24.33 ± 1.37^a	51.35 ± 12.47^b	47.95 ± 4.39^b
Ash (%)	1.41 ± 0.10^a	3.67 ± 0.54^a	4.09 ± 2.32^a
Salt (%)	0.30 ± 0.12^a	0.44 ± 0.18^a	0.51 ± 0.25^a
pH	5.98 ± 0.10^a	6.00 ± 0.08^a	6.03 ± 0.10^a

Means of each species with different superscripts (a, b) within a row are significantly different at $\alpha < 0.05$.

Table 3. Microbiological quality (mean ± SD) of FM, CSM and GSM ($n = 4$)

Microorganism (log CFU g^{-1})	FM	CSM	GSM
Total mesophilic count	7.5 ± 1.0^a	3.0 ± 2.3^a	4.0 ± 4.2^a
Fecal coliform	3.1 ± 0.9^a	2.2 ± 1.8^a	1.6 ± 1.3^a
E. coli	2.4 ± 2.0^a	1.4 ± 0.5^a	1.6 ± 1.2^a
C. perfringens	1.9 ± 0.8^a	0.7 ± 0.2^b	0.8 ± 0.2^b
Yeast and mold	3.9 ± 0.4^a	3.3 ± 2.3^a	3.8 ± 0.6^a
S. aureus	1.2 ± 0.6^a	0.8 ± 0.2^a	ND

Means of each species with different superscripts (a, b) within a row are significantly different at $\alpha < 0.05$.ND, not detected.

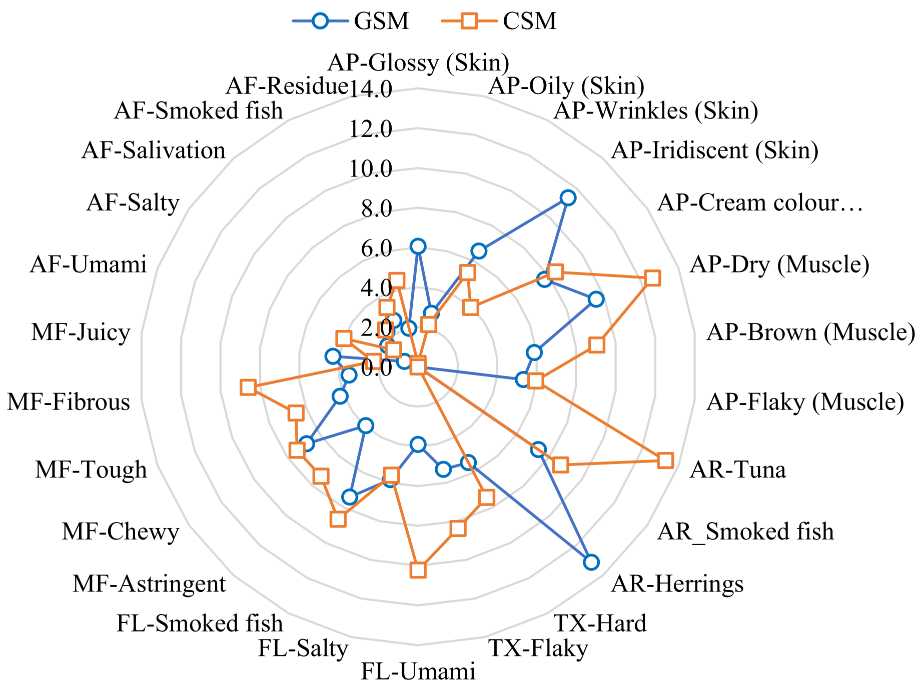

Figure 2. Spider web plot of sensory profile of CSM and GSM (AP, appearance; AR, aroma; TX, texture; FL, flavor; MF, mouthfeel; AF, aftereffect).

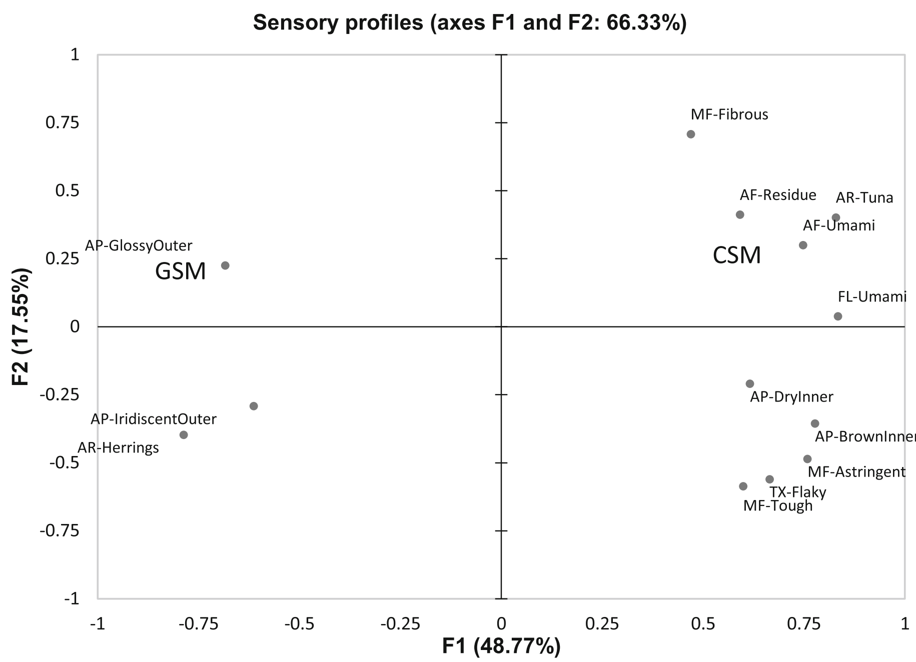

Figure 3. Product map showing product and descriptor loading of CSM and GSM (AP, appearance; AR, aroma; TX, texture; FL, flavor; MF, mouthfeel; AF, aftereffect).

13 descriptors. From Fig. 3, the first principal component (F1) explained 48.77% of the total variation of 66.33% in all the sensory attributes. GSM samples were located to the left and characterized by a glossy appearance, an iridescent color and a herring aroma. CSM samples were on the right and described to have brown muscle, a tuna aroma with an intense umami taste. The sample was also flaky, fibrous and left the mouth feeling dry (astringent).

DISCUSSION

Performance of smoking kilns

The efficiency of a kiln is measured by the specific fuel consumption, the throughput capacity, the length of time spent smoking and the quality of the final product, in comparison with another.[7,14,24] Concerning the throughput capacity, it was estimated that the Chorkor could load the most fish per smoking session, followed by the Cabin. From the CCT, the Cabin saved about 29% more firewood, making it more fuel efficient. This saving potential did not, however, meet the 40% fuel saving requirement of the Energising Development (EnDev) programme.[7] However, there was an added benefit of the Cabin as more charcoal (char) was saved, which the processors used to fuel their local stoves in the preparation of household meals. A study by IRI-CSIR *et al.*[15] compared the Chorkor kiln and Ahotor kiln (an improved kiln currently being promoted for adoption in Ghana) and gave the Ahotor kiln a fuel-saving potential of 32% over the Chorkor kiln. The Ahotor recorded higher fuel savings than those recorded by the Cabin in this study and this could be attributed to the fact that the moisture content of the firewood was high (61.1%) compared to that from this study which was 19.2%. Taylor[25] found that firewood with a moisture content of 60% and above burns slowly and can lead to incomplete combustion, which produces dirty smoke, which is not healthy. The best firewood for effective burning must therefore be properly seasoned/dried and must have a moisture content below 20%, which was the case in the present study.

The time spent smoking in the Cabin was 15% less and this corresponded to a higher processing rate (16%) compared to the Chorkor. The closed design of the Cabin and the control of air entering the fireplace may have contributed to its fuel and time savings as well as higher processing rate, as most of the heat was kept in the smoke chamber and the fire burned in a controlled way. The smoking time was less than that in a similar study by Entee,[7] who reported smoking times of 285 to 709 min (corresponding to processing rates of 190.4 and 27.5 g min^{-1}) in the Morrison and AWEP kilns, respectively. That for Chorkor was higher than in the present study but the FAO Thiaroye Technique had a rate of 44.2 g min^{-1}.

A comparison of the Chorkor and Cabin kilns with the AGFS showed that the latter performed best, followed by the Cabin and then the Chorkor kilns. In terms of throughput capacity, the latter could hold more fish per smoking cycle (maximum capacity of 500 kg) and smoke it faster than the former. Thus, the processing rate was much faster. This could be very useful, especially during the bumper fish season, in reducing the postharvest losses that are encountered.[26] The AGFS had a fuel-saving potential of 68% and 54% higher than the Chorkor and Cabin, respectively, which met the 40% fuel-saving requirement of EnDev.[7] The yield was, however, significantly lower in the AGFS and was a result of the superior drying achieved. This, combined with the reduced moisture content, could make products more shelf-stable, relative to those from the Chorkor and Cabin.[6] Yield, on the other hand, is also of high economic importance as the price of smoked fish mostly depends on the weight so this might affect the profitability of the operation.[3] The cost of fuel was higher than when firewood was used, and this is a result of the high price of LPG generally. However, with about 51% of Ghanaians dependent on firewood and another 35% relying on charcoal (derived from wood) as their primary fuel source, coupled with the fact that about 72% of the country is vulnerable to desertification, firewood is considered an unsustainable choice.[9]

Asamoah *et al.*[17] conducted a study on the safety of smoked products from the Chorkor, Cabin and AGFS, concerning polycyclic aromatic hydrocarbons (PAHs). Their study found that GSM had benzo(a)pyrene (BAP) and PAH4 (sum of benzo(a)anthracene, chrysene, BAP and benzo(b)fluoranthene) levels below the EU maximum limits of 2 and 12 μg kg^{-1}, respectively, while that from the Cabin was lower than from the Chorkor, but still higher than the EU limits. The low levels in the AGFS mackerel ensure a safe product for local consumption and for export to especially the EU market, which could promote its adoption.

Nutritional quality of fresh and smoked fish

The nutritional content of fish may differ according to species, body size, season, environmental factors and nutritional status.[27] The moisture, fat, protein and ash contents obtained for the fresh mackerel in the present study agreed with findings from other studies.[28-31] Smoking caused a significant reduction in moisture content (greater than 50%), relative to the raw materials. A product with a moisture content of less than 65% is considered to meet the industrial specification of 'smoked finished products'.[32] From the results, the smoked mackerel met this requirement. To inhibit the proliferation of spoilage microorganisms, such as mold, and therefore preserve smoked fish for a longer period, a moisture content of 25% or less (wet weight) has been recommended.[33] The final moisture content, however, depends on the desired products, whether soft-smoked or smoke-dried. Mackerel from both kilns is typically soft-smoked and thus not expected to meet the requirement above. This, therefore, accounts for the shorter shelf-life of the products (typically 1 to 3 days), if not refrigerated.[6]

Smoking resulted in a general increase in the protein, fat and ash contents, which corresponded to an increase in the dry matter content, resulting from dehydration. This agreed with the findings of several authors.[8,33,34] Protein constituted the greatest percentage of the dry matter in the smoked samples and this agrees with a study by Daramola *et al.*[35] A study by Suryanti and Suryaningrum[36] found significantly lower protein content in smoked tilapia fillets as compared to fresh ones and attributed this to protein denaturation and subsequent uncoiling of polypeptide chains during smoking. Temperatures of 100 °C have been reported to cause protein denaturation and the loss of essential amino acids.[37] This suggests that the two smoking kilns used possibly operated at a temperature low enough to prevent protein denaturation and keep the quality of the smoked fish. The higher fat content in the smoked fish as compared to the fresh fish might cause an increase in the energy value of the smoked fish, as suggested by Adeyeye *et al.*[31] Lipid oxidation can, however, occur, which may affect the flavor, odor and general quality of the smoked fish.[8] The increase in the ash content may be because of the deposition of mineral elements present in the salt during the brining process.[36] The nutritional quality of the smoked products did not differ significantly between the AGFS and the Cabin. This could be due to the similar moisture losses observed in smoked fish from both kilns, which allowed the concentration of nutrients not to significantly differ, as observed by Tiwo *et al.*[38]

The acidity of fish muscles generally decreases with smoking, as a result of high temperature, absorption of acid from smoke, dehydration and reaction of phenols, polyphenols and carbonyl compounds with protein and protein constituents.[8] The pH values of smoked samples in this study, however, increased slightly (but not significantly) from that of the raw samples. The pH is one of the most important factors that can influence microbial growth and cause spoilage of seafood.[39] A pH value of 7 presents optimal conditions for microbial growth, as most tolerate pH between 5 and 8.[40] The pH values of the smoked mackerel in the present study were all within this range and so their shelf life could be affected; thus proper storage is required.

Microbial quality of fresh and smoked fish

Fresh or processed seafoods are excellent substrates for the growth of most common bacterial agents of foodborne diseases, especially when held at improper temperatures.[6] In fish, the proposed limit of acceptance for human consumption of total mesophilic counts is 7 log CFU g^{-1}.[21,41] The initial quality of the raw mackerel in this study had counts exceeding this limit (7.5 log CFU g^{-1}), which might suggest poor handling. The Ghana Standards Authority has set limits for *E. coli* and S. *aureus* in fresh and smoked fish at 3 and 4 log CFU g^{-1}, respectively; and that for fecal coliform and yeasts and molds at 2 and 4 log CFU g^{-1}, respectively.[41,42] The results obtained showed fecal coliform counts above the limits in FM and CSM (possibly from post-smoking contamination) samples, with all others falling below the limit. The results suggest that smoking led to the final products having lower microbial counts than the fresh products. This could have resulted from the combined effects of salting, which lowered the water activity; high-temperature drying, which provided a physical surface barrier to the passage of microorganisms; and deposition of antimicrobial compounds, which delayed microbial growth.[8] Smoking also caused a general decrease in the prevalence of microorganisms except in the case of *E. coli*, which increased in CSM or remained the same. Fecal coliform and *E. coli* are indicator organisms, and their presence could indicate fecal contamination and the possible presence of pathogenic bacteria.[43] The presence of fecal coliforms and yeasts and molds may be a result of their high thermal tolerance, making smoking less effective, or poor adherence to good management practices after smoking.[44] This is consistent with observations by Aheto *et al*.[45] that smoking usually decreases total viable bacterial counts, while other microorganisms like molds and yeasts may persist due to their heat resistance. *C. perfringens* can produce heat-resistant spores that can cause food poisoning.[46] The results from the present study, however, show counts below the borderline limit of 10 to $<10^4$ reported by Center for Food Safety[47] in both fresh and smoked samples, an indication of their good quality.

Sensory quality of smoked fish

To ensure that a product does not experience market failure, sensory analysis is required. Consumers often demand products that are safe and of good nutritional and sensory quality.[48] The results indicated that overall, the cabin-smoked products had a more traditional smoky appearance, flavor and aroma, as opposed to the gas-smoked samples which had a more fried aroma, flavor and appearance. Consumers usually use the color of dehydrated foods as a quality indicator that determines their purchase decision.[23] In Ghana, the skin color of smoked fish ranges from black, dark brown, golden brown or light brown to dirty white; however, consumers prefer golden brown or dark brown color.[49] The Cabin products conformed to this and could be easily accepted by consumers, as compared to the gas-smoked samples. The lower smoky notes in the gas-smoked samples may have been because of insufficient smoke generation and time. This could further affect the acceptability of the product by consumers who are used to the smoked color, flavor and aroma of traditionally smoked fish in Ghana.

CONCLUSIONS

Three kilns, the Chorkor (traditional), Cabin and AGFS (improved) kilns, were investigated based on their performance and the quality of the smoked products produced. The results suggest that the AGFS and Cabin were more efficient than the Chorkor. Between the AGFS and Cabin, no significant differences were found in the nutritional and microbiological quality of their products. However, significant differences were found in the sensory attributes, mainly appearance, texture and flavor (aroma and taste). Based on the findings, it is recommended that further studies be carried out to assess the adoption of these kilns in Ghana.

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DATA AVAILABILITY STATEMENT

Research data are not shared.

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