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Assessment of Chemical Residues on the Preserved Smoked Fish in Wukari Local Government Area, Taraba State, Nigeria

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Abstract
Objective: This study investigated preservation practices, chemical applications, and perceptions of safety among smoked fishmongers in Wukari, Taraba State, over a 4-month period. The research specifically sought to identify the types of preservatives used, evaluate sellers' level of safety awareness, and determine the infrastructural barriers to adopting modern preservation technologies.

Method: A descriptive survey design was employed, utilising structured questionnaires administered to a sample of 148 fishmongers. Data were analysed using frequencies, percentages, and Chi-Square (χ^2) tests to assess the statistical significance of demographic distributions and their relationship with fish-selling practices.

Result: The study revealed that the trade is a vital economic activity dominated by middle-aged women (76%), with 94% of respondents citing it as a significant source of household income. Traditional smoking techniques are overwhelmingly preferred (93%), with 100% of sellers utilising "Aro" (hardwood-derived smoke) for preservation rather than synthetic chemical additives. While 100% of respondents believe their methods are safe, a significant 45% are unaware of national food safety regulations. Furthermore, the adoption of modern methods is currently hindered by a lack of equipment (57%) and inadequate storage facilities

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(25%), despite 100% of sellers' willingness to transition to improved techniques if provided with resources.

Conclusion: The study concludes that the smoked fish industry in Wukari relies on deeply rooted traditional knowledge and hardwood smoking ("Aro"), which is perceived as safe by practitioners but lacks scientific validation. The "perception-safety gap" and infrastructural deficits highlight an urgent need for government intervention. Recommendations include subsidising modern kilns, implementing health education programs on the risks of smoke inhalation, and establishing regulatory oversight to align traditional expertise with modern food safety standards.

Keywords: Chemical residues, preservation, smoked fish, post-harvest, deterioration

Introduction

Fish is a significant source of animal protein in human diets. Smoked fish is a traditional part of the diet of a large section of the world's population. However, the gap between fish demand and supply is widening due to population growth, poor post-harvest handling, a lack of processing and storage facilities, and the utilisation of unconventional fish species (FAO, 2010). In Nigeria, fish constitute 40% of animal protein intake, but 40% of the total fish catch is lost annually due to inadequate or poor preservation, processing, and handling (Oladosun & Tubor, 2006).

Several methods for fish smoking are available, and different smoked products have been developed in various parts of the world in relation to the properties of locally available raw materials and the general level of technology (Olley et al., 2008). Smoking is a traditional fish-processing method used to prevent or reduce post-harvest losses. Post-harvest losses in fish are represented by a net reduction in the amounts of nutrients potentially available to the consumer, either by direct physical loss or nutritional loss.

These factors affect consumer acceptability, commercial value, and income for fish farmers/traders (Bostock et al*.,* 2007). This study ascertains the chemical levels in smoked fish in old and new markets in Wukari City, Wukari Local Government Area, Taraba State, Nigeria.

Aim of the Study

This research aims to assess the chemical levels affecting the preservation of smoked Fish in old and new markets in Wukari, Wukari Local Government Area, Taraba State.

Objectives of the Study

The specific objectives of this study are to:

i. Determine the socio-economic characteristics of the respondents in Wukari,
ii. Determine the type of smoked fish species sold in Wukari city,
iii. Determine the type of preservative chemical used for the smoked fish species.

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Smoke and Smoked Fish Production

Smoking, as a method of preserving food with high levels of added salt, has been used for centuries for domestic purposes. As analytical techniques have developed in recent decades, the notion of traditional smoked products has been overturned. Whole groups of carcinogenic polycyclic aromatic hydrocarbons (PAHs), mutagenic nitrosamines, and other harmful substances, such as methanol and formaldehyde, have been detected in smoke and in smoked products. This has necessitated the development of environmentally friendly methods for smoking foods, based on effectively removing harmful substances from the smoke and on the use of the resulting smoke preparations.

Additionally, the harmful effects of excess sodium intake have spurred the development of technologies to produce low-sodium smoked foods. Investigation of the effects of smoking on colour, flavour and aroma became the basis for the construction of modern smoking devices, by which process control over smoking is possible. Most attention today is focused on liquid smoke (an aqueous smoke solution), which is well-studied, readily available, and has minimal potential for toxicity.

Smoked fish is one of the most attractive fish products. This accounts for the fact that nearly 20% of the total fish supply in the French market is smoked. Cold-smoked fish is particularly interesting; depending on the fish species and size, the amount of salt used, and the thermal processing employed, it can be consumed with or without additional heat treatment.

Composition of Smoke

The chemical composition of smoke and its condensates remain incompletely elucidated. So far, 300 compounds have been identified in smoke, 288 in condensate, and about 68 in smoked foodstuffs. This testifies to the high reactivity of the basic components of smoke (alcohols, aldehydes, ketones, keto acids, esters) with smoked foods like fish. The most common compounds are phenols, which lead to the formation of all the effects of smoking. Forty-seven PAHs were identified in smoke, and about 20 PAHs were detected in smoked meat or fish. However, there are approximately 200 PAHs, some of which are carcinogenic or mutagenic. Studies have shown that not all PAHs are carcinogenic or mutagenic; however, one of the most common cancer-inducing PAHs is 3,4-benzopyrene, which is abundant in smoke (Yusuf et al*.,* 2015).

According to other sources, 660 distinct PAHs have been described to date, and approximately 100 PAHs and their alkaline derivatives have been identified in smoked fish. It has been shown that 15 PAHs exhibit mutagenic and genotoxic effects on the somatic cells of experimental animals in vivo (Stolyhwo & Sikorski, 2005). These genotoxic PAHs can be considered as potentially genotoxic and carcinogenic to humans. It is generally accepted that PAHs with molecular weights below 216 Da are not carcinogenic (Sander & Wise, 1997). PAHs in smoke are formed during wood combustion from practically all organic compounds in conditions of low oxygen supply and temperatures higher than 400ºC. The likelihood of PAH formation is exceptionally high when the temperature reaches more than 1000ºC (Skaljac et al., 2018). The PAH content in smoked fish and meats depends on several factors, the most important being the smoking method (artisanal or industrial) and the temperature at which wood pyrolyses.

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Temperature plays a significant role in PAH formation, as PAH concentration increases proportionally with pyrolysis temperature from 400 °C to 1000 °C. The optimal temperatures for wood pyrolysis, 300 to 600 °C, are also those at which more useful and fewer harmful compounds, particularly potentially carcinogenic PAHs, are produced (Vuković & Janković, 2017). However, the optimal temperature for wood pyrolysis is not achieved in traditional fish smoking, nor can the smoke be purified of carcinogens. Therefore, there is a risk that harmful compounds may occur at higher concentrations in such traditionally smoked fish products. In modern industrial facilities, smoke is produced in a generator that is separated from the fish. Under such conditions, the temperature of sawdust combustion, the presence of air (oxygen), and air circulation can be controlled. Additionally, the smoke is channelled from the smoke generator to the smoking chamber, where it can be purified using various techniques (Kilibarda et al., 2009).

Methods of Fish Smoking in Nigeria

a) Traditional method of smoking fish in Nigeria: The traditional way of smoking fish is done by leaving the fish to be processed naturally with smoke generated by burning wood. Moreover, usually, smokehouses (smoking kilns) are built for smoking fish. However, it is not getting a lot of prominence through the traditional way of smoking fish for export. Modern mechanical methods of fish preservation are gradually replacing traditional smoking. Due to the increase in aquaculture production in Nigeria and the demand for high-quality products abroad, there is a need to develop modern fish preservation and processing machinery and techniques to ensure effective fish processing and storage (Eyo, 2000). The modern smoking method has the following advantages:

i. More hygienic by producing the dead fish free from heavy smoke deposits.
ii. Less batch processing time than the traditional drying method.
iii. Removed labour and time involved in the rotation of fish repeatedly, like the labour needed to monitor the fish during smoking to avoid charring.
iv. Allows large-scale smoking operation.

b) Mechanical Fish Smoking Kiln

After extensive improvements, the mechanical smoking kiln was designed and fabricated as a modern fish-smoking machine. The use of a forced draft enhances drying and smoke application, whereas a remote heater source reduces much of the smoking time. The mechanical smoking kiln can be relied upon to produce a high-quality, uniform product that conforms to the internationally accepted standard.

Problems Associated with the Storage of Smoked Fish Species

Fish is highly perishable (Agbon et al., 2002), and various factors contribute to its spoilage. However, the quality of capture is important in determining spoilage rates. Notably are the fish health status, the presence of parasites, bruises and wounds on the skin and the mode by which the fish was captured. The quality of the caught fish depends on the handling and preservation it receives from the fishers after capture. Handling and post-capture preservation practices affect the degree of fish spoilage (Akinneye et al., 2007).

Eyo (2001) averred that an estimated 40% of total fish landing in Nigeria is lost as post-harvest losses. He also stated that an estimated 20% to 50% of the fish produced in remote

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coastal areas in Nigeria and many tropical countries perish before reaching consumers due to poor handling, preservation, and processing techniques and practices adopted by artisanal fishermen and fish entrepreneurs. In addition, substantial quality losses occur due to the absence of adequate technology and expertise to prevent them in many tropical countries (Clucas, 1990).

Pest Found on Stored Smoked Fish Species

Insects and mites often infest cured fish during and after processing, particularly in the tropics and subtropics, where year-round high temperatures and humidity are prevalent. Quantitative losses due to feeding damage by insect and mite pests on cured fish have been reported to be up to 30% due to fly damage during processing and up to 50% due to beetle damage during processing for several months. Examples of global losses of dried fish due to insect infestations are provided by Poulter et al. (2007). Rollings and Hayward (1963) estimated such losses at Lake Chad at 50%, while the FAO (2008) estimated dried fish weight losses due to *Dermestes spp*. damage during a 6-month storage period at 26-34%. The haste to get improperly dried fish to market increases the susceptibility of processed fish to blowfly and beetle infestations in storage (Eyo, 2001).

Arthropod pests commonly found on dried fish are beetles *(Coleoptera*), flies (*Diptera*) and mites (*Acarina*) (FAO, 2000). In Nigeria, species such as *Calliphora, Chrysomia, Lucilia*, and *Musca* (Diptera), *Dermestes maculatus* and *Necrobia rufipes* (Coleoptera), and their larvae have been reported as pests of dried fish (Osuji, 2005). Furthermore, *Lasioderma serricorne* has been reported as a pest of dried fish (FAO, 2010), and *Lardoglyphid* (mites), notably *Lardoglyphus konoi, Suidasia medamensis* and *Tyrophagus spp (*notably *castaneum* and *saxatile)* have been reported as pests of dried fish (FAO, 2010; Osuji, 2005; Busvine, 1980) from different parts of Nigeria and the tropics.

Eke *et al*. (2008) also found various types of anthropoid pests in varying degrees, which affect the nutritional and aesthetic quality of dried stored fish in Nsukka, Nigeria (See Table 1 below). They also reported an interesting finding from their research: a spider species (*Theridion saxatile*) was found to be resident in the dried matter of *Alestes spp*.

Table 1: Pest Found on Stored Smoked Fish Species

Fish name	Scientific name of pest	Common name of pest
Synodontis	*P. americana*	Cockroach
Oreochromis	*Lucillia spp*	Green butterfly
Hepsetus	*P. americana*	Cockroach
Gymnarchus	*Calliphora spp*	Blowfly
Labeo	*Calliphora spp*	Blowfly

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Fish name	Scientific name of pest	Common name of pest
Protopterus	*P. americana*	Cockroach
Hemisynodontis	*Calliphora spp*	Blowfly
Heterobranchus	*Lucillia spp*	Green butterfly
Alestes	*P. americana*	Cockroach
Heterotis	*P. americana*	Cockroach
Cod (Apama)	*Musca domestica*	Housefly
Cod (cod)	*Musca domestica*	Housefly

Control Methods of Smoked Fish Species Pests

Several authors have proposed various control methods to preserve dried fish for extended storage periods. Eyo (2001) proposed that fish be smoked and re-smoked to prevent microbial activity. Nwachukwu and Madubuko (2013) noted that delaying microbial spoilage of fish can be achieved by introducing additives, such as sodium lactate, to inhibit *Listeria monocytogenes* and *Clostridium botulinum*. Nwachukwu and Madubuko (2013) opined that Rosemary extract with ascorbic acid inhibits oxidative deterioration. Others proposed that dried fish be coated with oils or botanical extracts, such as *Piper guineense* (uziza), *Xylopia aethiopica* (uda), and *Monodora myristica (*ehuru).

Materials and Methods

Study Area

This study was conducted in the Wukari Local Government Area. Wukari is one of the sixteen Local Government Areas in Taraba State and is located in the state's southern zone. It lies at the coordinates 7.9303 ° N, 9.8125 ° E, covering an area of 4,308 km², with a total population of 241,546 according to the 2006 census. The vegetation of the area is savannah, with two climatic seasons: the wet season (April-October) and the dry season (November-March). It is the Traditional Headquarters of the Jukun and Wukari towns, which houses the Aku Uka Wukari, the Supreme Leader of the Jukun People. Jukun, Hausas and Tiv dominate the Local Government. Hausa is the primary language spoken in Wukari. Economic activity in the Local Government is primarily farming.

Source of Samples

All smoked fish species were obtained from Wukari City Markets, Wukari Local Government Area, Taraba State, Nigeria.

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Statistical Analysis
The data obtained were analysed using descriptive and inferential statistics. Descriptive statistics are frequency distribution and percentages; while inferential statistics were obtained through the use of the Chi-square test at a $p < 0.05$ significance level.

Table 2: Demographic and Experience Profile of Respondents (N=148)

Characteristic	Category	Frequency	Percentage (%)
Age	30–49 years	124	84
	Under 20	0	0
	20–29	13	9
	30–39	53	36
	40–49	71	48
	50 and above	11	7
Gender	Female	112	76
	Male	36	24
Education	Secondary Education	64	43
	Primary	42	28
	Tertiary	30	21
	No formal education	12	8
Experience	1–5 years	48	32
	Less than 1 year	37	25
	6–10 years	29	20
	More than 10 years	34	23

Source: Field Survey, 2024

The demographic analysis of the 148 smoked fish sellers in Table 2 reveals that mature, middle-aged women primarily dominate the business with a moderate level of formal education. Mature adults overwhelmingly dominate the industry. The largest group, 48%, is

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aged 40-49 years, followed by the 30-39 age group at 36%. Combined, the 30-49 age bracket accounts for 84% of the respondents, indicating that the business is most popular among adults in their 30s and 40s. There is minimal youth involvement: no participants under 20, and only 9% in the 20-29 age group. With respect to gender representation, there is a significant gender imbalance, with the sector being largely female-dominated. Females account for 76% (112 respondents) of the total sample. Males make up the remaining 24% (36 respondents). The prominence of women suggests they should be the primary target for any training or policy interventions. Most fish sellers possess some level of formal education, which is crucial for understanding and applying safety practices. The most significant proportion, 43%, has a secondary education. Primary education was reported by 28% of respondents, and tertiary education by 21%. Only 8% reported having no formal education. The data shows a mixture of newcomers and moderately established sellers in the trade. The most common length of involvement is 1-5 years, reported by 32% of respondents. A substantial portion (25%) are relative newcomers with less than 1 year of experience. Experienced sellers with 6-10 years and more than 10 years of experience make up 20% and 23%, respectively. This distribution highlights the coexistence of both novice and deeply experienced individuals in the market.

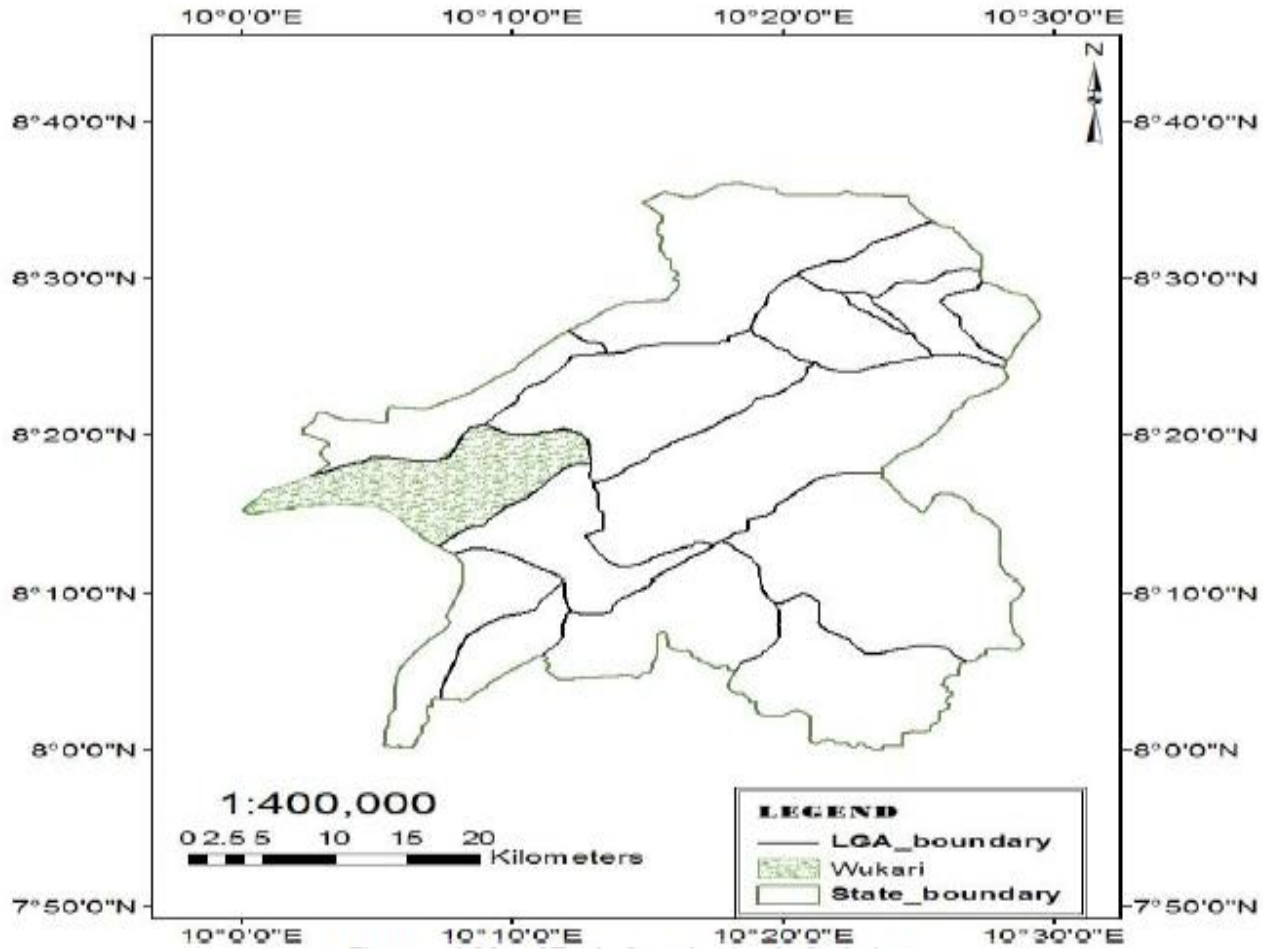

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Figure 1: Map of Wukari Local Government Area showing the study Area (Andrew et al., 2017).

Table 3: Smoked Fish Business Practices (N=148).

Practice	Category	Frequency	Percentage (%)
Sales Location	New Market	77	52
	Old Market	71	48
Dominant Fish Types Sold	Catfish	69	47
	Mackerel	65	44
	Tilapia	14	9
	Crayfish/Other	0	0
Preservation Method	Traditional Smoking	137	93
	Modern Smoking Techniques	11	7
Chemical Used	Aro (Firewood)	148	100
	All others (Kerosene, Formalin, etc.)	0	0
Storage Method	In Basket	130	87
	Sack	12	9
	Sealed Container	6	4

Source: Field Survey, 2024

Table 3 shows that the smoked fish trade in Wukari is concentrated in two markets, and focuses almost exclusively on two fish species, and relies heavily on traditional, chemically assisted preservation and basic storage methods. The distribution of sellers is relatively even between the two major markets. The New Market has a slightly higher percentage of respondents (52%), whereas 48% operate in the Old Market. This balance suggests that any interventions should target vendors in both locations. The sale of smoked fish is predominantly centred on two types: catfish (47% of respondents) and mackerel (44% of

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respondents). Only 9% of respondents sell tilapia, and none sell crayfish. This limited diversity means that future assessments of chemical residues should focus primarily on catfish and mackerel. With respect to preservation method and chemical use, an overwhelming majority of smoked fishmongers (93%) rely on traditional smoking techniques to preserve their fish. Only 7% use modern smoking techniques. This strong preference for traditional methods raises concerns about the control of chemical residues arising from inconsistent heat levels or materials used. In terms of preservation, all respondents (100%) use Aro, a traditional smoking hardwood, to preserve their smoked fish. No other chemicals, such as formalin, kerosene, or sniper, were reported. This uniform use of Aro is a significant finding that suggests it is the preferred and possibly only commonly available method, raising significant concerns about the safety and potential health risks of consuming "aro-preserved" fish. For post-preservation storage, after applying the preservation chemical, the majority of respondents (87%) store their smoked fish in baskets. This is followed by sacks (9%) and sealed containers (4%). The dominance of baskets, likely a traditional practice, may not provide optimal protection against contamination or pests. The low use of sealed containers suggests a gap in storage practices that could affect the quality and safety of the fish.

Table 4: Safety Perceptions and Awareness (N=148)

Safety/Awareness Issue	Response	Frequency	Percentage (%)
Seller's Perception of Method Safety	Yes, it is safe	148	100
	No	0	0
Awareness of Regulations/Guidelines	Yes	82	55
	No	66	45
Observed Changes in Quality	No	148	100
	Yes	0	0
Experienced Health Issues	No	148	100
	Yes	0	0
Basis for Safety Confidence	Reliance on Experience	81	55
	Confidence in Traditional Methods	37	25

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Safety/Awareness Issue	Response	Frequency	Percentage (%)
	Risk of Over-reliance on Perception	30	20

Source: Field Survey, 2024

The analysis of safety perceptions and awareness among the 148 smoked fish sellers in Table 4 reveals a high level of confidence in traditional practices, despite significant gaps in regulatory awareness and quality monitoring. The data indicate a unanimous belief in the safety of current preservation methods, with 100% of respondents (148) asserting that their methods are safe for consumers. This absolute confidence is further reflected in the reports on quality and health, as 100% of respondents reported no changes in the quality of smoked fish over time and had never experienced or reported health issues related to its consumption. While this suggests perceived consistency in the product, it may also indicate a lack of technical knowledge necessary to detect subtle quality degradation or long-term health risks associated with preservation chemicals.

Regarding regulatory literacy, the findings show a divided landscape. Approximately 55% (82 respondents) are aware of Nigerian regulations or guidelines for the safe production of smoked fish, whereas 45% (66 respondents) remain unaware. This highlights a significant knowledge gap that could hinder the adoption of standardised safety protocols. The sellers' confidence in their methods is primarily grounded in practical experience rather than scientific validation. The majority, 55% (81 respondents), rely solely on their years of experience to judge safety. Another 25% (37 respondents) expressed explicit confidence in traditional methods. In comparison, 20% (30 respondents) acknowledged the inherent risks of over-relying on personal perception. This distribution suggests that, although the workforce is experienced, there is a critical need for educational interventions to align these traditional practices with contemporary safety and health standards.

Table 5: Challenges, Significance, and Desire for Improvement (N=148)

Factor	Category	Frequency	Percentage (%)
Preservation Challenges	Lack of Equipment	84	57
	Inadequate Storage Facilities	38	25
	High Cost of Preservation	26	18
Significance to Household Income	Very significant	139	94

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Factor	Category	Frequency	Percentage (%)
	Moderately significant	9	6
Desire to Improve Preservation Method	Yes	148	100
	No	0	0
Suggested Improvements	Better Preservation Techniques	83	56
	Improved Storage Facilities	65	44
Willingness to Adopt New Methods	Yes	148	100
	No	0	0

Source: Field Survey, 2024

The analysis of the socio-economic impact and operational challenges in Table 5 reveals that smoked fish sales are a vital source of livelihood for the respondents. However, they are currently constrained by infrastructure and resource limitations. The business is critical to the community's financial stability, with 94% (139 respondents) reporting that the trade is "very significant" to their household income. The remaining 6% (9 respondents) view it as moderately significant, whereas none rated it as low in importance. This high level of economic dependency underscores the need to address the challenges these sellers face to ensure sustainable poverty alleviation and food security.

However, the industry faces significant structural hurdles, primarily revolving around equipment and logistics. Over half of respondents (57%; 84) identified a lack of appropriate equipment as their primary challenge, followed by 25% (38) who reported inadequate storage facilities. The financial burden of the trade is also evident, as 18% (26 respondents) cited the high cost of preservation as a significant barrier. These challenges directly influence sellers' recommendations for progress: 56% (83 respondents) call for better preservation techniques, and 44% (65 respondents) emphasise the need for improved storage solutions.
Despite these obstacles, there is a profound readiness for modernisation within the sector. 100% of the respondents expressed a desire to improve their current preservation methods and a willingness to adopt new methods if provided with the necessary training and resources. This perfect consensus (148 respondents) indicates that there is no cultural or personal resistance to change; rather, the gap lies in the availability of modern tools and formal training. These findings suggest that the community is a prime candidate for development interventions, as any provision of resources or technical education is likely to be met with total cooperation and immediate application.

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Table 6: Relationship Amongst Age, Gender, Education and Fish Selling Experience

Age	Frequency	Percentage (%)	Chi-Square (χ^2)	DF	P-Value
Under 20	0	0	127	4	1.71E-26
20-29	13	9			
30-39	53	36			
40-49	71	48			
50 and above	11	7			
Total	148	100			
Gender					
Male	36	24	39.02703	1	4.18E-10
Female	112	76			
Total	148	100			
Level of Education					
No formal education	12	8	38.5946	3	2.12E-08
Primary	42	28			
Secondary	64	43			
Tertiary	30	21			
Total	148	100			
How long have you been involved in fish selling?					
Less than 1 year	37	25	5.24E+00	3	1.55E-01
1-5 years	48	32			
6-10 years	29	20			
More than 10	34	23			

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Age	Frequency	Percentage (%)	Chi-Square (χ^2)	DF	P-Value
years					
Total	148	100			

The statistical analysis in Table 6 provides comprehensive validation of the demographic trends observed among the respondents, utilising Chi-Square tests to assess the significance of differences in distribution across age, gender, education, and experience. The results confirm that the demographic makeup of the smoked fish trade in Wukari is not random but follows specific, statistically significant patterns.

The age distribution shows the most significant statistical significance ($\chi2 = 127$, $p < 0.001$), confirming that the industry is predominantly composed of middle-aged individuals. With 84% of respondents concentrated in the 30–49 age bracket, the data suggests that this trade is a mature-market activity, likely requiring the stability or capital associated with middle adulthood. Similarly, gender representation shows a significant imbalance ($\chi2 = 39.027$, $p < 0.001$), with females comprising 76% of the workforce. This statistically solidifies the observation that smoked fish selling is a female-dominated sector in the study area, making gender-sensitive policy interventions essential.

Regarding educational attainment, the distribution is also statistically significant ($\chi^2 = 38.59$, $p < 0.001$). The prevalence of secondary (43%) and primary (28%) education indicates a literate workforce capable of engaging with formal training materials. Interestingly, while other categories showed high significance, the distribution of "Years of Experience" ($p = 0.155$) did not reach the standard threshold for statistical significance ($p < 0.05$). This indicates that, although the industry is dominated by specific age and gender groups, the length of time individuals have been in the business varies widely, ranging from newcomers to veterans, without a single dominant "experience profile."

Discussion

The smoked fish industry in Wukari is a vital socio-economic sector, primarily dominated by mature, middle-aged women: 84% of respondents were aged 30-49, and 76% were female. This demographic trend is consistent with the findings of Uche et al. (2017) and Adewumi et al. (2014), who noted that middle-aged women are the backbone of small-scale food processing in Nigeria due to traditional gender roles and the economic necessity of sustaining household income. Indeed, the trade is the financial bedrock for these families, with 94% of respondents identifying it as a "very significant" source of income.

Operationally, the trade is concentrated in Wukari's New (52%) and Old (48%) markets, with almost exclusive focus on Catfish (47%) and Mackerel (44%). Despite the sellers' moderate education levels—with 71% having completed at least primary or secondary school—preservation remains deeply traditional. An overwhelming 93% rely on traditional smoking, and 100% utilise "Aro" as their sole traditional smoking preservation chemical. This uniformity in chemical use, while currently preferred by sellers, raises significant

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toxicological concerns, as highlighted by Odeyemi and Ogunbanwo (2017) regarding unregulated chemical application in food. Furthermore, 87% of sellers continue to store their products in traditional baskets, a practice Adegoke et al. (2018) suggest should be replaced with sealed containers to prevent pest and environmental contamination.

There is a stark contrast between seller perception and scientific safety standards. While 100% of respondents expressed total confidence in the safety of their methods and reported no health issues, 45% of the workforce is entirely unaware of Nigerian food safety regulations. This suggests that their perception of safety is based on personal experience (55%) rather than technical knowledge. As Eyo (2001) and FAO (2016) warn, this lack of scientific awareness may lead sellers to overlook subtle quality degradation or long-term health risks associated with chemical residues. The sector currently faces a critical "infrastructure-knowledge gap." While sellers face major hurdles such as a lack of equipment (57%) and inadequate storage (25%), there is a unanimous willingness (100%) to adopt modern methods if provided with training. These findings indicate that the smoked fish industry in Wukari is prepared for modernisation; however, progress is currently stalled by the high cost of preservation and limited access to improved smoking technologies (Adewumi et al., 2014).

Conclusion

In conclusion, the smoked fish trade in Wukari is a vital livelihood dominated by a statistically significant demographic of middle-aged women with moderate formal education. While the industry is economically thriving, it is heavily reliant on traditional smoking techniques and the unvalidated use of "Aro" for preservation. The study highlights a critical "perception-safety gap": sellers maintain absolute confidence in their methods based on personal experience, yet nearly half remain unaware of national safety regulations. Despite these traditional roots, respondents' unanimous willingness to adopt new methods indicates strong potential for modernisation. However, progress is currently stalled by infrastructural challenges, specifically the lack of modern equipment and inadequate storage. To ensure public health and industry sustainability, it is essential to bridge this gap through targeted health education, regulatory oversight, and the provision of modern preservation tools.

Recommendations

Based on the research findings, the following recommendations are proposed to enhance the safety and sustainability of the smoked fish industry in Wukari:

1. Policy and Regulation: Establish strict food safety monitoring and laboratory assessments of preservatives like "Aro" to ensure all methods of application align with national health standards.

2. Infrastructure and Finance: Provide subsidised modern smoking kilns and sealed storage containers, supported by micro-loans and cooperatives, to help sellers overcome the high costs of equipment.

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3. Education and Training: Launch targeted health campaigns to replace traditional intuition with scientific knowledge regarding chemical residues, hygiene, and safe preservation techniques.

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