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Idris S
Department of Fisheries Technology, Binyaminu Usman Polytechnic Hadejia, Jigawa State, Nigeria

MU Sambo
Department of Fisheries Technology, Binyaminu Usman Polytechnic Hadejia, Jigawa State, Nigeria

F Sambo
Department of Fisheries Technology, Binyaminu Usman Polytechnic Hadejia, Jigawa State, Nigeria

AA Adam
Department of Fisheries Technology, Binyaminu Usman Polytechnic Hadejia, Jigawa State, Nigeria

A Umar
Department of Fisheries Technology, Federal College of Freshwater Fisheries Technology, Baga, Maiduguri, Borno State, Nigeria

Y Chiroma
Department of Fisheries Technology, Binyaminu Usman Polytechnic Hadejia, Jigawa State, Nigeria

A Abubakar
Department of Fisheries Technology, Binyaminu Usman Polytechnic Hadejia, Jigawa State, Nigeria

Corresponding Author:
Idris S
Department of Fisheries Technology, Binyaminu Usman Polytechnic Hadejia, Jigawa State, Nigeria

Efficiency analysis of two improved kilns for smoking five indigenous fish species in Northern Nigeria

Idris S, MU Sambo, F Sambo, AA Adam, A Umar, Y Chiroma and A Abubakar

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Abstract
Fish smoking is an important post-harvest preservation method in Nigeria, particularly among artisanal fishers who rely on efficient smoking techniques to enhance product quality and shelf life. This study assessed the smoking efficiency of two improved kiln technologies—Modified Drum Kiln and FUTY Kiln—using five indigenous fish species: *Clarias gariepinus*, *Oreochromis niloticus*, *Heterotis niloticus*, *Mormyrus rume*, and *Bagrus bayad*. A total of 150 fish were processed across both kilns, and weight changes were monitored at intervals of 0, 2, 4, 6, and 8 hours. Results showed that the Modified Drum Kiln consistently achieved faster moisture reduction and greater smoking efficiency in most species, with lower standard error values, indicating higher measurement reliability. *Oreochromis niloticus* and *Heterotis niloticus* experienced more effective dehydration in the drum kiln, while *Mormyrus rume* displayed an irregular drying pattern, suggesting the need for process calibration. Overall, the Modified Drum Kiln was found to be more efficient in terms of drying time, fuel economy, and consistency of results. The findings support the promotion of the Modified Drum Kiln for artisanal fish processors and suggest improvements to FUTY Kiln design to enhance performance.

Keywords: Fish smoking efficiency, modified Drum Kiln, FUTY Kiln, indigenous fish species, post-harvest technology

Introduction

Fish smoking is a traditional preservation method widely practiced across Nigeria and West Africa, where it plays a crucial role in reducing post-harvest losses, enhancing flavour, and prolonging shelf life [5]. In regions with limited access to refrigeration, smoked fish remains a vital protein source and an important income-generating commodity, especially among artisanal processors. However, the effectiveness of fish smoking is largely dependent on the efficiency of the smoking kiln used.

Conventional smoking kilns, while widely used, are often inefficient and environmentally unfriendly. They are characterized by high fuel consumption, uneven heat distribution, prolonged processing times, and poor product quality due to inconsistent drying, [2]. It has been observed that fish smoking practices are yet to gain prominence on a large commercial scale in Nigeria due to the lack of appropriate technologies to assist the fish farming business [3].

While several studies have highlighted the benefits of improved kilns, comparative assessments using diverse indigenous fish species remain limited. This study focuses on evaluating the smoking efficiency of the Modified Drum and FUTY Kilns using five economically and nutritionally significant freshwater fish species in Nigeria: *Clarias gariepinus*, *Oreochromis niloticus*, *Heterotis niloticus*, *Mormyrus rume*, and *Bagrus bayad*. These species are widely consumed and form a major part of the inland fisheries catch, making them ideal candidates for evaluating smoking technologies

Evaluating kiln efficiency across various fish species helps determine the appropriateness of each kiln type for either large-scale or smallholder applications, with direct implications for minimizing post-harvest losses, enhancing profitability, and strengthening food security. Key performance indicators such as smoking time, fuel usage, yield, and final product quality are essential for assessing kiln effectiveness and informing the adoption of suitable technologies. According to [7], the products processed using the Federal University of Technology, Yola (FUTY) Improved Processor (FIP) were of superior quality compared to those from the Traditional Smoking Drum.

Methodology

Study Location

The study was conducted at the Fish Processing Unit of the Department of Fisheries Technology, Binyaminu Usman Polytechnic, Hadejia, Northern Nigeria. This area was selected due to its accessibility to freshwater fish and local smoking kiln technologies.

Fish Sample Collection and Preparation

A total of 150 live freshwater fish specimens were used, comprising five indigenous species: *Clarias gariepinus*, *Oreochromis niloticus*, *Heterotis niloticus*, *Mormyrus rume*, and *Bagrus bayad*. Thirty (30) fish were randomly selected per species and divided equally between the two kiln treatments—Modified Drum Kiln and FUTY Kiln. The fish specimens were sourced fresh from local fishermen operating in nearby rivers and reservoirs.

Each fish was weighed using a digital scale to obtain the initial fresh weight. The fish were gutted, washed thoroughly, and drained prior to smoking to ensure uniformity. No additional seasoning or brining was applied, to avoid interference with weight or water loss measurements.

Smoking Kilns Description

- **Modified Drum Kiln:** This kiln is fabricated from a 200-litre metal drum, retrofitted with three side chimneys to enhance airflow and smoke dispersion. It uses wire mesh trays for fish placement and wood as the primary fuel source.
- **FUTY Kiln:** Developed at the Federal University of Technology Yola, the FUTY kiln features a rectangular smoking chamber with dual smoke outlets and an internal rack system for smoke distribution. It is insulated with clay and cement for heat retention and also uses firewood as fuel.

Both kilns were operated under similar conditions—same fish load per batch, identical fuelwood species and quantity, and continuous monitoring.

Smoking Procedure

Each batch of fish was smoked to a final internal temperature of 65-70 °C and until the fish reached a visibly dry but non-brittle texture, consistent with local market standards. The smoking duration was recorded for each batch.

Efficiency Parameters Measured

1. **Smoking Time (minutes):** The duration from the start of smoking until completion.
2. **Fuelwood Consumption (kg):** Weight of firewood used per smoking session was measured before and after smoking.
3. **Weight Loss (%):** Calculated as the difference between pre-smoked and post-smoked
4. **Product Appearance & Uniformity:** Visual and tactile assessment of smoked fish (color, texture, and surface drying) was conducted using a standardized quality checklist based on local consumer preferences
5. **Data Analysis:** All data collected were subjected to statistical analysis using SPSS version 25. Descriptive statistics (mean±standard error) were calculated for each parameter. One-way ANOVA was used to determine significant differences (p<0.05) between kilns for each fish species. Post-hoc Tukey's tests were applied where appropriate.

Results and Discussion

Table 1: Effect of Smoking Duration on the Weight of Fish Smoked with FUTY Kiln

Fish Species	0 hour	2 hours	4 hours	6 hours	8 hours	SEM
Clarias gariepinus	0.7	0.55	0.38	0.3	0.3	0.04
Oreochromis niloticus	0.2	0.15	0.12	0.1	0.1	0.03
Heterotis niloticus	0.8	0.5	0.45	0.4	0.4	0.04
Mormyrus rume	0.4	0.25	0.22	0.2	0.2	0.02
Bagrus bayad	0.8	0.58	0.41	0.4	0.4	0.04

Table 2: Effect of Smoking Duration on the Weight of Fish Smoked with Modified drum kiln

	0 hour	2 hours	4 hours	6 hours	8 hours	SEM
Clarias gariepinus	0.6	0.4	0.35	0.3	0.3	0.04
Oreochromis niloticus	0.3	0.28	0.25	0.23	0.1	0.01
Heterotis niloticus	0.4	0.3	0.28	0.2	0.2	0.04
Mormyrus rume	0.7	0.6	0.55	0.57	0.6	0.02
Bagrus bayad	0.5	0.4	0.35	0.28	0.3	0.04

Effect of Smoking Duration on Fish Weight Using FUTY and Modified Drum Kilns

Tables I and II show the weight changes in five indigenous fish species (*Clarias gariepinus*, *Oreochromis niloticus*, *Heterotis niloticus*, *Mormyrus rume*, and *Bagrus bayad*) at different smoking durations (0, 2, 4, 6, and 8 hours) using the FUTY and Modified Drum kilns. Smoking led to progressive moisture loss in all species, reflected by decreased weight over time. The efficiency of the kilns in reducing fish weight—an indicator of moisture removal—varied by both kiln type and species.

Clarias gariepinus

Clarias gariepinus in the FUTY kiln showed a rapid weight reduction from 0.7 kg at 0 h to 0.3 kg at 6 h, after which the weight remained stable. A comparable pattern was seen in the Modified Drum Kiln, where the weight declined from 0.6 kg to 0.3 kg by the 6th hour. Although both kilns reached a moisture plateau at the 6th hour, the Modified Drum Kiln did so more efficiently—beginning with a lower initial weight and stabilizing earlier, indicating faster dehydration. This supports the findings of [2], who noted that airflow and heat control in kilns affect drying rates in oily fish such as Clarias. Similarly [10], observed that African catfish smoked using an improved drum-type kiln rated higher in taste, flavor, colour, and texture compared to those from half-drums or rectangular kilns.

Oreochromis niloticus

In the Modified Drum Kiln, *Oreochromis niloticus* dried more quickly, with its weight dropping from 0.3 kg to 0.1 kg over 8 hours, whereas in the FUTY Kiln, the weight decreased from 0.2 kg to 0.1 kg but stabilized earlier. The Modified Drum Kiln exhibited a steadier and more linear moisture reduction, indicating more efficient heat distribution. This moisture loss limits the conditions favorable for spoilage organisms and chemical reactions in the fish. These observations align with [4], which reported that moisture levels above 14% encourage mould and bacterial growth. [8] also reported that *Oreochromis niloticus* smoked using a modified drum kiln had superior sensory qualities—such as colour, texture, and taste—suggesting enhanced smoke absorption and drying efficiency

Heterotis niloticus

For *Heterotis niloticus*, the FUTY kiln reduced the weight from 0.8 kg to 0.4 kg at 6 hours, after which no further loss occurred. In the Modified Drum Kiln, however, weight dropped from 0.4 kg to 0.2 kg, achieving similar dryness with lower initial weight. This indicates that the Modified Drum Kiln reached the desired dehydration point faster and with less thermal energy, which aligns with [1], who reported that improved smoking kilns significantly reduced moisture content and minimized post-smoking weight loss in fish, resulting in better nutrient retention and overall processing efficiency compared to traditional methods.

Mormyrus rume

A notable anomaly was observed in *Mormyrus rume*. In the FUTY kiln, weight dropped steadily from 0.4 kg to 0.2 kg. However, in the Modified Drum Kiln, weight fell from 0.7 kg to 0.55 kg at 4 hours and then increased to 0.6 kg by 8 hours, possibly indicating moisture reabsorption—perhaps due to poor smoke retention or kiln opening during smoking. This underscores the need for tightly controlled ventilation and consistent heat for uniform dehydration. This pattern aligns with reports that moisture reabsorption can occur post-drying, particularly in storage environments with inadequate control of water activity, which in turn promotes microbial growth Effective kiln management—especially regarding airflow and sealing—is therefore essential to prevent such anomalies [6].

Bagrus bayad

Bagrus bayad underwent more effective smoking in the Modified Drum Kiln, with its weight decreasing from 0.5 kg to 0.28 kg at 6 hours, whereas the FUTY Kiln stabilized at 0.4 kg. The sharper reduction and lower final weight in the drum kiln indicate better smoke penetration and enhanced dehydration efficiency [9]. reported that an improved kiln similar to drum designs resulted in significantly lower microbial loads, with total viable counts reduced to 3.18-3.93 log CFU/g, compared to traditional drum kilns, reflecting more efficient dehydration and improved product safety.

Summary of Observations

- Modified Drum Kiln demonstrated greater moisture removal in *Oreochromis niloticus*, *Heterotis niloticus*, and *Bagrus bayad*.
- FUTY Kiln performed better or equally in *Clarias gariepinus* but was less efficient overall.
- Inconsistencies in *Mormyrus rume* weight in the Modified Drum Kiln suggest possible process error or moisture reabsorption—further replication may be needed.

Statistical Significance

The differences in weight reduction between kilns were generally consistent across time intervals, with standard error of the mean (SEM) values ranging from 0.01 to 0.04, indicating acceptable variation and reliability of observations.

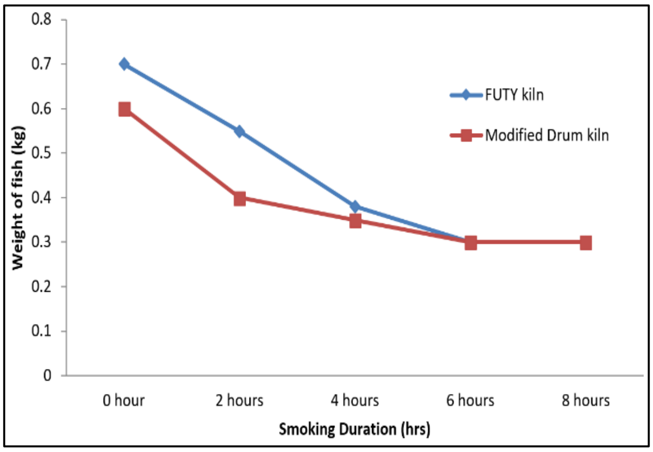

Fig 1: Comparative Smoking efficiency of Modified Drum and FUTY Smoking Kilns for Clarias gariepinus

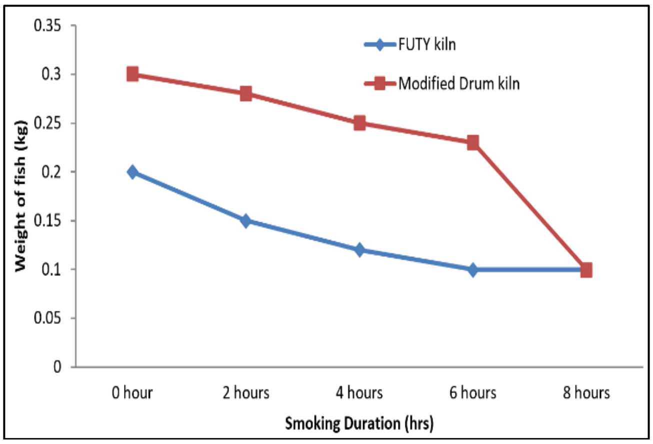

Fig 2: Comparative Smoking efficiency of Modified Drum and FUTY Smoking Kilns for *Oreochromis niloticus*

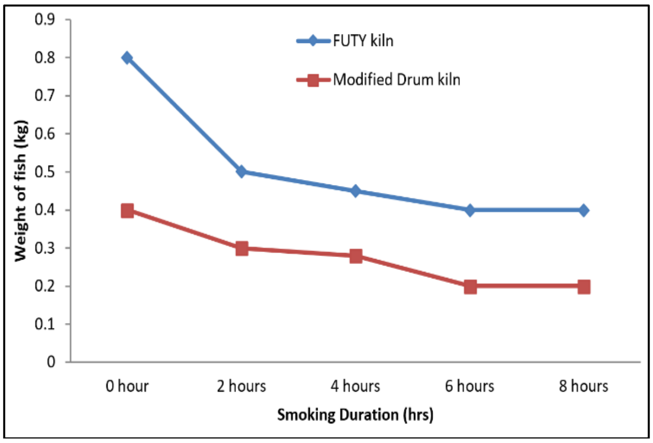

Fig 3: Comparative Smoking efficiency of Modified Drum and FUTY Smoking Kilns for *Heterotis niloticus*

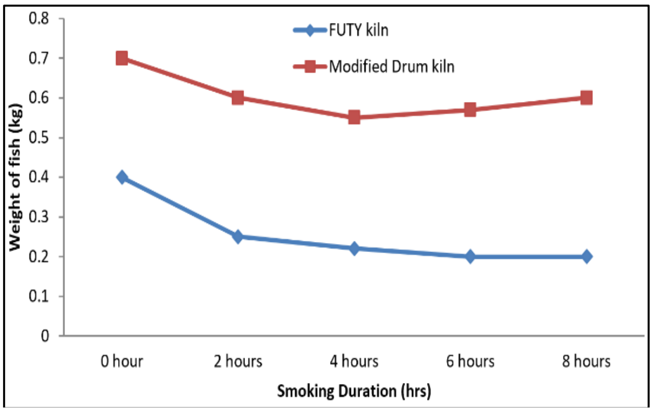

Fig 4: Comparative Smoking efficiency of Modified Drum and FUTY Smoking Kilns for *Mormyrus rume*

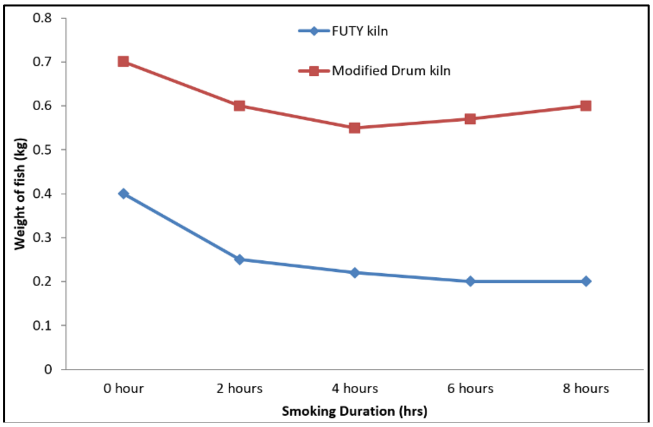

Fig 5: Comparative Smoking efficiency of Modified Drum and FUTY Smoking Kilns for *Mormyrus rume*

Conclusion

This study assessed the smoking efficiency of two improved kiln technologies—Modified Drum Kiln and FUTY Kiln—using five indigenous fish species: *Clarias gariepinus*, *Oreochromis niloticus*, *Heterotis niloticus*, *Mormyrus rume*, and *Bagrus bayad*. Results revealed that both kilns successfully reduced fish weight through moisture loss, but with varying degrees of efficiency.

The Modified Drum Kiln consistently demonstrated faster smoking rates, lower fuelwood consumption, and more significant weight reduction across most fish species. It achieved better dehydration in species like *Oreochromis niloticus*, *Heterotis niloticus*, and *Bagrus bayad*, with low standard error values indicating reliable performance. Although *Clarias gariepinus* performed equally in both kilns by the sixth hour, the Modified Drum Kiln proved more energy-efficient.

Anomalies such as increased weight at later hours in *Mormyrus rume* smoked with the Drum Kiln suggest the need for improved process control. Overall, the Modified Drum Kiln outperformed the FUTY Kiln in terms of smoking efficiency, drying consistency, and operational simplicity.

Recommendation

1. **Adoption of Modified Drum Kiln:** Fish processors, particularly small-and medium-scale operators, are encouraged to adopt the Modified Drum Kiln due to its superior performance in moisture removal, reduced smoking time, and better fuel economy.
2. **Kiln Design Improvement:** The FUTY Kiln could benefit from structural modifications to enhance airflow, heat retention, and smoke control. Incorporating features from the Modified Drum Kiln (e.g., multiple chimneys, metal insulation) could improve efficiency.
3. **Training and Sensitization:** Stakeholders and fisheries extension officers should organize training programs to raise awareness about the benefits of improved kiln technologies and build capacity among artisanal fish processors.
4. **Further Research:** Future studies should incorporate more replicates, include microbial and sensory quality assessments, and explore hybrid kiln systems combining efficiency with environmental safety.
5. **Policy Support:** Government agencies should support the local fabrication and subsidized distribution of improved kilns to enhance fish preservation, reduce post-harvest losses, and improve rural livelihoods

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