

NUTRITIONAL COMPOSITION, BACTERIAL LOAD AND ORGANOLEPTIC QUALITY OF FARM-RAISED CATFISH (*Clarias gariepinus*, Burchell 1822) FROM THE DORMAA MUNICIPALITY, GHANA

ADDO, S., SOWAH, W., AMPONSAH, S. K. K., ISSIFU, K. & ASAMOAH, E. K.
(A.S., S. W. & A E. K.: Department of Marine and Fisheries Science, University of Ghana, Legon, Accra, Ghana.; A. S. K. K.: Department of Fisheries and Water Resources, University of Energy and Natural Resources, Sunyani, Ghana.; I. K.: Fisheries Commission, Ministry of Fisheries and Aquaculture Development, Bono Region, Ghana.)
*Corresponding author's email: niidaddo@gmail.com

ABSTRACT

The aim of this study was to assess the quality of farm-raised African catfish (*Clarias gariepinus*, Burchell, 1822) in the Dormaa Municipality, Ghana. Thirty (30) individuals of freshly harvested fish of average weight 912.78 ± 16.43 g obtained from a fish farm and an equal number of smoked farm-raised fish of average weight 769.19 ± 6.48 g were used for the study. The mean values obtained for the proximate analysis of fresh catfish were: moisture (77.4 ± 1.94 %), ash (1.34 ± 0.26 %), fat (0.57 ± 0.17 %), protein (17.58 ± 0.23 %) and total carbohydrate (4.45 ± 1.55 %) and those for the smoked fish were: moisture (11.63 ± 0.43 %), ash (7.06 ± 0.66 %), fat (9.31 ± 1.80 %), protein (25.72 ± 1.51 %) and 53.34 ± 0.15 % for total carbohydrate. The overall acceptability of fresh and smoked farm-raised catfish ranged from 3.2-4.6 and 3.0-3.8 respectively. There were significant differences ($P < 0.05$) in the nutritional, bacterial and organoleptic qualities between the fresh and smoked catfish. Results from the study revealed higher nutritional composition in smoked catfish and lower bacterial loads in both fresh and smoked fish except *E. coli*, which must be of concern for consumer safety. It is recommended that farmed catfish should be smoked before consumption to obtain maximum nutritional benefit.

Keywords: Consumer safety, nutrition, food microbes, Ghana, consumer acceptability

Introduction

In Ghana, fish is considered the prime source of animal protein alluding to its relatively large scale of production and consumption in comparison with other protein source alternatives such as meat. The African Catfish in Ghana, otherwise known as (*Clarias gariepinus*), is an extremely vital freshwater fish and hence being the second most cultured freshwater fish in the country (FAO, 2016; MOFAD, 2023). Due to its distinctive taste,

texture and flavour, it has largely been accepted in most parts of Ghana, with evidence of their wide acceptability being shown in their extensive distribution and cultivation in most ponds nationwide.

In Ghana, the African catfish is predominantly obtained from fish farms and locally consumed in the smoked form (Asiedu *et al.* 2018). However, fish handling during processing, storage, distribution and marketing is of much concern, especially, in

rural communities and could compromise the quality, including the organoleptic. Poor fish quality has dire consequences, which transcend the loss of an important protein source to the health of the consumer. Fish has been implicated in several outbreaks of food-borne infections. It is a potential vehicle for food-borne diseases such as cholera, listeriosis, salmonellosis and others. Fish spoilage microorganisms, like *Pseudomonas* spp. and *Proteus* spp. have also been associated with fish (Aboagye *et al.*, 2020).

Consumers in recent times, have begun to comprehend that their choice of food can have a subsequent impact on their health (Franz & Nowak, 2010). Research indicates that modern consumers of varied age groups are well informed of the nutritional and health benefits derived from fish consumption (Bamberger-Gateau *et al.*, 2005; He, 2009; Kaimakoudi *et al.*, 2013; Morales & Higuchi, 2020; Sachettini *et al.*, 2021).

In the Dormaa municipality in the Bono Region of Ghana, catfish is consumed both in

the fresh and smoked forms with majority of the affordable catfish products on the market coming from farms. The fish is more expensive if obtained from the natural environment, with the believe that it is tastier and healthier. But the continual dwindling of the quantity of catfish obtained from the wild and the high cost has drawn many consumers towards the consumption of farm-raised catfish.

This study was therefore undertaken to evaluate the nutritional, bacterial and organoleptic quality of farm-raised African catfish, *Clarias gariepinus* in the Dormaa Municipality of the Bono Region in Ghana.

Experimentation

The research was done in the Dormaa Central Municipality, located in the Brong Ahafo region and adding up to the other twenty-six (26) administrative districts within the region. Formed under the Local Government Act of 1993 (Act 462), it remains one of the oldest districts situated in the west of the Bono Region.

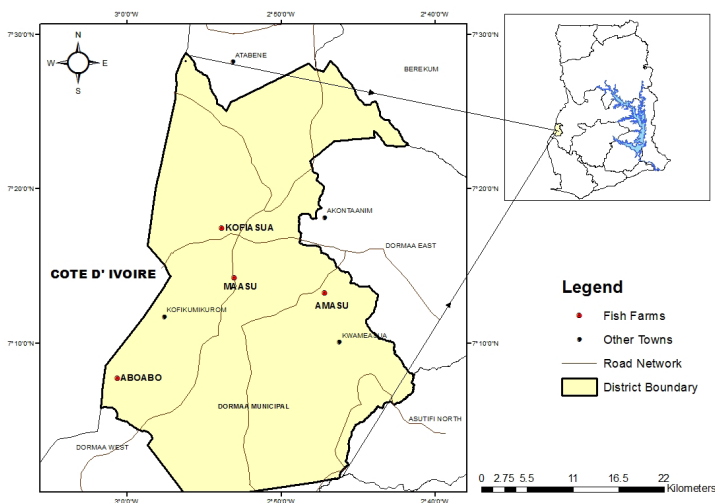


Fig. 1: A map of Ghana showing the Dormaa Municipal Area.

Thirty (30) samples of fresh fish and smoked samples of *Clarias gariepinus* were purchased from fish farms and markets, respectively within the municipality. Their corresponding length and weight data were taken using aseptic means to avoid cross-contamination and neatly packaged in sterile zip lock bags and kept in a chest cooled with ice. Fish samples were packaged aseptically, labelled accordingly and transported to the Food and Nutrition Laboratory, University of Ghana.

Proximate analysis of fish

The fish samples were sorted and grouped into individual farms for both fresh fish and smoked fish samples. Each grouping of the fish was blended and homogenized and samples kept for analysis under aseptic conditions. Analysis of the samples was done in triplicates for protein, fat, fiber and ash contents based on procedures defined by the Association of Official Analytical Chemists, AOAC (2005).

Moisture content

The amount of moisture was deduced by evaluating the pre and post-evaporation masses of the fish. The fish samples' moisture content was determined by measuring the initial mass (MINITIAL) of the sample using a digital weighing scale. The samples were then dried in an oven at 105 °C overnight till they reached a steady mass and the mass recorded as dried mass (M DRIED). Using the formula below, the amount of moisture in percentage was then The fish samples were then grounded in porcelain can until homogenized samples were obtained. Approximately 2g each of the homogenized samples was weighed to determine the proximate composition.

Crude protein

The Kjeldahl technique – determines a

sample's overall amounts of nitrogen once digested using a catalyst in sulphuric acid – was used to deduce the crude protein of the samples. The samples were digested with 15mls of concentrated Sulphuric acid (H_2SO_4) in combination with a catalyst (a mixture of potassium sulphate and copper sulphate) for about one and half hours and allowed to cool for about 15 min. The resulting digestate was distilled in the presence of strong alkali, sodium hydroxide (NaOH). The ammonia released was collected in an aqueous solution of boric acid and titrated against 0.01M HCl. The blank was determined following the same procedure. Based on the determined ammonia, equivalent nitrogen was calculated. To determine the crude protein in percentage, a factor of 6.25 was multiplied against the percentage of nitrogen of the sample (AOAC, 2005).

Ash content

The amount of ash contained in a sample is the white-coloured remains of the sample retained when ashed in a muffle furnace at approximately 550-600°C. The amount of Ash was determined by burning about 2g of each fish sample in a muffle furnace at 600°C for 2 hrs. The percentage remains weighed was regarded as ash content.

Fat content

The amount of fat was determined by oven-drying samples at 500C prior to removing the crude fat with petroleum ether in a Soxhlet extractor for 4 hours.

Total carbohydrate

Carbohydrates were deduced from the difference between 100% and the sum of ash, protein, moisture and fat contents and results recorded.

Microbiological analysis of fish

Enumeration of Total Viable Aerobic Count

Total viable aerobic bacteria of fish were enumerated by standard plate count (SPC) procedure (Maturin & Peeler, 2001). For enumeration of TVAC, 10 g sample was added to 90mL sterilized 0.1% peptone water, out of which an aliquot of 1mL was aseptically decanted into duplicate sterile Petri plate and sterile melted (around 40–45OC). Plate Count Agar was poured over it, rotated clockwise-anticlockwise, left to harden, then kept warm at an inverted position at 37°C for 24–48 hours. After incubation, the plates having well-spaced colonies (30–300) were used for counting and the colonies were counted by a colony counter (Stuart Scientific, UK). Total viable aerobic count per mL or per g was calculated by multiplying the average number of colonies per plate by reciprocal of the dilution and expressed as colony forming units(cfu) per milligram of the sample (AOAC, 1995).

Total coliform count

The total coliform count was determined on violet red bile agar (Oxoid) using pour plate technique and an overlay with the same agar after solidifying. Plates were aerobically incubated in inverted positions at 37°C for 24–48 h.

Staphylococcus aureus

Staphylococcus aureus was determined on Baird Parker Agar (Oxoid CM 275) supplemented by egg yolk tellurite at 37°C for 24–48 hours. Typical black colonies with zones around and atypical black colonies were considered as *Staphylococcus* species.

Escherichia coli

Escherichia coli were enumerated on EMB agar medium (Oxoid). At a temperature of

25°C, plates were kept warm aerobically upright for 48 hours.

Organoleptic assessment of fish

A five-point Hedonic scale as described by Sugri *et al.* (2010) was used to score samples for eye colour, odour/smell, skin feel/texture, skin colour and overall acceptability (Appendix 1). Blindly Coded samples were served to each member of 20 panelists for their sensory evaluation.

Statistical analysis

Data attained after the microbiological and proximate analysis were subjected to descriptive statistics to estimate the mean, maximum and medium values. Purposive random sampling used in selecting the respondents for the organoleptic studies. Organoleptic properties obtained from respondents were analyzed with the Social Package for Statistical Software (SPSS). Data cleaning in SPSS was done to ensure that values for the right codes were entered before analysis proceeded. Inferential statistics including sample T-test was employed to test whether or not there were differences regarding significance in proximate structure between the fresh and farmed catfish samples at a confidence level of 95 %. Information gained from analysis were presented in the form of spider web and bar graphs for easy understanding.

Results and discussion

Nutritional composition

From Figure 2, the mean concentration of moisture in the smoked farmed catfish was $11.63 \pm 0.43\%$ while in the fresh farmed catfish, the value was $77.40 \pm 1.94\%$. Using the T-test analysis, the difference in total concentration

for the assessed fish samples was significant ($p < 0.05$). The mean ash concentration in the smoked farmed catfish was 7.06 ± 0.61 % while in the fresh farmed catfish, the value was 1.34 ± 0.26 %. The mean fat concentration in the smoked farmed catfish was significantly higher (9.31 ± 1.80 %) than the fresh farmed catfish (0.57 ± 0.17 %). Mean per cent protein in the smoked fish was 25.72 ± 1.51 % while in the fresh fish, it was 17.58 ± 0.23 %. There was significant difference ($p < 0.05$). Total carbohydrate mean values in the smoked and fresh farmed catfish were 53.34 ± 0.15 and 4.45 ± 1.55 respectively. Using the T-test analysis, the difference in total concentration for the assessed fish samples was significant ($p < 0.05$).

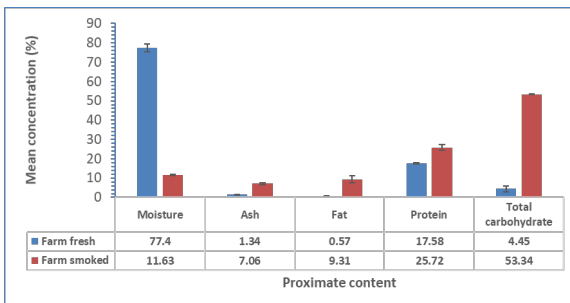


Fig. 2: Nutritional composition of fresh and farm-raised catfish from the Dormaa Municipality

The significant moisture reduction found in the smoked African catfish, *Clarias gariepinus* in relation to fresh catfish is due to the heat the fish samples were subjected to during the hot smoking process. Ikeme (1991) reported a moisture content range between 7 and 15 % for smoked catfish, which corroborates the moisture content of 11% from this study. Such relatively low moisture content implies that smoked catfish could have comparatively prolonged storage duration (3 – 9 months) than fresh catfish. This is because the conditions

are not conducive for the growth of bacteria responsible for spoilage (Daramola *et al.*, 2014). The percentage crude protein values were comparatively higher in smoked fish than fresh fishes. This observation followed the general rule of inverse relationship that exists between moisture and protein as well as moisture and fat. Okereke *et al.* (2014) in their studies on the comparative nutritional composition of smoked catfish (*Clarias gariepinus*) produced from NIOMR Smoking Kiln and Local Cut Drum Oven found similar observation in smoked and fresh catfish. The increase in protein might be because of fish dryness which intensified the proteins through the heat treatment of the fish, subsequently increasing the catfish's nutritional value. Furthermore, high crude protein value obtained for smoked *Clarias gariepinus* implies that it is a good source of pure protein, hence can aid in the adequate prevention of malnourishment in children, and necessary for the growing population in Ghana and other third world countries that depend on fish as their prime protein source.

The smoked fish's significant ash content increase as compared to the fresh fish could be assigned to dry matter increments for every unit of weight after the processes of drying and smoking (Adeyeye *et al.*, 2015). The high amount of ash in the smoked catfish according to the study (7.06) was in the range of 5.4 – 15 as reported by Ikeme (1991). This high amount of ash could be assigned to the loss of humidity. The relatively high level of fats in smoked catfish than in fresh catfish from the present study was at variance with studies by Sesugh *et al.* (2012). These researchers who studied 'Proximate analysis of smoked and fresh fish (cat and tilapia) in Ombi River Lafia Nasarawa State Nigeria' reported a higher level of fats and proteins in fresh catfish than

smoked catfish. This variation in observation maybe linked to the species environment condition, sex of species, and method of preservation. Generally, the significant changes in the proximate composition of the smoked catfish as compared to the fresh catfish may be attributed to the action of the heat from the smoke oven used.

Microbiological analysis

Table 1 provides the microbial content for both smoked and fresh farmed catfish. The mean amount of Total Viable Count in the smoked catfish was 4.2×10^5 CFU/g while in the fresh fish, the value was 2.2×10^5 CFU/g. These values depicted significant difference (p

> 0.05). The mean count of Total Coliform in the smoked fish was 0.0 CFU/g while that of the fresh fish was 8.7×10^2 CFU/g. The mean count of *Staphylococcus aureus* in the smoked and fresh fish was 2.8×10^3 CFU/g and 5.5×10^3 CFU/g correspondingly, showing insignificant difference ($p > 0.05$). The mean colony counts of *E. coli* in the smoked catfish was 2.5×10^3 CFU/g while in the fresh fish, the value was 2.3×10^3 CFU/g without significant difference ($p > 0.05$). Except for *E. coli*, the observed values were below the Ghana Standard Authority (GSA) and the International Commission on Microbiological Specifications for Foods (ICMSF) standards (1.0×10^7 cfu/g for TVC; 1.0×10^4 cfu/g for *Staphylococcus aureus* and 1.0×10^2 cfu/g for *E. coli*) (ICMSF, 1988).

TABLE 1

Microbial content of assessed smoked and fresh catfish from the Dormaa Municipality

Parameter	Mean Colony Counts (CFU/g)		
	Fresh	Smoked	P value
Total Viable Count	2.2×10^5	4.2×10^5	0.22
Total Coliform Count	8.7×10^2	0	0.34
<i>Staphylococcus aureus</i>	5.5×10^3	2.8×10^3	0.06
<i>Escherichia coli</i>	2.3×10^3	2.5×10^3	0.95

Bacterial development is the fundamental driver of fish waste; hence, it is reasonable to utilize bacterial count as a key of fish wholesomeness (Nahid *et al.*, 2016). The use of mild smoking treatment which does not achieve complete elimination of microbial load in smoked fish may have accounted for the presence of high bacterial growth in smoked catfish than in fresh catfish (Alao *et al.*, 2017). Nonetheless, the values of TVC derived for both fresh and smoked catfish fell within ICMSF's (1988) recommended microbiological limits for fish and other related products. The commended TVC limit for fish intake falls between 6 and

7 log cfu/g (ICMSF, 1988). Thus, smoked and fresh catfish from the study are of good quality. The high coliform count in the fresh farmed sampled recorded in the present study might be as a result of pollution arising from fertilizing ponds with animal waste (Daramola *et al.*, 2014). Thus, the use fresh farmed fish with little or no processing, necessitates a suitable percentage use of a selected antimicrobial agent. However, the absence of coliform in the smoked farmed fish could be attached to the processing technique (smoking). Swatawatsi (2008) in his studies on quality and safety of smoked catfish (*Aries talassinus*) using

paddy chaff and coconut shell liquid smoke found that the lower amount of coliform in smoked catfish was as a result of the smoking processing. Studies by Nahid *et al.* (2016) on the quality and safety aspect of four types of smoke-dried Chapila (*Gudusia Chapra*; Hamilton-Buchanan, 1822) fish in Dhaka also reported that smoke-drying process reduces bacterial load in fish. Also, Edris *et al.* (2017) who investigated microbiological assessment of some heat-treated fish products in Egyptian markets stated that the presence of coliform in food is largely dependent on inadequate hygienic measure and mishandling. The low level of pathogen including *Staphylococcus aureus* from the study of the smoked catfish may be due to the presence of low moisture content in the smoked catfish. It has been documented that high moisture content levels in the fish samples encourage the growth of microorganisms (Olaleye and Abegunde, 2015). Further this, Adeyeye *et al.* (2015) in their studies on Assessment of Microbial Safety and Quality of Traditional Smoked Bonga Shad (*Ethmalosa fimbriata*) from Lagos State, Nigeria attributed the presence of *Staphylococcus aureus* to post-processing

contamination. The presence of *Escherichia coli* which is indicative organism representing contamination by microorganisms from enteric origin may be due to the ineffectiveness of the smoking kiln (Olayemi *et al.*, 2012). The ineffectiveness of smoking was reliant on allowing contact between fish smokers and the fish during smoking, thus accounting for the relatively high amount of *Escherichia coli* in smoked fish than in fresh farmed fish from the study. Adeyeye *et al.* (2015) stated that the occurrence of *Escherichia coli* may serve as the presence of indicator organisms for faecal contamination of foods which precipitates from non-adherence to good management practices (GMPs).

Organoleptic properties

The results from the sensory evaluation of farmed fresh catfish are shown in Figure 3 and Table 2. Eye colour, skin colour, texture, odour and overall acceptability scored 3.2 ± 0.1 , 3.8 ± 0.1 , 4.0 ± 0.2 , 3.17 ± 0.2 and 4.6 ± 0.1 correspondingly. From the five sensory attributes, overall acceptability scored the highest, followed by texture with odour scoring the least.

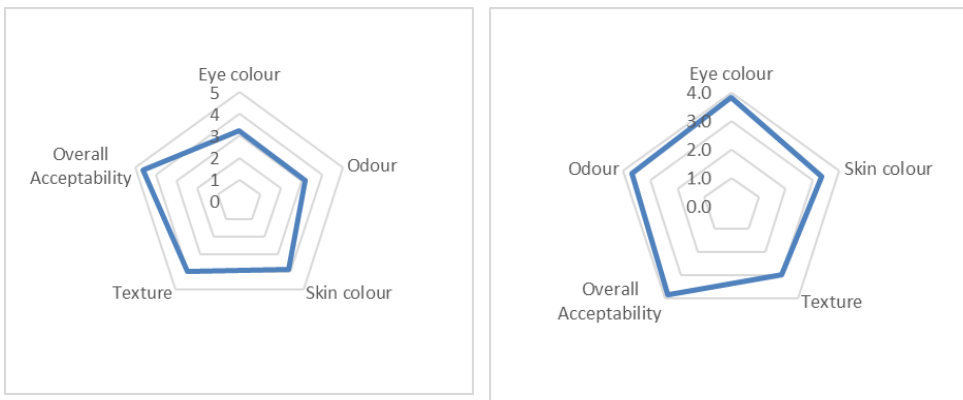


Fig. 3: Organoleptic properties of fresh (left) and smoked (right) farm-raised catfish.

Figure 3 shows the results from the sensory evaluation of smoked farm-raised catfish. From the five sensory attributes, overall acceptability scored the highest in both fresh and smoked catfish but the difference was significant ($P < 0.01$). The least scored attributes were odour (3.17) for fresh fish and skin colour (3.3) for smoked fish. All the organoleptic properties showed significant differences between fresh and smoked catfish (Table 2).

TABLE 2
Organoleptic attributes of fresh and smoked farm-raised catfish.

Attributes	Fresh	Smoked	P value
Eye colour	3.23	3.8	0.02
Skin colour	3.83	3.3	0.02
Odour	3.17	3.7	< 0.01
Texture	4	3.8	< 0.01
Overall acceptability	4.63	3.8	< 0.01

A similar observation was made by Yakubu and Ngueku (2015) who investigated smoked-dried fish for their organoleptic properties from five Lafia markets in Nigeria. From their studies, they observed that the odour and texture attributes of smoked fishes were low due to poor handling. Furthermore, the low level of the score for texture in the smoked farmed fish could be due to case hardening which causes checking, cracking and wrapping in smoked fishes. However, Achanta and Okos (1996) indicated that moisture lost from the surface of fish can be adequately slowed down at a drying rate that allows sufficient replacement from inside the fish to prevent crust formation. Modifications in muscle structure due to heating include coagulation of the perimysial and endomysial connective tissue, sarcomere shortening, myofibrillar fragmentation,

and coagulation of sarcoplasmic proteins and detachment of the myofibrils from the muscle fiber bundles in smoked fish may have accounted for the low score than observed for fresh farmed catfish (Rahman, 2007). Fish colour is a prime consumer appeal feature and smoke determines it. The smoked dark colour as compared to the slimy shiny dark colour of fresh farmed catfish could be due to the high temperature and type of fuelwood used (Toldra, 2010). This high temperature increases the concentration of the components of the dispersing phase of smoke and the rate of the carbonyl-amino reactions and polymerization of various components. Rahman (2007) mentioned that during smoking, the fish colour becomes apparent when the temperature at the fish surface gets to 54.4°C–60°C. Furthermore, the colour of the smoked catfish maybe due to the type of fuelwood used in smoking (Toldra, 2010). For instance, to impart the colour of the smoked product, resins and carbohydrate-rich wood (e.g., bagasse [sugarcane], beet refuse from sugar making, or coconut husks) is utilized. Nahid *et al.* (2016) stated that the colour varies from shades of black and brown to dirty white. According to Ziemba (1969) and Ruiter (1979), development of the colour of smoked products come from the reactions of carbonyl compounds, mainly glycolaldehyde and methylglyoxal available primarily in the vapour phase of the smoke, with the amino groups of proteins and nonprotein nitrogen compounds. The smoke phenols form stable colours in reactions with proteins at weak alkaline conditions. Additionally, the concentration of the smoked product's colour is basically in relation to the smoke's visual thickness and the duration of smoking. Therefore, increasing the velocity and temperature of smoke quickens colour development by intensifying the concentration

of the components of the dispersing phase of smoke and the rate of the carbonyl-amino reactions and polymerization of several constituents (Toldra, 2010). The high overall acceptability for fresh catfish by the panelist could be due to the consumer food habits and preference. Similarly, (Giullén & Manzano 2002) mentioned that consumers' food habit, as well as cultural attachments to traditional food, has an effect on consumer's preference. Further to this, high level of textural changes and colour coupled with limited cooking options for smoked fish may have accounted for the high overall acceptability for fresh farmed fish.

Conclusion

From the research, the nutritional profile of the smoked (processed) catfish was significantly higher than the fresh (unprocessed) catfish, which means that more consumption of smoked catfish by the people of the Dormaa Municipality is good for their health. *E. coli* counts were higher in both smoked and fresh fish, with levels beyond internationally acceptable limits and this is a threat to safe consumption. Organoleptically, fresh catfish appeared more acceptable than smoked fish which means that consumers may prefer buying fresh rather than processed fish on the market. In reference to the results and objectives of the research, the following recommendations were made i) consumers within the Dormaa Municipality should be sensitized to consume more smoked catfish due to its comparatively higher nutritional value, ii) catfish processors and traders' association in the Municipality need to be trained by the Fisheries Commission on efficient fish handling, processing and packaging for consumer safety and sustainability of their businesses and livelihoods and iii) research

into the development of effective smoking oven (one which will reduce the frequency of contact between fish processors and the fish products) is strongly advocated.

References

- ABOAGYE, E, TANO-DEBRAH K & KUNADU A. P. H. (2020) Microbial quality of fish along with the Tilapia, African catfish and Sardinella artisanal value chains in Kpong and James Town, Ghana. *Bonorowo Wetlands* **10**, 1-17.
- ACHANTA, S. & OKOS, M. R. (1996) Predicting the quality of dehydrated foods and biopolymers: research needs and opportunities. *Drying Technology*, **14** (6), 1329–1368.
- ADEYEYE S. A. O., OYEWOLE O. B., OBADINA A. O. & OMEMU, A. M. (2015) "Evaluation of Microbial Safety and Quality of Traditional Smoked Bonga Shad (*Ethmalosa fimbriata*) Fish from Lagos State, Nigeria". *Pacific Journal of Science and Technology*, **16** (1), 286-294.
- ADEYEYE S. A. O., OYEWOLE, O. B., OBADINA A. O. & OMEMU, A. M. (2015) Influence of smoking method on quality of traditional smoked Bonga shad (*Ethmalosa fimbriata*) fish from Lagos State, Nigeria. *African Journal of Food Science*, **9** (4), 200-207.
- ALAO, A. I., ADEOYE, B. K., FAMUREWA, J. A. V. & FAJOBI, D. O. (2017). Assessment of Nutritional Qualities of Direct Contact Biogas Smoked Catfish (*Clarias gariepinus*). *Research Journal of Food Science and Quality Control*, **3** (1), 1-10.
- AOAC (1995) Official methods of analysis (16th edition), Virginia: USA.
- AOAC (2005) Official method of Analysis. 18th Edition, Association of Officiating Analytical Chemists, Washington DC, Method 935.14 and 992.24.

- ASIEDU, B., FAILLER, P., & BEYGENS, Y. (2018) Ensuring food security: an analysis of the industrial smoking fishery sector of Ghana. *Agric Food Secur* 7, 1-11.
- CAHU, C., SALEN, P., & DE LORGERIL, M. (2004) Farmed and wild fish in the prevention of cardiovascular diseases: Assessing possible differences in lipid nutritional values. *Nutrition, Metabolism and Cardiovascular Diseases*, 14 (1), 34 - 41.
- DARAMOLA, J.A., ALAO, F.O., OSOFERO, S.A. & WEMIMO, O.O. (2014) Assessment of the Microbial and Sensory Qualities of Smoked African Catfish (*Clarias gariepinus*). *Journal of Agriculture and Environmental Sciences*, 3 (1), 11-22
- EDRIS, A. A., HASSANIEN, F. S., FAHIM AZIZ EL DIN, F. A., SHALTOUT, F. A. E., ELBABA, A. H. & ADEL, N. M. (2017) Microbiological Evaluation of Some Heat-Treated Fish Products in Egyptian Markets". *EC Nutrition*, 12(3): 124-132.
- FAO (2016). The state of world fisheries and aquaculture. Rome, FAO. 105 pp.
- FAO.(2004). Strategy for human capacity development. (ACFR/WP/HCB/I/3). The Strategy provides a practical checklist for individual capacity development initiatives and covers topics such as capacity needs assessment, training needs analysis, curriculum development, delivery, and monitoring and evaluation.
- FRANZ, A. & NOWAK, B. (2010) "Functional food consumption in Germany: A lifestyle segmentation study," DARE Discussion Papers 1003, Georg-August University of Göttingen, Department of Agricultural Economics and Rural Development (DARE)
- GIULLÉN, M. D. & MANZANOS, M. J. (2002) Study of the volatile composition of an aqueous oak smoke preparation. *Food Chemical*, 79, 283-292.
- HE, K. (2009) Fish, Long-Chain Omega-3 Polyunsaturated Fatty Acids and Prevention of Cardiovascular Disease—Eat Fish or Take Fish Oil Supplement? *Progress in Cardiovascular Diseases*, 52 (2), 95-114
- ICMSF (International Commission on Microbiological Specifications for Foods) (1988). *Microorganisms in Foods 4: Application of Hazard Analysis and Critical Control point Systems to ensure Microbiological Safety and Quality*. Blackwell Scientific: Oxford, UK.
- ICMSF (International Commission on Microbiological Specifications for Foods) (1986) *Microorganisms in Foods 2, Sampling for Microbiological Analysis. Principles and Specifications*, 2nd edn. Blackwell Science: Oxford, UK.
- IKEME, A. I. (1991) Studies on the fragmentation of smoked fish: In Processing of the FAO Export Consultation on Fish Technology in Africa No.467
- KAIMAKOUDI, E., POLYMEROS, K., SCHINARAKI, M-G. & BATZIOS, C. (2013) Consumers' attitude towards fisheries products. 6th International conference on Information and Communication Technologies in agriculture, food and Environment (HAICTA 2013). *Procedia technology*, 80 (811013), 90-96
- MATURIN, L. & PEELER, J. T. (2001) Aerobic Plate Count. In: Food and Drug Administration (FDA), *Bacteriological Analytical Manual Online*, 8th Edition, Silver Spring, Berlin, 1998.
- MOFAD (2023) Annual performance report, Fisheries and Aquaculture, Ghana. Ministry of Fisheries and Aquaculture Development.
- MORALES, L. E. & HIGUCHI, A. (2020) Should we spend more on fish?—How consumer beliefs about fish influence fish and meat expenditure shares. *J Sens Stud*. 2020; 35:e12556. <https://doi.org/10.1111/joss.12556>.

- NAHID, M. N., LATIFA, G. A., CHAKRABORTY, S. C., FARID, F. B. & BEGUM, M. (2016) Shelf life quality of smoke-dried freshwater SIS fish; Chapila (*Gudusia chapra*, Hamilton-Buchanan 1822) kakila (*Xenentodon cancila*, Hamilton-Buchanan; 1822) stored at laboratory condition (26-310C). *Journal of Agriculture and Veterinary Science*, **9**, 23-32.
- OKEREKE, A. N., OKPARA, J. Y. & OGUMUKA, S. O. (2014) Comparative Nutritional Composition of Smoked Catfish (*Clarias gariepinus*) Produced from NIOMR Smoking Kiln and Local Cut Drum Oven. *American Journal of Food Technology*, **9** (7), 377–381.
- OLALEYE, O. N. & ABEGUNDE, T. A. (2015) Microbiological Safety Assessment of Selected Smoked Fish in Lagos Metropolis. *British Microbiology Research Journal*, **9** (3), 1-5.
- OLAYEMI, F. F., ADEDAYO, M. R., BAMISHAIYE, E. I. AND AWAGU, E. F. (2011) Proximate composition of catfish (*Clarias gariepinus*) smoked in Nigerian stored products research institute (NSPRI) developed kiln. *International Journal of Fisheries and Aquaculture*, **3** (5), 96-98.
- OLAYEMI, F. F., RAJI, A. O., OYELESE, O. A., OYEWOLE, S. N. & OMODARA, M. A. (2013) Effective smoking kiln for developing country. *International Journal of Scientific and Engineering Research*, **4** (1), 847-853.
- RAHMAN, S. (2007) Resistant starch in cereals: exploiting genetic engineering and genetic variation. *Journal of Cereal Science*, **46**, 251–260.
- RUITER, A. (1979) Color of smoked foods. *Food Technology*, **5**, 54 – 63.
- SACCHETTINI, G., GRETA, C., GUENDALINA G., YUNG, H., MILENA, L., ANTÓNIO, M., FEDERICA, P., MARIAROSARIA, S., WIM, V. & ETTORE, C. (2021) Assessing consumers' attitudes, expectations and intentions towards health and sustainability regarding seafood consumption in Italy. *Science of the Total Environment* **789** (2021), 148049.
- SESUGH, A., LUTER, L., ISHAQ, E. & SUNDAY, Y. (2012) Proximate analysis of smoked and unsmoked (cat and tilapia) in Ombi River Lafia Nasarawa State Nigeria. *Elixir Food Science*, **53**, 11801–11803.
- SUGRI, I., NUTSUGAH, S. K., WIREDU, A. N., JOHNSON, P. N. T. & ADUGUBA, D. (2012) Kendall's Concordance Analysis of Sensory Descriptors Influencing Consumer Preference for Sweet Potatoes in Ghana. *American Journal of Food Technology*, **7**, 142-150.
- SWATAWATSI, F. (2008) Quality and Safety of Smoked Catfish (*Aries talassinus*) Using Paddy Chaff and Coconut Shell Liquid Smoke. *Journal of Coastal Development*, **12** (1), 47–55.
- TOLDRÁ, F. (2010) Handbook of Meat Processing. 2121 State Avenue, Ames, Iowa 50014- 8300, USA, 584.
- YAKUBU, M.M. & NGUEKU, B.B. (2015) Quality assessment of smoked-dried fish from five different markets in Lafia, Nigeria. *International Journal on Fishing and Aquatic Studies*, **2**, 135-139.
- ZIEMBA, Z. (1969) The role of chemical constituents of wood smoke in the coloring of the surface of food during smoking. *Roczniki Technologii Chemii Z. ywnosci*, **15**, 153–169