

## Original Research Article

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

#### Abstract

The effect of some processing methods on the carcass quality of *Oreochromis niloticus* from Federal University of Agriculture Makurdi Fisheries Research Farm was studied to determine their proximate composition and organoleptic qualities. A total sample of 40 *O. niloticus* were collected, of which 20 samples were smoked dried in a smoking kiln fueled by *Tectona grandis* and *Cocos nucifera* firewood while the remaining 20 were sun-dried. The samples were analyzed using standard methods according to AOAC (2005) to determine moisture, ash, crude protein, lipid, and fibre content. The organoleptic quality was assessed using a structured questionnaire based on Hedonic scale (Excellent = 10; very good = 8; good = 6; fair = 4 and poor = 2) using a panel of 12 randomly selected judges from the College of Forestry and Fisheries. Attributes for rating were taste, aroma, texture, appearance, and overall acceptability. Statistical analyses were performed using IBM SPSS statistics 20.0 software. Results obtained showed that crude protein ( $52.57 \pm 0.03$ ) and lipid content ( $8.90 \pm 0.01$ ) were higher in sundried carcass than in smoked carcass, with  $47.88 \pm 0.02$  and  $8.31 \pm 0.01$  for crude protein content and lipid content, respectively. Smoked *O. niloticus* maintained higher organoleptic quality with a higher acceptability ratio of  $4.80 \pm 0.12$  compared to the sundried samples ( $3.00 \pm 0.29$ ). 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 *O. niloticus*. Sun-drying is however recommended for nutritional retention while smoking remains the better choice for enhanced flavour and consumer preference.

**Key words:** *Oreochromis niloticus*, Nutrient value, Sunlight, Consumer Preference

#### 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 protein, essential fats, vitamins, and minerals (Gbolahan, 2023; Abdulwakilet *et al.*, 2024). Total contribution to the animal protein consumed in African is about 17% (FAO, 2022), making fish an important component of diets. The Nile tilapia (*Oreochromis niloticus*) is known be one of the most popular fish species in the African region (Vajargah, 2021; Siddhnath *et al.*, 2022; Geletu & Zhao, 2023). The fish is specifically valued for its high adaptability, rapid growth, and resilience to changing environmental variables (Ashouriet *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 high in aquaculture markets across the tropical and subtropical regions (Firmat *et al.*, 2013; Bandyopadhyay, 2022). Currently in Nigeria, animal protein intake from fish accounts for approximately 40 % (FDFA, 2021), thus an urgent need for effective preservation

Comment [AA1]: Review the sentence

Formatted: Font color: Red

methods to ensure the continuous availability of fish and its products so as meet with increasing demand as the population of the country continue to multiply rapidly (Ayuba *et al.*, 2019; Kafayat *et al.*, 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), 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). Fish quickly becomes unsuitable for consumption if it is not processed as a result of enzymatic activity, microbial contamination, and lipid oxidation (Ali *et al.*, 2022; Cortés-Sánchez *et al.*, 2024). High economic losses and issues of food security are prevalent in regions with limited access to modern processing facilities like refrigerators (Tsfay 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.

Comment [AA2]: Review sentence

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 & 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 (Okpanachiet *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 (Fitriet *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 heat-sensitive 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, depends heavily on prevailing weather conditions for it 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, with some documenting sun-dried fish as retaining higher protein content compared to smoked fish while other studies report the opposite (Tenyang *et al.*, 2020). There is also disagreement on

Comment [AA3]: Highlight some findings from previous studies to support this claim

the effect caused by these two preservation methods on the lipid content of fish. Mahmud *et al.* (2018) reported the possibility of reduced lipids due to higher temperatures by smoking which accelerates lipid oxidation, whereas sun-drying may result in higher lipid retention. 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.

## MATERIALS AND METHODS

### Study Location

The research was conducted at the Fisheries Research Farm of Joseph Sarwuan Tarka University, Makurdi-Nigeria. The research farm houses equipment required to carrying out studies in aquaculture and fisheries, thus permits studies on fish processing to be performed in a controlled setting. The climatic conditions of the location are also ideal for traditional fish processing methods like sun-drying, smoking and fermentation.

### Sample Collection and Preparation

A total sample of 40 live *Oreochromis niloticus* (Nile tilapia) were harvested from the grow-out ponds of the university. Each fish was properly eviscerated to prevent spoilage. The fish samples were then divide into two equal halves of 20 fish samples and was used for both smoking and sun-drying. Fish preparation was carried out concurrently for the two preservation methods.

### Process of Smoking

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. 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 smokin, the fish samples were monitored and observed periodically. Smoking was complete when the fish samples showed a golden-brown colour with a constant weight which confirmed attainment of expected level of dehydration. 5 fish samples were then randomly selected from the group of smoked *O. niloticus* samples and ground into a homogeneous mixture. The mixture was then stored in airtight containers for proximate composition analysis while the remaining samples were preserved for organoleptic assessment.

### Process of Sun-drying

**Comment [AA4]:** I suggest the author should highlight findings from previous studies that applied smoking and sun drying. There are very much available evidence pertaining the use of both methods in fish preservation. State their findings and what the present study is aimed to do different or add to the already existing findings.

**Comment [AA5]:** The Methodology section is poorly referenced. Mention the source of each method and state modifications (if any) that were applied to the method. Materials that were used to perform the experiment were not mentioned at all in this section.

**Comment [AA6]:** A brief description of the climatic conditions such as average temperature, humidity, annual rainfall etc in this location will be more valued.

**Comment [AA7]:** There s no mention of the weight or length of this fish sample

**Comment [AA8]:** After the first mention of both common and scientific names, it is ideal to choose and maintain either of them throughout the text.

**Comment [AA9]:** Include fish processing section. To describe how the fish were killed and prepared before they were subjected to each treatment (i.e. smoking or sun drying).

**Comment [AA10]:** How did you know this? A citation is required to support the claim.

**Comment [AA11]:** It will be good to mention the length of smoking in minutes or hours.

**Comment [AA12]:** How where they preserved?

The remaining 20 samples of *O. niloticus* 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 being contaminated with dust and soil. This setup also facilitated effective airflow around the fish. The fish samples were turned at intervals to ensure uniform drying across all surfaces. The drying process lasted for several days until the samples attained a stable weight, indicating moisture reduction. Similarly, 5 sun-dried fish samples were ground into powdered form and preserved in airtight containers for proximate analysis. The rest of the samples were kept for sensory test.

**Comment [AA13]:** You have to be specific and mention the actual intervals for turning and number of days that the fish samples were sun dried.

**Comment [AA14]:** How was the grinding done?

**Comment [AA15]:** How were they kept? Mention the packaging and the storage conditions.

### Methods of Proximate Analysis

The proximate analysis of smoked and sun-dried *O. niloticus* 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:

#### Moisture Content

Moisture content was determined by weighing about 10 g of each sample which was then oven-dried at 105 °C for a duration of 6 hours. The samples were then taken out in desiccator and allowed to cool and were weighed at intervals until there was no change in the weight of the sample. The difference between the initial and final weight of the sample was calculated as the moisture using the formula:

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

#### 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 °C for 12 hours. Ash content was calculated as the cooled residue (mineral content) as follows:

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

#### Lipid Content

The Soxhlet extraction method was utilized to analyze the lipid content of both smoked and sun-dried samples of *O. niloticus*. 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. The formula is given as:

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

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

### 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

### Crude Protein

Crude protein determination was carried out using the Kjeldahl method. 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.

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

### 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:

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

### 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. 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.

### 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 ( $P < 0.05$ ) to determine if there were any statistically significant differences between the variables of both fish samples.

## RESULTS

### Proximate Composition Analyses

Table 1 shows the results of the proximate composition of smoked and sundried *Oreochromis niloticus* at 95% confidence level ( $p < 0.05$ ). The sundried *O. niloticus* lost a significant higher amount of moisture ( $5.51 \pm 0.29$ ) compared to the smoked samples ( $8.08 \pm 0.14$ ). The smoked samples had a mean value of  $7.31 \pm 0.01$  for ash content less than the sun-dried

Formatted: Italian (Italy)

Formatted: Italian (Italy)

Formatted: Italian (Italy)

Formatted: Italian (Italy)

Formatted: Italian (Italy)

Formatted: Italian (Italy)

Comment [AA16]: Insert reference

Comment [AA17]: Mention the gender and age group of the panel members.

Comment [AA18]: State the statistical package that was used

carcass (7.99±0.01) while higher mean value of 8.90±0.01 was recorded for lipid contents for sundried *O. niloticus* against the smoked carcass with mean value of 8.31±0.01. The fibre content of sundried and smoked *O. niloticus* were 1.48±0.03 and 1.41±0.02, respectively which is 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 of *O. niloticus* for sundried and smoked carcass, respectively.

**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

#### Organoleptic Assessment

The result of organoleptic assessment of sundried and smoked *O. niloticus* 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 *O. niloticus* sample. Furthermore, the mean score for colour was also significantly different ( $p < 0.05$ ) in the two samples, smoked *O. niloticus* 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 *O. niloticus* 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 *O. niloticus* samples (4.80±0.12).

Comment [AA19]: Remove the bracket

**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

## 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*. A very key finding was 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 greater protein preservation in sun-dried fish. The reason to this may be as a result of lower heat generated from sunlight as compared to high temperatures from smoking, thus reduced denaturing and degrading of proteins (Nanaobiet *al.*, 2023). Exposure to heat in smoking could cause structural break of protein molecules which will eventually lead to lower protein retention in the fish product. 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. Another fascinating result of the current study was the 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 Tenyanget *al.* (2020), who documented greater lipid content in smoked fish. 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. Reports shows 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. This result is similar with reports of Hei and Sarojnalini (2012), who 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 some time 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 in sun-dried fish. 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

**Comment [AA20]:** Mention the fish species and state the result to show how it agrees with the present finding.

**Comment [AA21]:** Presently, rate of heating (temperature range) can be controlled in many smoking kiln. More reason you need to mention the brand/type of smoking kiln that was used in this experiment. And possibly state how the heating was controlled if that was done.

**Comment [AA22]:** Insert a reference

**Comment [AA23]:** What does this mean?

**Comment [AA24]:** Again, give a brief highlight stating the result, fish species

**Comment [AA25]:** Insert a reference

**Comment [AA26]:** Cite the report

**Comment [AA27]:** Refer to previous comments

**Comment [AA28]:** Avoid using 'some' in scientific presentation. I suggest you use 'longer time' here instead of some time.

**Comment [AA29]:** Refer to previous comments

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 Okpanachiet *et al.* (2018) and who stated that smoked fish has superior sensory appeal as a result peculiar 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. 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, its natural flavours and textures may be less appealing causing reduced market acceptability (Siddhnath *et al.*, 2022).

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.

### **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.

### **Conflict of Interest Statement**

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other journal for publication.

### **REFERNCES**

- Abd El-Hay, M. M. (2022). Processing and preparation of fish. In *Postharvest and Postmortem Processing of Raw Food Materials* (pp. 315-342). Woodhead Publishing.
- Abdulwakil, Olawale, Saba., Victor, Oscar, Eyo., Isa, Olalekan, Elegbede., Kafayat, Adetoun, Fakoya., Akinloye, Emmanuel, Ojewole., Fareed, Olatunji, Dawodu., Rashidat, Adebola, Adewale., Mohammad, Noor, Azmai, Amal. (2024). Sustaining the blue bounty: Fish food and nutrition security in Nigeria's evolving blue economy. *AIMS agriculture and food*, 9(2): 500–530 doi: 10.3934/agrfood.2024029
- Abraha B, Habtamu A, Abdu Mahmud, Negasi T, Xia W S, Yang F (2018) Effect of processing methods on nutritional and physico-chemical composition of fish: a review. *MOJ Food Process Technology*. 2018;6(4):376–382. DOI: 10.15406/mojft.2018.06.00191
- Akinneye, J. O., Amoo, I. A., & Bakare, O. O. (2010). Effect of drying methods on the chemical composition of three species of fish (Bonga spp., Sardinella spp. and *Heterotis niloticus*). *African Journal of Biotechnology*, 9(28), 4369–4373. <https://doi.org/10.4314/ajb.v9i28>.
- Akintola, S. L., Brown, A., Bakare, A., Osowo, O. D. and Bello. B. O. (2013). Effects of Hot Smoking and Sun Drying Processes on Nutritional Composition of Giant Tiger Shrimp (*Penaeus monodon*, Fabricius, 1798). *Poland Journal of Food and Nutritional Science* 63: 227-237.
- Ali, A., Wei, S., Ali, A., Khan, I., Sun, Q., Xia, Q., Wang, Z., Han, Z. & Liu, S. (2022). Research progress on nutritional value, preservation and processing of fish—A review. *Foods*, 11(22), 3669.
- Al-Ismaili, A. (2021). A review on solar drying of fish. *Journal of Agricultural and Marine Sciences [JAMS]*, 26(2), 1-9.
- Aman-Hassan, M. (2024). Physical, Chemical and Microbiological Changes Associated with Dry-Fish. In *Dry Fish: A Global Perspective on Nutritional Security and Economic Sustainability* (pp. 115-134). Cham: Springer Nature Switzerland.
- Ashouri, G., Hoseinifar, S. H., El-Haroun, E., Imperatore, R., & Paolucci, M. (2023). Tilapia Fish for Future Sustainable Aquaculture. In *Novel Approaches Toward Sustainable Tilapia Aquaculture* (pp. 1-47). Cham: Springer International Publishing.
- Association of Official Analytical Chemists (AOAC). (2005). *Official Methods of Analysis*. 18th ed. Gaithersburg, Maryland, USA: AOAC.
- Ayeloja, A. A, George, F.O.A, Akinyemi, A. A, Jimoh, W. A, Dauda, T. O. and Akinosho, G. A. (2013). Effect of Processing Methods on Nutritive Value of Catfish (*Clarias gariepinus*) *Food Science and Quality Management*. 11, ISSN 2224-6088
- Ayuba, L. O, Jackson, B. A, Onah, O. R, Adamade, C. A and Ozumba, I.C. (2019). Effects of Smoking Process and Conditions on the Proximate Composition of Catfish (*Clarias Gariepinus*). *Global Science Journals: 7*, (5) 1041-1052
- Bandyopadhyay, B. K. (2022). *Freshwater Aquaculture: A Functional Approach*. CRC Press.
- Bate, E.C and Bendall, J.R. (2010). Changes in fish muscle after death. *British Medical Bulletin*, (12): 2305.

- Belhabib, D., Sumaila, U. R. and Pauly, D. (2019). Feeding the Poor: Contribution of West African Fisheries to Employment and Food Security. *Marine Policy*, 100, 252-260. <https://doi.org/10.1016/j.marpol.2018.11.009>
- Boziaris IS, Kordila A, Neofitou C. (2011) Microbial spoilage analysis and its effect on chemical changes and shelf-life of Norway lobster (*Nephrops norvegicus*) stored in air at various temperatures. *International Journal of Food Sci and Technology* 46(4):887–895.
- Chan, C. Y., Tran, N., Cheong, K. C., Sulser, T. B., Cohen, P. J., Wiebe, K. and Nasr-Allah, A. M. (2021). The future of fish in Africa: Employment and investment opportunities. *PLoS ONE*, 16(12): e0261615. <https://doi.org/10.1371/journal.pone.0261615>
- Cortés-Sánchez, A. D. J., Diaz-Ramírez, M., Torres-Ochoa, E., Espinosa-Chaurand, L. D., Rayas-Amor, A. A., Cruz-Monterrosa, R. G. Aguilar-Toalá, J.E & Salgado-Cruz, M. D. L. P. (2024). Processing, Quality and Elemental Safety of Fish. *Applied Sciences*, 14(7), 2903.
- Devi, T., & Ramalakshmi, P. (2024). Recent Innovations in Seafood Preservation Methods. Chief Editor, 19, 3.
- FAO 2022. Fishery and Aquaculture Country Profiles. Nigeria. Country Profile Fact Sheets. Fisheries and Aquaculture Division, Rome. <https://www.fao.org/fishery/en/facp/159?lang=en>
- Federal Department of Fisheries and Aquaculture (FDFA). (2021). Annual Fisheries Statistics Report for Nigeria. Ministry of Agriculture and Rural Development, Abuja, Nigeria.
- Firmat, C., Alibert, P., Losseau, M., Baroiller, J. F., & Schlieven, U. K. (2013). Successive Invasion-Mediated Interspecific Hybridizations and Population Structure in the Endangered Cichlid *Oreochromis mossambicus*. *PLoS ONE*, 8(5). <https://doi.org/10.1371/journal.pone.0063880>
- Fitri, N., Chan, S. X. Y., Che-Lah, N. H. Jam, F. A, Misnan, N. M., Kamal, N., Sarian, M. N., Mohd-Lazaldin, M. A., Low, C. F. & Hamezah, H.S. (2022). A Comprehensive Review on the Processing of Dried Fish and the Associated Chemical and Nutritional Changes. *Foods*, 11, 2938. <https://doi.org/10.3390/foods11192938>
- Gbolahan, S. O. (2023). Establishment of Local Fish Farm “La’ Prestige Agro” LLC in Nigeria. *International Journal of Research Publication and Reviews*, 4(1): 1955-1963. doi: 10.55248/gengpi.2023.4156
- Geletu, T. T., & Zhao, J. (2023). Genetic resources of Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) in its native range and aquaculture. *Hydrobiologia*, 850(10): 2425-2445.
- Gupta, V., Tyagi, S., & Tripathi, R. (2024). Fish Catch: Processing and Preservation. *Nonthermal Food Processing, Safety, and Preservation*, 277-297.
- Hafez, N. E., Awad, A. M., Ibrahim, S. M., Mohamed, H. R., & El-Lahamy, A. A. (2019). Effect of Salting Process on Fish Quality. *Journal of Nutrition and Food Processing*, 2(1), 1–6. <https://doi.org/10.31579/2637-8876/011>
- Hei, A. and Sarojnalini, C. (2012) Proximate composition, macro and micro mineral elements of some smoke-dried hill stream fishes from Manipur. *Indian Journal of Natural Science*, 10(1): 59-65.

- Kafayat, Adetoun, Fakoya., Ayojesutomi, O., Abiodun-Solanke., Elizabeth, Olumuyiwa, Mangai. (2021). Implications of Production, Post-harvest and Consumption of Fish on Food and Nutrition Security: Nigeria as a Focal Country. doi: 10.1007/978-3-030-50672-8\_20
- Mahmud A, Bereket Abraha, Melake Samuel, Hamada M, Winta A, Elham M (2018). Fish preservation: a multi-dimensional approach. *MOJ Food Process Technology*. 2018;6(3):303–310. DOI: 10.15406/mojfpt.2018.06.00180
- Marbade, P. P., Thakur, V. K., Painkra, A., & Devi, N. (2024). Traditional and Advanced Methods of Fish Drying. In *Dry Fish: A Global Perspective on Nutritional Security and Economic Sustainability* (pp. 31-44). Cham: Springer Nature Switzerland.
- Msuku, L., & Kapute, F. (2018). Effect of smoking and sun drying on proximate composition of diplotaxodon fish species (Ndunduma) from Lake Malawi, Malawi. *African Journal of Food, Agriculture, Nutrition and Development*, 18(1), 13009–13018. <https://doi.org/10.18697/ajfand.81.16960>
- Musa, N., Likongwe, J., Kapute, F., Mtethiwa, A., & Sikawa, D. (2017). Effect of processing method on proximate composition of gutted fresh Mcheni (Rhamphochromis species) (Pisces: Cichlidae) from Lake Malawi. *International Food Research Journal*, 24(4), 1513–1518.
- Nanaobi, H., ChungkhamSarojnalini, D. N.&Romharsha, H. (2023). The Effect of Different Processing Methods on the Proximate Composition of Banded Gourami (Trichogasterfasciata). *Fishery Technology*, 60: 290-294.
- Okpanachi M.A., Yaro C.A., Bello O. Z (2018). Assessment of the Effect of Processing Methods on the Proximate Composition of *Trachurus trachurus* (Mackerel) Sold in Anyigba Market, Kogi State. *American Journal of Food Science and Technology*. 6(1):26-32. doi: 10.12691/ajfst-6-1-5.
- Oli, A. U., Okeke, P. A., Oli, C. C., Ibe, F. N.&Okogwu, J. D. (2024). Comparative Study of the Proximate Composition and Sensory Evaluation of Fresh and Smoke-dried Fish Species from Omambala River, Anambra State, Nigeria. *Applied Sciences*, 5(2): 44 – 50.
- Rasul, M. G., Yuan, C., Yu, K., Takaki, K. & Shah, A. K. M. A. (2022). Factors influencing the nutritional composition, quality and safety of dried fishery products. *Food Research*, 6(5): 444-466.
- Siddhnath, Ranjan, A., Mohanty, B. P., Saklani, P., Dora, K. C. & Chowdhury, S. (2022). Dry fish and its contribution towards food and nutritional security. *Food Reviews International*, 38(4): 508-536.
- Sultana, K., Jayathilakan, K., & Sajeevkumar, V. A. (2022). Chemistry of Animal Tissues. In *Advances in Food Chemistry: Food Components, Processing and Preservation* (pp. 385-437). Singapore: Springer Nature Singapore.
- Syeda Nusrat Jahan, Abdur Razzaq Joadder and Saiful Islam (2019) Assessment of proximate composition of oven dried *Channa punctatus* at three different temperatures. *International Journal of Fisheries and Aquatic Studies* 7(5): 311-314
- Tenyang, N., Ponka, R., Tiencheu, B., Djikeng, F. T., & Womeni, H. M. (2020). Effect of Traditional Drying Methods on Proximate Composition, Fatty Acid Profile, and Oil

Oxidation of Fish Species Consumed in the Far North of Cameroon. *Global Challenges*, 4(8), 2000007. <https://doi.org/10.1002/gch2.202000007>

Tesfay, S. & Teferi, M. 2017. Assessment of post-harvest losses in Tekeze dam and Lake Hashenge fishery association: Northern Ethiopia. *Agriculture and Food Security*, 4: 5-12

Tynchenko, V., Kukartseva, O., Tynchenko, Y., Kukartsev, V., Panfilova, T., Kravtsov, K. & Malashin, I. (2024). Predicting Tilapia Productivity in Geothermal Ponds: A Genetic Algorithm Approach for Sustainable Aquaculture Practices. *Sustainability*, 16(21), 9276.

Vajargah, M. F. (2021). A review of the physiology and biology of Nile tilapia (*Oreochromis niloticus*). *Journal of Aquaculture & Marine Biology*, 10(5), 244-246.

Zhuang, S., Hong, H., Zhang, L., & Luo, Y. (2021). Spoilage-related microbiota in fish and crustaceans during storage: Research progress and future trends. *Comprehensive Reviews in Food Science and Food Safety*, 20(1): 252-288.

UNDER PEER REVIEW