Asian Journal of Fisheries and Aquatic Research

Volume 26, Issue 12, Page 163-172, 2024; Article no.AJFAR.127387
ISSN: 2582-3760

Effects of Smoking and Sun Drying on the Carcass Quality of *Oreochromis niloticus* (Linnaeus, 1758)

Tivfa Samuel Gbaior [a], Agbo Ben Onaji [a], Orfega Benjamin Kwaghvihi [a], Athanasius Aondohemen Aende [a], Amighty Olorunpelumi Ricketts [a] and Donald Torsabo [a*]

[a] *Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University, P. M. B. 2373, Makurdi, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ajfar/2024/v26i12856

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/127387

Original Research Article

Received: 27/09/2024
Accepted: 29/11/2024
Published: 14/12/2024

ABSTRACT

The effect of smoking and sun-drying processing methods on the carcass quality of *Oreochromis niloticus* were studied to determine its proximate composition and organoleptic qualities. Totally 40 samples of fish were collected, of which 20 samples were smoked dried in a smoking kiln while the remaining 20 were sun-dried. The samples were analyzed using standard methods according to AOAC (2005). The organoleptic quality was assessed using a structured questionnaire based on

Corresponding author: Email: donald.torsabo@uam.edu.ng;

Cite as: *Gbaior, Tivfa Samuel, Agbo Ben Onaji, Orfega Benjamin Kwaghvihi, Athanasius Aondohemen Aende, Amighty Olorunpelumi Ricketts, and Donald Torsabo. 2024. "Effects of Smoking and Sun Drying on the Carcass Quality of Oreochromis Niloticus (Linnaeus, 1758)". Asian Journal of Fisheries and Aquatic Research 26 (12):163-72. https://doi.org/10.9734/ajfar/2024/v26i12856.*

Hedonic scale 10, 8, 6, 4, and 2 for excellent, very good, good, fair and poor, respectively using a panel of 12 randomly selected judges. The sensory parameters for rating were taste, aroma, texture, appearance, and general acceptability. Statistical analyses were performed using IBM SPSS statistics 20.0 software. Results obtained showed that crude protein (52.57 ±0.03) and lipid content (8.90 ± 0.01) were higher in sundried carcass than in smoked carcass, with 47.88± 0.02 and 8.31±0.01 for crude protein content and lipid content, respectively. Smoked carcass maintained higher organoleptic quality with a higher acceptability ratio of 4.80±0.12 compared to the sundried samples (3.00±0.29). Sun-drying gave an optimal retention of nutrient content while smoking enhanced the organoleptic quality of the fish. It is concluded that both methods are effective for the preservation of fish. Sun-drying is however recommended for nutritional retention while smoking remains the better choice for enhanced flavour and consumer preference.

Keywords: Fish; conservation-methods; carcass quality; consumer preference.

1. INTRODUCTION

Fish plays a crucial role in global food security (Belhabib et al., 2019; Chan et al., 2021) by providing high-quality nutrition, which is rich in protein, essential fats, vitamins, and minerals (Gbolahan, 2023; Abdulwakil et al., 2024). Total contribution of fish to the animal protein consumed in Africa is about 17 % (FAO, 2022), making fish an important component of diets. The Nile tilapia (*Oreochromis niloticus*) is a popular fish species in the African region (Vajargah, 2021; Siddhnath et al., 2022; Geletu and Zhao, 2023). The fish is specifically valued for its high adaptability, rapid growth, and resilience to changing environmental variables (Ashouri et al., 2023; Tynchenko et al., 2024). In addition to these characteristics, the versatility and mild flavor of *O. niloticus* makes it a staple food in both local diets with many fish markets across the tropics (Firmat et al., 2013; Bandyopadhyay, 2022). Currently in Nigeria, animal protein intake from fish accounts for approximately 40 % (FDFA, 2021). Fish is however a highly perishable food which experience spoilage immediately after harvest as a result to its high water and protein content (Abd El-Hay, 2022; Cortés-Sánchez et al., 2024), thus creating an ideal environment for the growth of microorganisms which further accelerate the rate of deterioration (Mahmud et al., 2018; Zhuang et al., 2021). High economic losses and issues of food security are prevalent in regions with limited access to modern processing facilities like refrigerators (Tesfay and Teferi, 2017). For example, it is estimated that 30-50 % of fish harvested in Nigeria is lost due to poor handling and inadequate processing facilities (FAO, 2022). This makes traditional preservation methods such as smoking and sun-drying very crucial in extending shelf life of fish. It also reduces post-harvest losses especially in rural areas where other methods of preservation are difficult to find due to their cost implications which are often not affordable by locals.

Smoking and sun-drying are fish preservation methods that have been widely utilized in tropical climates (Al-Ismaili, 2021; Marbade et al., 2024). The former involves exposing fish to controlled heat and smoke, during which the fish flesh is dehydrated and natural antioxidants are introduced to help prevent fish spoilage (Devi and Ramalakshmi, 2024). The process of smoking fish does not only prolong its shelf life but also enhances the sensory characteristics of fish such as flavour, aroma, and colour. This value addition makes fish more appealing to consumers (Okpanachi et al., 2018). The latter on the other hand, derives its energy from solar radiation which gradually reduces moisture content in a bid to inhibit microbial activities and delay fish spoilage (Gupta et al., 2024). Areas with abundant sunlight benefit better from this method of preservation. Fish preservation by sun-drying has been reported to effectively retain the nutritional quality of fish when performed under a good hygiene (Fitri et al., 2022).

While preservation of fish by both smoking and sun-drying helps to decrease the rate of spoilage, the impact of the two methods on the nutritional composition and sensory quality of fish varies (Rasul et al., 2022). Each of the two preservation techniques present peculiar challenges and advantages. Even though smoking is more efficient and relatively fast, it is energy-intensive and demands for a consistent fuel source, which can be costly or cause climate change (Rasul et al., 2022; Aman-Hassan, 2024). Furthermore, the high temperatures generated through smoking can denature proteins and cause degradation of particular nutrients like vitamins and minerals that are heatsensitive which could lead to a reduction in the nutritional quality of the fish (Sultana et al., 2022). Sun-drying which is however a low-costly and sustainable preservation method, it depends heavily on prevailing weather conditions to be effective making it unpracticable when there is high humidity (Al-Ismaili, 2021; Rasul et al., 2022). Fish is also exposed to contamination by dust, microbes and insects if not properly handled during sun-drying (Zhuang et al., 2021). Scientific studies have produced different reports on the nutritional impact of these preservation methods. Saeid et al. (2022) and Tenyang et al. (2020) reported higher moisture content in sundried fish compared to smoked fish. Furthermore, both researches stated that smoked *O. niloticus* retained lower protein and lipid content against the sundried preservation method. On the other hand, Kapile and Kapute (2020) reported significantly higher protein content in smoked fish compared to sundried fish. Olawumi et al. (2020) in their study on the nutritional assessment of *Hetero-clarias* and *Oreochromis niloticus* under the same preservation methods reported that sundried fish had lower scores for taste and texture, making it inferior to smoked fish. Similarly, the research of Kapile and Kapute (2020) shows that smoked fish was preferred to sun-dried fish for its superior flavour, taste, texture, and general acceptability.These discrepancies therefore present the need for a comprehensive and standardized analyses to determine the specific impacts of smoking and sun-drying on the quality of *O. niloticus* carcass considering its dietary importance especially in areas with limited protein resources. The current study focuses on key quality parameters which include proximate composition (protein, moisture, lipid, and ash content) and sensory characteristics such as taste, texture, and colour. This comparative study seeks to provide relevant information that can help consumers, producers, and policymakers in making informed decisions as to which is the optimal processing technique for *O. niloticus*. Findings of the study will also contribute to the development of best practices in fish preservation, ultimately supporting food security and economic resilience in regions that depend on fish as their primary source of protein.

2. MATERIALS AND METHODS

2.1 Study Location

This study was conducted at the Fisheries Research Farm of Joseph Sarwuan Tarka University, Makurdi-Nigeria. The area is characterized by an annual rainfall of about 1330.20 mm and a mean annual temperature of about 27.80 ^{0}C (Igomu et al., 2024). Makurdi experiences a relative humidity range of 44 % to 89 % with higher values being recorded during the wet season when the rains heavier (Mercilina et al., 2018). The climatic condition of the location is ideal for traditional fish processing methods like sun-drying, smoking and fermentation.

2.2 Sample Collection

A total sample of 40 live *Oreochromis niloticus* with an average weight of 310.22±6.93 g were harvested from the grow-out ponds of the university. The fish samples were then divide into two equal halves of 20 fish samples and was used for both smoking and sun-drying.

2.3 Processing of Fish

The processing of fish for sun-drying and smoking was done according to Okeke et al. (2022) The fish samples were descaled and eviscerated by cutting ventrally using a sharp knife then saline water was used to wash properly.

2.4 Smoking of Fish

Smoking for 20 fish samples was done traditionally using smoking kiln. Firewood (*Tectona grandis*) and *Cocos nucifera* (coconut) was used as sources of energy and smoke. These were with considered based on their steady, controllable burning properties and their accompanying peculiar aroma (Alassane et al., 2022). The fish samples were evenly spread on metal wire mesh which was on the chamber of the smoking kiln. This was done to ensure optimal exposure of the fish to heat and smoke. While on the under smoking, the fish samples were monitored and observed periodically. Smoking was complete at 105 minutes when the fish samples showed a golden-brown colour with a constant weight which confirmed attainment of expected level of dehydration.

2.5 Sun-Drying of Fish

The remaining 20 samples of fish for sun-drying were split open to increase surface area for drying. The fish were then placed on elevated drying racks to ensure maximum exposure to sunlight and prevent them from contamination by dust. This setup also facilitated effective airflow around the fish. The fish samples were turned at intervals of 60 minutes to ensure uniform drying across all surfaces. The drying process lasted for 11 days with 10 hours of drying (9 am to 5pm) daily until the samples attained a stable weight, indicating moisture reduction.

2.6 Packaging of Fish Products

Five (5) sun-dried and smoked fish samples were ground separately into powdered form using a blender and preserved in airtight containers for proximate analysis. While the remaining samples were preserved in polyethene bags at room temperatures (26.1 ^{0}C to 32.4 ^{0}C) for organoleptic assessment.

2.7 Methods of Proximate Analysis

The proximate analysis of processed samples was conducted according to standard methods (AOAC, 2005). This analysis included the determination of moisture, ash, lipid, fibre, crude protein and nitrogen free extract content for both smoked and sun-dried fish samples. The procedures that were followed are stated below:

2.7.1 Moisture content

Moisture content was determined by weighing 10 g of each sample, then Oven-dried at 105 ^{0}C for 6 hours, then taken out in desiccator and allowed to cool and were weighed at intervals according to AOAC (2005)

$$\% \text{ moisture content} = \frac{initial\ weight - final\ weight}{initial\ weight} \times 100 \quad (1)$$

2.7.2 Ash content

Determination of ash content involved measuring approximately 3 g of each sample and placing in crucible that was pre-weighed. The sample was then burnt in a muffle furnace at 550 ^{0}C for 12 hours. Ash content was calculated as the cooled residue (mineral content) as follows:

$$\% \text{ ash content} = \frac{weight\ of\ mineral\ content}{weight\ of\ sample} \times 100 \quad (2)$$

2.7.3 Lipid content

The Soxhlet extraction method was utilized to analyze the lipid content of both smoked and sun-dried samples of fish About 5 g of each sample was placed in a muslin cloth bag and put into Soxhlet extractor which contained 65 % petroleum ether (boiling point range 60-80°C) as the solvent. The extraction lasted for 6 hours, after which the solvent was evaporated and the weight of the extracted fat was used to calculate lipid content.

$$\% \text{ lipid content} = \frac{w_1 - w_2}{w_1} \times 100 \quad (3)$$

Where w_1 = weight of muslin cloth bag with sample; w_2 = weight of cleaned empty muslin cloth bag.

2.7.4 Fibre content

The trichloroacetic acid method was employed to determine crude fibre. The sample was digested to remove soluble components and the remaining residue was dried and weighed. The difference in weight of the sample was calculated as the crude fibre as given in the formula below:

$$\% \text{ crude fibre} = \frac{w_1 - w_2}{w_3} \times 100 \quad (4)$$

Where w_1 = final weight; w_2 = initial weight and w_3 = weight of processed sample

2.7.5 Crude protein

Crude protein determination was carried out using the Kjeldahl method (Bremner, 1965). The crude protein in the smoked and sun-dried fish sample were calculated by multiplying the total nitrogen by an empirical factor of 6.25.

$$\% \text{ crude protein} = \% \text{ nitrogen} \times 6.25 \quad (5)$$

2.7.6 Nitrogen-Free Extract (NFE)

The nitrogen-free extract which is an estimate of water-soluble polysaccharides was calculated by subtracting the sum of percentages of moisture, ash, lipid, fibre and crude protein from 100. It was calculated as follows:

$$\% \text{ NFE} = 100 - (\% \text{ moisture} + \% \text{ ash} + \% \text{ lipid} + \% \text{ fibre} + \% \text{ crude protein}) \quad (6)$$

2.8 Organoleptic Assessment

A structured questionnaire based on a 10-point Hedonic scale (Excellent (10), Very Good (8), Good (6), Fair (4), and Poor (2)) was used to quantify preferences. A sensory panel of 12 judges was constituted to include both staff and students of the College of Forestry and Fisheries. The panel comprised of both gender for fair assessment (Adibe et al., 2018). They were guided on the criteria for scoring points on five attributes which were taste, aroma, appearance, texture, and overall acceptability. Both smoked and sundried samples of *O. niloticus* were then consistently presented to panel in a blind-tested format for rating based on their perceptions.

2.9 Statistical Analysis

Data that was obtained from both proximate analysis and organoleptic assessment were used to perform a pairwise t-test at 95 % confidence level ($P<0.05$) using SPSS version 20 to determine if there were any statistically significant differences between the variables of both fish samples.

3. RESULTS

3.1 Proximate Composition Analyses

Table 1 shows the results of the proximate composition of smoked and sundried *Oreochromis nilotius* carcass at 95% confidence level ($p < 0.05$). The sundried samples lost a significant higher amount of moisture (5.51±0.29) compared to the smoked samples (8.08±0.14). The smoked samples had a mean value of 7.31±0.01 for ash content less than the sun-dried carcass (7.99±0.01) while higher mean value of 8.90±0.01 was recorded for lipid contents for sundried fish against the smoked carcass with mean value of 8.31±0.01. The fibre content of sundried and smoked fish were 1.48±0.03 and 1.41±0.02, respectively which was statistically significant at ($p < 0.05$). The crude protein of the sundried fish sample had a higher value of 52.57±0.03 than the smoked carcass (47.88±0.02). Lastly, the mean values of 23.56±0.25 and 27.02±0.14 were recorded as nitrogen free extract for sundried and smoked carcass, respectively.

3.2 Organoleptic Assessment

The result of organoleptic assessment of sundried and smoked fish samples are presented in Table 2. The sundried sample had a lower score of 3.05±0.18 for mean taste than the smoked carcass with 4.60±0.13. The mean aroma was significantly different ($p < 5.05$) in the two samples with smoked carcass of *O. niloticus* recording a greater mean score of 4.10±0.16 against 2.75±0.24 for sundried sample. Furthermore, the mean score for colour was also significantly different ($p < 0.05$) in the two samples, smoked fish had a higher score of 4.50±0.15 compared to sundried with 3.20±0.29. Similarly, the mean texture score was significantly different ($p < 0.05$) in the two samples, as the smoked sample recorded a mean score of 4.20±0.16 against the sundried with 3.00±0.26. For general acceptability, sundried samples scored lesser (3.00±0.29) than smoked samples (4.80±0.12).

4. DISCUSSION

The results of this study present obvious differences between smoking and sun-drying preservation methods in respect to their effect on the nutritional and organoleptic qualities of *Oreochromis niloticus*. Results show that the sun-dried fish samples retained a higher crude protein content after processing compared to smoked carcass of *O. niloticus*. This result agrees with the findings of Musa et al. (2017), who also reported significantly ($P<0.05$) higher crude protein content (45.2 ± 0.05 %) against sundried fish with a 34.1 ± 0.07 % mean loss in crude protein. This could be as a result lower heat generated from sunlight as compared to high temperatures from smoking, thus reduced denaturing and degrading of proteins (Ali et al., 2022; Nanaobi et al., 2023). Exposure to heat in smoking could cause structural breakdown of protein molecules which will eventually lead to lower protein retention in the fish product (Saeid et al., 2022; Lawal and Alu, 2024). This shows that the sun-drying preservation method is a better choice when there is a target to maintain protein levels in fish. This method is more suitable for communities where fish is the major source of protein. The current study however, is dissimilar with the research of Kapile and Kapute (2017) who reported 67.20 % for crude protein content in *Oreochromis shiranus*, significantly higher than the 52.50 % found in the sun-dried fish. This could be due to the difference in fish species used for the experiment.

The result of the current study shows little difference in the mean values of lipid content of the two samples with the sun-dried sample being higher. This contradicts the report of Tenyang et al. (2020), who documented significantly greater ($P<0.05$) lipid content (35.16 ± 1.11) in smoked fish than in sun-dried fish with lipid content of 32.19 ± 0.90. An explanation to the observed difference could be due to high levels of heat and duration of smoking which could lead to rapid oxidation and subsequent volatilization of lipid, as such leading to reduced content.

Vignesh et al. (2024) states that lipids are susceptible to oxidation when heated which is further exacerbated when smoke compounds react with fatty acids, causing a break down and reduction in levels of lipid. This result means that in order to ensure the preservation of lipids, the sun-drying method may be preferred to smoking. The former however makes fish product more susceptible to contamination especially when carried out in unhygienic conditions.

Statistical analysis shows there was a significant difference in the moisture content of the two fish samples with smoked *O. niloticus* carcass retaining higher moisture content than the sun-dried samples. Hei and Sarojnalini (2012), stated that smoking generally leads in higher retention of moisture retention in fish products as a result of the enclosed environment peculiar with smoking kiln, which tends to trap some of the moisture. Sun-drying on the other hand allows for exposure to open-air which facilitates complete dehydration. Lower moisture in sun-dried fish lengthens its shelf life which can be kept for longer periods without refrigeration. Nevertheless, one advantage with the higher moisture in smoked fish is that it often contributes to a softer texture which could be a better choice for many consumers though at the expense of reduction in the lifespan of the product. This presents both methods with peculiar advantages in that while sun-drying will extend the shelf life of fish products, smoking tends to improve quality in terms of texture which may permit greater acceptability and marketability. The mineral content represented by ash in the current study was also insignificantly higher in sun-dried *O. niloticus* samples than in smoked samples. This finding corroborates the research of Msuku and Kapute (2018), who reported greater ash content (13.81±0.14) in sun-dried *Diplotaxodon* species as compared to the smoked fish (12.96±0.72). This difference could be as a result of the low heat generated by sun-drying, which prevents the loss of volatile minerals. In communities where, mineral intake from other food sources is limited, fish preservation using sun-drying method provides a nutritional advantage of mineral preservation using sun-drying method. These results further confirm sun-drying method as a better option to retain nutritional quality of fish as smoking method could make fish vulnerable to loss of minerals due to volatilization at high temperatures.

In terms of fish quality assessment using sensory perception, the scores obtained for both preservation methods differed with the proximate analyses as smoked fish samples of *O. niloticus* scored higher on attributes such as taste, aroma, and overall acceptability. These results are similar with those documented by Akinneye et al. (2010) and Okpanachi et al. (2018) and who stated that smoked fish has superior sensory appeal as a result pecular flavors imparted by smoke. The compounds from the smoke interact with the natural flavor of fish and lipids therein, which gives fish an aroma and taste that is appealing (Oli et al., 2024). Adding to it, the golden-brown colour that accompanies smoking enhances visual appeal which could be a crucial factor in consumer preference. Sun-dried fish which however lacks these flavours but rather maintains a firmer texture consequent complete dehydration recorded lower scores in organoleptic assessment. Despite the assurance of retaining more nutrients by preserving fish using sun-drying method, it's natural flavours and textures may be less appealing causing reduced market acceptability (Siddhnath et al., 2022).

Table 1. Proximate composition of smoked and sundried *Oreochromis niloticus*

Treatment	Moisture	Ash	Lipid	Fibre	Protein	NFE
Sundried	5.51±0.29	7.99±0.04	8.90±0.01	1.48±0.03	52.57±0.03	23.56±0.25
Smoked	8.08±0.14	7.31±0.01	8.31±0.01	1.41±0.02	47.88±0.02	27.02±0.14
P- value	0.015*	0.003*	0.001*	0.015*	0.000*	0.007

***Significant at 95% confidence level (p<0.05), NFE- nitrogen free extract*

Table 2. Organoleptic assessment of Sundried and Smoked *Oreochromis niloticus*

Treatment	Taste	Aroma	Color	Appearance	Texture	GA
Sundried	3.05±0.18	2.75±0.24	3.50±0.25	3.20±0.29	3.00±0.26	3.00±0.29
Smoked	4.60±0.13	4.10±0.16	4.30±0.16	4.50±0.15	4.20±0.16	4.80±0.12
p-value	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*

**Significant at 95% confidence level (p<0.05), GA- General acceptability*

The results of the current study provide a better comprehension of salient issues that accompany fish preservation most especially in communities that cannot afford modern fish preservation methods like canning and refrigeration. The sun-drying method proves to better retain nutrients in fish and extend shelf life of fish and fish products especially in areas which refrigeration is not a choice. However, fish that is smoked may be more desirable in markets where consumers place much value on the improved flavour and texture not minding if some nutrients were lost in the process of smoking. The marked differences between the two preservation methods emphasizes the need to always consider the specific demands of a population or target market with respect to both nutrient content and sensory attributes before making a choice of which fish preservation method to use.

5. CONCLUSION

This study concludes that higher levels of protein, lipids, and mineral in *Oreochromis niloticus* are better retained using the sun-drying method of preservation while smoking on the other hand better enhances sensory attributes, thus giving fish superior taste, aroma, and appearance which may attract higher market value.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENTS

The authors are grateful to the Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University, Makurdi in whose facility this research was conducted.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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