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PERFORMANCE EVALUATION OF TROPICAL BIOFUELLED FISH SMOKING STRUCTURES

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ABSTRACT

Environmental and hygienic concerns associated with traditional fish smoking structures restrict the sale and consumption of smoked products to local markets. This study evaluated the performance of three(improved kiln oven (IKO), mud-type ovens (MTO) and extended drum ovens (EDO)) locally available Biofuelled-fish smoking structures and proposed modifications to improve product quality.Three groups of prepared freshwater catfish (*Clarias gariepinus*) with average live weights of 1.93 kg±46 g, 1.92 kg±50 g and 1.86 kg±50 g was used as test samples. Smoking profiles, final moisture content (FMC), smoking time, smoking temperatures, percentage weight loss (WL) and organoleptic evaluation (ORE) were the performance indicators used during evaluation. Smoking profiles showed similar pattern across the structures with distinct effects added by the biofuel and smoking configurations. FMC and WL of 74.1%, 74.1%, 72% and 0.50±0.060 g, 0.50±0.085 g, 0.47±0.0085 g was recorded after 14, 15 and 17 hours of smoking for IKO, MTO,and EDO respectively. Temperature ranges attained were62.3^{o}C - 83.7^{o}C, 45.6^{o}C - 65^{o}C and 34^{o}C - 48^{o}C respectively. ORE shows that MTO samples have the highest acceptability rating followed by the IKO and lastly the EDO. Humidity decreased with increase in smoking time across the three smoking structures. Low-cost equipment with processed sawdust as an alternative energy source was recommended to improve product quality and environmental sustainability.

Keywords: *Biofuel, Smoking, Catfish, sustainability.*

INTRODUCTION

Fish products contribute about 15% protein to about 4.3 billion people in the world. Generally, the agricultural sector contributed 20.24% to Nigeria's GDP with the fisheries sub-sector contributing 0.48% to Agriculture GDPin 2014 (FCWC, 2016). Domestic fish production from Aquaculture, Artisanal and industrial fisheries for 2014 were about 1.123 million metric tonnes but total consumption was about 3.32million metric tonnes, which implies that the 2.197million metric tonnes deficit was imported(FAO, 2014). The rise in global and domestic demand necessitates the transportation of fish and other related products over long distances to consumers and retailers as frozen, sun-dried or smoked to retain its quality. Sun drying, and smoking are widely accepted by traditional processors in the tropicsas a means of preserving perishable foods and probably one of the oldest which dates back to human civilization and was reported to have started shortly after cooking by fire were developed(Akande and Adeyemi, 2016;Eyo, A.A. 2001). This practice is highly valued and practiced not only for preserving food but also as a means of adding distinct flavours to smoked foods that reflect the landscape of the region in terms of forest diversification and the biofuels available for smoking. Smoked fish is a major source of animal protein in Nigeria, particularly the rural and peri-urban population (Eyo, 1992).Among the several methods adopted for long-term fish preservation in tropical countries, smoking has been reported as the simplest, which does not require sophisticated equipment or highly skilled workers (Olayemi *et al.,* 2011).However, cross the border sale of smoked fish remainslow in volume and value than frozen fish in most Sub-Saharan African countries wherehalf of the artisanal catch is consumed in smoked form. In Nigeria,about 70-80% of the domesticcatch is consumed locally in smoked form(Sirra, 20007;Abdullahi, *et al.,* 2001).This is largely due to the subsistence processing capacity and low processing technologies available.During smoking or pyrolysis (thermochemical decomposition of organic matter brought about by high temperatures), organic matter of wood isthermo-chemicallydecomposed, which results in the complete breakdown of itsthree main components: cellulose, hemicellulose,and lignin. These all influences the colours, flavours, preservation and surface texture of the smoked product. Controlling the process is paramount in producing quality products. Smoking is best achieved when the wood moisture content is below 25% and the combustion temperature is maintained ataround 400°C (Guillemette, 2013).This is best attained by increasing the biofuel heat and lowering humidity thus helping the food to dry more quickly and enhancing the shelve life of the smoked product. Smoke is a mixture of the three states of matter: an aerosol of solid particles, liquid drops,and vaporized chemicals. The vaporized chemicals account for only 10% of the volume and contributemore than 90% to the overall process. The chemical composition of the smoke depends on the energy source and the conditions of pyrolysis(Guillemette, 2013). To produce quality smoke, the biofuel must undergo an incomplete combustion of organic materials in the presence of limited supply of oxygen and medium temperature.

Commercial and domestic fish smoking in the tropics is mostly done in pits,raised platforms, extended-drum ovens or on galvanized iron sheets supported by planks where heating and smoking is difficult to control (Afolabi, 1984;Akande and Adeyemi, 2016).Commonly used biofuel includes unprocessed wood, charcoal, plant residues, wood shavings,and saw dust. Surveys conducted in 2003 and 2004 revealed wood fuel as the dominant (71%) energy sourceand charcoal occupying 1.7%(NBS, 2007).Smoking is mostly done on galvanized wire gauze suspended on medium to large round or rectangular mud or metallic structures with fire wood as an energy source.These local technologies as cheap and simple to construct as they may be often come with significant drawbacks such as; environmental concerns, long processing time, poor processing hygiene, low capacity, drudgery, charring of smoked fish, and low energy efficiency.Operational health hazards and safety concerns as reported by Olaoye *et al.,* 2015; is also a major drawback associated with local Biofuelled smoking structures. Thesefactors contribute to low product quality, low production capacity,profitability, and restricts cross-border trade capacity.Several agencies and research institutions have made effortsto salvage African fisheries industry through the provision of improved smoking structures that will address these challenges.Contrary to these efforts,local processors have consistently rejected these designs citing cost and the failure of these structures to address critical socio-economic and cultural factors as reasons for rejection.

The growing call to provide solutions to these challenges have challenged innovators and researchers to come up with solutions that will not only address food safety and environmental sustainability concerns but also address the cited reasons for rejecting previous designs.Therefore, an improved approach to proffer a lasting solution will involve a comprehensive study of dominant local smoking structures.This study is therefore aimed at conducting a comprehensive analysis of three traditional smoking structures and recommend solutions that will guide designers and fabricators in providing environmentally friendly designs that will not only meet socio-economic, cultural and quality demands but also meet local and international standards thus enhancing cross-border smoked fish trade.

MATERIALS AND METHODS

Fish sample selection and preparation

Freshwatercatfish (*Clarias gariepinus*) from the same origin and rearing characteristics as described by Sigurgisladottir *et al.,*(1997)were purchased from a localfish farm in Ibadan, Nigeria. The fish were divided into three groups with average live weight of 1.93 kg±46g (Group A),1.92 kg±50 g(Group B) and 1.86 kg±50 g (Group C).The samples were killed, bled, gutted, cleaned and individually weighed and tagged in accordance with prevailing traditional preparation chart shown in Figure 2. Dry salting technique as described by Mireille *et al.,* (2001) was used with refined iodized salt (Mr. Chef, Nigeria) and left for 2 hours to allow pellicle formationat room temperature (27^{o}C) before smoking.

(A)

(B)

Figure 1. An improvedkiln oven (A), mud-type oven (B) and extendeddrum oven (C)

Smoking equipment

Three dominant Biofuelled smoking structures (improved kiln oven (A), mud-type oven (B) and the extended drum oven (C) were carefully selected and compared for drying and smoking fresh watercatfish(Clarias gariepinus).

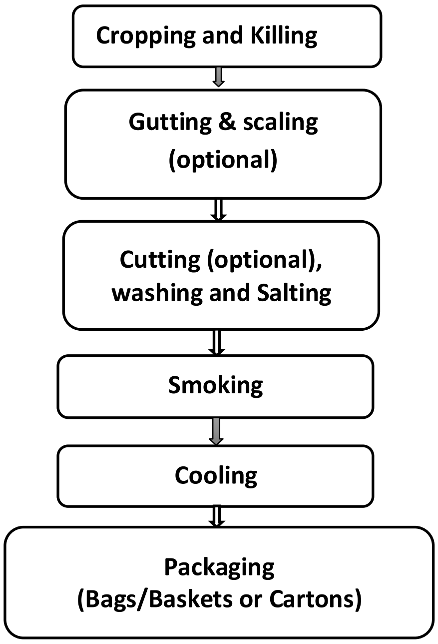

Figure 2. Flow-chart for traditional Fish Smoking in the tropics

The improved kiln oven (Figure 1A) is a square-shaped structure(internal dimension:1.3 m x 1.3 m x 1.3m) with six trays of length 1.2 m and breadth 0.6 m respectively. The mud-type oven(Figure 1B) is a rectangular shaped mud structure (0.6 m height, 0.8 m length and 0.9 m width) with galvanized wire gauze positioned at the top to hold the fish.The extended drum oven (Figure 1C) is a metallic cylindrical drum(diameter of about 0.5m and a height of 0.6 m) with an extended (about 0.3 m from the edge) spherical wire gauze to stack the fish. The mode of heating is similar in all the structures with firewood as the biofuel in the mud-type and extended smoking drum smoking ovens and charcoal as the energy source in the improved kiln.

Smoking procedure and evaluation

The surfaces of the galvanized wire gauze for the three structures were cleaned, greased with groundnut oil and slightly mopped with foamto prevent sticking of the fish samples to the wire gauze as proposed by Ikenweiwe *et al.,* (2010).The biofuels (firewood and charcoal) were weighed with a digital weighing scale (Poyear® by Poyear Industries with an accuracy of ±0.1 g). The prepared fish were weighed and arranged on the galvanized wire gauze(for the mud-type and extended metallic drum structures)and in metallicsmoking trays (for the improved smoking kiln). Ignited biofuels in batches of 20 kg each wereintroducedinto the smoking chambers to effect smoking and drying. The process was terminated for each structure after attaining a constant weight (Akande and Adeyemi, 2016).A consistent smoking time above 14 hours with minimum ambient conditions of 31.2^{o}C and 20% relative humidity were maintained for all the structures. Smoking conditions and fish weights were recorded every hour using a hygro-thermometer (WS HT 12 Temperature and Humidity pen).After smoking, the cooled samples were weighed to determine the percentage weight loss and placed in airtightpolythene bags for further analysis. The results obtained are presented in Table 1 and 2. Organoleptic evaluation (Table 1) of the smoked *Clarias gariepinus* was assessed by a 10-man panellist as prescribed by Desrosier and Desrosier, (1977); (using hedonic ten-point grading scale (poor (1 - 3), fairly good (4 - 5), good (6 -7) and very good (8 - 10).Performance evaluations of all the structures were done in triplicates.

Weight loss (%) (Moisture content)

The percentage weight loss was calculated using Equation (1)

$$MC(\%) = \frac{initial\ weight - final\ weight}{initial\ weight} \times 100\% \quad ...(1)$$

Energy content

The energy content of the biofuels used for smoking was determined using Equation (2)

$$E_c = specific\ energy\ value(MJ/kg) \times weight\ of\ fuel\ (kg) \quad ....(2)$$

For charcoal, the specific energy value or NHV (Net Heating Value) is 30MJ/Kg

For firewood, the minimum and maximum net heating values were used. These are given as;

Minimum NHV = 16 (MJ/Kg)

Maximum NHV = 21 (MJ/Kg)

Heat requirement

The amount of heat required to effect drying was determined after each hour for the three structures. This was evaluated using Equation (3). (Ehiem, et al., 2009)

$$Q_c = (W \times C_f \times \Delta T) + (H_{fg} \times MR) \quad ...(3)$$

Where Qc = Convective heat required to dry (Joules)

H = Latent heat of vaporization (2,413.7KJ Kg $^{-1}$)

C_f= Specific heat capacity of catfish (3.63 KJ kg. ^{o}C)

ΔT = temperature Change of smoking kiln (^{o}C)

MR = Amount of moisture removed (kg)

The actual amount of heat required for drying was estimated using Equation (4).

$$Q_T = m_a \times (h_f - h_i) \quad ....(4)$$

Where h_f and h_i are initial and final enthalpy of air at the experimental conditions.

Fire chamber efficiency

The fire chamber efficiency of the three smoking structures was determined using Equation (5)

$$n_f = \frac{Q}{M \times NHV} \times 100\% \quad ....(5)$$

Were n_f= chamber efficiency

Q = convective heat transfer (KJ)

M = Mass of charcoal used (kg)

NHV = Net heating value (MJ/kg)

RESULTS AND DISCUSSION

Final product quality

The time taken to attain an average weight loss above 70% for all the structures was between 14 and 17 hours. This extended smoking time was considered satisfactory by processors to produce quality products with the acceptable characteristic flavour and golden-brown colour associated with smoked catfish. The weight loss and heat requirements for the structures are shown in Table 2 and Table 3. The lowest heat requirement (3388.12 KJ) was observed for the extended drum oven after 17 hours of smoking.The direct heating and smoking effect of the biofuels (firewood and charcoal) used and the fixed distance of the fish from the heat source accounts for the high moisture loss observed across the three structures. Smoking and heating temperature was difficult to control because of the free air circulation and the fish oil dropping on the burning biofuels for mud type oven and the extended drum oven while the oil collection tray positioned at the bottom of each tray helps to prevent this in the improved kiln oven.

Organoleptic assessment of smoked samples

The flavour of smoked fish samples from the mud-type oven wasadjudged the best with a rating of 9.1 after 15 hoursof smoking while samples from the extended drum oven were ratedlowest with 6.7. Contrary to expectations, samples from the improved kiln oven were rated lower in flavour(7.5) probably due to the absence of the special flavour derived from firewood in the charcoal used. Samples from the extended drumovenobtained the lowest ratingin terms of all the organoleptic parameters due to over smoking and the burnt patcheson the samples (Table 1).The textures of samples the improved kiln and the mud-type oven were rated well (8.4 and 8.2) while smoked samples from the extended drum oven were adjudged of poor quality with the lowest rating of 2.8.Over smoking and unregulated heating accounted for this poor rating.

Table 1: Mean organoleptic values of fish smoked from different smoking structures

Attributes	IKO	MTO	EDO
Flavour	7.5	9.1	6.7
Texture	8.4	8.2	2.8
Colour/appearance	9.2	6.7	4.6
Smell	7.8	6.6	5.6
Acceptability	9.3	9.5	6.5

The colour and appearance of smoked fish is an important quality parameter used to assess smoked products (Idah and Nwankwo, 2013). Smoked samples from the IKO were best rated (9.2) while MTO and EDO were rated below average having 6.7 and 4.6 respectively.The fish samples smoked with the mud-type oven were the most acceptable (9.5) due to their neatness and attractive golden brown colour followed by the modified kiln oven (9.3). Smoked samples from the extended drum oven were the least in acceptability rating (6.5). Smell is also considered an important sensory quality parameter that guides consumers when selecting and buying smoked products. The smell of samples from IKO and MTO were rated above average with 7.8 and 6.6 while EDO had a poor rating of 5.6, which is unconnected with the charred nature of the samples.

The organoleptic assessment shows that the best samples with the highest acceptability rating were from MTO with an average rating of 9.5 followed by IKO with a mean value of 9.3. The samples had smooth-textured skin with good odour and an attractive golden brown colour, which is mostly desired in smoked fish.Thelow product quality observed in EDO(Table 1) wasprobably due to theuneven drying ofthe smoked product,poor heat and smoke distribution andthe charrednature of the smoked product, which is largely due to poor rotation, and closeness of the samples to the heat source.

Temperature profile

Smoking temperatures generally ranged between 62.3°C and 83.7°C for IKO; 45.6°C and 65°C for MTO; and 34°C and 48°C for EDO respectively. The temperature distribution pattern of the structures under loadis shown in Figure 3. EDO consistently maintained a lower temperature profile (below 50°C) throughout the smoking process, which accounts for an average moisture loss of 74.7% after 17 hours of smoke-drying. IKO and MTOhad relatively high temperature rangesbetween 62.3°C and 83.7°C respectively. This accounts for the lower smoking time of 14 h (Table 2) with an attractive golden-brown colour of the smoked samples.The presence of adequate insulation through lagging provided better heat conservation within the heating chamber of MTO; thus, reducing energy cost, energy loss to the environment and the smoking time. This was consistent with the result obtained by Akande and Adeyemi. (2016)during the performance evaluation of a similar Biofuelled detachable fish smoking kiln. The traditional mud-type structure maintained a good product quality in terms of colour and smell.The products were accepted because of its good flavour and texture. These are consistent with local demands. A gradual decline of temperatures was observed across the three structures as the biofuel is exhausted. Maximum temperatures of 65.2°C and 48.3°C were attained for MTO and EDO after a period of fluctuations that are consistent with ambient conditions. The open nature of these structures probably accounted for this, as the stacked products are not isolated from ambient conditions. Smoking temperatures dropped to a minimum of 62.3°C,49.3°C,and 35.8°C for IKO, MTO and EDO respectively. Final percentage weight losses of 74.1%, 74.1%,and 72% were attained for IKO, MTO and EDO after smoking for 15 h respectively.

Table 2:Biofuel typesand average weight loss of fish from smoking structures

Structures	Biofuel Type	Initial Average Weight (kg)	Final Average Weight (kg)	Weight Loss (%)	Smoking Time (hr.)
IKO	Charcoal	1.93±46	0.50±0.060	74.1	14
MTO	Firewood	1.92±50	0.50±0.065	74.1	15
EDO	Firewood	1.86±50	0.47±0.085	72.0	17

Drying profile and average weight loss

The drying profile is shown in Figure 4. Moisture content generally decreases with increase in smoking time for all the structures, which is consistent with normal smoking-drying processes. The fish moisture content gradually dropped by 28.5%, 42.7%,and 52.8% respectively during the first six hours of smoking for the extended drum oven, mud-type ovenand the improved kiln oven respectively. The samples smoked in the improved kiln oven showed a constant moisture loss in the first three hours. The average weightsof the samples finally reduced to 0.50±0.060kg, 0.50±0.065kg and 0.47±0.085kg after 14 h, 15 h and 17 hours for the IKO,MTO and EDO respectively. Table 2.

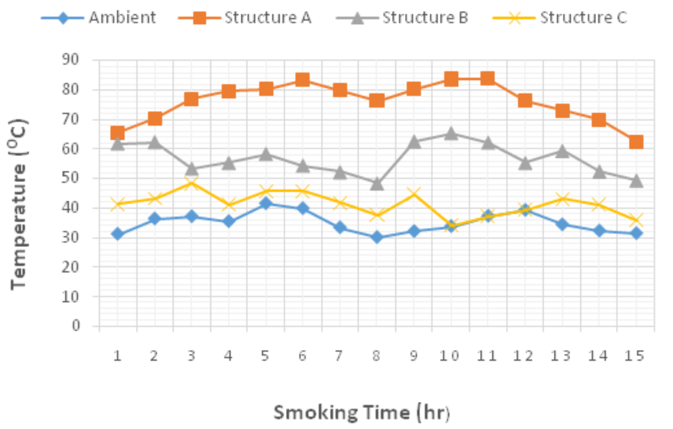

Figure 3. Temperature profile of the smoking structures at loading condition with 20 kg biofuel

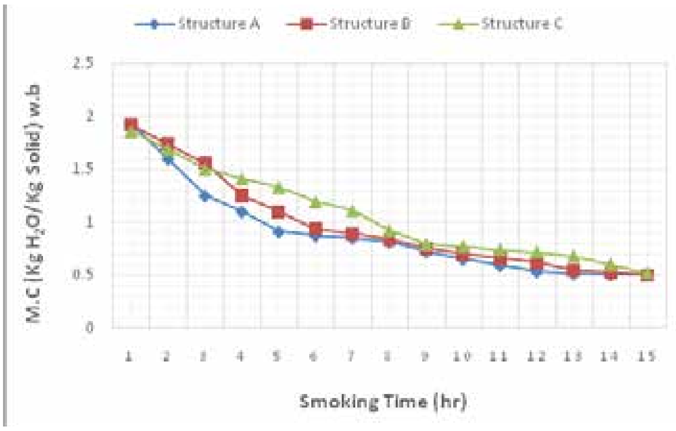

Figure 4. Drying profile of the smoking structures

Table 3:Net heating value and heat requirement of the smoking structures

Parameters	IKO	MTO		EDO	
Heat Transfer (MJ)	34.27	8.81		5.58	
		Maximum	Minimum	Maximum	Minimum
Chamber Fire Efficiency (%)	9.52	1.91	2.50	1.40	1.84
Heat requirement (kJ)	3,471.91	3450.52		3388.12	

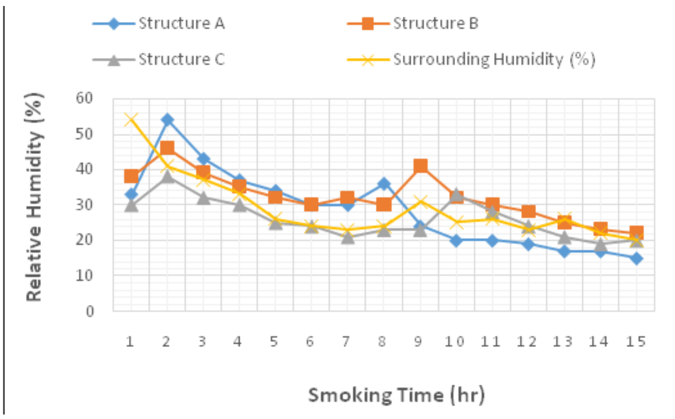

Figure 5. Humidity profile of the smoking structures

Relative humidity

The humidity profile (Figure 5) shows that the humidity of the three structures decreases with increase in smoking time. The closed enclosure of the improved kiln oven was responsible for the highest humidity (54%) recorded which gradually reduced to 15% after 15 h of smoking. The extended drum oven has an initial humidity of 30%, which gradually increased to 38% (highest value) after 2 h. A final value of 20% was recorded after 15 h of smoking which was consistent with the final ambient humidity. The mud type oven also attained 41% humidity after 9 h and gradually dropped to 22% after 15 h. The exposed nature of samples to the atmosphere accounts for the relatively close humidity profile of these structures with ambient conditions.

CONCLUSION

Generally, the three ovens showed similar smoking patterns and were effective in reducing moisture contents of samples to safe limits but showed different effects on smoked samples largely due to the biofuel type and oven configurations. The biofuel consumption was relatively lowerand more effective in the improved kiln oven with reduced charred samples compared to the extended drum and mud-type ovens. Designs with sawdust as the biofuel will help improve product flavour and environmental friendliness as this waste product will be productively engaged as against the use of firewood, which encourages deforestation and desertification.Fabricators are therefore encouraged to manufacture environmentally friendly designs and adaptations that will minimize health hazards and injuries associated with fish smoking.Further study isneeded to address the significant effects of smoking on the nutritional compositions of smoked samples and the optimum storage period ofproducts smoked using the three structures. This will further guide local manufacturers in making informed decisions during equipment design and fabrication.

Conflict of interest

The author(s) confirm that this article content has no conflicts of interest.

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