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Performance Evaluation of a Charcoal-Fired Fish Smoking Kiln

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ABSTRACT
Smoking is the process of flavouring or preserving food by either cold smoking a lower temperature or by exposing it to smoke from a burning object, typically wood. Smoking is globally acceptable for food products such as fish, meat, chicken, etc., but the traditional method is generally stressful and not hygienic which constantly pose health risks to producers and consumers. Considering this, a low-cost, effective, free-health risk and affordable smoking kiln was developed and evaluated for the use of farmers, households, and small and medium-scale industries for processing fish and other animal products. The machine was fabricated using locally available materials with charcoal as the heat source. The machine effectively smoked the fish samples with smoking time of two hours at average percentage moisture losses of 75.46%, 70.07% and 58.40%, and moisture removal rate of 37.73%/hr, 35.03%/hr and 29.20%/hr for Merluccius merluccius (Panla Fish), Oreochromis (Tilapia Fish), and Clupea harengus (Shawa Fish) species, respectively. The machine is thus recommended for households, farmers, small and medium scale processors.
KEYWORDS: *Charcoal, Fish, Smoking, Kiln, Drying, Performance Evaluation.*

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I. INTRODUCTION

Smoking is the process of flavouring or preserving food by either cold smoking it at a lower temperature of 12 to 25℃ [1] or by exposing it to smoke from a burning or smoldering object, typically wood [2]. This is done to give food flavour and preservation qualities. Food can also be smoked by coming in contact with liquid smoke vapours [3]. Smoking is the most important way to preserve fish and animals in Africa. Numerous organic chemical components, some of which are known to have antibacterial properties, make up wood smoke [4]. Food smoke flavouring can be achieved by condensing wood smoke into water, which creates liquid smoke. One of the concerns associated with smoked foods is the risk associated with the illicit use of chemically preserved wood [5].Smoked foods are safe if they are made from fresh raw materials free of natural toxins, chemical pollutants, pathogens, and parasites; and if the storage conditions do not encourage microbial proliferation or toxin production [6].

Fish products are smoked by combining the processes of salting, drying, and heating [2]. The smoking preservation technique improves sensory quality by controlling physicochemical parameters like pH, fatty acid content, texture profiling, etc. This enables higher-quality end fish products to be stored for longer periods of time [7]. Food that has been smoked inhibits the growth of microorganisms and decreases oxidative changes [4]. On the surface of processed fish, smoke from incompletely burned wood or sawdust releases volatile chemical compounds that inhibit the growth of bacteria [9].Smoking wood or sawdust releases a variety of complex chemicals like phenols, ethers, esters, hydrocarbons, acids, alcohols, and ketones, which are responsible for food colour and flavour development [10].Smoked food products are highly sought after by consumers because of their distinctive flavour and colour. Smoking can be divided into three types according to temperature: cold (12-25℃), warm (25-45℃), and hot (40-100℃) [4, 7].

In order to achieve a premium grade smoked product, it is essential to optimize the time, temperature, and sawdust material in the hot smoking procedure. The physicochemical assessment (pH level, fatty acid content, etc.), microbial growth measurement, and sensory evaluation (colour, texture, odour, flavour, and overall acceptance) established qualities of smoked fish products [12]. Heating is an effective method of maintaining the quality of food products, but it can also cause protein denaturation in food products, which reduces their nutritional and functional qualities [9].Polycyclic aromatic hydrocarbons (PAHs) in wood smoke and smoked foods have been shown to be possibly genotoxic and carcinogenic to humans, and smoked items have been found to be mutagenic and carcinogenic. Enzymes in the human body break down PAHs to produce DNA adducts that are carcinogenic and promutagenic [13, 14].

With kilns that range from conventional open fire to mud brick, cylindrical drum, and brick, fish is the most frequently smoked commodity in Nigeria [15]. Fish processing by kilning or hot smoking has been done for ages in most parts of the world. The absence of infrastructure and appropriate technology has prevented Nigerian fish smoking practices from becoming widely accepted.Quality control and improved hygienic conditions are difficult to maintain [15], and the market value of processed fish declines due to its damaged and unappealing appearance [16]. Therefore, a low-cost smoking kiln that is suitable for farmers, households, and small and medium-scale fish production was developed and evaluated, basedon these limitations.

II. MATERIALS AND METHODS

2.1 Material Selection

Various factors such as strength, durability, flexibility, weight, resistance to heatand corrosion, ability to cast, machinability, heatconductivity, as well as the cost of the materials,were considered when the machine was designed and fabricated. The fish smoking kiln was constructed using mild steeland galvanized steel. Galvanized steel was used for thewired mesh that comes in contact with the smoked fish,because of vulnerability of mild steel to corrosion whichmakes it not suitable for contact with food. Other materials used for the evaluation of the machine include: three fish species (Panla: *Merluccius merluccius*;Tilapia: *Oreochromis*; and Shawa: *Clupea harengus*), infrared thermometer, weighing scale, polythene bag, and charcoal.

2.2 Description of the Machine Components

The charcoal-powered fish smoker was designed to serve households, farmers,small and mediumscale industries. The machine consists of the following essential parts, which are described below.

2.2.1 Frame

The frame is made up of angle irons 37.5x 37.5 mm, welded together to form the mounting support for the smoking oven. The dimension is 900 mm x 600 mm x 360 mm. The charcoal tray was fixed 150mm from the ground, fish tray closed to the charcoal tray was fixed 105mm from the ground, and then the second fish tray was 500mm and the chimney 900 mm from the ground surface.

2.2.2 Fish Tray

This is the container into which the fish is loaded and smoked. It is constructed from sheet and wire mesh and has a dimension of 520 mm x 310 mm x 200 mm. The metal sheets were measured using measuring tape and cut to desired size and length to construct the fish tray.

2.2.3 Charcoal Tray

This is the container for the burning charcoal. It is constructed from metal sheets of thickness 1mm. The tray has the dimension of 520 mm x 310 mm x 200 mm.

2.2.4 Chimney

The smoking oven consists of chimney of length and width (250 mm x 100 mm) located at the top of the smoking oven to allow effective exit of smoke and excess heat.

2.3 Machine Description

The construction of the machine was carried out at Engineering Workshop, Federal College of Agriculture, Ibadan,Nigeria. The smoking cabinet, made from mild steel, is lagged with a fibre insulator purposely toprevent heat loss during smoke drying.The smoking chamber consists of set trays arranged into three rows and also a smoking rack with the same length and breath. The cabinet overall dimension is 520 mm x 310 mm x 200 mm and the dimension of the trays is520 mm x 310 mm x 200 mm. The trays have a channel fabricated totheir ends to allow for flow of food product drippings duringsmoking flowing out without accumulation. This channel isconnected to a pipe which runs from the top to the bottomat the back of the smoking kiln through which the channel of the others tray connects, collecting all product drippings andexpelling them to the outer part of the smoking kiln. The heat source of the smoking kiln is charcoal which iscontained in two pots, each with a dimension of 520 mm x 310 mm x 200 mm, placed by the sides of the rack system thatcarries the trays. Air circulation by convection is madepossible in the combustion chamber and carries heated airin all directions of the loaded trays with air inlets at the lower front of the smoking kiln facilitating the flow of heat.The chimney is fitted with an adjustable valve that controlsthe amount of heat build-up within the smoking kiln andconducts the smoke to the outdoor. The fabricated fish smoking kiln is shown in Plate 1.The machine was fabricated with tray arrangementsat the center of the kiln, so that heat source can be placed bytheir sides to allow indirect mode of heating. The region between the charcoal trays was perforated to allow inflow offresh air to support combustion and mobility of smoke inthe kiln. A tray system slightly sloped backward wasadopted to allow oil leaching from product flow into channelwhere it is collected.

Plate 1: Fabricated Fish Smoking Kiln

Plate 2: Fabricated Smoking Kiln

2.4 Smoking Procedure

The threefish species used for the tests, namely, *Merluccius merluccius* (Panla Fish), *Oreochromis*(Tilapia Fish), and *Clupea harengus* (Shawa Fish) were obtained from two different fish farms in Ibadan, Nigeria. The species are popular delicacies among the low and middle-income earners, vary in sizes, relatively cheap and affordable. They are fresh water fish species commonly found locally in the inland waters of Nigeria. The fish were eviscerated, thoroughly washed, brined and ready for smoking. The charcoal in the charcoal tray was first ignitedwith the help of kerosene and matches, the ignited charcoal was allowedto burn for few minutes to allow the kerosene odor to beexhausted. The brined fishes were then arranged on the tray, as the perforated tray surface was greased with groundnut oil to prevent the fishes from sticking unto the tray. The fishes were smoked dried until desired dryness was achieved and determined. At this level, the fishes turned brown with sweet smelling flavour. Charcoal was added at intervals during the smoking process to ensure there was no temperature drop. The smoke drying was stopped and the heating chambers (charcoal trays) were removed and the already smoked fishes were allowed to cool before packaging. The flow diagramfor the smoking of fish is presented in Figure 1.

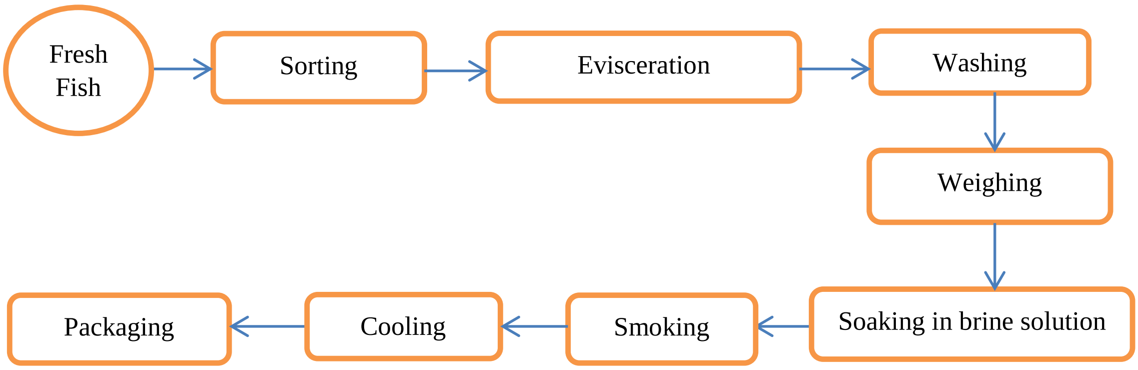

Figure 1: Flow Diagram for Smoking of Fresh Fish Product

2.4 Performance Evaluation of the Machine

The fish samples were weighed initially and arranged on the tray before being placed in the smoking kiln. Smoking/drying of the fish samples continued until a final weight was achieved and hence the percentage moisture loss during smoking wasdetermined from both the initial and final weight, as the smoking time was also recorded. The percentage moisture loss and moisture removal rate were calculated using the equations given by [4]. After smoking, the fish samples were allowed to cool and kept in a polythene bag to determine the shelf life.Therefore, the performance of the machine was evaluated using the following parameters:

2.4.1 Moisture Loss

The moisture loss is the ratio of initial weight of fresh fish samples to the final weight of smoked fish samples. It is calculated using the equation given by [4].

$$M_L = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

Where: $M_L = Moisture\ Loss\ (\%)$
$W_i = Initial\ weight\ of\ fresh\ fish\ samples\ (kg)$
$W_f = Final\ weight\ of\ smoked\ fish\ samples\ (kg)$

2.4.2 Moisture Removal Rate

The moisture removal rate is the ratio of percentage moisture loss to the total time of smoking. It is calculated usingthe equation given by [4].

$$M_R = \frac{M_L}{T} \quad (2)$$

Where: $M_R = Moisture\ Removal\ Rate\ (\%/hr)$
$M_L = Moisture\ Loss\ (\%)$
$T = Smoking\ Time\ (hr)$

III. RESULTS AND DISCUSSION

3.1 Smoking Test with Panla Fish(*Merluccius merluccius*)

The results of the performance evaluation tests on the fish smoker with Panla (*Merluccius merluccius*)are shown in Table 1. These indicated that the fishes were smoked atpercentage moisture losses of 65.00%, 68.75%, 73.33%, 78.57% and 91.67% for the five replicates, while therate of moisture removal of the smoking kiln was calculated to be 32.50%/hr, 34.38%/hr, 36.67%/hr, 39.29%/hr and 45.83%/hr for the five replicate samples. It was observed that the percentage moisture loss and the rate of moisture removal increases with decreases in the initial and final weight of the fish samples. The smoking temperature was determined to be 89℃ for two hours duration, this isin accordance with thefindings of [4, 16]whoreported that smoking temperature suitable for effectivedrying ranges between 80-90℃. It was also observed that atthe various tray levels of the smoking kiln, there was slight temperature difference. This could be due to the fact that hotair is of lighter density than cold air and floats upwards. The smoked Panla Fish (*Merluccius merluccius*) samples are shown in Plate 2.

Table 1: Performance Evaluation Tests on the Fish Smoker with Panla Specie(*Merluccius merluccius*)

Fish Sample	Time Taken (hrs)	Initial Weight (kg)	Final Weight (kg)	Moisture Loss (%)	Moisture Removal Rate (%/hr)
1	2	0.20	0.07	65.00	32.50
2	2	0.16	0.05	68.75	34.38
3	2	0.15	0.04	73.33	36.67
4	2	0.14	0.03	78.57	39.29
5	2	0.12	0.01	91.67	45.83
Total	**10**	**0.77**	**0.2**	**377.32**	**188.66**
Average	**2**	**0.15**	**0.04**	**75.46**	**37.73**

3.2 Smoking Test with Tilapia Fish(*Oreochromis*)

The results of the performance evaluation tests on the fish smoker with Tilapia Fish(*Oreochromis*)are shown in Table 2. These indicated that the fishes were smoked at percentage moisture losses of 60.00%, 64.29%, 69.23%, 75.00% and 81.82% for the five replicates, while the rate of moisture removal of the smoking kiln was calculated to be 30.00%/hr, 32.14%/hr, 34.62%/hr, 37.50%/hr and 40.91%/hr for the five replicate samples. It was observed that the percentage moisture loss and the rate of moisture removal increases with decreases in the initial and final weight of the fish samples. The smoking temperature was determined to be 82℃ for two hours duration, this is in accordance with theresults of [4, 16] whoreported that smoking temperature suitable for effective drying ranges between 80-90℃. It was also observed that atthe various tray levels of the smoking kiln, there was slight temperature difference. This could be due to the fact that hotair is of lighter density than cold air and floats upwards. The smoked Tilapia Fish (*Oreochromis*) samples are shown in Plate 3.

Table 2: Performance Evaluation Tests on the Fish Smoker with Tilapia Specie (*Oreochromis*)

Fish Sample	Time Taken	Initial Weight	Final Weight	Moisture Loss (%)	Moisture Removal Rate

	(hrs)	(kg)	(kg)		(%/hr)
1	2	0.15	0.06	60.00	30.00
2	2	0.14	0.05	64.29	32.14
3	2	0.13	0.04	69.23	34.62
4	2	0.12	0.03	75.00	37.50
5	2	0.11	0.02	81.82	40.91
Total	**10**	**0.65**	**0.2**	**350.33**	**175.17**
Average	**2**	**0.13**	**0.04**	**70.07**	**35.03**

3.3 Smoking Test with Shawa Fish(*Clupea harengus*)

The results of the performance evaluation tests on the fish smoker with Shawa Fish(*Clupea harengus*)are shown in Table 3. These indicated that the fishes were smoked at percentage moisture losses of 48.78%, 55.26%, 59.46%, 62.86% and 65.63% for the five replicates, while the rate of moisture removal of the smoking kiln was calculated to be 24.39%/hr, 27.63%/hr, 29.73%/hr, 31.43%/hr and 32.81%/hr for the five replicate samples. It was observed that the percentage moisture loss and the rate of moisture removal increases with decreases in the initial and final weight of the fish samples. The smoking temperature was determined to be 90℃ for two hours duration, this is in accordance with the findings of [4, 16] who reported that smoking temperature suitable for effective drying ranges between 80-90℃. It was also observed that at the various tray levels of the smoking kiln, there was slight temperature difference. This could be due to the fact that hot air is of lighter density than cold air and floats upwards. The smoked Shawa Fish (*Clupea harengus*) samples are shown in Plate 4.

Table 3: Performance Evaluation Tests on the Fish Smoker with Shawa Specie (*Clupea harengus*)

Fish Sample	Time Taken (hrs)	Initial Weight (kg)	Final Weight (kg)	Moisture Loss (%)	Moisture Removal Rate (%/hr)
1	2	0.41	0.21	48.78	24.39
2	2	0.38	0.17	55.26	27.63
3	2	0.37	0.15	59.46	29.73
4	2	0.35	0.13	62.86	31.43
5	2	0.32	0.11	65.63	32.81
Total	**10**	**1.83**	**0.77**	**291.99**	**145.99**
Average	**2**	**0.37**	**0.15**	**58.40**	**29.20**

3.3 Comparisons of the Smoking Tests with the three Fish Species

As shown in Table 4 and represented by Figure 2, the results indicated the comparisonof average performance evaluation tests for the three fish species: *Merluccius merluccius* (Panla Fish), *Oreochromis* (Tilapia Fish), and *Clupea harengus* (Shawa Fish). It was observed that Panla(*Merluccius merluccius*) has the highest moisture loss and moisture removal rate of 75.46% and 37.73%/hr, respectively, while the least moisture loss and moisture removal rate of 58.40% and 29.20%/hr, respectively, was found with Shawa (*Clupea harengus*) with the smoking time of 2 hours each.In the smoking kiln, since the heat source is notdirectly under the rack system, it floats to the upper part ofthe smoking kiln and the products at upper tray dry faster.

Table 4: Comparison Performance Evaluation Tests with the three Fish Species

Fish Specie	Time Taken (hrs)	Initial Weight (kg)	Final Weight (kg)	Moisture Loss (%)	Moisture Removal Rate (%/hr)
Panla (*Merluccius merluccius*)	2	0.15	0.04	75.46	37.73
Tilapia (*Oreochromis*)	2	0.13	0.04	70.07	35.03
Shawa (*Clupea harengus*)	2	0.37	0.15	58.40	29.20

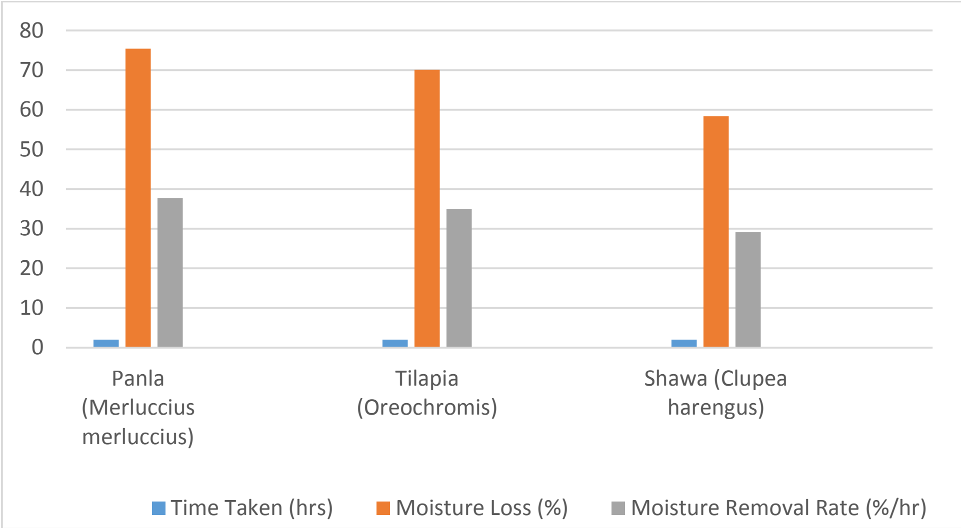

Figure 2: Comparison Evaluation Tests with the three Fish Species

Plate 2: Smoked Panla **Plate 2: Smoked Tilapia** **Plate 3: Smoked Shawa**

IV. CONCLUSION

A smoking kiln for production of smoked fish was fabricated and evaluated. The source of heat was charcoal, which was distributed by conduction and convectionwithin the smoking chamber and by radiation through chimney to the surrounding.The machine smoked the three fish species effectively with smoking time of two hours at average percentage moisture losses of 75.46%, 70.07% and 58.40%, and moisture removal rate of 37.73%/hr, 35.03%/hr and 29.20%/hrfor*Merluccius merluccius* (Panla Fish), *Oreochromis* (Tilapia Fish), and *Clupea harengus* (Shawa Fish) species, respectively.The machine is very easy to maintain, does not require special training and therefore recommended for households, farmers, small and medium scale processors.

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