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Development of an Electric Powered Fish Grilling Kiln

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Abstract: An electrically operated fish grilling kiln was developed and its performance was evaluated. The machine is a double walled structure having a dimension of 580 x 580 x 900m completely insulated all round with polyurethane of 254 mm thickness to conserve heat within the drying chamber. The internal wall of the kiln was made of Galvanized steel while the exterior was made of mild steel. The drying chamber has six sets of tray on racks. The kiln was mounted on a set of four wheels for ease of movement. The fish kiln has a temperature gauge to regulate the drying temperature as well as a fan to circulate the heated air and ensure even drying of the fish during operation. The drying chamber consists of four (4) heating elements with 1.5 Watt power rating each. Mackerel and Catfish were used for the performance evaluation of the machine. Results obtained from this test revealed that there exist a significant difference in the rate of drying of the Mackerel and Catfish. The average drying rate was 0.07 and 0.12kg/hr for Mackerel and Catfish respectively. The average weight losses recorded for Mackerel and Catfish in this study are 18.1 and 14.06% respectively within the first hour of drying. The electric grilling kiln was excellent in performance with the basic functions of grilling and drying fishes as evidenced by short processing time of the grilled fish samples.

Keywords: *Development, Performance, Electric, Fish, Grilling Kiln.*

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I. INTRODUCTION

Fish, a fascinating and diverse group of vertebrates, are an integral part of the world's aquatic ecosystems and play a pivotal role in maintaining ecological balance. Globally, there are approximately 30,000 to 33,000 identified species, with researchers predicting that many more remain undiscovered due to the vastness and complexity of aquatic habitats (Halicka, 2017; Helfman, 2013; Dario, 2015). These species inhabit a wide range of environments, from the depths of the oceans to high-altitude freshwater lakes, demonstrating exceptional adaptability and survival strategies across different ecological niches (Helfman, 2013). This diversity in habitat and physiology underscores their importance in ecological, biological, and nutritional studies. Fishes are broadly categorized into three major groups: jawless fish (Agnatha), cartilaginous fish (Chondrichthyes), and bony fish (Osteichthyes) (Helfman, 2013). Each of these groups exhibits unique structural, functional, and behavioral traits that enable them to thrive in specific environments. For instance, jawless fish, such as lampreys and hagfish, are primitive species with simple anatomical features, whereas cartilaginous fish like sharks and rays possess skeletons made of cartilage. Bony fish, the largest group, have ossified skeletons and exhibit remarkable diversity in size, shape, and function. The habitats of fish are as varied as their forms, ranging from deep marine environments over 8,000 meters below sea level to freshwater lakes located 5,000 meters above sea level (Helfman, 2013). This expansive distribution highlights their evolutionary adaptations, which include specialized gills for efficient oxygen exchange, fins for maneuverability, and scales for protection against environmental challenges (Farrell et al., 2011; Collectif, 2011). These features not only ensure their survival in extreme conditions but also make them excellent models for studying evolutionary biology and comparative physiology.

Despite their ecological significance, fish populations face increasing threats from human activities, including habitat destruction, pollution, and overfishing. These factors have led to significant declines in fish biodiversity, with many species now categorized as endangered or vulnerable

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(Helfman, 2013). Habitat modification, such as dam construction and urbanization, disrupts breeding grounds and migratory routes, while overfishing depletes populations faster than they can reproduce. Consequently, understanding fish biodiversity and physiology is critical for developing effective conservation strategies to mitigate these threats. Beyond their ecological roles, fish are an indispensable food source for humans, contributing significantly to global nutrition. According to Pandey and Upadhyay (2022), fish account for 14-16% of the global consumption of animal protein, making them a vital dietary component. Their nutritional profile is exceptional, containing high-quality protein, essential amino acids, and omega-3 and omega-6 fatty acids, which are crucial for cardiovascular health and brain function (Sedyaaw et al., 2024). Fish also provide essential vitamins and minerals, such as calcium, iodine, and vitamins A and D, which are important for metabolic functions and overall health (BAKHSH et al., 2023). Unlike other protein sources such as beef or pork, fish are widely accepted across cultures and religions, adding to their global appeal and consumption. Fishery activities are not only a source of food but also a significant contributor to livelihoods. They support over 100 million people worldwide by providing employment, income, and food security, particularly in developing regions (BAKHSH et al., 2023). Despite their immense value, challenges persist in ensuring the sustainability of fish as a food resource. Overfishing, environmental degradation, and climate change pose serious threats to the long-term availability of fish stocks, raising concerns about future food security and nutritional adequacy.

One of the primary challenges associated with fish as a food source is its high perishability. Post-harvest spoilage rates can range from 20-50% in regions like Nigeria, leading to substantial economic and nutritional losses (Luqman et al., 2024; Rumape et al., 2022). Preservation techniques play a crucial role in mitigating these losses by extending the shelf life of fish. Methods such as immediate icing, drying, freezing, and modified atmosphere packaging are widely used to slow microbial growth and enzymatic reactions, thereby maintaining quality and freshness (Mazhar et al., 2023; Sequino et al., 2023). Recent advancements in preservation technologies, including real-time quality monitoring systems, have further enhanced the effectiveness of these methods, ensuring better management throughout the supply chain (Wei et al., 2024). Despite these advancements, challenges remain in striking a balance between preserving fish and maintaining its natural qualities and nutritional value. Continuous innovation in preservation techniques is essential to address issues such as spoilage, loss of sensory attributes, and nutrient degradation. Emerging technologies, such as the development of a cost-effective portable electric fish grilling kiln, offer promising solutions to enhance the quality and economic viability of fish products. The portable electric fish grilling kiln is designed to optimize the Maillard reaction, a chemical process that occurs at temperatures above 155°C (310°F) and is crucial for flavor and aroma development in grilled fish (Tamanna and Mahmood, 2015). This reaction enhances the sensory appeal of fish by creating a desirable golden-brown crust while preserving its nutritional content. However, excessive heat can lead to the formation of harmful compounds such as acrylamide and advanced glycation end products (AGEs), which are associated with potential health risks (Ames, 2018; Shoukat and Manzoor, 2017). By employing controlled thermal processing, the electric kiln minimizes these risks while ensuring consistent quality and safety.

Fishes are not only vital for maintaining ecological balance but also serve as an indispensable resource for global nutrition and livelihoods. Their diversity, adaptability, and ecological roles highlight their importance in scientific research and conservation efforts. At the same time, addressing challenges related to perishability, overfishing, and environmental degradation is critical for ensuring their sustainable use. Innovations in preservation and processing technologies, such as the portable electric fish grilling kiln, represent significant advancements in enhancing the quality, safety, and economic value of fish products. These developments underline the need for a holistic approach to fish resource management, balancing ecological conservation with human needs and technological progress.

II. MATERIALAND METHOD

A. Materials Used for the Construction of the Electric Grilling Kiln

The materials used for the construction of the electric grilling kiln were chosen based on availability, cost, durability and functional properties. The materials used include:

- Angle Iron: Angle iron provides support for the body and the fish trays.
- Thermostat: Thermostat served as control switch for temperature.
- Mild Steel:Mild steel has good strength. It is used as the base for the drying chamber.
- Galvanized Sheet Metal: Galvanized sheet metal was used because of its toughness and ability to conduct heat. It was used to construct the walls and the hood. Gauge 16 was used for the inner wall while gauge 18 was used for the outer wall.
- Wire Mesh: Wire meshes were used to construct the trays because of its ability to allow air and drippings to pass through.
- 13 mm Bolts and Nuts: 13mm bolts and nuts were used to fasten the four panels (sides) together into a unit.
- Electric Heating Element: Electric heating elements were used to ensure circulation of hot air for uniform distribution of heat in the drying chamber.
- Other materials include: Paint, filler and plugs.

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B. Design Calculations

The design calculations were based on the following specifications and assumptions:

- The kiln operates at dry bulb (db) temperature of 200ºC
- Density and specific heat capacity of catfish are 1059 kgm $^{-3}$ and 2.63 kJkg^{-1}°C
- Batch capacity of the kiln
- Cross flow circulation of air
- Heat requirement
- Tray size of 250mm (length) by 500mm (width) and each tray can contain about 4.8 kg of fresh cat fish
- Trays are arranged vertically, 110mm apart in the drying chamber

➢ *Batch Capacity of the Kiln*

The batch capacity of each fish tray was calculated in relation to the volumeof fish it occupies. Each tray was designed to contain 3.34 kg of fish. Thevolumetric capacity of the kiln was calculated as given by Khurmi and Gupta (2005):

$$V = \frac{M}{\rho} \quad (1)$$

Where V= volumetric capacity of the kiln

M = mass of the material (kg)

ρ = Bulk density of fish (kg/m^3) = 1080 kg/m^3

➢ *Air Requirements Determination*

Drying Air area within the smoking/drying chamber, A_a, was estimated according to (Crapiste and Rotstein, 1997). for cross flow configuration:

$$A_a = nb'w \quad (2)$$

Where n = the no of trays

b'is difference between the vertical wire mesh and the wire mesh depth.

The drying rate was calculated as given by KhaniMoghani*et al.*,(2013). in Equation 3.

$$Ne == \frac{-Ss}{A}\left(\frac{dx}{dt}\right) \quad (3)$$

Where N is drying rate (kg/m^2.s) Ss = dried solid mass(kg), X = % MC $\left(\frac{m-mdried}{minitial}\right)$, t = time

➢ *Heat Requirements Determination*

The quantity of heat required to effect drying can be determined using the Equation (4) as reported by Ehiem*et al*., 2009.

$$Q_r = (V x\ C_f x \Delta T) + (H_L \text{ x } MR) \quad (4)$$

Where $Q_r$is the heat required to effect drying in kJ,

V = the kiln batch capacity

C_f = the specific heat capacity of catfish (2.63 kJ kg^{-o}C),

ΔT=200ºC,

The insulation thickness of 5 cm for rock wool with packing density of 80 kg m^{-3} was used. This was selected based on the recommendation of the (TIASA, 2001) as economic thickness of the lagging material for the equipment.

C. The Description of the Fish Grilling kilns

The fabricated electrically powered fish grilling kiln (Plate 1) is a double walled structure having a dimension of 580 x 580 x 900mm (L x W x H) completely insulated all round with polyurethane of 254 mm thickness to conserve heat within the drying chamber as well as prevent the operator from being exposed to intense heat.The internal wall of the kiln was made of Galvanized steel (GS) to avoid corrosion while the exterior was made of mild steel (MS). The kiln consists of the drying chamber having six sets of tray on racks. The trays were made of expanded metal of 250 x 500 mm mesh size (GS) welded to a square pipe of 254 mm thickness. The holding capacity of the kiln is 4.8 kg of fresh catfish. The kilns was mounted on a set of four wheels for ease of movement. The fish kiln also have a temperature gauge to regulate the drying temperature as well as a fan to circulate the heated air and ensure even drying of the fish during operation. The drying chamber consists of four (4) heating elements with 1.5 Watt power rating each.

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Plate 1: The Fabricated Electric Fish Grilling Kiln

D. Grilling Operation

The fishes were cleaned, eviscerated cut to smaller sizes and weighed in preparation for the grilling operation. The fabricated electrically powered fish grilling machine was first ran empty for 10 minutes using a three phase power supply with the kiln temperature set at 100ºC.The prepared fishes were loaded on the wire mesh trays in the grilling chamber of the electric kiln. The machine temperature was set to a temperature 200°C.As the grilling progresses, oil droplets (fish oil and water) oozed out of the fish. The weight loss of the fishes after each hour were noted and recorded. The rate of moisture removal (drying rate) was calculated from the data recorded during drying. The drying rate was calculated as given in equation 3.

Ne $== \frac{-Ss}{A}\left(\frac{dx}{dt}\right)$

III. RESULTS

Table 1: Weight Loss And Drying Rate Of Mackerel And Catfish

Drying time (hr)	Weight loss (kg)		Drying rate(kg/hr)		Average Drying rate (kg/hr)	
	Mackerel	Catfish	Mackerel	Catfish	Mackerel	Catfish
0	1.10	3.20	-	-	0.07 ± 0.04^b	0.12 ± 0.08^a
1	0.90	2.75	0.20	0.45		
2	0.72	2.60	0.18	0.25		
3	0.60	2.45	0.12	0.05		
4	0.55	2.35	0.05	0.10		
5	0.55	2.25	0.00	0.10		

^{ab}: means with different superscripts are significantly different at $p<0.05$

Table 2: Weight loss of Mackerel and Catfish in kilogram and percentage

Drying time (hr)	Weight loss (Kg)		Weight loss (%)	
	Mackerel	Catfish	Mackerel	Catfish
0	**1.10**	**3.20**	**0**	**0**
1	**0.90**	**2.75**	**18.1**	**14.06**
2	**0.72**	**2.60**	**20.00**	**5.45**
3	**0.60**	**2.45**	**16.67**	**5.77**
4	**0.55**	**2.35**	**8.33**	**4.08**
5	**0.55**	**2.25**	**0**	**4.26**
Average % weight loss	**50**		**30**	

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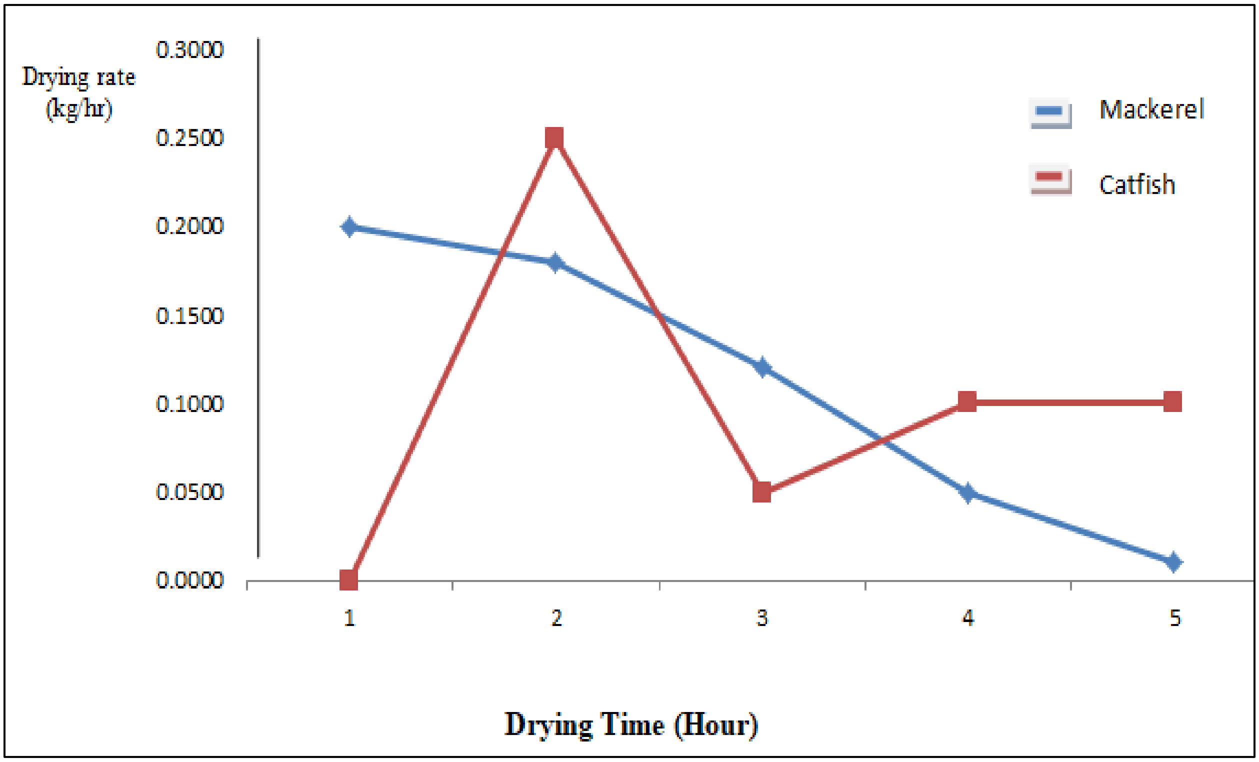

Fig 1: Drying Rate Curve of Mackerel and Catfish

IV. DISCUSSION

Tests were conducted to evaluate the performance of the fabricated electrically powered fish grilling kiln.

Table 1 shows that there exist a significant difference in the rate of drying of fish samples (i.e. Mackerel and Catfish) using electrically powered fish grilling kiln at drying temperature of 200°C. It was also observed that Mackerel fish had lower average drying rate (0.7kg/hr) than the catfish (0.12kg/hr). From Table 2 it can be deduced that the average percentage weight loss of the fishes were approximately 50 and 30% for Mackerel and Catfish respectively. The results of this study revealed that rate of drying of the fishes were significantly affected using electrically powered fish grilling kiln at the drying temperature of 200°C.

However, Table 2 shows that the weight losses recorded for Mackerel and Catfish were 18.1 and 14.06% respectively within the first hour of drying which is lower than what was achieved by (Ikenweiwe*et al.*, 2010) who reported an approximate percentage weight loss of 31- 47% within the period of 35 – 75minutes. This variation could be as a result of the heat source (Bolaji *et al.*, 2005) also reported that evaporation process is faster with the high temperature heat source thereby increasing the rate of drying.

Figure 1 shows that the drying of fish samples by the electrically powered grilling kiln at the drying temperature of 200°C. The drying rate was increasing at constant rate in the first hour of drying with catfish having higher drying rate of 0.45kgh^{-1} before dropping significantly to 0.25kgh^{-1} in the next hour after which the drying rate between 2 to 5 hours gradually reduced to 0.10kgh^{-1}.Mackerel also had similar trend of drying rate as catfish with lower drying rate that increases in the first hour to 0.20kgh^{-1} before dropping significantly to 0.18kgh^{-1} in the next hour and then gradually to 0.05kgh^{-1} between 2 to 5 hours of drying.

Furthermore, the average drying rate of Mackerel observed in this study was significantly lower than that of Catfish. This agrees with the finding of (Ikenweiwe*et al*., 2010). who found that *Clariasgariepinus* loss water rapidly than other type of fishes.

V. CONCLUSION

The following are the conclusion made

- The average drying rate of mackerel fish (0.07±0.04 kgh^{-1}) was lower than that of catfish (0.12±0.08)
- The electric grilling kiln was excellent in performance with the basic functions of grilling and drying fishes as evidenced by short processing time of the grilled fish samples.

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