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Original Research Article

Sensory Evaluation and Shelflife of Smoke-Cured *Clarias gariepinus* Preserved with Different Sources of Fuel Energy

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KEYWORDS
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Shelf life,
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ABSTRACT
The impact of three smoking media (firewood, charcoal, and sawdust) on the sensory qualities and nutritional composition, lipid oxidation products, and microbial quality of smoked Clarias gariepinus during 28 days storage at room temperature was investigated in this study. Fish samples were tested on Days 0, 7, 14, 21 and at day 28. According to the sensory analysis of results, at Day 0 all samples were very well accepted were taste (8.03-8.58), aroma (8.23–8.45), texture (8.43–9) and color (7.83-9). However, scores decreased over time ($p < 0.05$) to 1.09–1.82 on Day 28. The firewood-smoked fish had the best sensory scores throughout storage (taste: 5.00). Proximate composition indicated a gradual decline in crude protein from Day 0 to Day 28. Firewood-smoked fish decreased from 44.71% to 19.92%, charcoal from 39.42% to 16.03%, and sawdust from 37.54% to 10.02%. Lipid oxidation (TBARS) increased steadily, with sawdust attaining the highest value (10.74 mg MDA/kg) at Day 28, compared to charcoal (10.56 mg MDA/kg) and firewood (10.10 mg MDA/kg). Microbial analysis showed substantial bacterial and fungal loads from the start, ranging between 2.8×10^6–9.1×10^6 CFU/ml for bacteria and 1.7×10^6–6.1×10^6 CFU/ml for fungi on Day 0. Microbial counts rose consistently during storage, with sawdust-smoked samples recording the highest loads (>10^7 CFU/ml by Day 28), while firewood-treated samples showed comparatively lower microbial growth. Overall, firewood emerged as the most effective smoking medium, producing fish with superior sensory quality, higher protein retention, lower lipid oxidation, and better microbial stability. The study demonstrates that smoking medium significantly influences both the shelf life and safety of smoked catfish, underscoring the need for improved smoking technologies and post-processing hygiene to minimize spoilage and enhance product quality.

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INTRODUCTION

Fish are an essential source of animal protein, micronutrients and essential fatty acids for millions of people worldwide (Badoni *et al*., 2021). In sub-Saharan Africa, fish is a major part of the diet and a major contributor to food security and nutrition (Muringai *et al*,

2021). Among the different species cultivated and consumed, *Clarias gariepinus* (commonly known as African catfish) is the most widely farmed and economically valuable fish species in the region (Langi, 2024).

The use of smoke derived charcoal, saw dust and wood from the incomplete combustion of plant materials has a long history in various traditional practices, including its application in food preservation methods such as fish smoking (Majumdar, 2019:Ovie *et al* 2025). This method not only dehydrates the fish, reducing water activity and thereby microbial proliferation, but also deposits a complex mixture of compounds on the fish surface (Adeyeye & Oyewole, 2019) , some of which possess antimicrobial and antioxidant properties (Soares *et al.,* 2016). Additionally, smoking imparts a distinctive flavor and aroma to the product, enhancing its sensory appeal (Messina *et al.,* 2021). However, traditional fish-smoking practices often rely on open pits and biomass such as wood, which have various health, environmental and quality concerns (Osineye *et al*., 2020). Smoke from these sources may contain polycyclic aromatic hydrocarbons (PAHs) (Adeyeye and Oyewole, 2016), some of which are known carcinogens. With the growing emphasis on sustainable food systems and clean energy, there is a growing interest in exploring alternative sources of energy for fish consumption (Lindgren *et al*., 2018). These include coconut husks, maize husks, wood dust, rice husks, briquettes and other agricultural residues (Daramola *et al*., 2020). These alternative fuels differ in their combustion characteristics, smoke composition and thermal energy output, which may in turn affect drying efficiency, chemical composition, microbial stability and flavour of smoked fish (Oli *et al*., 2024).

Moreover, the shelf life of smoked fish is an important factor in determining its commercial potential, particularly for processors supplying urban markets or exporting smoked products (Geraldo, 2023). Securing a longer and more predictable shelf life reduces losses, improves profitability and increases consumer loyalty. However, to achieve this, it is necessary to examine systematically how different smoking methods affect the spoilage pattern, microbial growth and oxidative degradation of *Clarias gariepinus* smoked using different fuels. By examining a variety of fuels - such as wood, coconut shells, wood shavings, and maize husks.

The aim of this study is to identify the most efficient and sustainable solutions for small-scale processors. The study will also help to fill the knowledge gap in post-harvest fish technology, in particular by optimizing traditional processing techniques for better quality and safety.

MATERIALS AND METHODS

Study Area

The research was conducted at Department of Fisheries Fish farm Campus II, Delta State University, Abraka, located on coordinates of Latitude: 5.7906°N & Longitude: 6.1040° E Ethiope East Local Government Area of Delta State, Nigeria

Duration of Study

The duration of the study was 6 months, from July to December 2025.

Sample Collection and Preparation

A total of 96 samples of four treatments with 24 replicates (0,7, 14 and 28) fresh *Clarias gariepinus* samples, each weighing between 500g and 700g, was sourced from Department of Fisheries and Aquaculture, Atakpor farm and Abraka Open market to check for variability in taste and texture, shelflife, based on different culturing media. Upon procurement, the fish will be transported in ice boxes to the Department of Fisheries and Aquaculture fish farm processing facility to maintain freshness. The fish were washed thoroughly with clean water after evisceration, and split open longitudinally to facilitate uniform smoke penetration.

Research Design

A complete randomized design was used for this experiment to evaluate the effects of different fuel sources on the sensory qualities, shelf-life, microbial quality, and chemical composition of smoke-cured *Clarias gariepinus*. The study involved processing fish samples using various fuel types such as wood, charcoal and sawdust under controlled conditions and analyzing the resulting products over a defined storage period. The prepared fish was divided into five groups, each designated for smoking with a specific fuel type.

Fuel Sources, and Smoking Process

Three different fuel sources used in traditional fish smoking for this study are listed below: Firewood (Rubberwood -Hevea brasiliensis) as Control), Sawdust: By-product from wood processing industries.and Charcoal: Processed wood product with consistent burning properties.Each fuel type was used in a separate smoking kiln to prevent cross-contamination. Smoking was conducted using traditional drum kilns equipped with wire mesh racks. The fish was smoked at temperatures ranging from 70°C to 90°C for 6 to 8 hours, (Idah & Nwankwo, 2013). ensuring uniform exposure to heat and smoke. Post-smoking, the fish was cooled to ambient temperature and packaged in Aluminum Foil Pouches for storage and analysis. The efficiency of each fuel type was assessed based on several measurable factors:

Smoking Duration

The time required for each batch of fish to achieve the target internal temperature of ≥65°C, 6 to 8 hours, which was essential for reducing microbial activity and enzymatic spoilage, depends on several factors including the fish species, size, and drying conditions (Idah & Nwankwo, 2013; Nwabueze *et al.,* 2015 Awhefeada *et al*; 2025).

Fuel Consumption Rate of Wood, charcoal and Saw dust

The weight (in kilograms) of fuel used per kilogram of fish smoked was recorded to evaluate energy efficiency, following the methodology described by Taherzadeh-Shalmaei *et al.,* (2021).

Economic Cost

The market price of each fuel source was documented to evaluate cost-effectiveness, considering both acquisition cost and performance.

Residue Yield

The quantity and nature of residual ash or soot produced will be noted as indicators of combustion efficiency and environmental sustainability (Asen *et al.,* 2024)

These data was used to recommend the most sustainable and economically viable fuel source for small-scale fish processors, aligning with the goal of promoting environmentally friendly and health-conscious processing techniques in the Niger Delta region.

Sensory Evaluation

Sensory evaluation was conducted to assess the organoleptic qualities of the smoked fish, focusing on taste, aroma, texture, and color. A panel of eleven semi-trained individuals undergraduate students both male and female that are familiar with smoked fish products, was assembled for this purpose. The evaluation employed a 9-point hedonic scale, where 1 represents "dislike extremely" and 9 represents "like extremely" (Yang & Lee, 2018). Assessments was carried out on days 0, 7, 14, 21 and 28 of storage under ambient conditions (25°C to 30°C) at room temperature. Each panelist evaluated coded samples to eliminate bias, and the average scores was recorded for analysis.

Shelf Life Assessment

The shelf life of the smoked fish products was monitored over a 28-day period under ambient storage conditions. Observations was made for signs of spoilage, including changes in color, texture, odor, and the presence of slime. The point at which the fish exhibited unacceptable sensory qualities or microbial counts exceeding acceptable limits was considered the end of its shelf life.

Microbiological Analysis

Microbiological analyses was performed to determine the microbial quality of the smoked fish samples over the storage period. Samples were examined on days 0, 7, 14, 21, and 28. The following parameters were assessed:

Preparation of Culture Media

The media used were prepared according to the manufacturer's instructions. The media used were Plate Count Agar, MacConkey Agar, Mannitol Salt Agar for Bacterial count and Isolation while Potato Dextrose Agar was use for Fungi count and isolation

Preparation of Plate Count Agar

28 grams of nutrient agar (NA) powder was dissolved in 1 litre of distilled water in a conical flask covered with cotton wool and aluminium foil paper. It was mixed thoroughly and sterilized by autoclaving at 121^{0}C for 15 minutes. The medium was cooled to 45-50^{0}C and then dispensed aseptically into sterile petri dishes under sterile condition. *MacConkey Agar*: 51.55g of MacConkey agar was weighed with analytical weighing balance dissolved in 100 ml distilled water. It was gently heated on hot plate to dissolve completely for 5 minutes. It was sterilized at 121^{0}C for 15 minutes, cooled under room temperature, and dispensed into petri dishes.

Isolation of bacteria

1g of the sample was weighed and placed in 9ml sterile normal saline water, to prepare an initial sock solution and allowed to stand for 30 minutes. Serial dilution 10^1, 10^2, 10^3 and 10^4 were prepared and used as diluent. then transferred aseptically to sterile petri plates. 1ml of aliquots from each dilution were inoculated into a petril dish and the prepared plate count agar (for bacteria growth) was poured in aseptically and incubated at 37°C for 18 - 24 hours. After successful growth of microorganisms, the colonies were enumerated and the results per dilution count were recorded. The number of colony forming unit per milliliter was calculated with the formula (Aneja,2018) ,

$$\text{Cfu/g} = \frac{number\ of\ colonies}{volume\ plated\ x\ dilution\ factor}$$

Pure culture

One single colony was identified and re-streaked as a primary inoculant on the surface of a nutrient agar plate medium. Pure cultures were checked from nutrient agar plates. After achieving a pure culture, the same colony was streaked onto a nutrient agar slant. These cultures were incubated at 37°C for 24 hours.

Identification and Cultural characteristics

Each colony morphology e.g., size, shape, margin, elevation, consistency, color, transparency was and

biochemical test was determined according to (Cheesebrough 2002).

Biochemical Test

Catalase Test

This is a test to detect the presence or absence of catalase enzyme. The catalase enzyme catalyses the breakdown of hydrogen peroxide to release free oxygen gas and the formation of water. A few drops of freshly prepared 3% hydrogen peroxide were added onto the bacterial isolates smeared on a slide. The production of gas bubble indicated catalase enzyme positive.

$2\ H_2O_2 \rightarrow 2\ H_2O + O_2$

Urease Test

The urease test was used to determine the ability of an organism to split urea in the presence of the enzyme urease. The bacterial isolates were inoculated into slants of urea medium and incubated at 37^0C for 24-48 hours. Urease positive cultures produced a red-pink colour due to changes in the colour of the indicator

$NH_2CO.NH_2 + H_2O \rightarrow 2NH_3 + CO_2$

Citrate Utilization Test

This test was based on the ability of some organisms to utilize citrate as a sole source of carbon. This was carried out by inoculating the test organism in test tube containing Simon's citrate medium and this was incubated at 37^0C for 24 - 48 hours. The development of deep blue colour after incubation indicates a positive result.

Indole Test

Indole test is performed to determine the ability of the organism to split tryptophan molecule into indole. This test is performed to help differentiate species of the family enterobacteriaceae.

Kovac's reagent which contains hydrochloric acid, dimethylaminobenzaldehyde and amyl alcohol is used. Inoculate broth with the test organism and incubate for 18 – 24 hours at 370C. Add 5ml of Kovac's reagent down the inner wall of the tube. Development of bright red colour at the interface of the reagent and the broth within seconds after adding the reagent is indicative of the presence of indole and is a positive test while absence is negative.

Oxidase test

This was done by emulsifying a test organism on a piece of filter paper soaked with a freshly prepared oxidase reagent before observation is done. A blue or purple colour indicate a positive test

Cell Morphological

Gram staining

Smears of the bacterial isolates were prepared and heat fixed on clean grease free slides. The smears were stained for one minute with crystal violet. This was washed out with distilled water. The slides were flooded with dilute Grams' iodine solution for one minute. This was washed off with distilled water and the smears were decolorized with 95% alcohol for 30 seconds and rinsed off with distilled water. The smears were then counter stained with safranin solution for one minute. Finally, the slides were washed off with distilled water, air dried and observed under oil immersion objective.

The slides were observed under the microscope using oil immersion objective (×100) to classify the bacteria isolate under gram negative and gram positive organisms. According to Gram's description of staining procedure in routine bacteriology, gram negative bacteria stayed pink while the gram positive bacteria remained purple (Prescott, Harley and Klein, 1999).

Fungi Procedure

Preparation of Potato Dextrose agar

39 grams of Potato dextrose agar powder was dissolved in 1 litre of distilled water in a conical flask covered with cotton wool and aluminium foil paper. It was mixed thoroughly and sterilized by autoclaving at 121°C for 15 minutes. The medium was cooled to 45-50°C and before dispensing aseptically into petri dishes. Plates were then incubated for 72 hours at room temperature (25°C).

Isolation of fungi

1g of the sample was weighed and placed in 9ml sterile distilled water and allowed to stand for 30 minutes. The aliquot was then transferred aseptically to sterile petri plates. The prepared agar (for fungi growth) was poured in aseptically and incubated for 72 hours at room temperature (25°C). After successful growth of microorganisms, the colonies were counted with a colony counter.

Cultural Characteristics

Each colony morphology e.g., size, texture, color, reverse colour, was determined by physical examination.

Pure Culture

One single colony was identified and re-streaked as a primary inoculum on the surface of a potato dextrose agar plate medium to make a pure culture. After achieving a pure culture, the same colony was streaked onto potato dextrose agar slant. These cultures were incubated at 25°C for 72 hours.

Lactophenol Cotton Blue Mounting of Fungi

Lactophenol cotton blue is a stain commonly used for making semi-permanent microscopic preparation of fungi. It stains the fungi cytoplasm and provides a light blue background, against which the wall of hyphae can readily be seen. It contains four constituents: phenol, which serves as fungicides; lactic acid, which act as a clearing agent; cotton blue, which stains the cytoplasm of the fungus; and glycerine, which gives semi- permanent

preparation. A permanent preparation may be by incorporating polyvinyl alcohol in place of glycerine into the mounting medium.

For rapid and routine examination of almost all type of fungi, spores and spore bearing structures are tested out on a clean slide in a drop of mounting fluid (lactophenol cotton blue) and a cover-glass placed over the preparation which is then ready for microscopic examination.

Procedure

A drop of lactophenol cotton was placed on a clean slide. Transfer a small tuff of fungus, preferably with spore or spore boring structures into the drop on the slide using a flamed cooled needle. Gently tease using an inoculating needle. Mix gently the stains with the mold structures. Place a cover-glass over the preparation taking care to avoid trapping air bubbles in the stain.

Chemical Analysis

Chemical analyses was conducted to evaluate the nutritional quality and stability of the smoked fish products. The following parameters were measured:

Proximate Procedure

The Crude proteina and moisture content were analysed according to Association of Analytic chemist (AOAC, 2023) as explained below;

Moisture content determination

Equipment: oven, weighing balance, Apparatus: beaker, Spatula crucible/beaker, desiccator

Procedure: Oven dry crucible at 105^0C for an hour to ensure dryness, (when using beaker, oven dry for 5 minutes). Transfer beaker/crucible into desiccator to cool for about 30 minutes. Weigh the crucible in an electronic balance and record as W_1. 1g of sample is weighed into the pre-weighed crucible/beaker $W_{2\ and\ the}$ crucible/beaker and content is oven dried at 105^0C for 3 hours, place in a desiccator to cool for about 10 minutes and weigh then put back in the oven till a constant weight is obtained W_3.

$$\%\ \text{Moisture Content} = \frac{W2\ -\ W3}{W2\ -\ W1}$$

Crude protein determination

Equipment: weighing balance, spectrophotometer. Apparatus: conical flask, heating mantle, volumetric flask, Reagents: 0.1N HCl, conc. H_2SO_4, 40% NaOH, Boric acid indicator, mixed catalyst (copper sulphate, and sodium sulphate)/Digestion mixture.

Procedure :Weigh 0.5g-1g of the sample into a conical or volumetric flask Add 10ml of Conc. H_2SO_4 and 1g of mixed catalyst or a mixed catalyst tablet.The flask is swirled in order to mix the contents thoroughly and then placed on a heat source to start the digestion for about 2hr till the mixture becomes whitish or a clear light green color.The digest is cooled and transferred to a 100ml volumetric flask and volume was made up to mark with distilled water (record the amount of water used to make up to the 100ml mark).The standardized boric acid and about 3 drops of methyl red indicator is put in the volumetric flask of the set up to trap any ammonium produced in the process of distillation.25ml of diluted digest was introduced in the distillation tube as well as 25ml of 40% NaOH was gradually added. Distillation is continued for at least 10 minutes and NH3 produced is collected as NH4OH in a conical flask containing 25ml of 4% Boric acid and methyl red indicator. During distillation, yellowish colour appears due to NH4OH. 20ml of distillate is then titrated against standard 0.1N HCl solution till the appearance of pink colour.and % crude protein content is calculated.

Calculation;

$$\%\ \text{Crude Protein} = \frac{S \times N \times 0.014 \times D \times 100 \times 6.25}{\text{Weight of sample} \times V}$$

Where

S = sample titration reading

N = Normality of HCl

D = dilution of sample after digestion

V = volume taken for distillation

0.014 = milliequivalent weight of Nitrogen.

Statistical Analysis

Data obtained from sensory, microbiological, and chemical analyses was subjected to appropriate statistical treatment using descriptive statistics (means, standard deviations) to summarize data and One-Way Analysis of Variance (ANOVA) was used to test for significant differences between treatment groups (i.e.,different fuel types). Where ANOVA indicates significant differences, and Duncan's Multiple Range Test (DMRT) was applied for post hoc comparison at a 95% confidence level ($p < 0.05$), following the approach described by Agbangba *et al*. (2024). All statistical computations will be carried out using SPSS version 25 (IBM Corp., Armonk, NY, USA) .

RESULTS AND DISCUSSION

The results of various analyses conducted is presented below:

Sensory Evaluation

Table 1: Chi-Square Tests of Independence between Tasters' Responses and Drying methods within Days for Taste, Aroma, Texture and Colour

Days	Taste		Aroma		Texture		Colour	
	Chi Square value	Sig.	Chi Square value	Sig.	Chi Square value	Sig.	Chi Square value	Sig.
Day 0	2.69	0.61	11.57	0.17	7.00	0.32	4.43	0.62
Day 7	10.37	0.24	17.30	0.14	21.27	0.02	25.67	0.03
Day 14	11.21	0.08	10.50	0.03	13.07	0.04	11.33	0.08
Day 21	7.20	0.13	4.88	0.30	12.72	0.05	9.33	0.05
Day 28	0.92	0.63	6.89	0.03	3.22	0.52	2.20	0.33

Result in Table 1 shows the Day 0, assessments for taste, aroma, texture and colour were independent of smoking method ($p>0.05$). For Day 7, same result for taste and aroma ($p>0.05$). but not for texture and colour ($p<0.05$). Assessments were also independent of smoking method for taste and colour on Day 14, taste, aroma and colour on Day 21, and taste, texture and colour on Day 28 ($p>0.05$), by dependent on smoking methods for aroma and texture on Day 21, and for aroma alone on Day 28 ($p<0.05$).

Table 2: Variations in sensory attributes with Days

Days	Taste	Aroma	Texture	Colour
Day 0	8.58 ± 0.11^{a}	8.15 ± 0.16^{a}	8.03 ± 0.14^{a}	8.27 ± 0.16^{a}
Day 7	6.70 ± 0.21^{b}	6.52 ± 0.23^{b}	6.18 ± 0.25^{b}	6.18 ± 0.32^{b}
Day 14	5.30 ± 0.10^{c}	4.76 ± 0.13^{c}	5.36 ± 0.17^{c}	4.15 ± 0.14^{c}
Day 21	3.76 ± 0.12^{d}	3.45 ± 0.11^{d}	4.21 ± 0.15^{d}	2.64 ± 0.14^{d}
Day 28	1.73 ± 0.08^{e}	1.21 ± 0.07^{e}	1.82 ± 0.08^{e}	1.09 ± 0.05^{e}

^{a,b,c,d,e} Means with different superscripts within each column differ significantly ($p<0.05$)

Table 2 above shows how the scores decreased over time ($p < 0.05$) to 1.09–1.82 on Day 28. the sensory analysis of results, at Day 0 all samples were very well accepted where taste is (8.03-8.58), aroma (8.23–8.45), texture (8.43–9) and color (7.83-9).

Table 3: Effect of Drying media on sensory attributes of fish

Drying Media	Taste	Aroma	Texture	Colour
Firewood	5.53 ± 0.33^{a}	5.31 ± 0.37^{a}	5.60 ± 0.31^{a}	4.95 ± 0.39a
Sawdust	5.00 ± 0.34^{b}	4.55 ± 0.33^{b}	4.82 ± 0.30^{b}	4.09 ± 0.34^{b}
Charcoal	5.11 ± 0.33^{b}	4.60 ± 0.33^{b}	4.95 ± 0.30^{b}	4.36 ± 0.37^{b}

^{a,b,} Means with different superscripts within each column differ significantly ($p<0.05$)

Table 4 Shows that firewood-smoked fish had the best sensory scores throughout storage(taste: 5.00).

Table 4: Days by Drying Media Interaction Effect on Sensory Attributes

Days	Drying Media	Taste	Aroma	Texture	Colour
0	Firewood	8.55 ± 0.16	8.64 ± 0.20	8.18 ± 0.23	8.55 ± 0.25
	Sawdust	8.64 ± 0.20	7.91 ± 0.25	7.91 ± 0.32	8.09 ± 0.32
	Charcoal	8.55 ± 0.21	7.91 ± 0.34	8.00 ± 0.19	8.18 ± 0.26
7	Firewood	7.36 ± 0.24^{a}	7.64 ± 0.24^{a}	7.09 ± 0.41^{a}	7.27 ± 0.57^{a}
	Sawdust	6.18 ± 0.46^{b}	5.91 ± 0.34^{b}	5.64 ± 0.36^{b}	4.91 ± 0.44^{b}
	Charcoal	6.55 ± 0.28^{ab}	6.00 ± 0.40^{b}	5.82 ± 0.42^{b}	6.36 ± 0.41^{a}
14	Firewood	5.73 ± 0.19^{a}	5.09 ± 0.28	6.00 ± 0.27^{a}	4.64 ± 0.28^{a}
	Sawdust	5.09 ± 0.09^{b}	4.55 ± 0.21	4.91 ± 0.28^{b}	3.82 ± 0.23^{b}
	Charcoal	5.09 ± 0.16^{b}	4.64 ± 0.15	5.18 ± 0.23^{b}	4.00 ± 0.13^{ab}
21	Firewood	4.18 ± 0.23^{a}	3.73 ± 0.24	4.73 ± 0.24^{a}	3.18 ± 0.26^{a}
	Sawdust	3.45 ± 0.16^{b}	3.36 ± 0.15	3.91 ± 0.28^{b}	2.45 ± 0.21^{b}
	Charcoal	3.64 ± 0.20^{ab}	3.27 ± 0.14	4.00 ± 0.19^{b}	2.27 ± 0.14^{b}
28	Firewood	1.82 ± 0.12	1.45 ± 0.16^{a}	2.00 ± 0.13	1.09 ± 0.09
	Sawdust	1.64 ± 0.15	1.00 ± 0.00^{b}	1.73 ± 0.14	1.18 ± 0.12
	Charcoal	1.73 ± 0.14	1.18 ± 0.12^{ab}	1.73 ± 0.14	1.00 ± 0.00

^{a,b,} Within each Day, means with different superscripts within the column differ significantly ($p<0.05$)

This table 4 shows how the taste, aroma, texture, and colour of the smoked/dried fish changed over the 28-day storage period when different drying materials firewood, sawdust, and charcoal were used. All fish samples started off with high sensory scores on Day 0, regardless of the drying method. The taste, aroma, texture, and colour were all rated between 7.9 and 8.6, showing that the freshly smoked fish were very appealing.

Day 7: Firewood-smoked fish maintained the best sensory quality, scoring significantly higher than sawdust-dried fish. Sawdust-smoked fish showed the fastest drop in taste, aroma, texture, and especially colour. Charcoal-smoked fish performed in between, not as good as firewood but better than sawdust.

This suggests that firewood preserves sensory attributes better in early storage.

Day 14: The decline in quality continued for all drying methods. Firewood-smoked fish still had higher taste and texture scores, although the differences in aroma were not statistically significant across media. Sawdust again had the weakest scores, especially in colour. Charcoal remained moderate, comparable to sawdust in some attributes but slightly better in colour.

Day 21: Sensory qualities dropped further across all treatments. Firewood gave the highest scores in taste, texture, and colour, showing it continues to preserve quality better. Sawdust consistently had the lowest ratings, meaning fish dried with sawdust deteriorated fastest. Charcoal again showed moderate stability but was not as good as firewood.

Day 28: The sensory qualities of all fish samples were very low, with scores around 1–2. Differences between drying media were small, although: Aroma differed significantly: Firewood > Charcoal > Sawdust. Colour and texture were equally low across media.

Proximate Composition of Firewood(F), Sawdust(S) and Charcoal (C)

Table 5: Showing Proximate Composition of Firewood, Sawdust and Charcoal for Day 0,7,14,21 and 28

Parameters	Days	Treatments		
		F	S	C
Moisture	0	22.90 ± 2.85[b]	32.72 ± 1.57[a]	24.03 ± 2.22[b]
	7	49.18 ± 3.75	56.07 ± 7.29	48.04 ± 5.48
	14	41.54 ± 1.47[b]	51.96 ± 2.56[a]	43.47 ± 1.33[b]
	21	51.13 ± 5.35	55.08 ± 6.39	57.31 ± 2.62
	28	58.34 ± 1.56	66.24 ± 9.54	59.06 ± 3.22
Crude Protein	0	44.71 ± 1.34[a]	37.54 ± 0.57[b]	39.42 ± 1.14[b]
	7	37.31 ± 1.17[a]	33.14 ± 3.76[b]	34.01 ± 1.72[b]
	14	37.75 ± 1.48[a]	31.97 ± 1.59[b]	37.36 ± 0.35[a]
	21	24.10 ± 1.62	19.27 ± 3.08	23.61 ± 1.59
	28	19.92 ± 0.23[a]	10.02 ± 1.34[b]	16.03 ± 1.98[a]
Lipid Oxidation	0	1.20 ± 0.23[b]	2.31 ± 0.36[a]	2.21 ± 0.30[a]
	7	1.41 ± 0.11	1.86 ± 0.50	1.66 ± 0.11
	14	4.81 ± 0.24	5.80 ± 0.81	5.83 ± 0.29
	21	8.69 ± 0.23	9.32 ± 0.23	8.96 ± 0.23
	28	10.10 ± 0.25	10.74 ± 0.16	10.56 ± 0.13

[a,b] Within each row, means with different superscripts differ significantly ($P<0.05$)

The Proximate composition in Table 5 indicated a gradual decline in crude protein from Day 0 to Day 28. Firewood-smoked fish decreased from 44.71% to 19.92%, charcoal from 39.42% to 16.03%, and sawdust from 37.54% to 10.02%. Lipid oxidation (TBARS) increased steadily, with sawdust attaining the highest value (10.74 mg MDA/kg) at Day 28, compared to charcoal (10.56 mg MDA/kg) and firewood (10.10 mg MDA/kg).

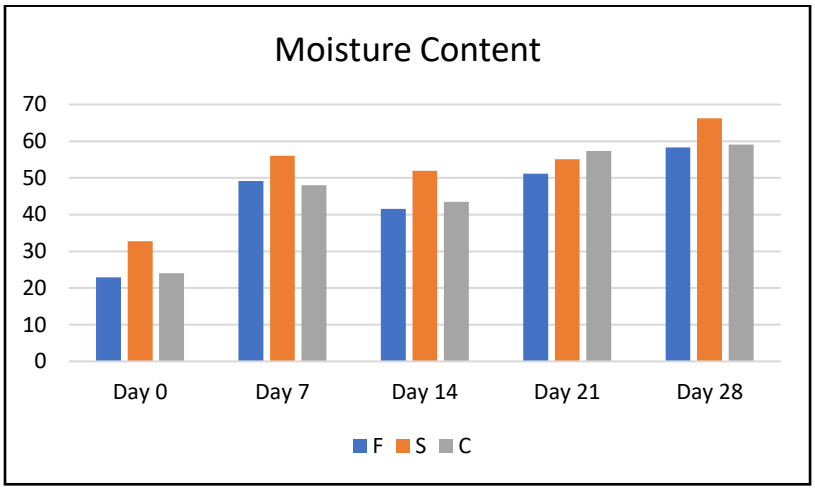

Figure 1: Showing Moisture Content for Day 0,7,14,21 and 28

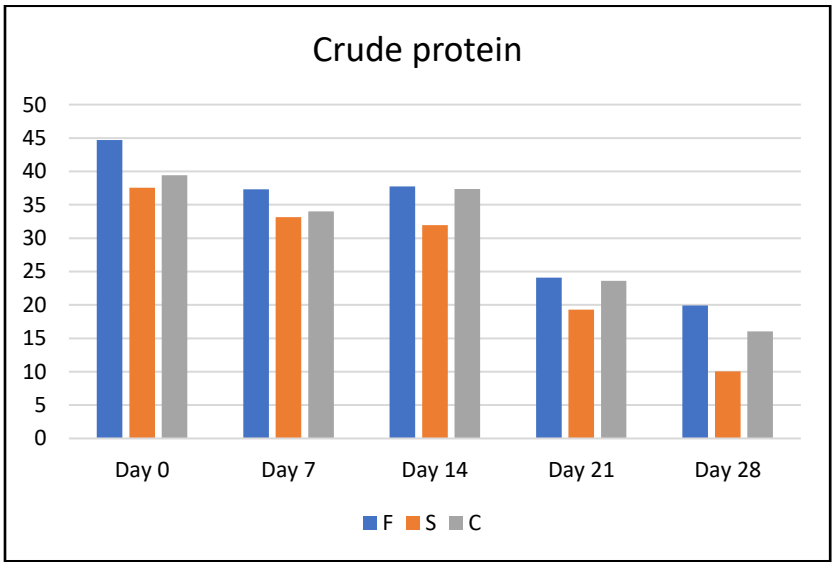

Figure 2: Showing Crude Protein Content for Day 0,7,14,21 and 28

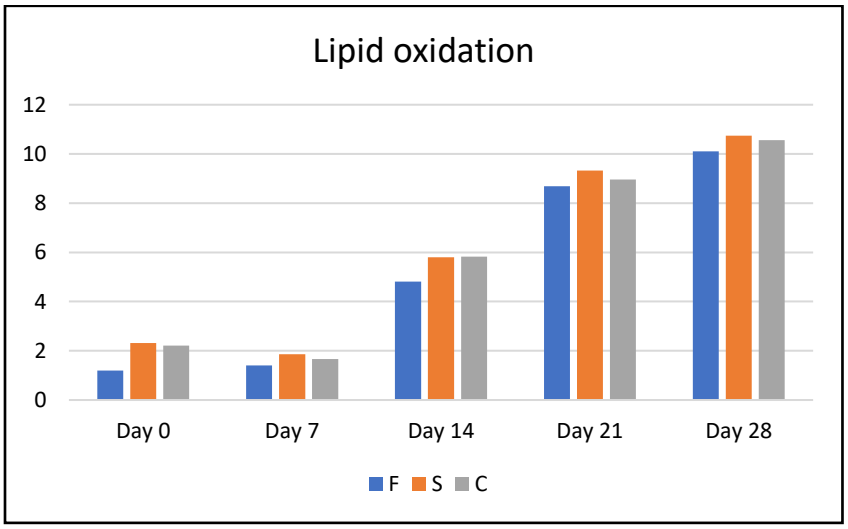

Figure 3: Showing Lipid Oxidation for Day 0,7,14,21 and 28

Table 6: Weight of Fuel Energy per kg of Fish Before Smoking

Fuel Type	Fuel Used	Fish Weight	Fuel per kg Fish
Firewood	14 kg	5 kg	2.80 kg/kg fish
Charcoal	3.5 kg	5 kg	0.70 kg/kg fish
Sawdust	6 kg	5.5 kg	1.09 kg/kg fish

Table 6 presents the amount of fuel needed to smoke a given weight of fish varied significantly across the fuel types. Firewood required the highest quantity, using 14 kg to process 5 kg of fish, which equals 2.80 kg of fuel per kilogram of fish. Sawdust required 6 kg to smoke 5.5 kg of fish, giving a moderate value of 1.09 kg of fuel per kg of fish. Charcoal was the most efficient fuel, requiring just 3.5 kg to smoke 5 kg of fish, amounting to 0.70 kg/kg fish. This shows clearly that charcoal burns with greater efficiency and delivers more usable heat per kilogram compared to firewood and sawdust.

Table 7: Cost of Fuel Used

Fuel Type	Cost (₦)
Sawdust	₦1,000
Firewood	₦3,000
Charcoal	₦2,000

Table 7 presents the cost of Fuel used as sawdust was the most affordable option at ₦1,000, followed by charcoal at ₦2,000, while firewood was the most expensive at ₦3,000. This difference in cost is important for processors working on low budgets, as the price of fuel directly affects the profitability of fish smoking.

Table 8: Fuel Residue After Smoking

Fuel Type	Residue Weight (kg)
Charcoal	0.50 kg
Sawdust	0.20 kg
Firewood	2.50 kg

Table 8 shows Fuel Residue After Smoking. The residue left after smoking helps to show how much of the fuel actually burned. Firewood left behind the largest amount of unburned material (2.50 kg), suggesting that it burns less efficiently. Charcoal produced 0.50 kg of residue, while sawdust left the least (0.20 kg). This means sawdust and charcoal burn more completely and waste less material compared to firewood

Table 9: Smoking Time

Fuel Type	Start Time	End Time	Duration
Sawdust	11:51 am	6:30 pm	**6 hrs 39 mins**
Charcoal	1:00 pm	6:00 pm	**5 hrs 00 mins**
Firewood	12:30 pm	6:40 pm	**6 hrs 10 mins**

Table 9 Smoking duration, and Smoking time also varied by fuel source. Sawdust produced the longest smoking time at 6 hours and 39 minutes, while firewood took 6 hours and 10 minutes. Charcoal resulted in the shortest smoking duration of 5 hours, indicating that it generates more stable and intense heat, allowing the fish to smoke faster than with the other fuels.

Table 10: Weight of Fish After Smoking

Fuel Type	Final Weight of Fish (kg)
Sawdust	2.5 kg
Charcoal	1.8 kg
Firewood	1.8 kg

Table 10 shows the final weight of fish after Smoking, the fish weights were reduced due to moisture loss. Fish smoked with sawdust retained the highest final weight (2.5 kg), showing that it dries the fish more gently. Both charcoal and firewood produced final weights of 1.8 kg, suggesting a more intense drying process, and therefore greater moisture loss, when these fuels are used.

Table 11: Showing Price of Fresh Fish Per Kg before Processing

Parameter	Value
Price per kg	₦1,700

Table 11 Price of Fresh Fish Before processing, fresh fish cost ₦1,700 per kg. This forms the baseline cost for evaluating profitability after smoking.

Microbiological Analysis

Table 12: Total Heterotrophic Bacteria

Days	Treatments		
	F	**S**	**C**
0	50.20 ± 7.91^{b}	73.60 ± 8.48^{a}	54.00 ± 10.37^{b}
7	56.86 ± 29.81^{c}	88.20 ± 16.89^{a}	67.20 ± 40.09^{b}
14	113.40 ± 18.34^{b}	157.50 ± 11.09^{a}	155.20 ± 6.82^{a}
21	191.60 ± 18.14^{b}	272.80 ± 54.09^{a}	195.20 ± 18.19^{b}
28	296.86 ± 56.41^{c}	368.00 ± 45.40^{a}	317.29 ± 58.19^{b}

^{a,b}Within each row, means with different superscripts differ significantly (P<0.05)

Table12 shows general bacteria that grow on the fish during storage.

Day 0 (Freshly Smoked Fish) Sawdust-smoked fish (73.60) had the highest number of bacteria, significantly more than firewood (50.20) and charcoal (54.00). Sawdust allowed more bacteria to survive immediately after smoking.

Day 7 Sawdust again recorded the highest bacterial load (88.20), Charcoal (67.20) and firewood (56.86) had lower counts. Bacteria increased for all treatments, but sawdust still promoted the fastest bacterial growth.

Day 14 Bacteria increased sharply in all samples. Sawdust (157.50) and charcoal (155.20) were significantly higher than firewood (113.40). Middle of storage period shows rapid microbial multiplication, with firewood still performing best.

Day 21 Sawdust (272.80) had extremely high counts, significantly higher than firewood (191.60) and charcoal (195.20). Sawdust-smoked fish deteriorated very fast with heavy microbial growth.

Day 28 (End of Storage) Sawdust remained the worst (368.00), Charcoal moderate (317.29) and Firewood lowest (296.86) but still high. All fish were heavily contaminated by Day 28, but firewood-smoked fish still had the slowest bacterial build-up. Sawdust consistently had the highest bacterial contamination at all storage days. Firewood had the lowest counts, showing it preserved the fish better. Charcoal stayed in the middle. Bacterial load increased sharply as days progressed, indicating progressive spoilage.

Table 13: Showing Total Heterotrophic Fungi

Days	Treatments		
	F	**S**	**C**
0	4.80 ± 0.80	8.80 ± 2.35	6.40 ± 0.81^{NS}
7	37.60 ± 6.87	31.57 ± 5.82	27.00 ± 4.11^{NS}
14	42.20 ± 3.14^{b}	55.00 ± 8.44^{a}	38.00 ± 2.49^{b}
21	206.80 ± 5.52^{b}	234.80 ± 7.03^{a}	211.80 ± 10.42^{b}
28	276.71 ± 6.07^{b}	309.40 ± 2.79^{a}	299.57 ± 8.32^{ab}

^{a,b}Within each row, means with different superscripts differ significantly (P<0.05)

Table 13 –Presents the Total Heterotrophic Fungi (THF) which includes molds and yeast that grow during storage.

Day 0 No significant differences (NS = Not Significant), Sawdust (8.80) had slightly higher fungal load than charcoal (6.40) and firewood (4.80).Fungal contamination was low and similar across all treatments at the start.

Day 7 Fungal load increased across the board. Firewood (37.60) was highest but differences were not statistically significant.Fungi began to grow early, but the pattern wasn't yet distinct.

Day 14 Sawdust (55.00) had significantly higher fungi than firewood (42.20) and charcoal (38.00). Sawdust conditions favoured fungal growth.

Day 21 Fungi increased drastically. Sawdust (234.80) had significantly the highest fungal load. Sawdust-smoked fish deteriorated fastest due to both bacteria and fungi.

Day 28 Sawdust remained highest (309.40), followed by charcoal (299.57), then firewood (276.71). Differences were significant between sawdust and firewood, but charcoal overlapped. By Day 28, fungal contamination was very high for all treatments, indicating severe spoilage.

Discussion

Sensory Evaluation

The sensory evaluation results provide a clear picture of how the different smoking or drying methods influenced the taste, aroma, texture, and colour of the fish samples over the 28-day storage period. What stands out most is that the influence of smoking method was not constant over time it changed as the product aged, which reflects how smoked fish naturally deteriorates or stabilizes during storage.

Day 0 (Freshly Smoked Fish): At the very beginning, all four sensory qualities taste, aroma, texture, and colour were not significantly affected by the drying/smoking method. This means that immediately after processing, the different methods produced fish samples that tasters found similar. In practical terms, no method had an advantage in sensory quality at Day 0, and consumers would likely accept any of the products equally.

Day 7 (Early Storage Changes Begin): By Day 7, the picture started to change. Taste and aroma remained unaffected by the drying method, showing that the flavour profile of the products was still stable and comparable. However, texture and colour now differed significantly between smoking methods. This suggests that: Some methods may cause the fish to firm up faster or lose firmness differently, While certain smoking methods may maintain colour better, others may cause more fading or darkening within the first week. This early divergence highlights that post-processing texture and colour stability depend strongly on the drying method used.

Day 14 (Mid-Storage Divergence) By Day 14, more pronounced differences emerged. Taste and colour remained similar across methods, meaning these traits were still stable. But aroma and texture now varied significantly depending on the smoking method. At this point, the chemical changes associated with storage such as oxidation of fats or moisture loss may have interacted differently with each drying method, producing noticeable aroma changes. Texture differences becoming significant again also suggest that some methods retain moisture or structural integrity better over time.

Day 21 (Approaching the End of Good Shelf life): Around Week 3, significant changes continued to appear selectively:Taste, aroma, and colour were still statistically similar across methods, indicating these qualities remained fairly resilient. Texture, however, showed a significant difference once again. This indicates that texture is the most sensitive attribute to storage and processing variation. By this point, the structural breakdown of muscle fibres may be more noticeable in some drying methods than others.

Day 28 (Late Storage – Aroma Becomes Key): At the final stage of storage, most sensory traits (taste, texture, and colour) were no longer significantly different between smoking methods. This suggests that by 28 days, the sensory qualities of all samples had declined to similar levels, or the earlier differences became less pronounced. However, aroma still differed significantly. Aroma is often the first indicator of spoilage or oxidative changes, so this result suggests that: Some smoking methods preserve aroma better over long storage periods, While others might allow the

Fuel Consumption and Efficiency

The results of this study reveal clear differences in the performance of firewood, charcoal, and sawdust as fuel sources for smoking fish. These differences reflect not only the physical properties of each fuel type but also their efficiency, cost-effectiveness, and influence on the final quality and yield of smoked fish. Overall, the findings align with trends reported in previous studies, although some variations were observed.

Charcoal required the least amount of fuel per kilogram of fish (0.70 kg/kg), demonstrating superior energy efficiency compared to firewood (2.80 kg/kg) and sawdust (1.09 kg/kg). This agrees with the report of Oparaku & Mgbenka (2012)**,** who observed that charcoal burns hotter and more consistently than firewood, resulting in lower fuel usage during fish smoking. Similarly, Abah & Egbe (2016) noted that charcoal provides steady heat with minimal smoke, leading to faster cooking times and better energy use.

On the other hand, firewood required the highest fuel quantity. This supports findings by Akinola *et al*. (2006)**,** who reported that traditional firewood smoking is fuel-intensive due to incomplete combustion and heat loss. Sawdust performed moderately in terms of fuel use, aligning with Onyeke *et al*. (2018), who stated that sawdust briquettes burn efficiently but produce less intense heat, making them suitable for slow and gentle smoking.

Cost of Fuel

Cost analysis showed that sawdust was the cheapest fuel (₦1,000), followed by charcoal (₦2,000) and firewood (₦3,000). Similar cost patterns have been reported by Orina *et al*. (2017), who found that sawdust and other biomass residues are significantly cheaper for artisanal processors, especially in regions where sawmills are common. The high cost of firewood reflects increasing scarcity and regulation of forest resources, a trend also highlighted by FAO (2015).

Fuel Residue and Combustion Behavior

Sawdust left the least residue (0.20 kg), followed by charcoal (0.50 kg), while firewood produced the highest residue (2.50 kg). This mirrors earlier reports by Adeyeye *et al*. (2017), who found that sawdust briquettes burn almost completely due to their fine particle composition, leaving minimal ash. The high residue from firewood is consistent with findings from Oyekanmi et al. (2019), indicating that

natural logs often burn unevenly and produce more char and unburnt portions.

Smoking Duration

Charcoal produced the shortest smoking time (5 hours), while sawdust and firewood required over 6 hours. This agrees again with findings of Akinola *et al*. (2006), who emphasized charcoal's ability to maintain steady heat for faster drying. Sawdust's longer smoking time supports observations by Onyeke *et al*. (2018), who reported that sawdust burns slower, making it more suitable for mild and prolonged drying processes.

Final Weight of Smoked Fish

Smoked fish treated with sawdust retained the highest weight (2.5 kg), while fish smoked with charcoal and firewood both weighed 1.8 kg after smoking. This may be due to the gentler heat from sawdust, allowing slower moisture loss. Similar results were reported by Sodamola et al. (2014), who observed higher product yield under mild-temperature smoking. Conversely, charcoal and firewood tend to produce higher temperatures, accelerating dehydration and reducing final product mass, as noted by Fasakin *et al*. (2010).

Economic Implications

With fresh fish priced at ₦1,700 per kg, the choice of fuel directly affects profit margins. Charcoal provides faster processing but results in lower final weight, while sawdust gives a higher yield at lower fuel cost, potentially improving profitability. This echoes Orina *et al*. (2017), who recommended sawdust as a cost-saving option for small-scale processors.

Moisture, Crude Protein and Lipid Content Evaluation

Initial Values (Day 0)

Firewood-smoked fish recorded the highest CP (44.71%), followed by charcoal (39.42%) and sawdust (37.54%). This mirrors findings by Olayemi & Adediran (2013) who noted that higher smoking temperatures lead to: better protein stabilization, lower water activity and reduced enzymatic degradation Thus, firewood-sourced smoke likely provided better protein preservation at the start of storage.

Changes During Storage (Day 7–28)

Protein content consistently decreased in all treatments. By Day 28, values dropped significantly: Firewood: 19.92%, Charcoal: 16.03% and Sawdust: 10.02% (lowest). This reduction mirrors findings from Fapohunda & Ogunkoya (2006) – protein losses occur due to proteolysis, microbial action, and oxidative denaturation during storage. Oforka *et al*. (2012) – high ambient temperature accelerates protein breakdown in smoked fish.

The greater decline in sawdust-smoked samples corresponds with their higher moisture levels, which favor: microbial proliferation, protease activity and faster denaturation This result compares very closely with Omojowo & Abdullahi (2010) who reported that protein content is inversely related to moisture level during storage.

Comparative Summary Firewood (F): Highest protein retention best preservation, Charcoal (C): Moderate retention, Sawdust (S): Fastest degradation poorest shelf life

Lipid Oxidation (Thiobarbituric Acid Reactive Substances, TBARS)

Initial Values (Day 0)

TBARS were significantly higher ($P<0.05$) in sawdust (2.31 mg MDA/kg) and charcoal (2.21) compared to firewood (1.20).

Higher initial oxidation in sawdust matches Emire and Gebremariam (2010) who reported that lower-temperature smoke contains higher amounts of partially combusted particles, which can deposit oxidation catalysts on fish surface.

Progression With Storage (Day 7–28)

Lipid oxidation increased steadily across all treatments up to Day 28:

Firewood: 10.10, Sawdust: 10.74 and Charcoal: 10.56. This trend agrees strongly with earlier research: García-Arias *et al*. (2003) – lipid oxidation increases significantly during storage of smoked fish because unsaturated fatty acids react with oxygen.

Adeosun *et al*. (2016) – reported that smoked fish stored at ambient temperature shows exponential TBARS increase due to breakdown of polyunsaturated fatty acids (PUFAs).

Comparative Summary, Sawdust (S): Highest oxidation → poorest oxidative stability, Charcoal (C): Similar to sawdust due to fine particle smoke and Firewood (F): Lowest oxidation → best product stability Integrated Interpretation (Moisture–Protein–Oxidation Relationship). The data strongly supports the classic deterioration triangle reported in fish processing literature:

High moisture → High microbial load → Protein loss and lipid oxidation → Rancidity & spoilage**.** This pathway is widely supported by studies such as Eyo (2001) – moisture is the most important determinant of smoked fish shelf life Abolagba & Uwagbai (2011) – microbial growth accelerates nutrient loss. Akinola *et al*. (2006) – lipids oxidize faster in moist fish during storage

Variation in Sensory Attribute across Storage Day

The sensory scores for taste, aroma, texture, and colour show a very clear and consistent pattern: all attributes declined steadily and significantly as storage time increased, with each day showing a statistically different score from the others ($p < 0.05$). This tells a simple but powerful story the longer the smoked fish stayed in

storage, the more its eating and visual qualities deteriorated.

Day 0 – Fresh and Highly Acceptable On Day 0, the fish scored the highest across all attributes:

Taste: 8.58, Aroma: 8.15, Texture: 8.03, Colour: 8.27. High initial scores reflect the characteristic fresh-smoked quality, aligning with observations by Olayemi & Adedayo (2012) that smoked fish is most acceptable immediately after processing.

Day 7 – Noticeable Decline Begins: By Day 7, there was a sharp and significant drop across all sensory parameters. Taste and aroma dropped to around 6.5–6.7, while texture and colour reduced to a little above 6. This early decline is normal because even properly smoked fish begins to lose moisture, oxidative reactions begin slowly, and the colour starts to fade.

Despite the drop, the fish samples at Day 7 still remained moderately acceptable. The reduction in scores is expected as oxidative and microbial activities begin slowly. Several authors, including Agbon et al. (2002), noted significant declines within the first week of storage due to moisture loss and chemical changes.

Day 14 – Mid-Storage Quality Loss: The downward trend continued by Day 14. Taste fell to 5.30, aroma to 4.76, and colour dropped dramatically to 4.15. Texture (5.36) seemed slightly better preserved than aroma and colour, but still showed notable reduction.

At this stage, consumers would begin to notice clear changes in the product—less appealing smell, loss of characteristic smoked colour, and the beginning of textural softening or dryness. Overall acceptability was beginning to drift toward the lower limit of consumer tolerance. Aroma and colour dropped sharply, consistent with reports that lipid oxidation becomes more pronounced by the second week (Horner, 1997). Colour degradation is a common outcome of pigment breakdown caused by exposure to air and heat.

Day 21 – Significant Deterioration: By the third week, the deterioration became quite pronounced. Scores fell below 4 for most attributes, showing that: The flavour was fading, the aroma was weakening or developing off-notes, the colour had lost its brightness, and the texture was becoming poor, though still slightly higher than colour. At this point, the fish was no longer attractive for most consumers and was approaching unacceptable quality. With scores falling below 4, the fish had entered the late deterioration phase. This corresponds with the timeline provided by FAO (2012), which estimates a 2–4 week sensory shelf-life for traditionally smoked fish stored without refrigeration.

Day 28 – Very Low Sensory Quality: At the end of the storage period, all attributes had collapsed to very low values: Taste: 1.73, Aroma: 1.21, Texture: 1.82 and Colour: 1.09

These scores show that after 28 days, the fish had lost nearly all its desirable sensory characteristics. Extremely low sensory scores confirm that the product had passed acceptable limits. Similar end-stage deterioration has been documented by Abolagba & Iwasokun (2010), who noted severe texture breakdown and off-flavour development after long ambient storage.

At this stage, the product was sensory unacceptable and unsuitable for consumption.

Effect of Drying Media on Sensory Attributes of Smoked Fish

The results in Table 4.3 show that the type of drying medium used during smoking had a meaningful influence on how consumers perceived the taste, aroma, texture, and colour of the fish. All four sensory attributes differed significantly among the drying methods ($p < 0.05$), indicating that each medium imparted its own characteristic effect on product quality. The significant differences among drying media indicate that the smoke source contributes uniquely to flavour, aroma, texture, and colour. This aligns with findings by Eyo (2001) and FAO (2012), which emphasize that firewood, charcoal, and sawdust differ in combustion properties and smoke composition

Firewood – Best Overall Sensory Performance

Fish smoked with firewood consistently received the highest scores across all attributes: Taste: 5.53, Aroma: 5.31, Texture: 5.60 and Colour**:** 4.95. These values show that firewood produced fish with the most appealing flavour, smell, and mouthfeel, likely due to the rich smoky compounds naturally generated from burning logs. Firewood produced the highest scores across all sensory parameters. The superior acceptance is consistent with studies by Fapohunda and Ogunkoya (2006) and Horner (1997), which found that firewood generates richer aromatic compounds such as phenols that enhance flavour and improve preservation.

The steady heat distribution of firewood likely contributed to better texture and colour as well.

Sawdust – Lowest Sensory Scores

Fish dried with sawdust had the lowest sensory ratings, especially for: Taste **(**5.00), Aroma (4.55), Texture (4.82) and Colour (4.09)**.** Panelists found these samples less flavourful, less aromatic, and generally less firm. The colour score was particularly low, suggesting that sawdust smoke may produce more uneven Sawdust samples had the lowest scores, likely due to the rapid and inconsistent burning nature of sawdust. Previous studies by Abolagba and Iwasokun (2010) reported similar findings, noting that sawdust-smoked fish often appears duller and less aromatic. This indicates that sawdust may not be the ideal medium for producing high-quality smoked fish.

Charcoal – Intermediate Quality

The fish smoked with charcoal had sensory scores that fell between firewood and sawdust: Taste: 5.11, Aroma: 4.60, Texture: 4.95 and Colour: 4.36. Charcoal generally provides cleaner heat with less smoke, which may explain the moderate scores. It produced fish that were acceptable but not as flavourful or aromatic as firewood-smoked samples. Colour development was slightly better than sawdust but still inferior to firewood.Charcoal produced moderate scores. Charcoal burns cleaner with less smoke, which may reduce the intensity of flavour and aroma. FAO (2012) notes that charcoal is preferable for uniform heating but produces minimal smoke compounds responsible for strong sensory appeal. This explains its intermediate performance relative to firewood and sawdust.

Overall Trends and Practical Meaning

Across all sensory attributes—taste, aroma, texture, and colour—the pattern is clear: Firewood consistently produced fish that tasters found more appealing, showing that it imparts richer flavour, stronger aroma, firmer texture, and more attractive colour. Sawdust produced the weakest sensory qualities, while charcoal provided only moderate quality.

Interaction Between Storage Days and Drying Methods

The interaction results suggest that the influence of drying media is not constant—its effect changes as storage progresses. This interactive effect has been noted in works by Ikutegbe and Sikoki (2014) and Akinola et al. (2010), who reported that initial sensory differences may diminish or intensify depending on how each processing method interacts with storage-induced chemical changes.

In this study, early storage differences were driven mostly by texture and colour, Mid-stage differences reflected aroma changes due to oxidation and Late-stage differences centred around aroma, a key spoilage indicator. This confirms that the choice of drying medium influences not only initial sensory quality but also the rate and pattern of deterioration.

Overview of Microbial Load and Morphology (Day 0)

At the start of storage (Day 0), all samples—F (firewood), S (sawdust), and C (charcoal)—already harbored relatively high counts of heterotrophic bacteria and fungi, which is consistent with other studies on post-smoking contamination. For example, Eyo (2001) and Fapohunda and Ogunkoya (2006) reported significant microbial presence even immediately after traditional smoke-processing, due to incomplete sterilization and post-processing contamination.

Bacterial Counts and Morphology

The CFU/ml ranged widely (2.8×10^6 to 9.1×10^6). This suggests diverse bacterial loads, which is typical of traditionally processed fish where temperature and smoke penetration vary during smoking (affected by smoking medium and duration). Previous reports similarly observed variable loads: Nguz and Zewdu (2016) found that smoked fish often contain microbial loads $>10^6$ CFU/g when post-smoking handling isn't hygienic.Saalia and Kortei (2016) noted that traditional smoking seldom eliminates all bacteria, especially when cooling and packaging are sub-optimal.

The morphology data entire, lobate, filamentous margins; milky/opaque colours; flat/raised elevations are consistent with typical colony characteristics of common fish spoilage and environmental bacteria (Holt et al., 1994). Convex, entire milky colonies usually reflect Staphylococcus or Bacillus species

Biochemical and Identification Findings

Across all treatments on Day 0, your isolates were mostly catalase-positive and oxidase-negative common traits in fish spoilage bacteria such as Staphylococcus spp., Bacillus spp., and Escherichia coli.

The presence of S. aureus and E. coli even at Day 0 echoes Olaoye et al. (2018), who isolated these from smoked catfish suggesting persistent contamination despite smoke exposure. Studies like Mboto and Nsan (2013) also stress that non-uniform heat distribution in traditional smoking allows survival of heat-tolerant bacteria.

Fungal Load and Identification (Day 0)

Fungi counts ranged from ~1.7×10^6 to ~6.1×10^6 CFU/ml on Day 0. This is high but not unexpected, especially in humid storage conditions and open smoking systems where mould spores from the environment easily settle on fish surfaces.

Most commonly identified fungi:Aspergillus niger, Aspergillus flavus, Aspergillus japonicus and Penicillium spp. Their presence is concerning due to mycotoxin production reported in A. flavus (e.g., aflatoxins), which pose food safety risks (Pitt and Hocking, 2009).

Temporal Trends (Day 7, 14, 21, 28)

Total Heterotrophic Bacteria and Fungi

The summarized data show a clear significant increase in bacterial and fungal counts over time—a pattern widely documented in stored fish microbiology.

Bacteria: Increased progressively from Day 0 to 28 across all treatments, with the highest loads in the sawdust (S) treatment at each time point. Fungi: Similar upward trend, with the highest counts consistently in sawdust-treated samples. . Eyo (2001) and Odoemelam (2010) noted that storage especially at ambient temperatures promotes bacterial proliferation due to moisture residence and nutrient availability.Onyelobi and Fayemi (2016) documented that fungal counts increased over time in smoked fish stored under similar conditions, particularly when moisture condensation occurred.

Day 7 Specifics
By Day 7, significant rises in CFU/ml, especially in sawdust samples, point to rapid microbial growth early in storage consistent with Ikutegbe and Sikoki (2014), who observed that poorly dried or unevenly smoked fish show early peak microbial loads.
Identified bacteria such as E. coli, Klebsiella spp., and Proteus spp. at Day 7 are typical of environmental contamination and cross-contamination during handling.
Day 14 Dynamics
On Day 14, the continued appearance of Gram-negative bacteria like Pseudomonas aeruginosa and Vibrio cholerae is of particular concern. These organisms thrive in moist, less competitive environments. Widely reported as spoilage bacteria in refrigerated and ambient storage (Gram et al., 2002; Tajkarimi et al., 2010) .This aligns with your observation that microbial composition diversified over time, especially in charcoal (C) and sawdust (S) groups, indicating that the drying method influences species most likely due to differences in residual moisture and smoking intensity.
Day 21 and Enterobacteriaceae Proliferation
By Day 21, high counts of Enterobacteriaceae (including Klebsiella, Shigella, and E. coli) indicate substantial fecal or environmental contamination and poor hygienic handling—a pattern consistent with Saalia and Kortei (2016), who emphasized Enterobacteriaceae as indicators of poor fish processing hygiene.
Interestingly, Bacillus anthracis appeared in your Day 21 and Day 28 samples—a rare but serious finding. While not common in smoked fish literature, studies have shown that Bacillus spp. can survive heat and remain dormant in spores, reactivating under storage (Khoo, 2009).
Day 28 – Peak Contamination
Day 28 results show the highest bacterial loads (>10^7 CFU/ml) with predominantly Gram-negative rods (Escherichia coli, Klebsiella pneumoniae, Streptobacillus spp.), plus Gram-positives like Bacillus cereus. This trend mirrors findings by Ishola et al. (2015) and Onyenekwe and Akusu (2018), who attributed late-stage spoilage to opportunistic bacteria that proliferate after initial smoke-sensitive flora decline.
Fungi at Day 28 especially Aspergillus and Fusarium species also showed high CFU counts, indicating that prolonged storage without adequate moisture control promotes mould dominance. This progression is well-documented in Akinyemi et al. (2011) and Pitt and Hocking (2009).

Impact of Smoking Medium on Microbial Dynamics
Across all days, sawdust (S) generally had the highest heterotrophic counts and fungal loads. This supports literature indicating that: Sawdust smoke generates less uniform heat compared to firewood or charcoal (Eyo, 2001). Poor smoke penetration allows microorganisms to survive initial processing and proliferate during storage. Firewood (F) often had lower bacterial counts initially, aligning with Fapohunda and Ogunkoya (2006), who noted that traditional firewood smoking produces more penetrating heat and a broader spectrum of phenolic antimicrobial compounds. Charcoal (C) typically showed intermediate contamination levels, likely due to moderate heat and slower smoke deposition, which some authors (e.g., FAO, 2012) suggested might reduce oxidative damage but also permit some bacteria to survive.

Public Health and Food Safety Implications
The presence of: Enteric bacteria (E. coli, Shigella spp.),,Opportunistic pathogens (Pseudomonas spp., Klebsiella spp.), Mycotoxin-producing moulds (A. flavus, Fusarium spp.). Echoes serious food safety concerns reported by Saalia and Kortei (2016) and Olatunde et al. (2017). These findings suggest that traditional smoked fish stored without adequate drying, good handling, or hygienic packaging is at high risk of spoilage and may pose a health risk to consumers.
Microbial counts increase with storage time is Consistent with *Eyo (2001); Onyelobi and Fayemi (2016).* Diverse bacterial species including pathogens Matches *Saalia and Kortei (2016); Boonla et al. (2014)*. Fungi dominated by *Aspergillus* species Supports *Akinyemi et al. (2011); Pitt and Hocking (2009)*. Smoke medium affects survival and growth Supported by *Fapohunda and Ogunkoya (2006)*
In conclusion, microbial load increased significantly from Day 0 to Day 28, reflecting progressive spoilage. Firewood smoking offered somewhat better microbial control than sawdust and charcoal. The diversity of bacteria and fungi identified is similar to what has been reported in traditional smoked fish studies, highlighting persistent contamination risks. The presence of pathogenic and toxin-producing organisms underscores the need for improved processing, storage hygiene, and post-smoking handling.

CONCLUSION
This study shows that the type of smoking material firewood, charcoal, or sawdust greatly affects the quality and shelf life of smoked *Clarias gariepinus* during 28 days of storage. Among the three materials, firewood consistently produced the best results, followed by charcoal, while sawdust offered the poorest overall quality.
From the sensory evaluation, all freshly smoked fish were generally acceptable in taste, aroma, texture, and colour. However, as storage progressed, their quality gradually declined. Firewood-smoked fish retained good sensory qualities for a longer period, while sawdust-smoked fish showed noticeable deterioration much earlier. This highlights how different smoking materials influence flavour development and the ability of the fish to resist spoilage.

The proximate composition also changed with storage time. Moisture levels increased steadily, while crude protein decreased across all treatments—a typical trend for smoked fish stored under ambient conditions. Firewood-smoked samples retained the highest protein content and had better moisture stability than the other treatments. Meanwhile, lipid oxidation increased in all the samples as days passed, but firewood-smoked fish showed the slowest oxidation rate. Sawdust-smoked fish recorded the highest and fastest increase in rancidity, making them more vulnerable to spoilage.

Microbiologically, all samples showed some level of contamination right from Day 0, which reflects the common challenges with traditional smoking and handling practices. Microbial loads increased significantly as storage continued, and sawdust-smoked fish always had the highest counts. Firewood-smoked fish had the lowest microbial growth, most likely because firewood produces stronger heat and smoke compounds that slow down microbial activity.

Overall, this study clearly demonstrates that firewood is the best smoking material among the three tested. It delivers better nutritional quality, slower lipid oxidation, more stable sensory attributes, and lower microbial growth. Charcoal performs moderately well, while sawdust presents the highest risk of quality loss during storage.

The findings emphasize the need for better smoking practices and improved kilns to ensure safer and longer-lasting smoked fish products. Using firewood or enhanced smoking technologies can help reduce post-harvest losses, improve fish quality, and support the livelihoods of fish processors. Future studies could explore controlled storage conditions, packaging methods, or natural preservatives to further extend the shelf life beyond 28 days.

RECOMMENDATIONS

Based on the results of this study, the following recommendations are proposed to improve the quality, safety, and shelf life of smoked *Clarias gariepinus*:

1. Promote the Use of Firewood as the Preferred Smoking Material
   Since firewood consistently produced the best sensory, nutritional, and microbial outcomes, fish processors should be encouraged to use firewood especially hardwoods that generate steady heat and rich smoke compounds. Training programs should emphasize the advantages of firewood over sawdust.
2. Improve Traditional Smoking Kilns
   The high microbial loads observed suggest a need for better smoking structures. Improved smoking kilns (e.g., Chorkor, Altona, or FAO Thiaroye smokers) should be promoted to: provide uniform heat, reduce contamination, slow down moisture reabsorption, and minimize lipid oxidation.These technologies can significantly extend shelf life.
3. Encourage Hygienic Handling Throughout the Processing Chain
   Many microbial problems begin even before smoking. Therefore:fish should be washed thoroughly,processors should avoid placing fish on contaminated surfaces,utensils must be cleaned regularly, and smoking areas should be kept free from insects, dust, and rodents. Improving hygiene will reduce spoilage and health risks.
4. Adopt Better Packaging and Storage Practices
   Since moisture and oxidation increased quickly during storage, processors should consider: packaging smoked fish in airtight or moisture-proof materials,storing products in cool, dry environments,exploring low-cost vacuum packaging or modified atmosphere packaging (MAP) if available. Proper packaging can significantly slow down quality deterioration.
5. Avoid Sawdust as a Primary Smoking Material
   Because sawdust-smoked samples had the poorest sensory scores, fastest oxidation, and highest microbial loads, it should not be recommended for processing fish intended for long storage. If used at all, it should be combined with other fuels and handled under controlled conditions.
6. Sensitize Processors on the Dangers of Lipid Oxidation
   Awareness campaigns should educate fish processors about rancidity, off-flavours, and the health implications of oxidative spoilage. They should be taught practical ways to minimize oxidation, such as: using high-quality fuel materials, avoiding prolonged exposure to air, using proper packaging for storage.

REFERENCES

Abdel-Naeem, H. H., Sallam, K. I., and Malak, N. M. (2021). Improvement of the microbial quality, antioxidant activity, phenolic and flavonoid contents, and shelf life of smoked herring (Clupea harengus) during frozen storage by using chitosan edible coating. *Food Control*, *130*, 108317.

Abdul, I. M., Kamilu, M., Maiyanga, I. E., Yaji, I. L., Yerima, A. K and Ibrahim, A. T. (2024). The Role of Post-Harvest Technologies in the Handling and Preservation of Fish and Fish Products in Nigeria: A Mini-Review. *Journal of Agriculture, Aquaculture, and Animal Science*, *1*(1), 1-4.

Adeyeye, S. A. O. (2019). Smoking of fish: a critical review. *Journal of Culinary Science & Technology*, *17*(6), 559-575.

Adeyeye, S. A. O., Oyewole, O. B., Obadina, O., Adeniran, O. E., Oyedele, H. A., Olugbile, A., and Omemu, A. M.

(2016). Effect of smoking methods on microbial safety, polycyclic aromatic hydrocarbon, and heavy metal concentrations of traditional smoked fish from Lagos State, Nigeria. *Journal of Culinary Science & Technology*, *14*(2), 91-106.

Agbangba, C. E., Aide, E. S., Honfo, H., and Kakai, R. G. (2024). On the use of post-hoc tests in environmental and biological sciences: A critical review. *Heliyon*, *10*(3).

Ahmed, N., Thompson, S., and Glaser, M. (2019). Global aquaculture productivity, environmental sustainability, and climate change adaptability. *Environmental management*, *63*, 159-172.

Akinwole, A. O., Fawole, O. O., and Oyediran, F. S. (2024). Nutritive and organoleptic evaluation of the African catfish (*Clarias gariepinus*) smoked with briquette and charcoal. *Journal of Agriculture and Food Sciences, 22*(1), 69–76.

Alosias, J. (2020). A review on the application of improved fish handling and smoking: safe quality and potential business venture for developing countries. *London Journal of Research in Science: Natural and Formal*.

Aneja, K.R. (2018). *A Textbook of Basic and Applied Microbiology*, New Age International Publishers, New Delhi.

Arvanitoyannis, I. S., and Kotsanopoulos, K. V. (2012). Smoking of fish and seafood: history, methods and effects on physical, nutritional and microbiological properties. *Food and bioprocess technology*, *5*, 831-853.

Asamoah, E. (2018). The quality and shelf life of Atlantic mackerel (Scomber scombrus) as influenced by smoking technology, packaging material and storage temperature. *Nations University Fisheries Training Programme, Iceland[Final Project]*.

Asen, B., Akombo, P. M., Annune, P. A and Nyakuma, B. B. (2024). Assessing Nutrient Retention, Cost-Effectiveness and Fuel Efficiency of Charcoal Briquettes for Fish Smoking in Nigeria. *Engineering Proceedings*, *67*(1), 77.

Assogba, M. F., Anihouvi, E. L., Adinsi, L., Boukary, B. S., Kpoclou, Y. E., Mahillon, J., and Anihouvi, V. B. (2021). Sensory profiling of meat and fish products obtained by traditional grilling, smoking and smoking-drying processes. *Journal of Aquatic Food Product Technology*, *30*(4), 378-391.

Awhefeada, O. K., Bekederemo, B. O., Akpomughe, E., & Okpu, P. N. (2025). Morphometric Characterization, Heterosis Expression, and Growth Performance of Genetically Improved Farmed Tilapia and Red Tilapia Hybrids for Sustainable Aquaculture Development. *Journal of Science Research and Reviews*, *2*(2), 145-155. https://doi.org/10.70882/josrar.2025.v2i2.102

Badoni, P., Nazir, I., Aier, M., Maity, P. B., Samanta, S., and Das, A. (2021). Significant role of fish nutrients with special emphasis to essential fatty acid in human nutrition. *Int. J. Curr. Microbiol. Appl. Sci*, *10*, 2034-2046.

Budaraga, I. K. (2017). Effect of Combination Treatment of Liquid Smoke Concentration, Soaking Time, Packaging and Different Storage Time To Yield And Moisture Content nila Fish Fillet (Oreochromis niloticus). *International Journal of ChemTech Research*, *10*(1), 77-88.

Cheesbrough, M. (2002). District Laboratory Practice in Tropical Countries (Part 2). Trpical Health Technology Publishers, Greatn Britain 40-56pp.

Cyprian, O. O., Van Nguyen, M., Sveinsdottir, K., Jonsson, A., Tomasson, T., Thorkelsson, G., and Arason, S. (2015). Influence of smoking and packaging methods on lipid stability and microbial quality of C apelin (M allotus villosus) and Sardine (S ardinella gibossa). *Food science & nutrition*, *3*(5), 404-414.

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

Daramola, J. A., Fasakin, E. A., and Famurewa, J. A. V. (2020). Fish smoking kiln using agricultural wastes as energy source (A). *The International Journal of Engineering and Science*, 9(4), 29–33.

Don, S., Lekshmi, M., and Kumar, S. H. (2025). Microbiological quality and safety of processed and packaged fish and fishery products. In *Quality Analysis and Packaging of Seafood Products* (pp. 305-333). Academic Press.

Ekelemu, J. K. Nwabueze, A. A. Irabor, A. E. and Otuye, N. J. (2021). Spicing: A means of improving organoleptic quality and shelf life of smoked catfish. Scientific African, 13; 1-7. E00930. https://doi.org/10.1016/j.sciaf.2021.e00930.

Geraldo, V. (2023). *Good Manufacturing Practices (Gmp) To Improve The Safety And Quality Of Smoked Fish* (Doctoral dissertation, University of Cape Coast).

Huong, D. T. T. (2014). The effect of smoking methods on the quality of smoked mackerel. *United Nations University Fisheries Training Programme, Iceland [final project]*.

Hussein, M. A., Merwad, A. M., Elabbasy, M. T., Suelam, I. I., Abdelwahab, A. M., and Taha, M. A. (2019). Prevalence of enterotoxigenic *Staphylococcus aureus* and Shiga toxin-producing *Escherichia coli* in fish in Egypt: Quality parameters and public health hazard. *Vector-Borne and Zoonotic Diseases, 19*(4), 255–264. https://doi.org/10.1089/vbz.2018.2336

Idah, P. A., and Nwankwo, I. (2013). *Effects of smoke-drying temperatures and time on physical and microbial quality of fish*. African Journal of Agricultural Research, 8(46), 5932–5937. https://doi.org/10.5897/AJAR2013.7222

Krishnan-Sarin, S., O'Malley, S. S., Green, B. G and Jordt, S. E. (2019). The science of flavour in tobacco products. *World Health Organization technical report series*, *1015*, 125.

Langi, S., Maulu, S., Hasimuna, O. J., Kaleinasho Kapula, V., and Tjipute, M. (2024). Nutritional requirements and effect of culture conditions on the performance of the African catfish (Clarias gariepinus): a review. *Cogent Food and Agriculture*, *10*(1), 2302642.

Lindgren, E., Harris, F., Dangour, A. D., Gasparatos, A., Hiramatsu, M., Javadi, F and Haines, A. (2018). Sustainable food systems—a health perspective. *Sustainability science*, *13*, 1505-1517.

Majumdar, R. K. (2019). *Traditional Technology of Fish Preservation in Northeast India*. In *Technologies for Value Addition in Food Products and Processes* (pp. 127–162). Apple Academic Press.
March, A., and Failler, P. (2022). Small-scale fisheries development in Africa: Lessons learned and best practices for enhancing food security and livelihoods. *Marine Policy*, *136*, 104925.

Messina, C. M., Arena, R., Ficano, G., Randazzo, M., Morghese, M., La Barbera, L and Santulli, A. (2021). *Effect of cold smoking and natural antioxidants on quality traits, safety and shelf life of farmed meagre (Argyrosomus regius) fillets, as a strategy to diversify aquaculture products*. *Foods*, 10(11), 2522.

Muringai, R. T., Mafongoya, P., Lottering, R. T., Mugandani, R., and Naidoo, D. (2021). Unlocking the potential of fish to improve food and nutrition security in sub-Saharan Africa. *Sustainability*, *14*(1), 318.

Nwabueze, A. A. and Atokpe, I. Q. (2015). Fish smoking: A post-harvest technology in Delta State, Nigeria. Proceedings of the 49th Annual Conference of the Agricultural Society of Nigeria. Asaba 2015 9th-13th November, 2015.1202-1206pp.

Ojelade, O. C., George, F. O. A., Abdulraheem, I., and Akinde, A. O. (2023). Interactions between pre-harvest, post-harvest handling and welfare of fish for sustainability in the aquaculture sector. In *Emerging Sustainable Aquaculture Innovations in Africa* (pp. 525-541). Singapore: Springer Nature Singapore.

Okpala, C. O. R and Korzeniowska, M. (2023). Understanding the relevance of quality management in agro-food product industry: From ethical considerations to assuring food hygiene quality safety standards and its associated processes. *Food Reviews International*, *39*(4), 1879-1952.

Oli, A. U., Okeke, P. A., Oli, C. C., Ibe, F. N., and 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 (NIJBAS)*, 5(2).

Osineye, O., Abiodun-Solanke, A. J., Mangai, E., Okeke, E., and Jahnezim, B. (2020). Comparison of polyaromatic hydrocarbon residue concentrations in Clarias gariepinus smoked with traditional and mechanical kilns. *Journal of Health and Pollution*, *10*(28), 201215.

Ovie, K. A., Okpu, P., Oster, F. N., & Emuesiri, A. (2025). Evaluation of Proximate Composition of Varying Black Soldier Fly (BSF) Larvae as an Alternative Protein Source. *Journal of Science Research and Reviews*, *2*(4), 1-8. https://doi.org/10.70882/josrar.2025.v2i4.95

Prajapat, B. (2024). *Fish Fermentation: Techniques and Uses*. Educohack Press.

Puke, S., and Galoburda, R. (2020). Factors affecting smoked fish quality: A review. *Research for rural development*, *35*(March), 132-139.

Rana, M. M., Mohibbullah, M., Won, N. E., Baten, M. A., Sohn, J. H., Kim, J. S., and Choi, J. S. (2021). Improved hot smoke processing of chub mackerel (Scomber japonicus) promotes sensorial, physicochemical and microbiological characteristics. *Applied Sciences*, *11*(6), 2629.

Soares, J. M., da Silva, P. F., Puton, B. M. S., Brustolin, A. P., Cansian, R. L., Dallago, R. M., and Valduga, E. (2016). Antimicrobial and antioxidant activity of liquid smoke and

its potential application to bacon. *Innovative Food Science & Emerging Technologies*, *38*, 189-197.

Taherzadeh-Shalmaei, N., Sharifi, M., Ghasemi-Mobtaker, H., and Kaab, A. (2021). Evaluating the energy use, economic and environmental sustainability for smoked fish production from life cycle assessment point of view (case study: Guilan Province, Iran). *Environmental Science and Pollution Research*, *28*(38), 53833-53846.

Tigabu, Y., Yimer, A., Mikael, F. H and Tadesse, S. (2022). Suitability of Wooden Plants for Making Smoked Products from Nile Tilapia Fish. *Livestock Research Results*, 544.

Wijerathna-Yapa, A., and Pathirana, R. (2022). Sustainable agro-food systems for addressing climate change and food security. *Agriculture*, *12*(10), 1554.

Yang, J and Lee, J. (2018). Korean consumers' acceptability of commercial food products and usage of the 9-point hedonic scale. *Journal of Sensory Studies*, *33*(6), e12467.

Zaki, H. M. B. A., Emara, M. M. T and Abdallah, M. R. S. (2021). Effect of smoke duration on compositional analysis, deterioration criteria, microbial profile and sensory attributes of marine and freshwater fish: a comparative study. *Adv. Anim. Vet. Sci*, *9*(8), 1259-1266.