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Extraction and Kinetics Parameters Analysis of the Extraction Process of Rice Bran Oil from Rice Milling Company Funtua, Katsina State, Nigeria.

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Abstract

This study evaluated the yield and kinetic parameters of the extraction process of rice bran oil using n-hexane as a solvent. The extraction process yield increased with temperature and contact time until equilibrium was reached, across various temperatures, moisture contents, and particle sizes. These parameters significantly influenced (95% confidence) the extracted oil yield. Extractions were conducted at 70°C, 80°C, and 90°C. The kinetic model revealed a first-order reaction, with the oil yield increasing from 8.60 g/L at 70°C to 15.68 g/L at 90°C after 1 hour and 30 minutes of extraction.

Keywords: Rice, Yield, Oil, Temperature, Kinetics.

Introduction

Rice is the second most consumed cereal and is a primary food for over 40% of the world's population, with Asian countries (China, India, Indonesia, Bangladesh, and Vietnam) leading the world in rice production (Martinez, 2013). The rice kernel contains only a small amount of oil (2–3%), found in the grain's outer layers. From the processing of paddy rice, 70% of the endosperm (white rice) is obtained as the main product, with the remainder as by-products (20% shell, 8% bran, and 2% germ) (Gul et al., 2015). Rice is one of the world's most important food crops, with more than half of the global population eating it as a staple. The bran, a by-product of the milling process, contains high levels of both tocopherols and tocotrienols, which comprise vitamin E, as well as high quantities of phytosterols, polyphenols, squalene, and oryzanol, acting as antioxidants in the body to promote good health and fight disease. Therefore, rice bran is an incredible source of vitamins, minerals, amino acids, and essential fatty acids. Rice bran contains about 18–22% oil (Cicero & Gaddi, 2001). Rice (*Oryza sativa*) is the most important food for most of the world's human population, especially in East and South Asia, the Middle East, Latin America, and the West Indies. It provides more than one-fifth of the calories consumed worldwide by humans. It is the second leading cereal crop for half of the world's population (Mian et al., 2014). The substitute source of energy known as renewable energy has gained consideration due to the increase in fossil fuel prices and environmental concerns about air and water

The positive outcomes of various generations of biofuels have made substantial contributions to the transportation sector. The production of biofuels using non-edible oils and algae has added advantages that other sources do not have due to their availability and conversion strategies to biofuels. Rice bran oil can be used in the production of biodiesel via transesterification (Baskar *et al.,* 2019).

Rice bran is used for edible oil production as a consequence of cell disruption with the release of lipase enzymes and various other anti-nutritional factors (trypsin inhibitors, hemagglutinin-lectin, and phytates) when the bran layers are removed from the endosperm. The contact between such enzymes and oil causes its hydrolysis and the release of free fatty acids and glycerol, thus drastically reducing its quality and shelf life (Lakkakula *et al.,* 2004). The degradation level of its oil can be so high that its usefulness for human or animal consumption is unsuitable, making its final destination suitable for use as fuel for boilers (Martinez, 2013). The use of vegetable oil that does not affect the food chain should be taken into account for the sustainable development of industrial processes. Also, due to its high production, rice bran can be a sustainable source for the synthesis of new bioproducts without the replacement of crops or the use of new cropping areas. All this would have repercussions in obtaining new products with a low carbon footprint. However, since vegetable oils have differences in both the type of fatty acids and their degree of unsaturation, as well as in their non-saponifiable constituents, this can impose conditions on their final use for the development of new products (Amarasinghe & Gangodavilage, 2004).

Oil extraction is defined as the process of separating triglyceride (TAG) lipids from the harvested and concentrated refinery biomass and can be done through a variety of mechanical or chemical manipulation techniques. Solvent extraction is the process of removing a solute component from the solid using a liquid solvent; it is also called leaching or solid-liquid extraction. According to this method, n-hexane yields the highest amount of oil compared to other solvents (Yang *et al.,* 2018).

Some of the works that have given attention to the study of extraction and kinetic parameters analysis of the extraction process of rice bran oil include Hussain et al. (2021), who obtained the highest oil yield (31.9%) and β-carotene (7.82%) of the rice bran dried at different temperatures and times for stabilization treatment, and the oil extracted using Soxhlet and Ultrasonic-assisted extraction (UAE). However, the quality and characteristics of rice bran usually depend on each country and even within each region due to the different rice varieties available, as well as different crop practices and milling of paddy rice. Therefore, in this paper, the oil extraction kinetics of rice bran is studied.

Materials and Methods

Sample Preparation

The sample (rice bran) used in this study was obtained from Alhaji Babangida Jaggabar rice milling company in Funtua, Katsina State, Nigeria. After obtaining the samples, they were dried in an oven at 70°C until the moisture content was sufficiently reduced. Subsequently, the dried samples were transferred, sealed in plastic, and preserved in the fridge to prevent deterioration before the extraction process.

Experimental Design

The design of the experiments carried out in this work was based on the fact that oil yield and its properties are functionally related to three factors: particle size, extraction time, and extraction temperature. The experiments to be conducted were designed with the aid of Design Expert 7.0 using the Box-Behnken approach of Response Surface Methodology (RSM). The maximum and minimum levels used for the factors considered are given in Table 2.1.

Table 1: Table of extraction parameters with limit

Variable	Unit	Minimum	Maximum
Sample	Mass(g)	10	15
Temperature	Celcius(c)	70	90
Time	Minutes(m)	60	120

Using the levels of the three factors given in Table 1, the design of the experiment resulted in seventeen (17) runs to be carried out, as shown in Table 2.

Table 2: Table of expert-designed

S/N	**Time(minutes)**	**Temperature(Celsius)**	**Sample(gram)**
1.	90	70	10
2.	90	90	10
3.	90	90	15
4.	120	90	12.5
5.	90	80	12.5
6.	90	80	12.5
7.	90	80	12.5
8.	90	80	12.5
9.	90	80	12.5
10.	90	90	12.5
11.	60	70	12.5
12.	60	80	10
13.	120	70	12.5
14.	120	80	10
15.	90	70	15
16.	120	80	15
17	60	80	10

Extraction Procedure

For each experiment carried out for the oil extraction, 10g of rice bran was wrapped in filter paper and placed inside the thimble chamber of the 250ml Soxhlet extractor, as shown in Figure 2. A round bottom flask containing n-hexane, as well as a condenser, was fixed to the extractor. 150ml of n-hexane was measured and poured into each of the tied rice bran samples, with foil used to cover the flasks to avoid evaporation of the solvent (n-hexane). Cool water flowing through the condenser was used to condense the evaporating solvent back into the Soxhlet extractor where the sample was packed to ensure sufficient extraction of the oil from the seeds. After a specified time, the mixture of the n-hexane and the extracted oil was separated from the solid chaff, and then n-hexane was removed from the extracted oil by gently heating off the mixture to evaporate the solvent. At the end of each experiment, the yield of the oil was obtained as the percentage of the extract from the seed using the equation below.

$$\text{Percentage yield (\%)} = \frac{Mass\ of\ oil}{Mass\ of\ smple} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Results and Discussions

Experimental Results

Extraction Kinetics

Before the study of the oil extraction kinetics, the optimal solvent-to-solid ratio to be used was determined. The table below shows the results obtained at different volume-to-mass ratios of solvent and rice bran, respectively. For the optimization of rice bran oil extraction, three extraction parameters were investigated: temperature, solvent-to-bran ratio, and contact time. The statistical summary of rice bran oil extraction utilizing CCD has been shown. Based on statistics, the highest-order polynomial model was selected where the model is not aliased. An insignificant lack of fit was achieved, and by focusing on maximizing the adjusted R-squared and predicted R-squared values, the linear model was suggested for the rice bran oil extraction. The regression analysis showed a determination (R-squared) value of 88.26%, which indicates that the proposed model can explain 88.26% of variations. Therefore, it can be concluded that the accuracy and the fitness of the linear model were adequate. From the results, it may be observed that the model p-value probability (F) is less than 0.05, which is an indication that the conditions in the model are significant. Furthermore, the model F-value of 14.64 implies the model is significant. For the current linear model, the values of probability F are less than 0.05 for factors A, B, and C, indicating the model terms are significant. It is also worth noting that factors A, B, and C mainly contribute to these findings.

3.3 Kinetics Study on Rice Bran Oil Extraction

Based on the experimental results obtained, data were collected to study the kinetics of rice bran oil extraction, as shown in Table 3.2.

Table 3: Experimental Result

S/N	Time(minutes)	Temperature(Celsius)	Sample(gram)	% of oil yield
1	90	70	10	6.80
2	90	90	10	10.80
3	90	90	15	17.80
4	120	90	12.5	22.52
5	90	80	12.5	13.60
6	90	80	12.5	13.61
7	90	80	12.5	13.64
8	90	80	12.5	13.00
9	90	80	12.5	13.65
10	90	90	12.5	15.68
11	60	70	12.5	8.60
12	60	80	10	6.12
13	120	70	12.5	20.48
14	120	80	10	21.12
15	90	70	15	19.20
16	120	80	15	25.13
17	60	80	10	7.43

Table 4: Kinetics of rice bran oil extraction

Time (minutes)	Sample (gram)	Oil Yield Y (mol/dm³)	Log Y (mol/dm³)	$(\frac{1}{\log Y})$(mol/dm³)	$(\frac{1}{\log Y})^2$ (mol/dm³)
60	12.5	8.6	0.93	0.12	0.014
90	12.5	15.68	1.1	0.06	0.004
120	12.5	20.48	1.3	0.04	0.002

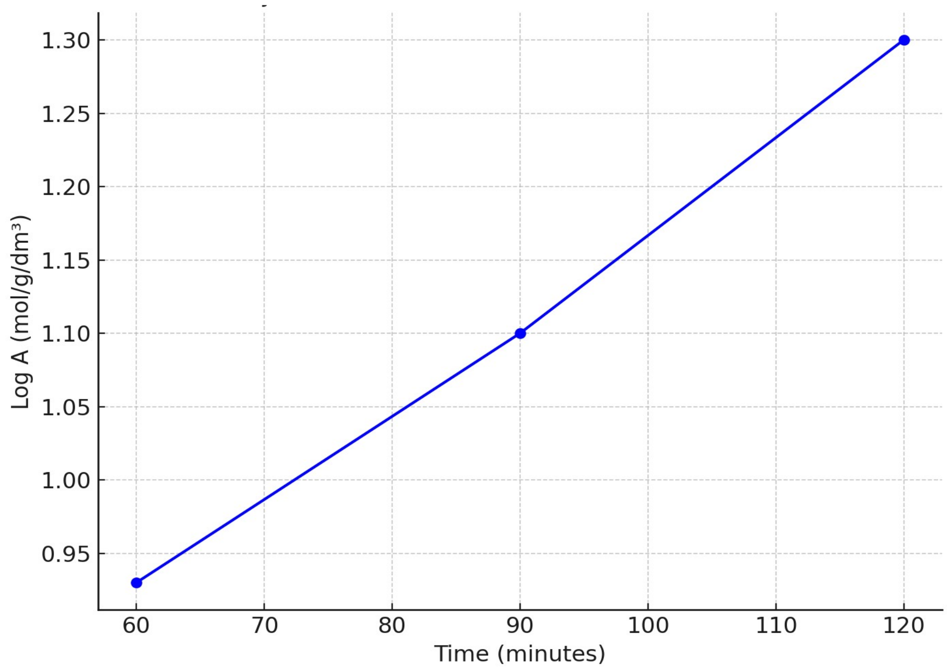

Figure 1. The oil extraction process from rice bran.

The graph indicates that the reaction follows first-order kinetics. This conclusion is drawn from the linear relationship between the logarithm of the remaining oil concentration (log(A)) and time, a characteristic behavior of first-order reactions (Topallar & Gecgel, 2021).

$$\text{Slope} = \frac{dA}{dT} = \frac{0.496}{80} = 0.0062$$

The log (A) slope versus time plot is calculated to be 0.0062. In first-order kinetics, the slope (m) of the plot is related to the rate constant (k) by the equation:

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$m = -k / 2.303$

Rearranging this equation to solve for k:

$k = -2.303 \times m$

Substituting the given slope value:

$k = -2.303 \times 0.0062 \approx -0.0143\ \text{min}^{-1}$

$k = 2.63\text{x}10^{-5}\text{s}^{-1}$

This rate constant value provides insight into the speed of the extraction process. A relatively small k value suggests a slower extraction rate, implying that modifications to extraction conditions, such as increasing temperature or optimizing solvent use, could enhance the process efficiency

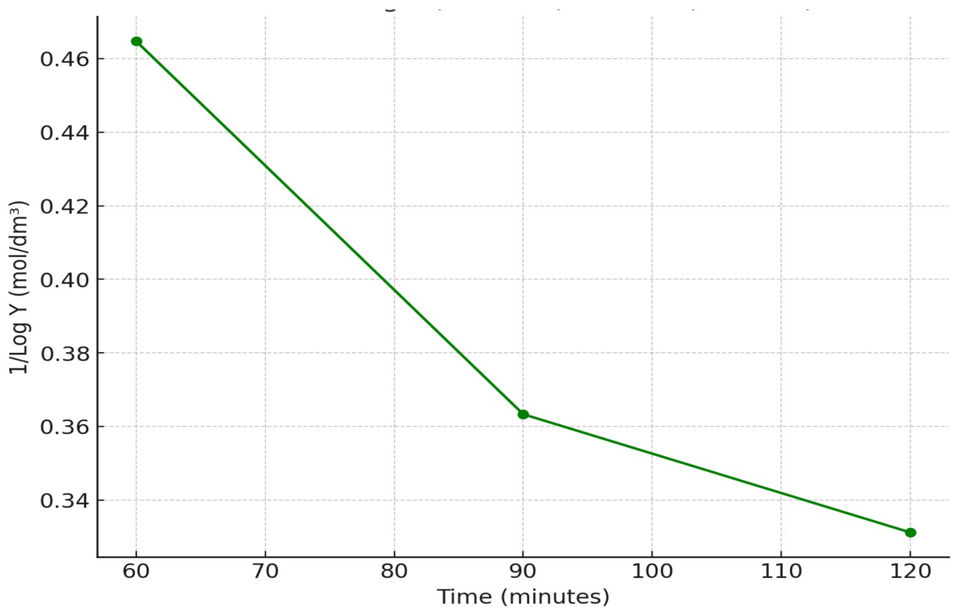

Figure 2: Relationship between the logarithm of the remaining oil concentration log (A) and time

$$\text{Slope} \frac{d\,1/A}{d\,t} = \frac{0.12-0.06}{90-60}$$

K=slope x 2.303

=0.022x2.303

$=0.0046m^{-1}=46x10^{-3}m^{-1}$

$=7.68x10^{-5}s^{-1}$

A constant K of 7.68×10^{-5} s implies a slower extraction process compared to Figure 1. However, the exact reaction order (whether truly first-order or zero-order) should be scrutinized further based on this graph.

3.4 Analysis of Variance (ANOVA) for Response Surface Linear Model

Table 5: Analysis of variance [Partial sum of squares]

Source	**Sum of** Squares	DF	**Mean** Square	**F** Value	Prob>F	
Model	514.83	3	171.61	47.32	<0.0001	significant
A	434.54	1	434.54	119.83	<0.0001	
B	1.85	1	1.85	0.51	0.4874	
C	78.44	1	78.44	21.63	0.0005	
Residual	47.14	13	3.63			

Lack of Fit	46.82	9	5.20	64.84	0.0006	significant
Pure Error	0.32	4	0.080			
CorTotal	561.97	16				

The Model F-value of 47.32 implies the model is significant. There is only a 0.01% chance that a Model F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case, terms A and C are significant. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The Lack of Fit F-value of 64.84 implies the Lack of Fit is significant. There is only a 0.06% chance that a Lack of Fit F-value this large could occur due to noise. A significant Lack of Fit is bad — we want the model to fit well

.**Table 6: Standard Deviation**

Std. Dev.	**1.90**	**R-Squared**	**0.9161**
Mean	14.22	AdjR-Squared	0.8968
C.V.	13.40	PredR-Square	0.8293
PRESS	95.94	AdeqPrecision	22.737

The "Pred R-squared" of 0.8293 is in reasonable agreement with the "Adj R-squared" of 0.8968. "Adeq Precision" measures the signal-to-noise ratio. A ratio greater than 4 is desirable. Your ratio of 22.737 indicates an adequate signal. This model can be used to navigate the design space

Design-Expert Plot

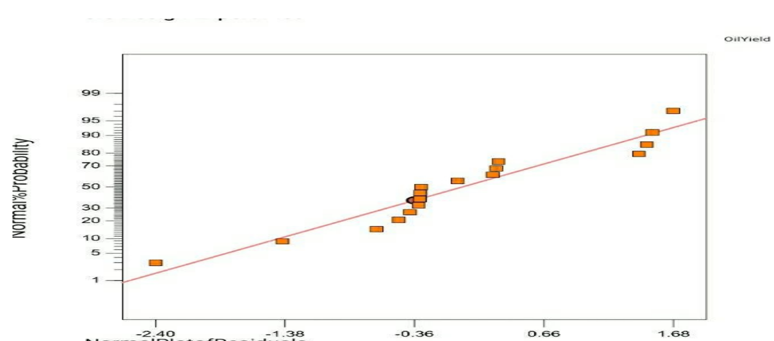

Figure 3: Normal Probability Plot of Residuals for Oil Yield Data

The normal probability plot of residuals shows that the residuals are mostly normally distributed, as evidenced by the close alignment of the points with the red diagonal line. This indicates that the model used to predict oil yield is valid and that the assumptions of normality are reasonably met. The minor deviations at the extremes suggest there may be slight outliers, but these do not appear to significantly affect the model's overall performance. This confirms the reliability of the regression analysis applied to the data.

Conclusion

The yield and kinetics parameters of the oil extraction process from rice bran using n-hexane as a solvent were evaluated for different temperatures, moisture contents of the solid phase, and particle sizes. The extraction process yield increased with an increase in temperature and contact time of solid particles with the solvent until reaching equilibrium (saturation of the solvent), for all the temperatures, moisture contents, and average particle sizes. These parameters significantly influenced the extracted oil yield. The extraction was conducted at different temperatures, and the kinetic model found that the extraction reaction was a first-order reaction. The increase in temperature led to a higher oil yield, demonstrating that higher temperatures enhanced the efficiency of the extraction process.

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