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Modelling and Optimisation of Oil Expression from Trunk Fish (*Mormyrus rume*)

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Abstract

Trunk fish (Mormyrus rume), is found in tropical and subtropical freshwaters bodies, particularly in west African region. They are cultured mainly for food and commercial purposes. Fish oil expression is the process of mechanically pressing oil from solid materials. The aim of this study was modelling of contentious oil expressed from trunk fish. With the objectives as to predict the oil yield from the optimum parameter; develop and validate the mathematical model for continuous mechanical oil expression. The current investigation used Response Surface Methodology (RSM) to optimise oil expression from Trunk fish. Shaft diameter was varied from 32.5 to 42.5mm, Shaft Speed from 25 to 85 rpm, pitch height from 10 to 30 mm and applied pressure from 10 to 25 N/m^2 to study their effects on fish oil yield with the aid of a two-level, four-factor central composite design (CCD). The second-order model developed accurately predicts the optimum oil yield. Highest oil yield was obtained from the empirical model as 27.8% at a screw diameter of 42.5mm, screw speed of 55rpm, pitch height of 20mm and applied pressure of 20 N/m^2. It was observed that the optimum oil yield of 27.8% is higher than the maximum oil yield of 27.1% with a 0.7% error, validating the model equation using optimal parameters: shaft diameter (42.5 mm) and applied pressure (20 N/m^2). This study concludes that optimising the extruder shaft enhances oil yield and efficiency. It is recommended that the developed model be applied in the manufacturing of shafts to maximise fish oil expression oil yield.

Nomenclature and units

mm	millimeter
$N/m2$	Newton per meter square
rpm	Revolution per minute
%	Percentage
Km	Kilometer

1.0 Introduction

The trunk fish (*Mormyrus rume*), a member of the family Mormyridae, is a notable species of electric fish commonly found in West African freshwater ecosystems (Kirschbaum *et al*, 2020). It is locally known as Miligi in Hausa, Dwangwa in Yoruba, and Ugbala in Igbo, reflecting its wide recognition and cultural importance among various ethnic groups in West Africa. This species is distinguished by its elongated, trunk-like snout, a small terminal mouth adapted for bottom feeding, and a slender, laterally compressed body. Adults can reach lengths of up to 1 meter, making it one of the larger representatives of its family (Abdulkarim *et al*., 2024). It is commonly harvested for local consumption and trade, contributing to food security and income generation for rural fishing communities. Despite its importance, there is limited research on the fish oil expression yield.

Fish oil expression is the process of mechanically pressing oil from solid materials. Traditional batch presses are obsolete, inefficient, and labour-intensive, with low oil yield as a major limitation. Mechanical oil extraction is crucial for adding value to food products such as fish oil, particularly in developing countries like Nigeria. Mechanical extraction is one of the oldest methods for oil recovery from solid matrices containing oil. Expression, which mechanically presses liquid out of a solid-liquid mixture (Brennan, 2009), is widely used in oil extraction from fish using solid-liquid separators. Oil recovery from fish, seeds, or other materials is influenced by various factors categorised into three groups: screw parameters (including the combined effects of screw speed and screw diameter), oleaginous material parameters (such as restriction size), and process parameters (including machine speed, moisture content, cooking time, temperature, and pressure) (Lonescu *et al*., 2014). To the best of the authors' knowledge, optimization of oil yield from *Mormyrus rume* using extruder, precisely the effects of four independent variables on oil yield, namely screw diameter, screw speed, pitch height and applied pressure, has not been reported in the literature. This study primarily focuses on modelling and optimisation of screw press process parameters, predict the oil yield and validate the developed mathematical model for continuous mechanical oil expression. This study investigates this gap by numerically altering those independent variables and assessing the effect on oil yield using Response Surface Methodology (RSM).

2.0 Materials and Methods 2.1 Sample preparation

Fresh fish sample Trunk fish was obtained from kainji lake basin New Bussa, Niger State, Nigeria. The experiment was carried out at the National Institute for Freshwater Fisheries Research (NIFFR) in New Bussa. located between latitudes 9°51’ and 10°55’N and longitudes 4°35’ and 4°51’E. The institute is situated at an elevation of 110 meters above sea level, spanning 24 km in width and 136 km in length. It lies within Borgu Local Government Area, which covers an area of 11,579.786 km² and had a population of 172,835 as recorded in the 2006 census. The equipment used was extruder, sieves, oven, electric heater, digital weight balance and titration setup. The fish samples were thoroughly gutted and washed manually to remove the unwanted materials from the fish's body after being caught from the river (Kainji Lake basin). The internal organs of the fish were removed using a stainless-steel knife. The remaining part of the fish is cut into strips to enhance a speedy preheating process before oil expression (Ayuba *et al*., 2018).

2.2 Oil Expression Procedure

The oil was expressed using a modified fish oil extruder, which is made up of three main units, namely the feeding unit, the compression and melting unit, all fabricated using locally available materials. The capacity of the extruder ranged from 17–20kg/h and was powered by a 3.0 hp, single–phase electric motor with an inbuilt reducing gear. All components through which the feed material (fish) will pass were made of stainless steel to prevent contamination and to withstand frictional wear. The experimental procedure was running the machine for about 5minute on no load before loading the pre-heated sample as described by (Akinoso, 2006). As the shaft speed decreases along the shaft diameter and pitch height, it provides the compressing force needed to squeeze out the entrapped oil from the pre-heated fish. The oil expressed and the cake from the sample were collected separately. At the end of the experiment, the expressed oil and the extract (cake) were collected and weighed separately. From the value obtained, the oil yield is calculated as follows %

Oil Yield $= \frac{Weigh\ of\ Oil}{Weight\ of\ expressed\ fish} x\ 100$ ....(1)

2.3 Experimental Design for Oil Expression

Minitab 20 software was employed to design the experimental trials, and the resulting data were statistically analysed to determine the effects of each independent variable namely, (i) shaft diameter, (ii) shaft speed, (iii) pitch height, and (iv) applied pressure along with their interactions on fish oil expression yield. The optimisation approach follows the response surface methodology, which involves iterative design adjustments. Two level 4-factors (2^4) experiment in Central Composite Design (CCD) was implemented using the Design Expert Software Package (Stat-Ease, Inc., Version 13.0, Minneapolis, USA). According to Dean and Voss (2009) the criteria was used to select the parameters that influence and maximize the oil yield in the continuous expression press with an extruder. The design points were determined by the expression $N= + +2\ 2^n\ n\ k$. Dean and Voss (2009). Statistical optimisation was carried out using a 2^4-run full factorial Central Composite Design (CCD) for these four variables, enabling the mathematical model's estimation of coefficients. The actual and predicted oil yields were used to assess the model's suitability. The variables and their levels were established based on literature and preliminary experiments (Olaoye *et al.*, 2018). The relationship between the operating parameters (independent variables) and the dependent response (oil yield) was determined using a quadratic, second-order polynomial model, as shown in Equation (2).

$$Y = \beta_0 + \sum_{i=1}^{2}\beta_i x_{i1} + \sum 2i\, \beta_{ii}\, x_{i2} + \sum_{i=1}^{n-1}\sum_{j=2}^{2}\beta_{ij}\, x_i\, x_j \ .... (2)$$

Where Y is the response, x_i and x_j are the un-coded independent variables b_0, b_i, b_{ii} and b_{ij} are intercepts, linear, quadratic and interaction coefficients, respectively.

3.0 Result and Discussions 4.4 Response Surface Methodology Diagnostic Plots

4.5 Analysis of variance (ANOVA) and significant factors of oil yield

The results from the regression analysis of the developed process model and response are presented in Table 4.

Table 4: ANOVA for Reduced Quadratic Model Response for Oil Yield:

Source	Sum of square	Df	Mean square	F-value	P-value	
Model	35.51	14	2.54	9.94	<0.0001	signifi
A	12.76	1	12.76	49.99	<0.0001	
B	0.0504	1	0.0504	0.197	0.6640	
C	0.4537	1	0.4537	1.78	0.2053	
D	18.20	1	18.20	71.30	<0.0001	
AB	0.6006	1	0.6006	2.35	0.1490	
AC	0.0756	1	0.0756	0.296	0.5954	
AD	0.1406	1	0.1406	0.550	0.4711	
BC	0.7656	1	0.7656	3.00	0.1069	
BD	0.1406	1	0.1406	0.550	0.4711	
CD	0.0056	1	0.0056	0.022	0.8843	
A^2	1.07	1	1.07	4.20	0.0611	
B^2	0.0044	1	0.0044	0.017	0.8975	
C^2	0.0319	1	0.0319	0.125	0.7294	
D^2	0.6419	1	0.6419	2.51	0.1368	
Residual	3.32	13	0.2553			
Lack of Fit	3.27	10	0.3271	20.66	0.0149	signifi
Pure Error	0.0475	3	0.0158			
Cor Total	38.82	27				

R Squared = 0.9185, Adjusted R Squared = 0.8225, 5% Level of Significance, RMSE = 0.442
A=shaft diameter, B=shaft speed, C=pitch height, D=applied pressure

The model was significant, as evidenced by the low Pvalue (0.0001) in the CCD ANOVA, as shown in Table 4. At the 95 per cent confidence level, a factor with a P-value of less than 0.05 is considered a significant factor that affects oil yield. Lack of fit has a P-value of 0.0149, which is higher than the significance level (0.05), indicating that the lack of fit is not significant. It indicates that the model equation did not suffer from a lack of fit. The whole quadratic model for the five independent parameters considerably impacts oil yield and can accurately predict it.

The fitness of the regression model was checked with the coefficient of determination, having an R^2 value of 0.9185. The p-value of 0.0149 **is** less than 0.05**, so** lack of fit is statistically significant at the 5% level. In other words, the deviations between the model predictions and the observed values cannot be explained by pure experimental error alone

The maximum oil yield of 27.1% (at corresponding shaft diameter, shaft speed, applied pressure and pitch height of 42.5mm, 55rpm, 40N/m^2 and 20mm respectively) and minimum oil yield of 23,2% (at corresponding shaft diameter, shaft speed, pitch height and applied pressure of 35.0mm, 70rpm, 25mm and 15N/mm^2, respectively) were obtained. The result showed that the three independent variables were relevant to the fish oil yield in the mechanical expression process, as different levels of process parameters gave different oil yields of fish. Figure 3 6 present 3-D response surface plots for the effect of input variables on oil yield of *Mormyrus rume*

4.5 Contour plot for yield against four independent variables

Simultaneous effect of four independent variables on the response oil yield is examined here. Effects of shaft diameter and shaft speed, shaft diameter and pitch height, shaft diameter and applied pressure as well as pitch height and applied pressure on the oil yield were only considered, because the P-values for the interactions of shaft diameter and applied pressure (0.0001) and shaft speed and pitch height (0.1069) were both higher than the level of significance (0.005), indicating that they had a significant effect on oil yield.

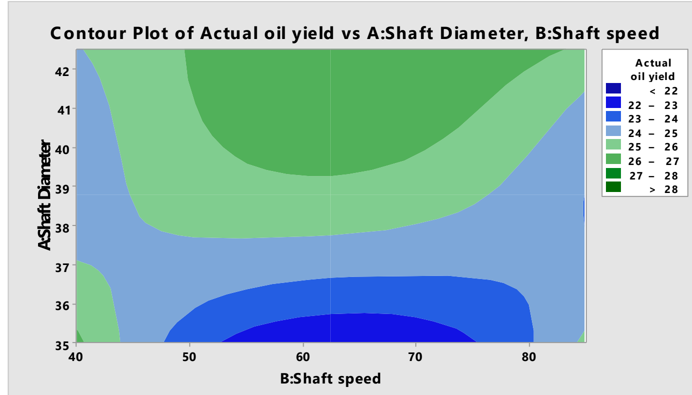

Figure 3: Contour plot of yield versus shaft diameter and shaft speed

4.6 Contour plot for yield versus shaft diameter and shaft speed

Figure 3 presents how shaft diameter and speed simultaneously affected the expressed fish oil yield. The oil yield is positively affected by both independent factors. An increase in shaft diameter from 35 to 42.5 mm enhanced the oil output from 24 to 27 % when the shaft speed was reduced to 60 rpm. The oil yield also increases, increasing the oil's and less fish extract. As the shaft speed increases to 70 rpm, the oil yield reduces from 27% to 25 %. This reduction in oil yield was a result of higher speed with limited pressure from the shaft for more oil yield.

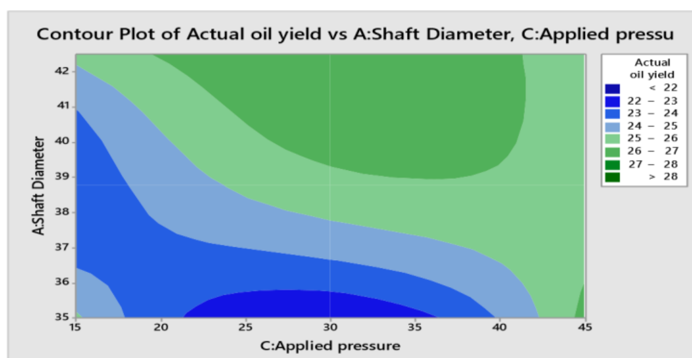

Figure 4: Contour plot of yield versus shaft diameter and applied pressure

4.7 Contour plot of yield versus shaft diameter and pitch height

Figure 4 presents how shaft diameter and pitch height simultaneously impacted the extracted oil yield. The oil yield is positively influenced by the shaft diameter and the pitch height. The influence of the interaction that exist between shaft diameter and pitch height of 15 mm and screw diameter of 37.5 mm, oil yield was found to be 24.6 % and at higher pitch height of 20 mm and 40.0 mm shaft diameter, oil yield of 25.3 % was obtained. Generally, as shaft diameter and pitch height increase, so does oil yield. This trend aligns with the findings of a study conducted by Bosede *et al*. (2018). An increase in shaft diameter from 37.5 to 42.5 mm enhanced the oil yield from 26 to 27.1 % when the pitch height was 25 mm. This is because the fish pulp needed more space to pass for exertion of more pressure by the shaft for more oil yield to flow out of the fish pulp.

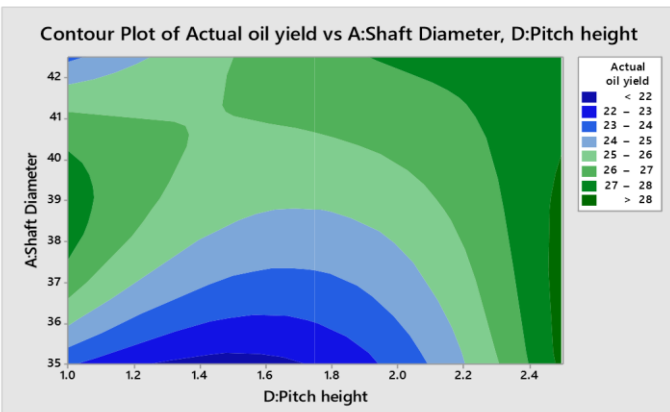

Figure 5: Contour plot of yield versus shaft diameter and pitch height

4.8 Experimental trial and predicted model for oil yield

Figure 6 compares the predicted fish oil yield and the experimental oil yield obtained from the experiments. The data points closely follow the line of best fit, indicating a strong alignment between the experimental and predicted values. This close correlation further validates the high R^2 value obtained in the study, which is near unity. These findings confirm that the regression model accurately predicts fish oil yield based on variations in screw diameter, screw speed, pitch height, and applied pressure during the expression process.

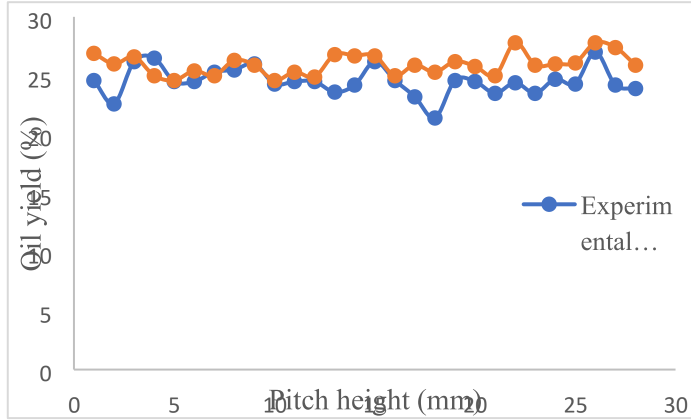

Figure 6: Experimental trial and predicted model for oil yield

4.0 CONCLUSION

Trunk fish was optimised using Response Surface Methodology (RSM) with a fractional factorial design (2^4) model of Minitab 20 software. From this study, it was observed that all four factors affect the oil yield of fish during expression, but the most significant is applied pressure, which has the highest influence in a regression model with the highest F-value, followed by shaft diameter, pitch height and shaft speed. This means that applied pressure significantly influences oil expression from fish and other oil-bearing materials. The results show optimum values of 42.5 mm, 40 N/mm^2, 20 mm and 55 rpm at a corresponding optimal oil yield of 27.1%. At the same time, the predicted oil yield was 27.8%, with a coefficient of variation of 2.06 and a percentage error of 0.6. Hence, the study has established optimum operation characteristic for the design of screw shaft for motorized fish oil expression machine, and this methodology could be effectively used in any process where an analysis of the optimum, effects and interaction of many experimental factors is studied. It is, therefore, recommended that the developed model be applied in manufacturing screw shaft to maximize fish oil expression efficiency.

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Declaration of conflict of interest

The authors have collectively contributed to the conceptualization, design, and execution of this journal. They have worked on drafting and critically revising the article to include significant intellectual content. This manuscript has not been previously submitted or reviewed by any other journal or publishing platform. Additionally, the authors do not have any affiliation with any organization that has a Mechanical Screw Expeller Validated by Response Surface Methodology.

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