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Oil Extraction from Rice Bran Using Conventional and Bio-based Solvents

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Abstract: Rice bran is the outer layer of the rice grain, rich in essential nutrients and bioactive compounds. It is a valuable by-product used for various purposes, including extracting rice bran oil (RBO) known for its health benefits. This study focused on extracting oil from the nutritious rice bran using conventional solvent (n-hexane) and bio-based solvent (iso-propanol) for comparison under diverse conditions. The RBO yields were analysed at different temperatures of 40^oC, 50^oC, and 60^oC, with bran-to-solvent ratios of 1:3, 1:5, and 1:7, and extraction times of 2, 4, and 6 hours. The highest yields were 12.4% for n-hexane at 60^oC, 1:7 ratio, and 6 hours, and 9.76% for iso-propanol at 60^oC, 1:7 ratio, and 4 hours. The extracted oil underwent comprehensive physical analysis, including density, acid value, free fatty acid, and iodine value test. The physical analysis revealed density values of 0.867 g/mL for n-hexane and 0.866 g/mL for iso-propanol. Acid values were 21.48 mg KOH/g (n-hexane) and 26.90 mg KOH/g (iso-propanol). Free fatty acid percentages were 10.74% (n-hexane) and 13.45% (iso-propanol). Iodine values were 65.48 mg (n-hexane) and 60.40 mg (iso-propanol). The collected data were analysed using response surface methodology (RSM) to optimize the extraction condition, predicting the highest yield at 60^oC, with a bran-to-oil ratio of 1:5 parts solvent, and an extraction time of 6 hours. Statistical analysis confirmed the significance of the optimization model ($p < 0.05$). Overall, this study provided valuable insights, advancing more efficient and effective RBO production methods.

Keywords: rice bran; extraction; n-hexane; iso-propanol

1. Introduction

Paddy produces 73.5% white rice, 3.5% broken rice, 15% husk, and 8% rice bran when it is milled [1]. In recent years, rice bran has been studied for its potential biological functions, which include antioxidant and anti-inflammatory effects, cancer prevention, coronary heart disease prevention, and cholesterol reduction [2, 3]. Furthermore, rice bran contains 18%-22% oil, as well as a variety of bio-active phytochemicals such as oryzanol, phytosterol, tocotrienol, squalene, polycosanol, phytic acid, ferulic acid, and inositol hexaphosphate [4]. Rice bran oil (RBO) has grown in popularity as a nutritious component and is now a lucrative by-product of the rice processing industry [5, 6].

An important by-product of the rice milling industry, RBO may be produced from rice bran using a variety of methods. Solvent extraction is one of the popular techniques, which involves dissolving the oil from the rice bran using a solvent [7, 8]. n-hexane is the popular solvent utilized due to its ability to remove oil from rice bran. For RBO extraction, other methods exist, including enzymatic techniques, supercritical fluid extraction, ultrasound-assisted extraction (UAE), and microwave-assisted extraction [8-18]. The choice of solvent, temperature, pressure, duration, and the ratio of rice bran to solvent are the factors that affect the extraction of RBO. To get the most oil out of the extraction process, these characteristics must be carefully taken into account and adjusted [19-21].

RBO is a highly valued vegetable oil due to its numerous health benefits and diverse industrial applications. It is extracted from the bran layer of rice kernels, which contains a significant amount of oil. However, the oil content in rice bran is relatively low, making it challenging to extract efficiently. Hence, several extraction techniques have been developed to overcome this challenge. Table 1 provides a summary of different extraction techniques used to extract RBO.

The choice of solvent is a crucial factor in solvent extraction. Factors such as selectivity, solubility, safety, and cost should be taken into account when choosing a solvent. Different solvents have varying degrees of oil extraction effectiveness, environmental impact, and renewability. According to reports, various solvents can produce distinct natural molecules from a particular substance, resulting in variances in the extract's composition [5, 13, 23]. n-hexane is one of the most often utilised solvents in RBO extraction [12, 13, 23]. Although extremely efficient in removing the oil from rice bran, this solvent is hazardous and combustible, necessitating specific handling and disposal. n-hexane is a volatile organic compound (VOC), which raises environmental issues due to its propensity to contaminate the air and impair human health. On the other hand, iso-propanol has also been utilised as a solvent in RBO extraction [9]. Since it is safer for the environment and less harmful than n-hexane, iso-propanol has been proven to be more effective in extracting RBO [9, 20]. Moreover, n-hexane exhibits a lower boiling point in comparison to iso-propanol, rendering it more volatile and potentially more perilous in extraction procedures. RBO extraction has also been done using ethanol and has the benefit of being able to extract additional substances from the rice bran, such as phytosterols and antioxidants [24, 25].

Nonpolar solvents can also be used to reduce the extraction of polar substances such as polysaccharides and improve extraction efficiency [26, 27]. Therefore, based on the comparative study, iso-propanol, which is a "green" alternative solvent, and n-hexane, which is a traditional solvent, were selected for further study to investigate their impact on RBO yield. A solvent extraction technique was carried out to extract the RBO as it was the most widely used method due to the reason of its technology availability and the variety of advantages that can provide such as the ability to facilitate effective oil recovery [5, 9, 13]. Through the utilization of organic solvents, solvent extraction efficiently releases and concentrates oil components from the intricate structure of rice bran, optimizing the yield and the utilization of resources. Moreover, the technique's remarkable versatility extends to accommodating various types of oil, making it particularly suitable for the investigation of solvents such as n-hexane and iso-propanol which allows it to encompass the comprehensive array of oil constituents found within rice bran. This study also focuses on optimizing the parameters such as temperature, ratio, and extraction time that affect the RBO yield via response surface methodology (RSM). The application of RSM helps to predict the ideal condition to obtain maximum yield (%) and identify the performance of n-hexane and iso-propanol solvent on extracting the RBO [23, 26]. In this study, RSM was used to optimize extraction parameters such as extraction temperature ($X1$), solvent-bran ratio ($X2$), and extraction time ($X3$). The selection of these criteria was made to gather comprehensive data regarding the extraction process and to encompass a broad spectrum of scenarios. This study also utilised a three-factor, three-level Box-Behnken design (BBD) to determine the optimal Soxhlet conditions for extracting oil from RBO.

Table 1. Summary of extraction technique for RBO production.

Technique	Theory/Concept	Advantages	Disadvantages	References
Solvent extraction	Extraction of oil from rice bran by dissolving the rice bran in the organic solvent such as hexane and iso-propanol.	Low energy consumption Effective oil recovery Versatile in accommodating various solvents	Toxicity of solvent (n-hexane) Required high purity of solvents to be used Costly	[5,9,13]
Supercritical fluid extraction (SFE)	Oil extraction based on the temperature and Pressure manipulation, uses Supercritical fluid (usually S-CO_2) as the extraction solvent.	Faster and more efficient extraction Environmentally friendly	Requires specialized equipment and is more expensive to implement when compared to other methods Complex process	[9,22]
Mechanical pressing (Cold pressing)	Extracting oil from rice bran using mechanical force. It is a physical process that does not involve the use of chemicals or high temperatures.	Environmentally friendly Simple and straightforward Does not required heat or solvent	High labour intensity High residual oil rate High cost and power consumption Easy to cause protein denaturation. Lower oil yield extracted compared to other methods/techniques	[9,10]
Enzyme assisted aqueous extraction (EAAE)	Extracting oil from rice bran using enzymes such as Cellulose, α-amylase and pectinase to break down the oil and make it more accessible for extraction.	Good quality of oil No chemical pollution Low energy consumption Good retention of protein, polysaccharide and other components	Easy to cause protein denaturation. Enzymes used in the process can be expensive. Time-consuming process Shorter shelf life	[11,14, 15]
Ultrasound assisted extraction (UAE)	Used ultrasonic waves to agitate the rice bran and oil, causing the oil to become more accessible for extraction.	Reduce extraction time, energy and solvent to be consumed. Environmentally process	Requires specialized equipment (high Cost) Large amount of labour	[9,12,16]
Microwave assisted extraction (MAE)	Uses microwave energy to increase the efficiency of the extraction process. The process involves the use of microwaves to heat the rice bran and oil, causing the oil to become more accessible for extraction.	High yield and Purity Reduce time and solvent consumption	The need for special equipment Low selectivity Unavoidable reaction in high temperature	[7,17,18,20]

2. Materials and methods

2.1. Raw material

Fresh rice bran was obtained from a local rice mill located in Kota Belud district, Sabah, Malaysia. The bran had been passed through a 30-mesh sieve (700 mm aperture size) to remove the paddy kernels, broken grains, hull fragments, and unwanted foreign materials. After sieving, the rice bran was immediately stabilized before storage to prevent enzymatic rancidity. The rice bran was heat-dried using a dry oven for 10 minutes at 115^{o}C and weighed.

2.2. Apparatus and chemicals

In this study, Soxhlet extractor was used for RBO extraction, Rotavapor model R-215 was utilized for the separation of solvent and oil after extraction for purification purposes. n-hexane with ≥ 99.9 % purity and iso-propanol with ≥ 99.9 % supplied by Sigma Aldrich.

2.3. Oil extraction

The RBO extraction process using both n-hexane and iso-propanol as solvent was carried out by using Soxhlet apparatus The extraction process was done at 40, 50, and 60^{o}C, and bran to solvent ratio at 1:3, 1:5, 1:7 w/v for 2, 4, and 6 hours. A sample of 50 g of rice bran was placed into the thimble and covered with gauze at the top layer and the solvent, solvent was filled in the round-bottomed flask. The extract with the solvent was separated by a rotary evaporator which was filtered using filter paper [4, 28].

2.4. Determination of oil yield

After the extractions, all the samples were filtered twice using Whatman filter paper to separate the oil from the used rice bran. The separated rice bran oil yield was weighed, and the yield was calculated as per 50 g of rice bran basis using the Equation (1):

$$RBO\ yield, (w/w) = \frac{WRBO(g)}{WRB(g)} \times 100 \quad (1)$$

where $WRBO(g)$ is the weight of RBO extracted from the experiment and $WRB(g)$ is the weight of the rice bran before the oil extraction.

2.5. Characterization of extracted oil

Physical characteristics of oil samples derived from the Soxhlet extraction were assessed. Free fatty acid percentage (FFA), oil density, iodine value, and acid value were chosen. These oil qualities were chosen based on other investigations in the same field. It is essential to comprehend these qualities since they affect the stability, shelf life, and suitability of the oil for diverse applications. All oil attributes were tested twice during oil analysis.

2.6. Determination of free fatty acid (FFA)

The acid value (AV) and free fatty acid percentage (FFA, %) of both oil samples were determined following the procedures used by Asmare and Gabbiye [29]. The AV was calculated first, and the FFA content in the RBO was then calculated using the Equation (2):

$$FFA, \% = AV/2 \quad (2)$$

25 mL of a 1:1 combination of diethyl ether and ethanol was added to 5 g of oil in a 250 mL conical flask and mixed thoroughly to determine the AV in accordance. The solution was titrated with 0.1 N KOH after adding 5 drops of phenolphthalein indicator, and the titration's end point was confirmed after constant shaking (change from colourless to pink). During the titration, the amount

of 0.1 N KOH (V) consumed was noted. Equation (3) was used to compute the sample's total acidity, expressed as mg KOH/g.

$$AV = \frac{56.1 \times N \times V}{WRBO} \tag{3}$$

where N is the normality of KOH used, V is the volume (mL) of ethanolic KOH, and $WRBO$ is the weight (g) of RBO sample.

2.7. Determination of oil density

A 50 mL volumetric flask was used in the technique to measure the density of the oil samples, and it was completely dried before use to prevent contamination. The reading was then reset to zero and a dry flask was put on a sensitive electronic balance. Using a pipette, the extracted rice bran oil sample was then added to the flask. By dividing the weight by the volume, the density of the oil was estimated. After repeating the procedure, the average value was calculated. The densities of the oil samples were calculated at room temperature. The density of RBO was calculated using the Equation (4):

$$Density\ of\ RBO\ (w/v) = \frac{WRBO(g)}{VRBO(mL)} \tag{4}$$

where $WRBO(g)$ is the weight of the oil sample and $VRBO$ is the volume (mL) of the oil sample. It is important to note that the density of the oil will vary depending on the temperature, so it is usually measured at a specific temperature, usually at 20°C. The density of oil samples can vary depending on the oil extraction method, the variety of rice used, and the growing conditions.

2.8. Determination of iodine value

A weight of 0.25 g of the oil sample was weighed and transferred to a 250 mL flask, along with 20 mL of chloroform, to dissolve the oil sample. The mixture was then pipetted with the 20 mL Wijs reagent's iodine monochloride solution. The flask was sealed and kept in the dark for one hour, with occasional shaking. After an hour, the liquid was taken out of the dark and 50 mL of distilled water and 10 mL of a 15% potassium iodide solution were added. Once the cork was securely fastened to the flask, the mixture was thoroughly shaken. After the iodine was released, sodium thiosulfate (0.1 N solution of $Na_2S_2O_3.5H_2O$) was added, and the mixture was gently agitated until the yellow colour lightened. After that, 5 drops of 1% starch indicator were added to the mixture, and the titration was continued until the blue tint disappeared [30]. Equation (5) was used to calculate the IV of the oil sample.

$$IV = \frac{Vb - Vs}{W} \times 12.69 \times N \tag{5}$$

where Vb is the volume (mL) of sodium thiosulfate used for the blank, Vs is the volume (mL) of sodium thiosulfate used for the sample, and N is the normality of sodium thiosulfate, and W is the mass of the sample used (g).

2.9. Optimization using response surface methodology (RSM)

RSM was used to optimize the extraction conditions for a particular product utilising three process parameters which are the extraction temperature, extraction time, and bran to solvent ratio. The extraction time, temperature, and bran to solvent ratio were all restricted to being between 2 and 6 hours, 40°C to 60°C, and 1:3 to 1:7, respectively. These parameters were selected to collect thorough information on the extraction process and to cover a wide range of situations. The best conditions for the RBO extraction process can be determined by examining the connection between these process variables and the response variable, which improves process effectiveness. An overview of the coded values for the process parameters is shown in Table 2.

Table 2. Coded values of process parameters and corresponding responses.

Symbol	Parameter	Units	Level -1	Level 0	Level 1
$X1$	Extraction temperature	°C	40	50	60
$X2$	Bran to solvent ratio	-	1:3	1:5	1:7
$X3$	Extraction time	hour	2	4	6
Y	Response (yield of RBO)	%	Y1	Y2	Y3

3. Results and discussion

3.1. Effect of extraction temperature to RBO yield

Figure 1 illustrates the experimental outcomes of the RBO yield for both n-hexane and iso-propanol solvents. The extraction process maintained constant rice bran to oil ratio of 1:5 and an extraction time of 4 for the study.

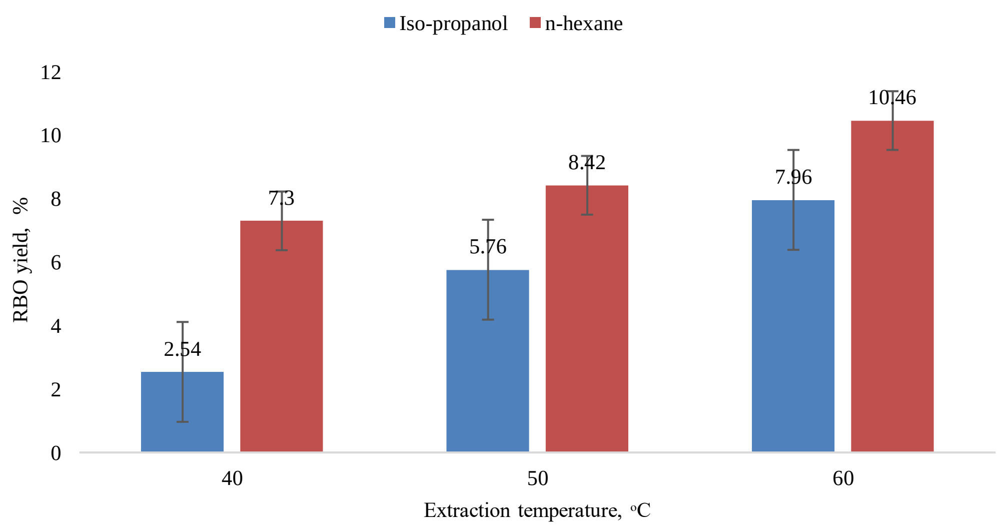


Figure 1. Effect of extraction temperature to RBO yield for n-hexane and iso-propanol.

Based on Figure 1, both solvents used showed an increase in yield of RBO when the extraction temperature increased. At 40°C, iso-propanol produced 2.54% RBO, but n-hexane produced 7.30% RBO. When the extraction temperature was raised to 60°C, the RBO yields increased significantly to 7.96% and 10.46% for iso-propanol and n-hexane, respectively. Djaeni et al. [12] evaluated the extraction process at various temperatures (40, 50, and 60°C) and observed the maximum yield at 60°C with a 1:5 ratio, which is consistent with the findings. In addition to that, Pimpa et al. [4] also discovered that 60°C has produced a better yield than lower temperatures. The increase in yield with temperature could be attributed to increased oil ingredient solubility and diffusion rates, allowing for a more efficient extraction process. Higher temperatures also have promoted faster mass transfer rates and decreased solvent viscosity which makes it easier to extract oil from rice bran. However, the yield achieved from n-hexane solvent exceeds that of iso-propanol. This disparity can be attributed to the varied solubility properties of the two solvents. Because of its higher lipid solubility, n-hexane is frequently utilised in oil extraction procedures. Iso-propanol, on the other hand, has lower lipid solubility and hence produces a lesser amount of RBO. Moreover, the difference in boiling points between iso-propanol and n-hexane can influence the extraction process. The temperatures utilised in this study were lower than the boiling points of both solvents, to ensure stability and prevent evaporation. Thus, n-hexane which has a lower boiling point will facilitate a faster evaporation rate and improves the mass transfer of oil components from rice bran, resulting in a more effective extraction process, whereas iso-propanol's higher boiling point may have contributed to its low oil yield when compared to n-hexane at all tested temperatures [26].

3.2. Effect of rice bran and solvent ratio to oil yield

Figure 2 illustrates the effect of the solid-liquid ratio for both n-hexane and iso-propanol solvents on the RBO yield, while considering a constant extraction temperature of 60°C and an extraction time of 4 hours.

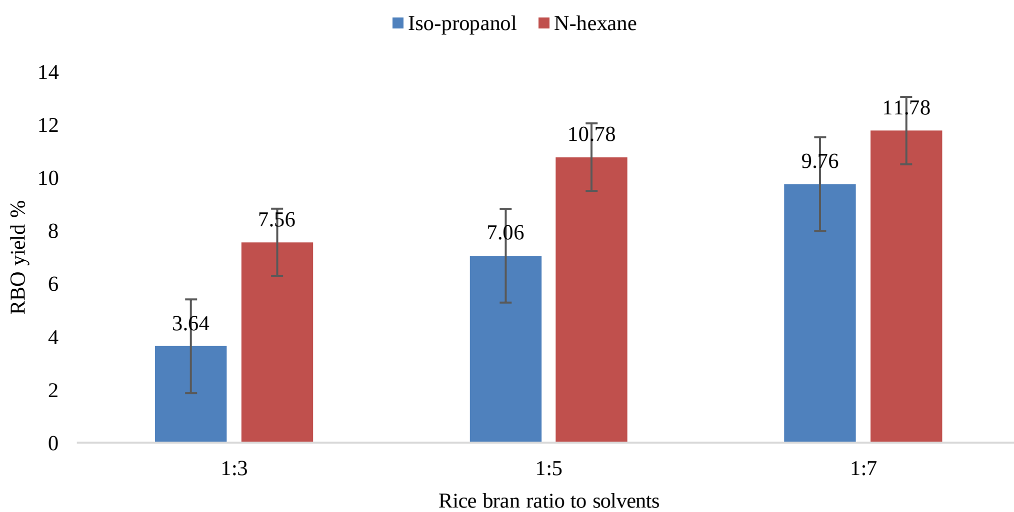


Figure 2. Effect of rice bran and solvent ratio to RBO yield for iso-propanol and n-hexane.

Based on Figure 2, the RBO yield increases as the solid-liquid ratio increases for both iso-propanol and n-hexane solvents. Iso-propanol yielded 3.64% at a ratio of 1:3, ascended to 7.06% at a ratio of 1:5, and increased further to 9.76% at a ratio of 1:7. Similarly, the RBO yield for n-hexane increased from 7.56% at a ratio of 1:3 to 10.78% at a ratio of 1:5 and 11.78% at a ratio of 1:7. This condition is caused by an oil concentration difference between the surface of the rice bran and the solvent. As the solid-liquid ratio increases, more solvent comes into contact with the rice bran, resulting in a larger concentration gradient. This enhanced concentration gradient encourages oil diffusion and extraction from rice bran, resulting in higher RBO yields [12]. According to Suryati et al. [31], which extracted 50 g of rice bran and used a 250 mL n-hexane solvent (ratio 1:5) resulted in a yield of 13.5%. On the contrary, Nasir et al. [32] carried out an experiment with 50 g of rice bran and 350 mL of the solvent resulted in a yield of 18.34%. The present study shows a similar trend of increasing yield, but with lower yield obtained probably due to extraction method and different rice bran samples. Furthermore, it is notable that greater extraction of RBO was obtained by n-hexane compared to iso-propanol which can be explained due to n-hexane's non-polar nature, which efficiently interacts with the non-polar lipids in RBO. Iso-propanol's polar nature makes it less effective in extracting these non-polar lipids. The chemical composition of RBO and the selectivity of n-hexane contribute to its superior extraction performance.

3.3. Effect extraction time to oil yield

Figure 3 illustrates the experimental outcomes of the RBO yield under different extraction time sfor both n-hexane and iso-propanol solvents. The extraction process maintained constant rice bran to oil ratio of 1:5 and an extraction time of 60°C for the study.

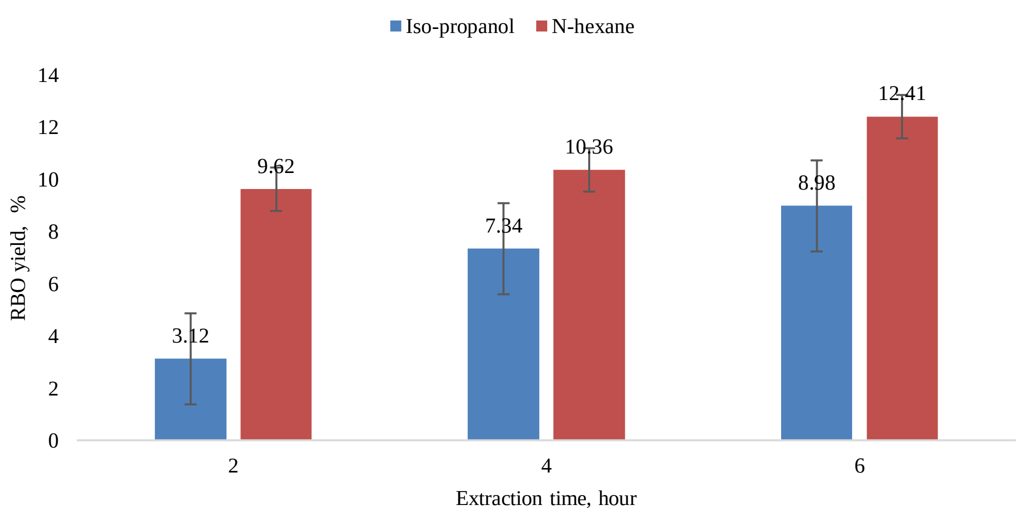


Figure 3. Effect of extraction time to RBO yield for iso-propanol and n-hexane.

From Figure 3, it can be observed that the RBO yield increased with longer extraction times for both iso-propanol and n-hexane solvents. For iso-propanol, the RBO yield was 3.12% at an extraction time of 2 hours, which increased to 7.34% at 4 hours and further increased to 8.98% at 6 hours. Similarly, for n-hexane, the RBO yield increased from 9.62% at 2 hours to 10.36% at 4 hours and reached 12.41% at 6 hours. The oil yield of 12.41% obtained in the present study agrees with past studies which obtained 13.5% of oil yield within 7 hours of extraction time [31]. This can be attributed to the extended duration allowing for a more complete extraction of oil constituents. The relationship between extraction time and RBO yield can be explained by the diffusion process during extraction. Longer extraction times provide more time for the solvent to penetrate the rice bran and dissolve the oil components. This allows for a more efficient extraction, leading to higher RBO yields.

3.4. Characterization of extracted RBO

The highest yields achieved were 12.4% for n-hexane at 60^{o}C, 1:7 ratio, and 6 hours, and 9.76% for iso-propanol at 60^{o}C, 1:7 ratio, and 4 hours. These two RBO samples were chosen to analyse the physical attributes of the oil. Density measurements yielded valuable insights into mass-volume relationships, serving as a cornerstone for accurate measurements within diverse processes. On the other hand, the AV assessment provided insights into acidity levels, directly influencing both shelf life and flavour quality, whereas FFA % contributed to understanding oil purity and overall quality. Concurrently, the IV assumption played an instrumental role in evaluating unsaturation levels, thereby impacting oxidation potential, nutritional considerations, and inherent stability during subsequent storage and culinary applications. Table 3 shows the findings of the physical examination for both samples of RBO.

Table 3. Physical analysis result of RBO sample.

Properties	n-hexane	Iso-propanol
Density, g/mL	0.867	0.866
AV, mg KOH/g	21.48	26.90
FFA, %	10.74	13.45
IV, mg I2/g	65.48	60.40

According to Table 3, the density values for n-hexane and iso-propanol-extracted oils are comparable, differing by just 0.866 g/mL and 0.867 g/mL, respectively which are also quite similar to the density stated in the literature [32,33]. The slight density change implies that the extraction solvents have little to no impact on the total mass and volume of the oils. The iso-propanol-extracted oil displays greater values for the AV and FFA % than the n-hexane-extracted oil. The AV for iso-propanol is 26.90 mg KOH/g, whereas the value for n-hexane is 21.48 mg KOH/g, showing a slightly higher level of acidity in between [34]. Iso-propanol and n-hexane both have FFA% of 13.45% and 10.74%, respectively. Each sample shows a higher amount of AV and FFA% compared to the literature where the FFA% of crude RBO is around 1-2% [33]. The differing extraction processes and the interaction of iso-propanol with the oil's constituents, which enhanced acidity, may be accountable for the higher AV and FFA % in the extracted oil. Iodine values for both oils, 60.40 mg I2/g sample for iso-propanol and 65.48 mg I2/g for n-hexane, are lower than expected. The properties of both n-hexane and iso-propanol-extracted oils are generally within the acceptable range, the slight differences observed between the two solvents may be attributed to their different extraction mechanisms.

3.5. Statistical analysis and optimization

The study focused on three factors which are extraction temperature ($X1$), solvent-bran ratio ($X2$), and extraction time ($X3$), and their respective impacts on the yield of RBO (Y). The design of experiments (DOE) constructed to plan the experimental run with the desired range of each factor and their respective levels are shown in Table 4.

According to Ahmad et al. [35], process optimization involves estimation of coefficients, prediction of responses and checking acceptability of the developed model. The linear model was suggested for the rice bran oil extraction and the resulted linear model in terms of coded variables is as follows, Equation (6):

$$R = 4.9367 + 1.97X1 + 3.06X2 + 2.93X3 \quad (6)$$

where, R denotes the outcome, which in this case is the % of the yield of RBO, and $X1$, $X2$, and $X3$ are the coded variables, which are related to the process variables temperature, solvent-bran ratio, and extraction time, respectively. The coefficients of 1.97, 3.06, and 2.93 in the model equation, respectively, show the influence of each process variable on the response. The correlation coefficient of 1.97 for $X1$ indicates that a one-unit increase in the coded value of temperature $X1$causes a 1.97-unit increase in the percentage yield of RBO (R), providing the other variables of $X2$ and $X3$ are held constant. Similarly, the effects of the solvent-bran ratio and extraction duration on the response are shown by the coefficients of $X2$ and $X3$ for the 3.06 and 2.93, respectively.

Table 4. Design of experiment for three independent variables and experimental results.

Run	**Extraction temperature, $X1$**		**Solid to solvent ratio, $X2$**		**Extraction time, $X3$**		**RBO yield, Y**	**Predicted RBO yield**
	Coded value	**Actual value**	**Coded value**	**Actual value**	**Coded value**	**Actual value**		
1	-1	40	0	1:5	0	4	2.54	2.96
2	0	50	0	1:5	0	4	5.76	4.93
3	1	60	0	1:5	0	4	7.96	6.89
4	1	60	-1	1:3	0	4	3.64	3.84
5	1	60	0	1:5	0	4	7.06	6.89
6	1	60	1	1:7	0	4	9.76	9.96
7	1	60	0	1:5	-1	2	3.12	3.97
8	1	60	0	1:5	0	4	7.34	6.89
9	1	60	0	1:5	1	6	8.98	9.83

3.6. Model fitting and summary statistics

Experiments based on the recommended optimal medium parameters were used to validate the mathematical model created using the RSM approach. In order to evaluate the effectiveness and precision of the model, a statistical t-test was also carried out utilizing a number of statistical measures, such as the coefficient of determination (R^2), adjusted R^2, and root mean square error (RMSE). Table 5 and 6 display the summary of fit statistics and the ANOVA.

Table 5. Summary of fit statistics.

Statistics	Values
Mean of response	6.24
R^2	0.9323
Adjusted R^2	0.8917
RMSE	0.8640
Observations	9

RMSE value shows 0.8640 which indicates a strong prediction accuracy of the linear model. R^2 value shows that the linear model accounts for about 93.23% of the response's variability.

Additionally, Table 6 ANOVA findings demonstrate that the model component is significant with a p-value of 0.0024, which is less than 0.05, further demonstrating the linear model's suitability for explaining the variation in the response variable. The linear model appears to be a reasonable and appropriate description of the response surface in the investigated extraction process, which indicates that the model is fit to the study. This is supported by the provided fit statistics and the close match between the anticipated and actual RBO yields. This study was also supported by Ahmad et al. [35] who found comparable results using a linear model for the parametric optimization of rice bran, demonstrating the significance of the model terms.

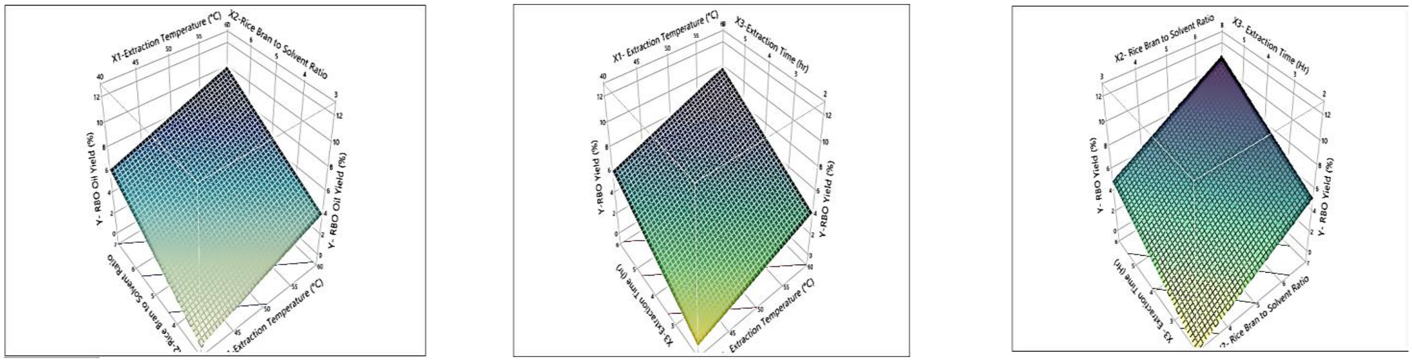
Table 6. Analysis of variance (ANOVA) for regression model.

Source	Sum of square	DF	Mean square	F value	P value	Remarks
Model	51.4206	3	17.1402	22.9577	0.0024	significant
$X1$	15.5236	1	15.5236	20.7924	0.0061	significant
$X2$	18.7272	1	18.7272	25.0833	0.0041	significant
$X3$	17.1698	1	17.1698	22.9973	0.0049	significant
Residual	3.7330	5	0.7466			
Lack of fit	3.3087	3	1.1029	5.1911	0.1655	Not significant
Pure error	0.4243	2	0.2121			
Cor. total	55.1536	8				

Table 6 shows that all three variables have a statistically significant effect on the variability of the response variable, or RBO yield. The model shows a strong capacity to describe the observed variation in the response with a sum of squares (SS) of 51.4206 and 3 degrees of freedom (DF). The mean square (MS) value for the model is 17.1402, and the related F-value and p-value are 22.9577 and 0.0024, respectively. The low p-value indicates that the model's inclusion of the three factors significantly contributes to explaining the response variability, further supported by the relatively high F-value. Each component has a significant impact on the RBO yield. The SS for extraction temperature ($X1$) is 15.5236, the F-value is 20.7924, and the p-value is 0.0061. Similarly, the SS for rice bran to solvent ratio ($X2$) is 18.7272, the F-value is 25.0833, and the p-value is 0.0041. With an SS of 17.1698, an F-value of 22.9973, and a p-value of 0.0049, extraction time ($X3$) is likewise significant. The importance of these variables shows that variations in extraction temperature, rice bran-to-solvent ratio, and extraction time have a significant effect on the RBO yield. The study also contains residual, lack of fit and pure error components. With a value of 3.733 and 5 degrees of freedom (DF), the residual SS represents the model's unexplained variance or error. The SS for lack of fit, which measures the difference between the model and the observed data points, is 3.3087 with 3 degrees of freedom (DF). Notably, the lack of fit is not statistically significant (p-value is 0.1655), showing that the model fits the data satisfactorily. The pure error SS is 0.4243, with two degrees of freedom (DF) indicating variance between replicates.

3.7. Interpretation of the 3D response surface plots

The model's 3D response surface plots from Figures 4 (a-c) depicts the investigation of the interaction effects of the process variables.



(a) **(b)** **(c)**

Figure 4. 3D Surface Plot of response with respect to (**a**) extraction temperature ($X1$) with solvent–bran ratio ($X2$) (**b**) extraction temperature ($X1$) with extraction time ($X3$) (**c**) bran solvent ratio ($X2$) with extraction time ($X3$).

The effect of temperature ($X1$) and rice bran to solvent ratio ($X2$) on RBO production percentage is depicted in Figure 4(a). Temperature is clearly a highly crucial component influencing oil recovery. The percentage of oil output increases with increasing temperature and decreasing ratio of rice bran to solvent. This is due to the increased solubility of oil in the solvent at higher temperatures, which results in a higher percentage of oil extracted. Wang et al. [26], reported similar findings. Figure 4(b) depicts the 3D surface plot for the interaction of extraction temperature ($X1$) and extraction time ($X3$) on the percentage oil yield from the extraction process, respectively. The results reveal that as the extraction time increases with increasing temperature, so does the proportion of oil extracted from rice bran. The influence of extraction time on the response value (oil yield) is significant; however, the rise is less sharp than that of temperature increment. This suggests that the solvent-bran ratio can affect the amount of oil extracted, with larger ratios offering a more accessible surface area for oil extraction. The interaction impact of solvent-bran ratio ($X2$) and extraction duration ($X3$) on oil yield is depicted in Figure 4(c). As the solvent-bran ratio grows with increasing extraction time, so does the percentage yield of rice bran oil. This shows that the solvent-bran ratio ($X2$), rather than the extraction duration ($X3$), is a critical parameter with a greater impact on the percentage of oil recovery from rice bran. Higher solvent-bran ratios offer a larger volume of solvent to interact with the rice bran, resulting in enhanced extraction efficiency. Increasing the extraction period also allows for more extensive contact between the solvent and the bran, which aids in oil extraction. As a result, the response variable, which is the oil yield, increases with the interaction of solvent-bran ratio and extraction time.

3.8. Interpretation of optimum condition

Based on Figure 5, the maximum value of the response function with the highest desirability of 0.954 has been achieved by using a set of process variables that have been identified with the help of numerical optimization techniques. The objective of this optimization was to maximize the response function, which is the % of yield of RBO, within the specified lower and higher boundaries of 2.54% and 9.83%, respectively. The ideal values for the process variables were found to be at 60°C, 1:5, and 6 hours, respectively.

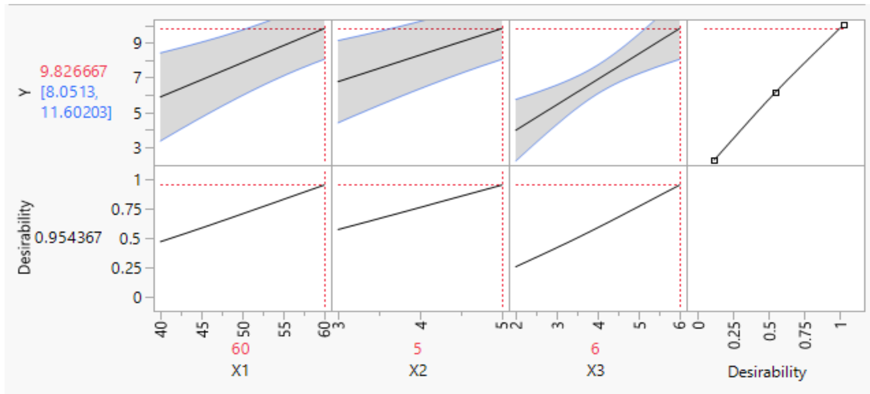


Figure 5. Optimum condition to obtained maximum desirability.

These findings show how well the numerical optimization technique works in identifying the best process variables for a high percentage of RBO yield. The comparison between predicted and actual yield are shown in Table 7.

Table 7. Predicted and actual comparison.

Properties	Experimental condition, X			Response, Y
	Extraction temperature	Rice bran to solvent ratio	Extraction time, hr	RBO yield, %
Predicted	60	1:5	6	9.83
Actual	60	1:5	6	8.98
	Error, %			8.65%

The difference between the expected and actual RBO yields resulted in an 8.65% inaccuracy which is considered significant in this context [36, 37]. These differences can be ascribed to a variety of variables, including experimental uncertainties, sample variations, and potential errors throughout the analytical process.

4. Conclusions

The study successfully evaluated the performance of n-hexane and iso-propanol solvents for RBO extraction, with both showing promising results. Both solvents were tested for their ability to extract oil from rice bran samples and were shown to be successful in extracting rice bran oil, with only minor differences in yields. Temperature, solvent-bran ratio, and extraction time were found to significantly influence oil yield, with higher temperatures leading to increased yields. The study revealed that increasing the temperature from the starting circumstances considerably increased the oil output. Changing the solvent-bran ratio and increasing the extraction time had a similar positive connection with enhanced oil yield. Physical analyses provided insights into the quality of the extracted oil. To achieve higher oil extraction, the final goal was optimized by utilizing the most appropriate solvent, iso-propanol. A linear model was created and tested for optimization. According to ANOVA, temperature, together with the solvent-bran ratio and extraction time, are the key variables that can affect the percentage of oil extracted from rice bran. The expected result indicates that the maximum oil yield that may be obtained under extraction circumstances of 60°C, 6 hours, and a ratio of 1:5 is 9.83% (w/w). It is important to note that this study is only for experimental purposes and not for any commercial or consumption item and usage of the oil for cooking based on this experiment methodology is not advisable.

Conflict of interest

The authors declare no competing interests.

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