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Development of an Extruder for the Expression of Oil from Trunk Fish *mormyrus rume*

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ABSTRACT
Oil extracted from *Mormyrus rume* is highly valued for its nutritional benefits, highlighting the need for a simple and efficient processing device for fish oil extraction. This study focused on developing a contamination-free fish oil extruder. The machine was designed based on the principle of pressure differentials, where the pressure applied to the incoming fish pulp is compared to that exerted on the discharged material. Preheated fish are poured through the machine hopper and were compressed through a tapered screw conveyor with a shaft that narrows towards the discharge end and both the pressliqour and the cake are collected via the discharge outlets The maximum fish oil yield of 28.5 % was obtained from *Mormyrus rume* at a screw diameter of 42.5 mm and a pressing time of 15 minutes. The machine's throughput capacity was recorded at 0.75 kg/h, while the oil expression rate was 0.2 kg/h at a fish-to-water ratio of 2:0.5. The highest oil expression efficiency of 80.0% was achieved at a heating time of 10 minutes, a screw diameter of 42.5 mm with a constant screw rotation speed of 55 rpm. The machine is expected to be applicable for extracting oil from other fish species and oil-bearing materials with similar physical properties. This innovation presents a reliable and efficient method for the mechanical expression of high-quality fish oil.
Keywords: Trunk fish, throughput capacity, extruder, screw shaft

1 INTRODUCTION

The rapid advancement of science and technology, coupled with economic challenges, has increased the demand for cost-effective and efficient machine development. Engineers and technologists strive to replace traditional, labour-intensive methods with innovative solutions that enhance productivity and efficiency. Additionally, the global market's competitive nature necessitates continuous improvements in product design to meet growing demands (Ayuba *et al.*, 2018).

Fish oil is distinguished by its high content of omega-3 and omega-6 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are essential for human health. It is widely utilized not only in food but also in industries such as pharmaceuticals, cosmetics, and soap production (Hee *et al.*, 2008). The consumption of omega-3 and omega-6 fatty acids has been linked to improved cardiovascular health and plays a crucial role in brain and nervous system development, particularly during pregnancy and infancy (Ruxton *et al.*, 2004).

The physiochemical properties of fish oil, as reported by Bako *et al.* (2017), include specific gravity, refractive index, saponification value, iodine value, peroxide value, and acid value. Traditional fish oil extraction methods, such as boiling fish viscera, are often inefficient and result in the degradation of nutritional quality. Alternative extraction methods include solvent extraction, batch extraction, and continuous expression using extruders. To achieve high-quality oil extraction, selecting optimal processing conditions is essential. This study aims to develop a specialized machine for extracting fish oil from Trunk fish (*Mormyrus rume*).

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2 MATERIALS AND METHODS

2.1 Material Collection and Preparation

Fresh *Mormyrus rume* fish samples were sourced from the Kainji Lake Basin in New Bussa, Niger State, Nigeria. The fish were thoroughly washed and manually degutted to remove dirt and unwanted materials. After defrosting, the fish were cut into strips to facilitate faster preheating before oil extraction, as illustrated in figures 1 and 2 (Ayuba *et al.*, 2018).

Figure 1: Fresh Trunk fish (*Mormyrus rume*)

Figure 2: Cut fish ready for pre-heating

2.2 Determination of Optimal Process Parameters for Fish Oil Expression

Fish oil extraction was carried out using a modified fish oil extruder, which consists of three primary units: the feeding unit, the compression and melting unit. The entire extruder was fabricated using locally available materials. The extruder had a processing capacity of up to 17 kg/h and was powered by a 5.0 hp single-phase electric motor connected to a reducing gear. To prevent contamination and withstand frictional wear, all components that came into contact with the feed material (fish) were constructed from stainless steel.

The experimental procedure involved running the machine for approximately five minutes without load before introducing the preheated fish samples, following the method described by Akinoso (2006). As the screw pitch decreases along the screw shaft, it generates the necessary compressive force to expel the trapped oil from the preheated fish. The cooked fish mass was fed into the extruder hopper, where it was pressed to separate fat-free dry solids from the liquid fraction (oil and water). The extracted solids were processed into fish meal, a common ingredient in animal feed.

After five minutes of operation, the liquid fraction (press liquor) was subjected to further separation using a separating funnel. Initially, the press liquor was filtered through a muslin sack and washed with a measured quantity of hot water before being transferred to the separating funnel for oil and water separation.

The final stage of oil processing, known as polishing, was performed using a centrifuge to remove impurities before storage. Both the extracted oil and the residual fish cake were collected and weighed separately. From these values, key performance indicators such as oil yield, expression efficiency, and machine throughput were calculated (Arlabosse *et al.*, 2011; Oke *et al.*, 2015). The schematic diagram of the extruder is presented in Figure 3.

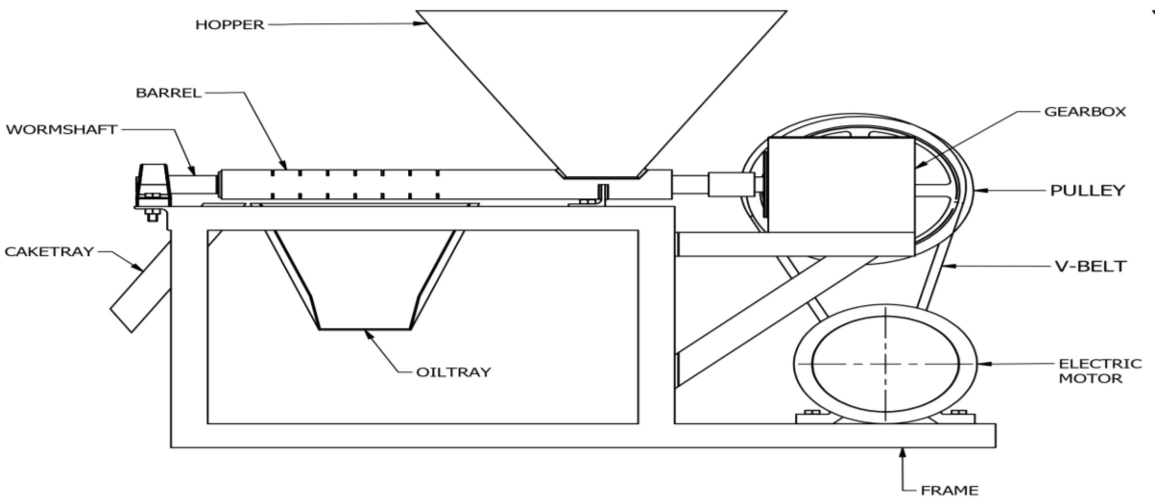

Figure 3: Schematic diagram of the fish oil extruder

2.3 Machine Operational Principle:

The raw material used in this study is the *Mormyrus rume* fish species, sourced from freshwater, where it is widely available. The machine operates based on the principle of pressure differential, comparing the pressure applied to the incoming fresh fish with that exerted on the discharged material. One of the key factors affecting the performance of a screw press is the compression ratio, which is defined as the ratio of the volume of material displaced per revolution of the shaft at the feed section to the volume displaced at the discharge section.

2.3.1 Design Analysis and Calculations

The development of the experimental machine was based on existing data and insights from the expression process using a modified extruding machine. The machine was designed to:

I. Efficiently extract fish oil by pressing the fish mass through a tapered screw shaft at the discharge end.
II. Minimize any chemical degradation or contamination of the extracted fish oil.

The experimental machine was designed to be simple, easy to fabricate, and user-friendly, requiring no specialized technical expertise for operation.

2.3.2 Forces Acting on the Screw Thread

The primary forces acting on the screw thread include:

- Compression force, which facilitates the movement and pressing of the fish.
- Frictional force, which arises due to the motion of the screw.

As the screw shaft compresses the fish, pressure builds up along its length, starting from a minimum value at the feed end and reaching a maximum at the discharge end. Figure 4 illustrates the elemental load (L) acting over a unit length of the thread. This load (L) is applied perpendicular to the threaded surface along the helix of the screw. The axial and radial forces are subsequently resolved to analyse the system's mechanical efficiency.

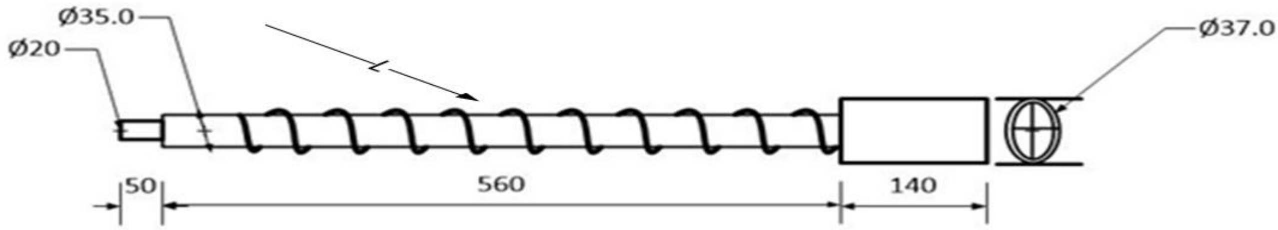

Figure 4: Schematic diagram of tangential force acting on the conveyor flight screw.

2.3.3 Machine Component Design

Careful consideration was given to the selection of materials for the machine's components to ensure compliance with engineering standards. The key components of the fish oil extruding machine are outlined in Table 1, while the detailed design calculations are provided in the appendix section.

Table 1: Part consideration and material used for shaft production

S/N	Component	Material	Specification (mm)
1	Screw shaft	Stainless steel	42.5 x 750
2	Iron rod	Stainless steel	12.5
3	Electrode	Stainless steel	E306
4	Cylindrical barrel	Stainless steel	45
5	Bearing	Cast and steel iron	45
6	Electric motor	Composite	5 hp
7	Arc welding machine	Iron and cast	BOSH 230/300AC

2.4 Description of the Fish Oil Machine (Extruder)

The machine consists of the feeding chamber (hopper), expelling unit, discharge units, frame electric motor and gear reduction motor. The hopper is pyramidal in shape and made of 1mm gauge stainless steel sheet. The expelling unit consists of a screw shaft which is made of stainless steel with a perforated barrel also made of stainless-steel iron outer casing. The screw is divided into three sections; the feeding, milling and discharge sections as it tapers. The friction and pressure produced by the screw on the barrel causes the mass to heat up, thus facilitating oil expression as the screw grinds and presses the fine mass against the expelling chamber.

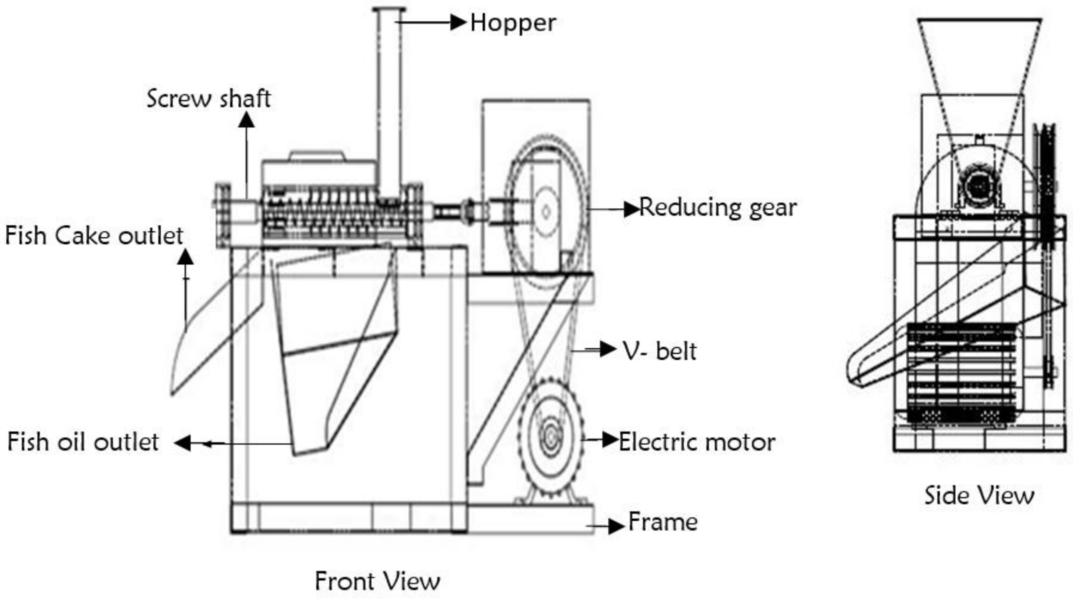

Figure 5: Design of the extruding machine showing basic components

The oil flows through the perforation in the casing and is collected beneath the expeller chamber while the residue (cake) is extruded from the unit through the cake discharge outlet.

The frame was constructed from 50 x 50 mm angle iron. The dimension of the machine were 1200mm high, 250mm wide and 850mm long. 1.0 kW gear reduction motor rotating at 80 rpm was used to supply the required power to rotate the screw shaft. A pulley of 35 mm diameter was used to reduce the speed further to 55 rpm. All the components of the machine are firmly fastened together with bolts and nuts to allow easy dismantling for transportation. The prime mover is a (5hp) electric motor of 1450rpm speed connected to a reducing gear with V-belt and pulley arrangement. Other parts of the machine are shown on the orthographic view of the machine are shown on Figure 5.

2.5 Performance Evaluation of the Machine

The machine was operated by preheating 5.5 kg of fish for 15 minutes before feeding it into the hopper. Inside the pressing barrel, the screw shaft transported and compressed the fish mash to expressed oil. The expressed oil and press liquor were separately collected and weighed. Based on the obtained values, oil yield, expression efficiency, and machine throughput were calculated. Mathematically, oil yield (OY), expression efficiency (Ee), and throughput capacity (Tc) were determined following the methods described by Oyeleke and Olaniyan (2007), Arlabosse *et al.* (2011), and Oke *et al.* (2015). Figure 6 shows the operational flow chart of fish oil expression process.

$$Oil\ yield = \frac{weight\ of\ oil}{weight\ of\ expressed\ fish} \times 100\ \% \tag{1}$$

$$\%\ Expression\ Efficiency = \frac{oil\ yield}{total\ oil\ content} \times 100\ \% \tag{2}$$

$$Throughput\ capacity = \frac{weight\ of\ expressed\ fish}{processing\ time} \tag{3}$$

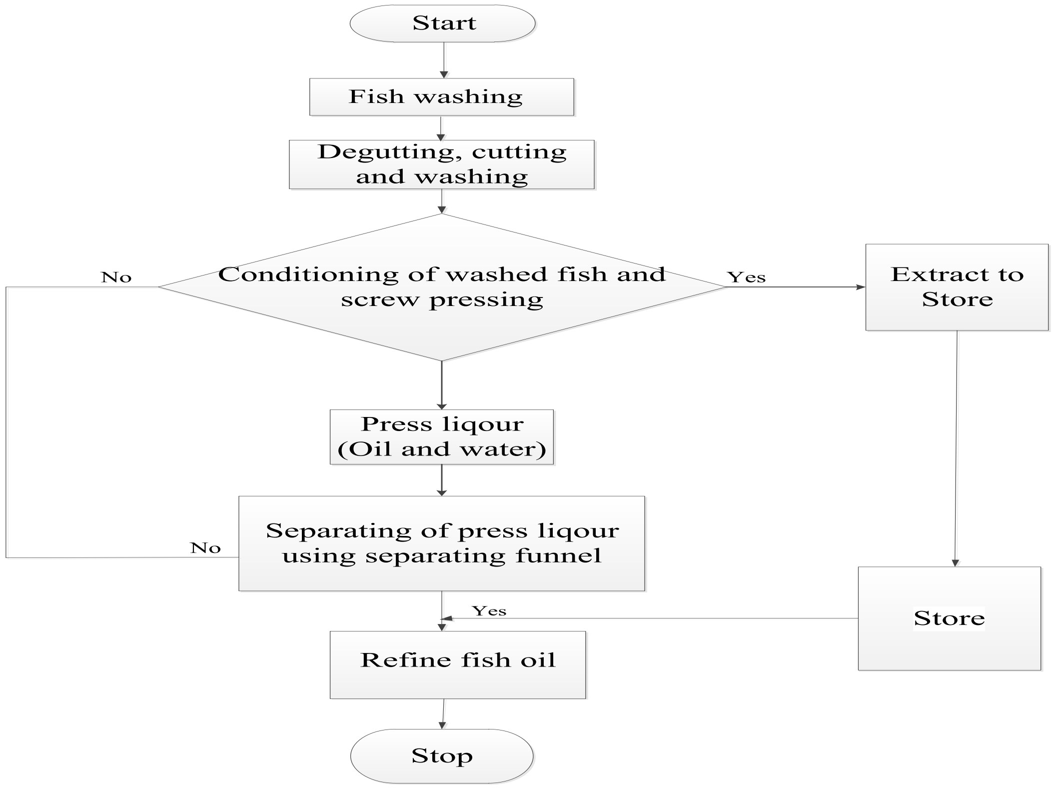

Figure 6: Flow chart of the operations in fish oil expression

The summary of data from the preliminary trials evaluating the impact of screw diameter, screw speed, pitch height, and pressing time on oil yield is presented in Table 2, with the findings discussed below.

3 RESULTS AND DISCUSSIONS

3.1 Effect of Screw Diameter on Oil Yield at Different Pressing Times

Figure 4 illustrates the relationship between screw diameter and oil yield at various pressing times. As the screw diameter increases, the oil yield also rises exponentially at each pressing time. A similar outcome has been reported by various researchers studying oil expression (Olufemi *et al.*, 2015). The correlation between oil yield and screw diameter at a pressing time of 20 minutes was determined through regression analysis, as presented in Equation 4.

$$Q_y = 24.357 - 1.537E - 15A + 3.0D - 1.05 \quad (R^2 = 0.9818) \tag{4}$$

where Q_y = oil yield, A = screw diameter (mm) and D = pressing time (min).

The maximum screw diameter and the oil yield were obtained as 42.5 mm and 27.8 % respectively. The maximum screw diameter is significant in determining the power required for an appropriate fish oil expressing machine. (Kerfai *et al.*, 2017). Figure 6 illustrates the relationship between screw diameter and the pressing time expressed from Trunk fish. Based on the graph, a power-transformed regression equation was derived, as shown in Equation 5.

$$P = 25.75b + 7.58^{0.012} \quad (R^2 = 0.9716) \tag{5}$$

where, b = barrel pressure (N/m^2) and P = pressing time (min)

Olufemi *et al.* (2015) developed a similar expression to relate applied pressure to plant leaf juice pressing time, represented as PT = 48.567 + 4.030.037. The predicted pressing time in their study was lower than the observed value for pressed fish pulp in this research, highlighting that the correlation is material-specific. This difference may be due to variations in the type of oil-bearing material and the textural resistance of Trunk fish compared to shea nut seeds (Kerfai *et al.*, 2017).

Extending the pressing time to 20 minutes increased the oil yield of Trunk fish from 25% to 28.8%, suggesting that beyond this screw diameter, further pressing time does not significantly enhance oil expression (Kerfai *et al.*, 2017). This indicates that most of the oil has already been expressed. To further improve oil yield, additional techniques such as pulsed electric field-assisted pressing or thermal-assisted mechanical dewatering could be explored.

3.2 Validation of the Developed Model

Due to optimizing the selected parameter for maximizing the oil yield, the numerical solution was attempted through software. From the response surface methodology model, the optimized parameter were presented in table 2 below.

Table 2: Numerical solution to achieve maximum fish oil yield (Ayuba *et al.*, 2024)

Variables	Optimum Conditions
Screw diameter	42.5 mm
Screw Speed	85 rpm
Pitch height	20 mm
Pressing time	15 min

3.3 Effect of Screw Diameter on Oil Yield at Different Pressing Time

The oil yield at the different screw diameter with respect to pressing time is presented in figure 7. At each screw diameter there is progressive increase in the oil yield, this is as a result of pressure differential that is been exerted by the screw shaft. (Ayuba *et al.*, 2024). The oil yield gradually reduces with time as the pressing time increase above 20 min this is explained by the fact that the fish is initially compressed rapidly; as pressing continues and the cake becomes more compacted and its thickness increases, the permeability of the material decreases, leading to higher internal resistance to oil flow. Consequently, the rate of oil release declines, and the additional yield obtained with prolonged pressing becomes minimal. The oil flows out almost immediately about 81% of the oil is recovered after 15 min. of pressing.

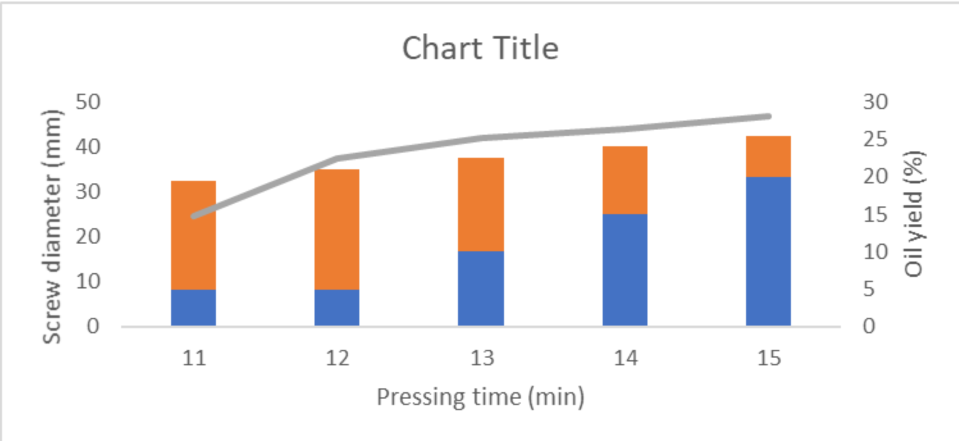

Figure 7: Effect of screw diameter on oil yield at different pressing times

3.4 Effect of Pressing Time on the Expression Efficiency of the Extruder

The experimental images depict the fresh fish used in the study, the expressed fish oil, and the press liquor during the separation process, as shown in figures 8, 9, 10, and 11, respectively. Figure 7 illustrates the effect of pressing time on oil yield at different screw diameters. The results indicate that as the screw diameter increases, efficiency also improves. Ayuba *et al.*, 2024). At a screw diameter of 42.5 mm, the highest efficiency recorded was 81.7%, while the lowest efficiency of 71.6% was observed at a screw diameter of 37.5 mm. Overall, the machine demonstrated high performance across all pressing times, primarily due to the increased screw diameter and extended pressing duration (Ayuba *et al.*, 2024).

Achieving optimal conditions at the discharge point has been a significant challenge in screw press operations (Singh & Bargale, 2000). However, this study confirms that regular pressing of fish enhances oil expression in the experimental machine. Similar trends of 26.4% and 26.9% oil yield were reported by Bako *et al.* (2017) in the extraction of oil from mackerel (*Scomber scombrus*) using an extruder. Likewise, Bello *et al.*, (2018) observed a comparable pattern when expressing oil from nurse tetra (*Brycinus nurse*) using a hydraulic press (Model: CAM Radstock-Avon 076134226). The maximum machine throughput capacity was recorded at 10.6 kg/h, with a pressing time of 15 minutes and a fish load of 3.5 kg (Table 3), resulting in a fish expression rate of 17 kg/h.

Figure 8: Fish for experimental trials

Figure 9: Press liquor during separation process

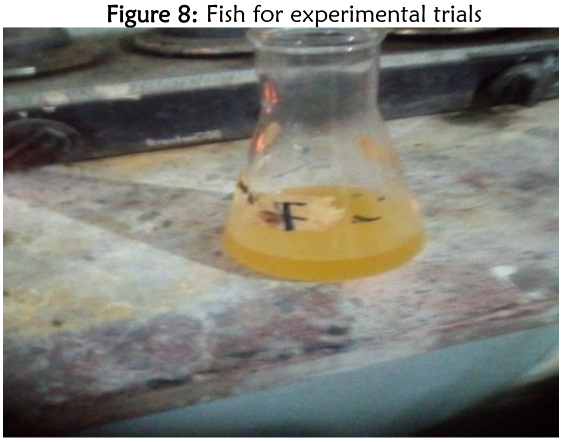

Figure 10: Expressed fish oil

Figure 11: Fish extract/cake

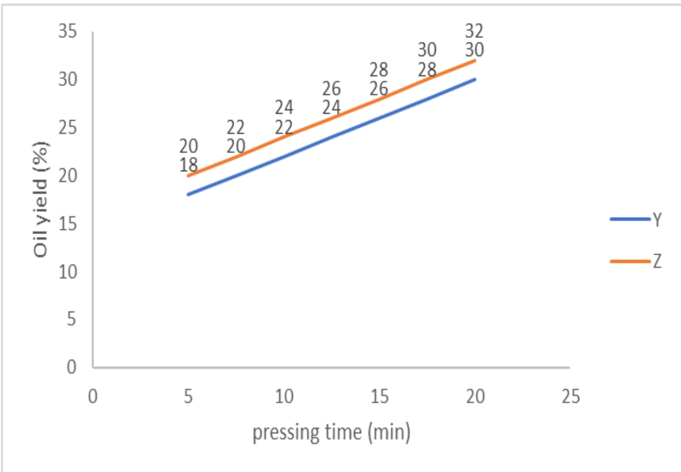

Figure 12: Effect of pressing time on oil expression efficiency and oil yield

3.5 Effect of Heating Time on Machine Performance

The machine was evaluated based on oil yield, expression efficiency and throughput capacity, the highest oil yield was obtained when 7.0 kg of fresh fish was expressed at 100 min heating time, 10 minutes of pressing time with oil yield of 28.5 %, 75.0 % expression efficiency and 0.7 kg/h throughput capacity. Which show a slightly different from the finding of Bako *et al.*, 2018 and Olufemi 2015 whose oil yield was 26.4 % and 26.9 %, while the lowest oil yield of 24.1 % was obtained at 12.0 kg of fresh fish with expression efficiency of 69.7 % and 0.75 kg/h throughput capacity, this also show that the machine has comparative advantage over that of Aregbesola *et al.* (2009) with similar result in the expression of date palm fruit juice at 22.5 %. This may be due to the nature of raw materials used during oil expression that increased the quantity of oil from the machine, also identified a similar occurrence in their study of production of herbal tea from *Hibiscus sabdariffa* calyxes. Table 3 present the results obtained during evaluation of the machine.

Table 3: Effect of heating time on the machine throughput capacity

S/N	Quantity of fresh fish (kg)	Heating time (min)	Pressing time (min)	Oil yield (%)	Expression efficiency (%)	Throughput of machine (kg/h)
1	5.5	90	10	27.2	80.0	1.1
2	7.0	100	15	28.5	75.0	0.7
3	10	100	15	25.0	65.7	0.6
4	12.0	110	20	24.1	69.7	0.75

4 CONCLUSIONS

A performance test was conducted on the extruder, confirming its efficiency in extracting oil from Trunk fish (*Mormyrus rume*). It achieved an average extraction efficiency of 80.0%. Overall, the machine's performance parameters improved with an increase in screw diameter and pressing time, with a maximum oil yield of 27.8% recorded at a screw diameter of 42.5 mm and a pressing time of 20 minutes. The extruder attained a maximum throughput capacity of 1.1 kg/h at a 5-minute pressing time and a heating temperature of 80°C. The highest oil expression efficiency was 69.7%, yielding 279 g of oil from 15 kg of fresh fish.

This extruder is suitable for both small- and large-scale oil expression in rural and urban communities. It has the potential to create employment for at least two individuals while simultaneously producing fish oil and fish cake for agricultural, domestic, and medicinal applications.

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