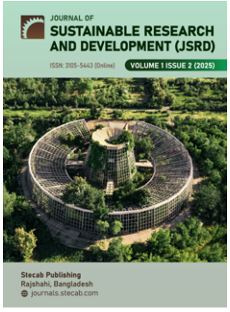

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Research Article

Nutritional Evaluation of Nile Tilapia (*Oreochromis niloticus*) Processed by Different Drying Methods in Akwa Ibom State, Nigeria

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About Article

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ABSTRACT

This study evaluated the effect of different drying methods on the proximate composition, mineral and vitamin content, and heavy metal concentrations of *Oreochromis niloticus* obtained from Esuk Nwaniba, Uruan Local Government Area, Akwa Ibom State, Nigeria. Fish samples were processed using four drying methods: air drying (FAD), oven drying (FOD), firewood drying (FWD), and firewood + polythene drying (FWP). Proximate parameters (moisture, crude protein, crude lipid, crude fiber, crude ash, and nitrogen-free extract) were determined using AOAC procedures; energy values were calculated with the Atwater system; minerals and heavy metals were analyzed by Atomic Absorption Spectrophotometry (AAS); and vitamins were determined using HPLC and spectrophotometry. Results revealed statistically significant differences across drying methods ($p < 0.05$). Oven drying retained the highest crude protein (58.66%), lipid (19.13%), energy value (454.21 kcal/100 g), minerals (Ca, K, Fe, P), and vitamins (A, D, E, C, B12). In contrast, firewood + polythene drying produced the poorest nutritional quality, with reduced protein and lipid, the lowest micronutrient retention, and elevated ash levels. Toxicological evaluation showed that oven- and air-dried samples had heavy metal concentrations within FAO/WHO permissible limits, whereas FWP samples exceeded Pb limits by over 100% (0.62 mg/kg vs. 0.30 mg/kg permissible) and Cd limits by 20%, posing serious food safety risks. The findings suggest that oven drying is the most nutritionally efficient and safest method, while the use of polythene in fish drying compromises both nutritional value and consumer health. Adoption of controlled drying technologies and strict prohibition of polythene burning are strongly recommended to improve food safety and nutritional security in local communities.

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1. INTRODUCTION

Fish is among the most important sources of animal protein for humans, providing essential amino acids, lipids, vitamins, and minerals that contribute significantly to nutritional security. In many developing countries, including Nigeria, fish is often preferred to meat and poultry due to its relatively lower cost, availability, and ease of preparation (Nnaji *et al.*, 2010). Nile tilapia (*Oreochromis niloticus*), one of the most widely cultivated and consumed freshwater fish species, is valued not only for its high-quality protein but also for its favorable lipid profile and digestibility. As a result, it forms an integral part of the diet in several Nigerian communities.

Despite its nutritional importance, fish is highly perishable due to its high moisture content, which supports rapid microbial growth and enzymatic spoilage shortly after harvest. To address this problem, various preservation methods such as smoking, drying, and refrigeration are used (Okpoji *et al.*, 2025). Among these, smoking and drying are the most widely practiced in Nigeria because they are relatively affordable, accessible, and capable of extending shelf life while also imparting desirable sensory qualities (Isioma *et al.*, 2016). However, the choice of drying method has a considerable effect on both the safety and nutritional quality of fish (Okpoji *et al.*, 2025).

Traditional firewood smoking is the most common method employed in rural fishing communities, but it is associated with nutritional losses as well as contamination by polycyclic aromatic hydrocarbons (PAHs) produced during incomplete combustion (Akpambang *et al.*, 2009; Okenyi *et al.*, 2016). Oven drying and air drying have been suggested as safer alternatives, with oven drying in particular allowing controlled temperature regulation that helps preserve nutrient content while reducing contamination risks (Larsson *et al.*, 1993; Perugini *et al.*, 2006). The use of polythene as a fuel additive in some traditional practices is of special concern, as it not only contributes to excessive PAH formation but may also affect the nutrient composition of the final product (Okpoji *et al.*, 2025).

Previous studies have reported variations in proximate composition of fish subjected to different drying regimes, including differences in moisture, protein, lipid, ash, and caloric content (Isioma *et al.*, 2016; Okenyi *et al.*, 2016). Since the nutritional value of fish is a key determinant of its contribution to dietary health, it is essential to evaluate how different processing methods influence nutrient retention. Such knowledge will provide a basis for promoting safer and nutritionally superior drying techniques. The aim of this study was to evaluate the effects of different drying methods on the proximate composition, energy value, mineral and vitamin retention, and heavy metal contamination of *Oreochromis niloticus* (Nile tilapia). It was hypothesized that oven drying would preserve the highest nutrient content and maintain heavy metal concentrations within safe limits, whereas the inclusion of polythene in traditional drying would significantly compromise nutritional quality and pose toxicological risks. This work is novel in providing an integrated nutritional and toxicological assessment of fish drying practices in Nigeria, thereby offering new evidence to guide safer and more sustainable food processing methods.

2. LITERATURE REVIEW

Fish is a vital source of animal protein, providing essential amino acids, lipids, vitamins, and minerals that support human nutrition and health (Nnaji *et al.*, 2010). However, due to its high moisture content, fish is highly perishable and prone to rapid microbial and enzymatic spoilage. Preservation methods such as smoking and drying are therefore widely employed to extend shelf life. Traditional firewood smoking remains the dominant preservation technique in rural Nigerian fishing communities (Okpoji *et al.*, 2023). Although affordable and effective in extending shelf life, this method is associated with nutrient losses and contamination by polycyclic aromatic hydrocarbons (PAHs) formed during incomplete combustion (Akpambang *et al.*, 2009; Okenyi *et al.*, 2016). Such contamination raises public health concerns, as chronic exposure to PAHs has been linked to carcinogenic effects (Alonge, 1988; Akpan *et al.*, 1994).

In contrast, oven drying has been identified as a safer and more nutritionally efficient alternative. Controlled heating conditions help retain protein integrity and lipid quality while minimizing contamination risks (Larsson *et al.*, 1993; Perugini *et al.*, 2006). Similarly, air drying can preserve nutrients to a moderate extent, though higher residual moisture may compromise microbial stability (Isioma *et al.*, 2016). Nutritional losses also extend to vitamins and minerals. Heat-sensitive vitamins such as vitamin C are particularly vulnerable during uncontrolled firewood drying, while fat-soluble vitamins (A, D, E) are better preserved under oven drying conditions (Andrzej & Zdzislaw, 2005). Minerals such as calcium, iron, and zinc are critical for human health, yet their concentrations in fish can be significantly reduced by high-heat drying methods (Isioma *et al.*, 2016).

A critical concern in recent years is the use of polythene as a combustion aid in firewood smoking. While this practice is widespread in some rural settings, it introduces toxic residues, elevates heavy metal concentrations, and further reduces nutrient retention (Akpambang *et al.*, 2009; Okenyi *et al.*, 2016). Despite these risks, there remains limited research that simultaneously evaluates both the nutritional and toxicological consequences of polythene-assisted drying methods.

3. METHODOLOGY

3.1. Sample Collection and Preparation

Fresh Nile tilapia (*Oreochromis niloticus*) samples were obtained from Esuk Nwaniba landing site in Uruan Local Government Area, Akwa Ibom State, Nigeria. The fish were washed with clean water, gutted, and divided into four equal portions for processing. Each portion was subjected to a different drying method: air drying (FAD), oven drying (FOD), firewood drying (FWD), and firewood + polythene drying (FWP). The dried fish samples were homogenized, ground into fine powder using a clean electric blender, and stored in airtight containers prior to laboratory analysis. All analyses were carried out in triplicate.

3.2. Proximate Analysis

The proximate composition of the samples was determined following standard methods described by the Association of Official Analytical Chemists (AOAC, 2005). The parameters analyzed included:

• Moisture content: Determined by oven drying 2 g of sample at 105 °C until constant weight.

• Crude protein: Estimated by the Kjeldahl method; nitrogen content multiplied by a conversion factor of 6.25.

• Crude lipid: Extracted using Soxhlet apparatus with petroleum ether as solvent.

• Crude ash: Measured by incinerating 2 g of sample in a muffle furnace at 550 °C for 5 hours until a white residue was obtained.

• Crude fiber: Determined by sequential acid (1.25% H_2SO_4) and alkaline (1.25% NaOH) digestion followed by ashing.

• Nitrogen-free extract (NFE): Calculated by difference:

• NFE= 100 − (moisture + protein + lipid + ash + fiber).

3.3. Energy Value Determination

The caloric value of the samples was calculated using the Atwater general factor system:

Energy (kcal/100 g) = (4×Protein) + (9×Lipid) + (4×NFE); where protein, lipid, and NFE are expressed in grams per 100 g of dry matter.

3.4. Mineral Analysis

The mineral content (Ca, Mg, K, Na, Fe, Zn, and P) was determined using Atomic Absorption Spectrophotometry (AAS, Model AA-7000, Shimadzu, Japan) after wet digestion. About 2 g of each dried sample was digested with a mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a ratio of 3:1 on a hot plate until a clear solution was obtained. The digests were filtered, diluted with deionized water, and analyzed. Phosphorus was determined colorimetrically using the vanadomolybdate method with a UV–Vis spectrophotometer at 420 nm. Results were expressed in mg/100 g dry weight.

3.5. Vitamin Analysis

Selected vitamins (A, D, E, C, and B12) were determined using High-Performance Liquid Chromatography (HPLC, Model LC-20AT, Shimadzu, Japan). Fat-soluble vitamins (A, D, E) were extracted with ethanol and petroleum ether, saponified with alcoholic KOH, and analyzed on a C18 reverse-phase column with UV detection at respective wavelengths. Vitamin C was determined by titration with 2,6-dichlorophenolindophenol (DCPIP) and confirmed spectrophotometrically at 520 nm. Vitamin B12 was measured using HPLC with a UV detector at 361 nm. Results were expressed as µg or mg per 100 g dry weight depending on the vitamin.

3.6. Heavy Metal Analysis and Quality Assurance

Lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) were determined using Atomic Absorption Spectrophotometry (AAS) after acid digestion. Approximately 2 g of each dried fish sample was digested with 10 mL of concentrated nitric acid and 2 mL of perchloric acid at 180 °C until a clear solution was obtained, filtered, and diluted to 25 mL with deionized water. Concentrations of metals were expressed in mg/kg dry weight and compared with FAO/WHO Codex Alimentarius permissible limits for fishery products.

To ensure the reliability of the results, Quality Assurance and Quality Control (QA/QC) procedures were strictly applied. Certified reference materials (CRMs) for fish tissue were analyzed alongside the samples to verify instrument accuracy. Recovery experiments were conducted by spiking blank samples with known concentrations of Pb, Cd, Hg, and As, and recovery rates were maintained within 90–105%. Method detection limits (MDLs) were established as three times the standard deviation of replicate blank measurements to guarantee sensitivity. Duplicate determinations and reagent blanks were included in every analytical batch to monitor precision and potential contamination.

3.7. Statistical Analysis

Data were expressed as mean ± standard deviation (SD) of triplicate determinations. Statistical analysis was performed using Analysis of Variance (ANOVA) to assess differences among treatments, and means were separated using Duncan's Multiple Range Test at a significance level of $p < 0.05$. Graphs and tables were generated using Microsoft Excel and SPSS software (Version 25).

4. RESULTS AND DISCUSSION

The proximate composition of *Oreochromis niloticus* subjected to different drying methods is presented in Table 1. The results revealed significant variation in nutrient composition across the four treatments. Moisture content was highest in air-dried fish (11.42 ± 0.18%) and lowest in oven-dried fish (8.23 ± 0.11%). Crude protein content ranged between 48.26 ± 0.27% (FWP) and 58.66 ± 0.15% (FOD), with oven-dried samples retaining the highest protein levels. Lipid content was also highest in oven-dried fish (19.13 ± 0.09%) compared with firewood + polythene drying (12.86 ± 0.14%).

Ash content was elevated in FWP samples (13.24 ± 0.20%), while the lowest ash values were recorded in oven-dried samples (7.32 ± 0.13%). Crude fiber showed little variation across treatments, ranging between 1.05 ± 0.07% and 1.32 ± 0.06%. The nitrogen-free extract (NFE) was highest in firewood-smoked fish (24.56 ± 0.22%) and lowest in oven-dried samples (15.23 ± 0.19%).

The calculated energy values of the fish also varied significantly, ranging from 368.49 kcal/100 g (FWP) to 454.21 kcal/100 g (FOD). Oven-dried fish consistently showed superior retention of protein, lipid, and overall caloric content, whereas firewood + polythene drying resulted in the least nutritional quality.

Table 1. Proximate composition (%) and energy values (kcal/100 g) of *Oreochromis niloticus* subjected to different drying methods

Parameter	FAD (Air-dried)	FOD (Oven-dried)	FWD (Firewood-dried)	FWP (Firewood + Polythene)
Moisture (%)	11.42 ± 0.18a	8.23 ± 0.11c	9.37 ± 0.15b	10.86 ± 0.12a
Crude Protein (%)	52.14 ± 0.21b	58.66 ± 0.15a	54.23 ± 0.19b	48.26 ± 0.27c
Crude Lipid (%)	15.62 ± 0.17b	19.13 ± 0.09a	16.32 ± 0.11b	12.86 ± 0.14c

Ash (%)	9.12 ± 0.14b	7.32 ± 0.13c	10.15 ± 0.16b	13.24 ± 0.20a
Crude Fiber (%)	1.21 ± 0.05	1.05 ± 0.07	1.18 ± 0.06	1.32 ± 0.06
NFE (%)	20.49 ± 0.20b	15.23 ± 0.19c	24.56 ± 0.22a	13.42 ± 0.18c
Energy (kcal/100 g)	421.53 ± 1.15b	454.21 ± 0.98a	436.27 ± 1.02ab	368.49 ± 1.20c

**Values are means ± SD of triplicate determinations. Means with different superscripts within a row differ significantly ($p < 0.05$).*

The mineral composition of *Oreochromis niloticus* varied significantly with drying method. Oven drying (FOD) consistently retained the highest mineral values, recording elevated calcium (162.8 mg/100 g), potassium (225.3 mg/100 g), phosphorus (212.7 mg/100 g), and iron (9.7 mg/100 g). These values were significantly higher than those in air-dried (FAD), firewood-dried (FWD), and firewood + polythene-dried (FWP) samples ($p < 0.05$). In contrast, fish processed with firewood and polythene had the lowest concentrations of nearly all minerals, with calcium (138.7 mg/100 g), magnesium (26.1 mg/100 g), and zinc (3.6 mg/100 g) markedly reduced compared with other methods. Air drying and firewood drying retained moderate mineral levels but did not outperform oven drying as shown in Table 2.

Table 2. Mineral composition (mg/100 g dry weight) of *Oreochromis niloticus* subjected to different drying methods

Parameter	FAD (Air-dried)	FOD (Oven-dried)	FWD (Firewood-dried)	FWP (Firewood + Polythene)
Calcium (Ca)	145.2 ± 3.5b	162.8 ± 4.2a	152.6 ± 3.9ab	138.7 ± 3.4c
Magnesium (Mg)	28.6 ± 1.1b	32.4 ± 1.4a	29.8 ± 1.3b	26.1 ± 1.2c
Potassium (K)	210.5 ± 5.1b	225.3 ± 5.4a	218.7 ± 5.0b	198.2 ± 4.9c
Sodium (Na)	62.7 ± 2.0b	68.5 ± 2.3a	65.4 ± 2.2ab	58.9 ± 1.9c
Iron (Fe)	8.4 ± 0.4b	9.7 ± 0.5a	8.9 ± 0.4b	7.2 ± 0.3c
Zinc (Zn)	4.1 ± 0.2b	4.9 ± 0.2a	4.3 ± 0.2b	3.6 ± 0.1c
Phosphorus (P)	198.4 ± 4.8b	212.7 ± 5.0a	204.1 ± 4.6ab	189.5 ± 4.2c

Values are means ± SD (n=3). Means with different superscripts within a row differ significantly ($p < 0.05$).

Vitamin content was also influenced by the method of drying. Oven-dried samples retained the highest concentrations of vitamins A (210.3 µg/100 g), D (14.2 µg/100 g), E (4.2 mg/100 g), C (5.5 mg/100 g), and B12 (2.5 µg/100 g). These levels were significantly higher than those recorded in other treatments ($p < 0.05$). Air drying preserved vitamins moderately, while firewood drying showed reductions, particularly in vitamin A and C. Firewood + polythene drying caused the greatest nutrient losses, with vitamin A (162.7 µg/100 g), vitamin E (2.8 mg/100 g), and vitamin B12 (1.7 µg/100 g) being the lowest among all treatments. This suggests that the combined effect of uncontrolled high heat and toxic smoke accelerates vitamin degradation as shown in Table 3.

Table 3. Vitamin composition of *Oreochromis niloticus* subjected to different drying methods

Vitamin	FAD (Air-dried)	FOD (Oven-dried)	FWD (Firewood-dried)	FWP (Firewood + Polythene)
Vitamin A (µg/100 g)	185.6 ± 4.5b	210.3 ± 5.1a	176.2 ± 4.3c	162.7 ± 4.0c
Vitamin D (µg/100 g)	12.5 ± 0.4b	14.2 ± 0.5a	11.9 ± 0.4b	10.3 ± 0.3c
Vitamin E (mg/100 g)	3.6 ± 0.1b	4.2 ± 0.1a	3.4 ± 0.1b	2.8 ± 0.1c
Vitamin C (mg/100 g)	4.9 ± 0.2b	5.5 ± 0.2a	4.2 ± 0.2c	3.6 ± 0.1c
Vitamin B12 (µg/100 g)	2.1 ± 0.1b	2.5 ± 0.1a	2.0 ± 0.1b	1.7 ± 0.1c

The heavy metal content of *Oreochromis niloticus* also varied across treatments. Oven drying and air drying yielded Pb and Cd concentrations within FAO/WHO permissible limits (Pb ≤ 0.21 mg/kg; Cd ≤ 0.05 mg/kg). Firewood drying, however, elevated Pb levels (0.35 mg/kg), approaching the maximum safety threshold of 0.30 mg/kg, although Cd, Hg, and As remained within limits. The most concerning results were observed in firewood + polythene drying, where Pb (0.62 mg/kg) and Cd (0.12 mg/kg) exceeded FAO/WHO limits. Mercury (0.19 mg/kg) and arsenic (0.15 mg/kg) in FWP samples remained below maximum allowable concentrations but were significantly higher than in oven-dried samples. These results indicate that the use of polythene in fish drying introduces toxic contaminants, making the method unsafe for human consumption as shown in Table 4.

Table 4. Heavy metal concentrations (mg/kg dry weight) of *Oreochromis niloticus* subjected to different drying methods.

Metal	FAD (Air-dried)	FOD (Oven-dried)	FWD (Firewood-dried)	FWP (Firewood + Polythene)	FAO/WHO Limit*
Lead (Pb)	0.21 ± 0.01^{b}	0.18 ± 0.01^{b}	0.35 ± 0.02^{a}	0.62 ± 0.03^{c}	0.30
Cadmium (Cd)	0.05 ± 0.01^{b}	0.04 ± 0.01^{b}	0.07 ± 0.01^{b}	0.12 ± 0.01^{c}	0.10
Mercury (Hg)	0.11 ± 0.01^{b}	0.09 ± 0.01^{a}	0.14 ± 0.01^{b}	0.19 ± 0.02^{c}	0.50
Arsenic (As)	0.07 ± 0.01^{b}	0.05 ± 0.01^{a}	0.09 ± 0.01^{b}	0.15 ± 0.02^{c}	0.20

Values are means ± SD (n=3). Means with different superscripts within a row differ significantly ($p < 0.05$). FAO/WHO Codex Alimentarius permissible limits for fishery products.

4.1. Discussion

The present study demonstrates that the method of drying exerts a significant influence on the nutritional and toxicological profile of *Oreochromis niloticus*. Differences were observed not only in proximate composition but also in mineral, vitamin, and heavy metal concentrations, highlighting the complex trade-offs between preservation techniques, nutritional quality, and food safety.

Oven drying (FOD) emerged as the most effective method for nutrient retention. This technique preserved the highest levels of crude protein (58.66%) and lipid (19.13%), as well as superior mineral and vitamin concentrations. The high nutrient density of oven-dried fish reflects the advantage of controlled temperature and uniform heating, which minimize thermal degradation and nutrient leaching. Previous studies (Larsson *et al.*, 1993; Perugini *et al.*, 2006) have similarly reported that oven drying maintains protein integrity and lipid stability better than traditional firewood smoking. The elevated caloric value in oven-dried samples (454.21 kcal/100 g) further demonstrates its nutritional superiority.

In contrast, firewood + polythene drying (FWP) produced the poorest results, with marked reductions in protein, lipids, minerals, and vitamins. Protein denaturation at uncontrolled high temperatures and oxidative degradation of lipids likely contributed to nutrient losses. The burning of polythene appears to exacerbate these effects by releasing toxic fumes and residues, which not only impair nutrient retention but also deposit harmful substances on fish tissues (Anarado *et al.*, 2023; Okpoji *et al.*, 2025). The diminished vitamin levels in FWP samples, particularly vitamins A, C, and E, suggest significant thermal degradation and oxidative damage, in line with the observations of Andrzej and Zdzislaw (2005) on vitamin loss during high-temperature smoking. Notably, the markedly higher ash content recorded for FWP reflects an increased inorganic residue load from combustion by-products and particulate deposition, which can co-occur with mineral and heavy-metal contamination; this is consistent with the elevated Pb and Cd measured in FWP samples. Mineral analysis revealed that oven-dried samples retained the highest concentrations of calcium, potassium, phosphorus, and iron, nutrients critical for bone development, oxygen transport, and metabolic function. Firewood + polythene drying yielded the lowest values, reflecting both direct nutrient losses and possible contamination effects. This finding is important because minerals such as iron and zinc are often deficient in local diets; thus, unsafe drying practices may exacerbate micronutrient malnutrition.

Vitamin analysis reinforced the superiority of oven drying. Fat-soluble vitamins A, D, and E were better preserved under controlled heating, whereas firewood and especially polythene combustion led to significant degradation. Vitamin C, a heat-labile compound, showed the most reduction across all treatments, but oven drying retained more than firewood and FWP, confirming its role in minimizing thermal destruction. The observed reductions in vitamin B12 in firewood and FWP treatments are also concerning, as this vitamin is scarce in plant-based diets and fish is a key dietary source.

The toxicological results are of particular concern. Oven- and air-dried samples recorded heavy metal concentrations within FAO/WHO permissible limits, making them safe for consumption. Firewood drying raised Pb levels close to unsafe limits, while firewood + polythene drying exceeded permissible limits for Pb and Cd. This suggests that burning polythene releases toxic heavy metals and associated contaminants, which are then deposited on fish surfaces during processing. Similar findings were reported by Akpambang *et al.* (2009) and Okenyi *et al.* (2016), who linked unsafe smoking practices to elevated polycyclic aromatic hydrocarbons (PAHs) and heavy metal contamination in fish. The implications for food safety are profound, as chronic exposure to Pb and Cd is associated with neurotoxicity, kidney damage, and carcinogenesis.

Moisture trends also provide insight into shelf stability. Air drying resulted in higher residual moisture (11.42%), which increases susceptibility to microbial spoilage and shortens shelf life. Oven drying, on the other hand, produced lower moisture (8.23%), enhancing preservation and reducing microbial risk. This supports Isioma *et al.* (2016), who emphasized oven drying as an effective preservation method that improves stability without compromising nutritional quality.

5. CONCLUSIONS

This study demonstrated that drying methods significantly affect the proximate composition, mineral and vitamin retention, and toxicological safety of *Oreochromis niloticus*. Oven drying proved to be the most effective method, preserving the highest levels of protein, lipid, energy value, minerals, and vitamins while maintaining heavy metal concentrations within FAO/WHO permissible limits. Air drying retained moderate nutrients but left higher residual moisture, which may compromise shelf stability. Traditional firewood drying produced lower protein and vitamin values and elevated lead levels close to safety thresholds, while firewood + polythene drying resulted in the poorest nutritional quality and exceeded permissible limits for Pb and Cd, making it unsafe for human consumption.

The findings highlight the dual nutritional and toxicological implications of fish processing methods. Nutritionally, unsafe drying practices reduce the dietary contribution of fish to protein and micronutrient intake. Environmentally, the combustion of polythene introduces toxic residues that contaminate food and increase consumer health risks. Based on these results, the use of polythene in fish drying should not merely be discouraged but must be strictly prohibited and enforced through regulatory measures. Adoption of safer drying technologies, particularly oven drying, is strongly recommended as a sustainable alternative to improve both food safety and utritional security in local communities.

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