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Research Article

Response Surface Methodology with Central Composite Design (RSM-CCD) Study on Coconut Oil Transesterification Using Zeolite-A as Catalyst

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Abstract
Biodiesel is a form of renewable energy source that is of particular importance, since it has been commercially produced and applied as a practical fuel. However, the price of biodiesel is still higher than that of petrochemical fuel, reflecting the need for optimizing the production process in order to reduce the cost. Current study was conducted to optimize the biodiesel production from coconut oil catalyzed by zeolite-A (zeo-A) produced by hydrothermal method utilizing rice husk silica (RH-SiO_2) and food-grade aluminum foil (FGAF), followed by calcination of the zeolite at 550 °C for 6 h. Physical characteristics of the zeolite were obtained using different characterization techniques, including XRD, SEM, and BET. The zeolite was applied in transesterification experiments with the aid of response surface methodology based on central composite design (RSM-CCD) for evaluating the influence of catalyst load, the ratio of methanol to oil, and reaction duration on coconut oil conversion. A polynomial model with an analysis of the data variance indicates that the highest yield of biodiesel was produced from the experiment run for 1 h, loaded with 2.5% catalyst, and methanol to oil volume ratio of 5:1. Under optimum conditions, the biodiesel yield of 98% was achieved or a 2% error from the maximum yield (100%) as predicted by the model. In this respect, satisfactory optimum conditions for transesterification were successfully achieved with the aid of the RSM-CCD method applied.

Keywords: transesterification, coconut oil, zeolite-A, biodiesel, RSM

1. INTRODUCTION

Among various renewable energy sources, biodiesel is of particular interest since this biofuel has been prepared from different feedstocks, including vegetable oils [1][2] and microalgae lipids [3], as it has reached commercial scale production and application by blending it with petrochemical diesel at certain proportions [4][5]. For example, B20 fuel is the term used for a mixture of 20% biodiesel from flaxseed oil and 80% pure diesel and applied in Bangladesh [6], a blend of 40% biodiesel from waste cooking oil and 60% pure diesel (B40) is applied in Malaysia [7], and biodiesel from palm oil-diesel blends (B30, B40) are used in Indonesia [8]. Successful commercialization of biodiesel implies that role of this biofuel in global energy platforms will continue to increase [9][10]. At present, the main feedstocks for industrial-scale biodiesel production is still palm oil in both Indonesia and Malaysia [11]. However, due to the concern of food security issues associated with the use of palm oil, many investigations have been devoted for investigating biodiesel production from various alternative feedstocks, such as *Ricinus communis* oil [12][13], groundnut oil [14], waste cooking oil [15], rubber seed oil [16][17], coconut oil [18][19], and sunflower oil [20]. Of the various raw materials mentioned above, coconut oil is a very promising feedstock for biodiesel production in Indonesia, because coconut plants can grow well in almost all regions of the country. Furthermore, coconut plants are relatively easy to cultivate with relatively low cost. Despite this promising potential, most plantations are owned by small companies, with limited production, therefore, the quantity of coconut oil is not sufficient to be utilized as the main raw material.

Despite the successful commercialization of biodiesel, it must be acknowledged that the price of biodiesel is still more expensive than that of fossil biodiesel. Due to this drawback, many studies have been focused on the optimization of transesterification to make the production process more cost-effective. Obtaining an optimum condition is important since transesterification is a multivariable reaction, in which the three most

Table 1. Variables used to design experimental matrix.

Variable	Symbol	Levels		
		-1	0	1
CL (%)	A	2.5	5	7.5
M/O ratio	B	3	4	5
t (min)	C	15	37.5	60

determining variables are the catalyst load [21]-[23], alcohol to oil rasio [16][19], reaction temperature [19], and reaction time [18]. To establish optimum conditions for transesterification, the application of statistical methods is attracting growing interest from many researchers. Of particular interest is a statistical technique known as response surface methodology (RSM) [7][24]. The main advantage provided by this technique is the disclosure of the effect of interaction between variables on the reaction of interest. This interaction effect is not obtained using a partial optimization approach, in which the optimum condition was formulated based on the optimum value of every single variable determined in sequence. Due to the advantage it offers, the RSM technique has been used to optimize transesterification reaction of varied raw materials including palm oil [24][25], waste cooking oil [7][26], coconut oil [27], *Podocarpus falcatus* oil [27], soybean oil [23], rubber seed oil [28], neem, animal fat, and jatropha oils [29]. Overall, the findings of the aforementioned previous studies demonstrate the usefulness of the RSM technique in formulating the optimum condition for transesterification of various feedstocks [30]. For this fundamental finding of previous workers, in this present work, the RMS was applied to optimize zeolite-A catalyzed transesterification of coconut oil involving three variables, i.e., catalyst load (CL, %), methanol to oil (M/O) ratio, and reaction time (t, min).

2. MATERIALS AND METHODS

2.1. Materials

Reagent grade sodium hydroxide (NaOH), nitric acid (HNO_3), and methanol (CH_3OH) were reagent grade from Merck. Rice husks, food-grade aluminum foil (FGAF), and coconut oil were supplied by local companies in the city of Bandar Lampung. Oven (Memmert UN Universal 321 Model), Thermolyne 1100 Mode Muffle furnace, Xpert MPD type XRD instrument, ZEISS EVO MA 10 SEM Instrument, Quantachrome Instruments type BET instrument, Shimadzu GCMS-QP2010 SE GC-MS instrument was used to analyze biodiesel produced and NIST12 MS Library Software was used to identify chemical components of the biodiesel.

2.2. Methods

2.2.1. General Procedure

The experiments carried out in this research consisted of extraction of rice husk silica (RH-SiO_2) using sol-gel method, utilization of RH-SiO_2 and FGAF as raw materials for preparation of zeolite-A using hydrothermal technique followed by characterization using XRD, SEM, and BET. Zeolite-A synthesized was then used to catalyze transesterification of coconut oil, focussing on RSM for optimization of the reaction. The biodiesel produced was analyzed by GC-MS method.

2.2.2. Extraction of RH-SiO_2

Extraction of RH-SiO_2 was carried out following previous research [31]. The rice husks were cleaned and dried before use. Then, 50 g of rice husks were extracted with 1.5% NaOH in 100 mL then boiled for 30 min, and finally aged for 24 h. The filtrate was collected by filtration and then neutralized using 10% HNO_3 solution. The SiO_2 gel formed was subjected to 24 h aging treatment, followed by 8 h oven drying at 100 °C, and finally crushed and sieved.

2.2.3. Synthesis of Zeolite-A

Preparation of zeolite-A was conducted using the procedure applied by previous worker [31]. First, 20 g of NaOH were dissolved in 250 mL of distilled water and the solution was divided into two portions. The first (150 mL), was used to dissolve

30 g of RH-SiO_2, while the second (100 mL) was used to dissolve 13.5 g of food-grade aluminium foil. The two solutions were mixed, and the mixture was stirred at stirring rate of 500 rpm for 3 h at atmospheric pressure. The mixture was transferred into an autoclave and left at room temperature for 24 h for aging purposes. The autoclave was then placed in an oven for crystallization process at 100 °C for 72 h. The solid formed was washed and dried at 100 °C in an oven for 8 h. The solid was subjected to calcination at 550 °C for 6 h, ground into powder, and finally sieved using a 250 nm mesh.

2.2.4. Transesterification Reaction

Transesterification reaction was carried out in a 500 mL round flask, with a transesterification apparatus connected to a refluxing condenser. The mixture of coconut oil, methanol, and catalyst at specified amounts was allowed to react at 70 ºC for varied times. Fixing the reaction temperature at 70 °C was based on boiling temperature of methanol used, in order to ensure the optimum contact between the oil and the methanol. Increased to higher temperature was not appropriate higher temperature will cause the methanol exist as vapor and therefore limit its contact with the oil. After the reaction, the mixture was filtered to separate the filtrate from the catalyst. The biodiesel and unreacted (residual) oil were separated using a separating funnel, and then the oil conversion was determined according to Equation 1 [12].

$$Oil\ conversion = \frac{V_i - V_f}{V_i}\ x\ 100\% \qquad (1)$$

where V_i represents the volume of coconut oil used as reactant, and V_f represents the volume of the remaining oil.

2.2.5. Proposed Model and Statistical Analysis

As previously mentioned, transesterification optimization was attempted by applying RSM based

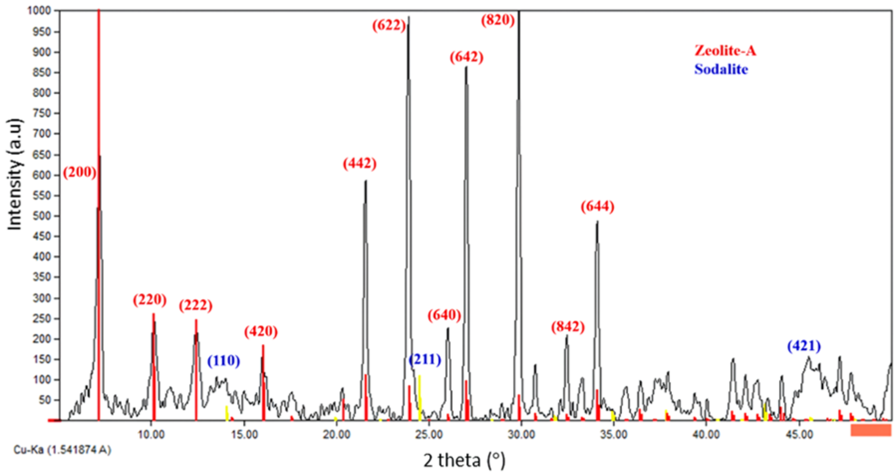

Figure 1. XRD profile of zeolite-A prepared.

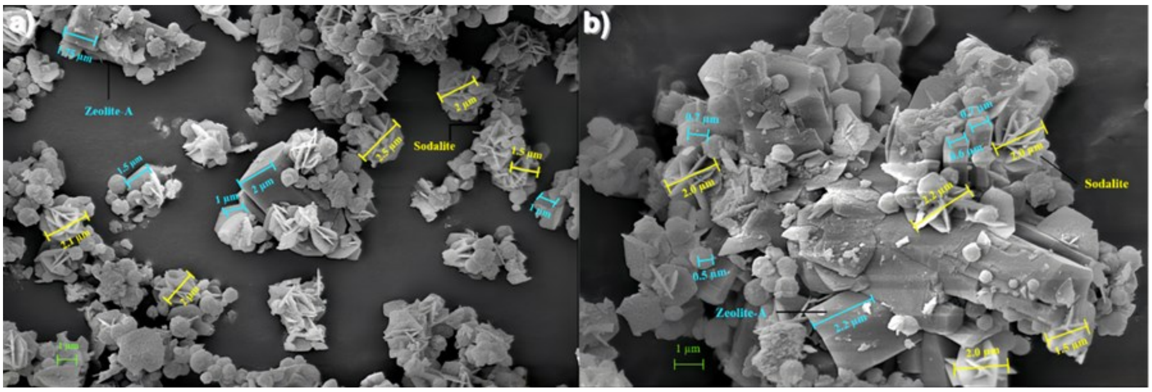

Figure 2. SEM image of synthesized sample with magnification of 10,000× (a) and 15,000× (b) showing the existence of zeolite-A and sodalite.

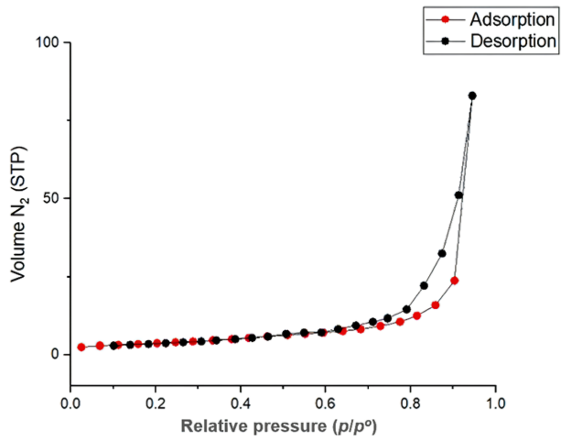

Figure 3. The N_2 adsorption and desorption of the synthesized zeolite-A.

Table 2. Experimental matrix, experimental oil conversion, and predicted oil conversion based on polynomial model.

Run	A	B	C	Oil Conversion (OC%)	
	CL (%)	(M/O) ratio	t (min)	Experimental	Predicted
1	5	3	60	98	98.99
2	5	5	37.5	90	92.99
3	7.5	4	37.5	77	73.57
4	2.5	3	37.5	32	38.86
5	5	4	60	99	99.88
6	2.5	5	37.5	81	74.18
7	2.5	4	37.5	49	50.43
8	5	4	37.5	80	74.94
9	2.5	5	15	70	70.93
10	7.5	4	37.5	67	73.57
11	5	4	15	70	73.04
12	2.5	3	60	80	75.13
13	5	3	15	69	62.18
14	7.5	4	37.5	77	73.57
15	5	3	60	98	98.99
16	7.5	3	15	70	72.85
17	5	5	37.5	90	92.99
18	7.5	5	37.5	88	85.92
19	2.5	5	60	98	100
20	7.5	5	60	100	99.53

on CCD. The CCD was selected since this technique is known to offer strong predictive and optimization capabilities, as well as better model precision compared to other methods. For these reasons, the CCD technique has been applied by other workers in order to investigate optimum conditions for transesterification of various feedstocks, such as Jatropha oil [32], sunflower oil [33], and waste cotton-seed cooking oil [34]. Investigation of the influence of independent variables, including catalyst load (CL, %), methanol to oil (M/O) ratio, and reaction time (t, min), and interactive effects of these variables on biodiesel yield as dependent variable was based on the proposed polynomial regression model shown in Equation 2 [25][26].

$$\hat{y} = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{j=1}^{i-1} \beta_{ij} X_i X_j + \varepsilon \qquad (2)$$

In the above model, ŷ = biodiesel yield as a response, β_0 = the intercept, X = independent variables, i is a linear coefficient, j is a quadratic coefficient, β_i = coefficient of linear interaction, β_{ii} = coefficient of quadratic interaction, and β_{ij} = coefficient of interaction effect, k = the number of factors investigated, and ε = random error [26]. The features of variables used to design experimental matrix are shown in Table 1.

The levels of variables used, as listed in Table 1, were used since these values are the most commonly applied in transesterification of vegetable oils, although some studies involved different values should be acknowledged and respected. Using statistical software (Design-Expert 13.0, USA), the variable features as shown in Table 1 were used to generate experimental matrix consisting of 20 transesterification experiments with varied levels of the variables. The features of the model include the significance and the fitness, the effect of a single variable, and the effect of interaction between independent variables on the response variable were evaluated using analysis of variance (ANOVA. If the experimental and predicted data are not significantly different (close to each other), the model is accepted (satisfactory). As a basic reference, a model is considered valid if the R^2 > 75% or the p-value ≤ 5%, with a level of confidence of 95% [35]. Visualization of the relationships between independent and dependent variables was prepared by drawing 3D response surface profiles and contour plots.

3. RESULTS AND DISCUSSIONS

3.1. Zeolite-A Characterization

Figure 1 represents XRD profile of the sample synthesized, indicating that the sample is crystalline material. Analysis of the diffractogram pattern using Match! Version 3.4.2 Build 96 software revealed that the sample is composed of zeolite-A as a primary phase and sodalite as a minor component. These two phases have also been reported by Djozing et al. in the sonohydrothermal synthesis of zeolite A [36]. SEM images displaying surface morphology of the zeolite-A produced as presented in Figure 2 support the XRD diffractogram, which suggests the presence of zeolite-A and sodalite as crystalline phases. As seen in Figure 2, the images are marked by coexistence

Table 3. The results of ANOVA for quadratic model proposed.

Source	Sum of Square	Degree of Freedom	Mean Square	F-value	P-value
Model	5548.87	9	616.54	20.04	< 0.0001*
A	572.60	1	572.60	18.61	<0.0001*
B	938.08	1	938.08	30.49	0.0002*
C	490.99	1	490.99	15.96	<0.0001*
AB	160.30	1	160.30	5.21	0.0456*
AC	121.17	1	121.17	3.94	0.0753
BC	136.59	1	136.59	4.44	0.0613
A^2	722.41	1	722.41	23.48	0.0007*
B^2	132.97	1	132.97	4.32	0.0643
C^2	424.30	1	424.30	13.79	0.0040*
Residual	307.68	10	30.77		
Lack of Fit	241.01	6	40.17	2.41	0.2069
Pure Error	66.67	4	16.67		
Total	5856,55	19			

***Note:** R^2 = 0.9475, adj R^2 = 0.9002, pred R^2 = 0.7256, adeq precision = 15.7104, C.V % = 7.01

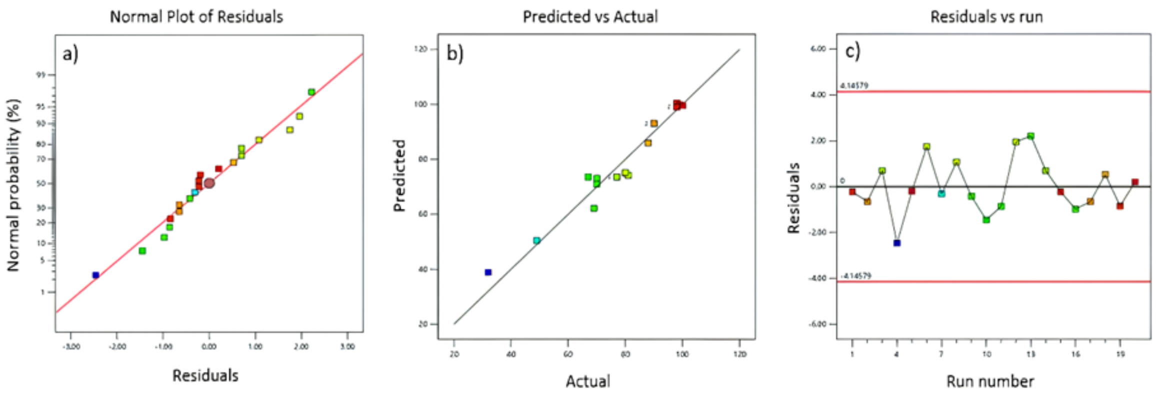

Figure 4. (a) Plot of experimental and predicted, (b) actual result data, and (c) residuals vs runs.

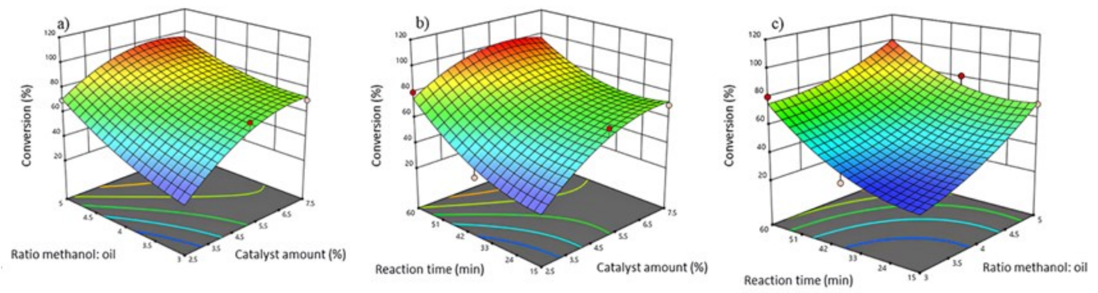

Figure 5. The surface response plots displaying interactions between variables (a) CL vs M/O ratio, (b) CL vs t ratio, and (c) M/O ratio vs t.

particles in the form of cubic shape, which is a unique shape of zeolite-A [31][37], and the particles look like a ball of thread [38], which is a characteristic shape of sodalite.

Characterization of the sample using BET produced the N_2 adsorption and desorption isotherm shown in Figure 3. The presence of a hysteresis loop marks the isotherm, and according to IUPAC classification, the isotherm belongs to type IV, implying that the sample is mesoporous material [38], with a pore diameter ranging from 2 to 50 nm. This pore diameter was suggested by previous workers to promote the passage of the reactants (vegetable oil) through the pores of the catalyst during transesterification reaction of waste vegetable oil for production of biodiesel [39]. Other characteristics of the sample provided by BET analysis are specific surface area (118.164 m^2/g), total surface area (13.447 m^2), average pore diameter (38.330 nm), and total pore volume (0.129 cm^3/g). Type IV isotherms have been reported by several workers as a characteristic adsorption-desorption feature of various mesoporous adsorbents, such as zeolites. As an example, Tao et al. reported the synthesis of mesoporous zeolite-A and suggested that this mesoporosity resulted in reduced mass transfer resistance, thereby enhancing the diffusion of reactant molecules when the zeolite is applied as catalyst [40]. This type IV isotherm was also displayed by hierarchical zeolite Y applied as catalyst for production of biodiesel from waste vegetable oil [39]. The zeolite-Y synthesized was reported to have surface area 331.628 m^2/g and an average pore size of 7.5073 nm. The pore size of the zeolite Y falls within the mesoporous range of 2 –50 nm, allowing the passage of the reactants through the pores [39]. In another study, zeolite specified ZRP-5 zeolite, applied as catalyst for production of biodiesel from oleic acid, was characterized using BET and observed that the type IV isotherm feature, with specific surface area of 312 m^2/g, and total pore volume of 0.240 cm^3/g [41].

3.2. Transesterification Result and Data Analysis

The predicted oil conversions and the actual conversions obtained from the experiments, presented in Table 2, display that both the predicted and actual results are varied depending on the values of the three variables involved. This variation reflects that the three variables affect to different extents on the reaction under investigation.

The data obtained from experiments were then analysed using Design Expert 13.0 software to generate the polynomial model which indicates the effect of the investigated factors (linear and quadratic), as well as the effect of interaction between the factors. The following model was then produced in Equation 3.

$$\hat{y} = 74.94 + 11.57A + 11.96B + 13.42C - 5.70AB - 6.34AC - 4.99BC - 12{,}94A^2 + 6.09B^2 + 11.52C^2 \quad (3)$$

In the polynomial equation above, positive coefficients were obtained for CL (A), the M/O ratio (B), duration of reaction (C), quadratic effect of methanol to oil ratio (B^2), and quadratic effect of reaction time (C^2), which means that they have a synergistic effect on the oil conversion. For the rest of the terms, negative coefficients were found, suggesting that they have an antagonistic effect on the reaction. The experimental data obtained were also evaluated using ANOVA method, and the significance of the coefficient of parameters was considered in terms of probability (P) value as presented in Table 3.

The value of P was then used as a criterion to reject the H_0 if the $P < 0.05$ and vice versa if the value of $P > 0.05$, which means that the H_1 is rejected. In this regard, since the P-value according to the model is less than 0.05, the H_0 is rejected and H_1 is accepted. More specifically, the model was found to have the P-value < 0.0001 indicating very strong evidence against the H_o, confirming the statistical significance of the model proposed. The P -value indicates the probability of error that can be used to confirm the significance of each regression coefficient. Another result of ANOVA is the F-value of 2.41, which implies that the Lack of Fit is not significant compared to pure error. In addition, there is a 20.69% possibility that the Fit F-value is due to noise.

Figure 4(a) shows a good normal distribution graph while Figure 4(b) shows the prediction and actual conversion graph. On the other hand, Figure 4(c) shows the residual versus run graph that the data are randomly distributed and approach the center line (0) without crossing the red line, which means that there are no outlier data, and meets the assumption of homoscedasticity.

The consequence of interaction effect between CL and M/O is displayed in Figure 5(a), demonstrating that the higher the M/O ratio the higher the conversion of coconut oil into biodiesel. It is also observed that increased CL to a maximum point led to increased oil conversion but then decreased. Interaction effect between CL and reaction time (t) is shown in Figure 5(b), demonstrating that the longer time, the greater the oil conversion, while increased catalyst load initially led to increased oil conversion to a maximum value and then decreased. Previous workers suggest that the use of excessive amounts of catalyst will increase the viscosity of the mixture and cause mixing problems during transesterification reaction, thus decreasing oil conversion into biodiesel [42]. The effect of interaction between the M/O ratio and t on oil conversion (OC) is depicted in Figure 5(c), showing that the OC increases as both the M/O oil ratio and t increase.

3.3. Optimization Process

Statistical analysis using CCD was applied to formulate the optimum oil conversion based on the polynomial model proposed. The criteria for optimization and the optimum conditions are

Table 4. Optimization criteria for coconut oil transesterification investigated.

Variables	Goal	Level	
		Lower value	Upper value
CL (%)	In the range	2.5	7.5
M/O ratio	In the range	3.0	5.0
Reaction time (t, min)	In the range	15.0	60.0
Oil conversion (%OC)	Maximum	32.0	100.0

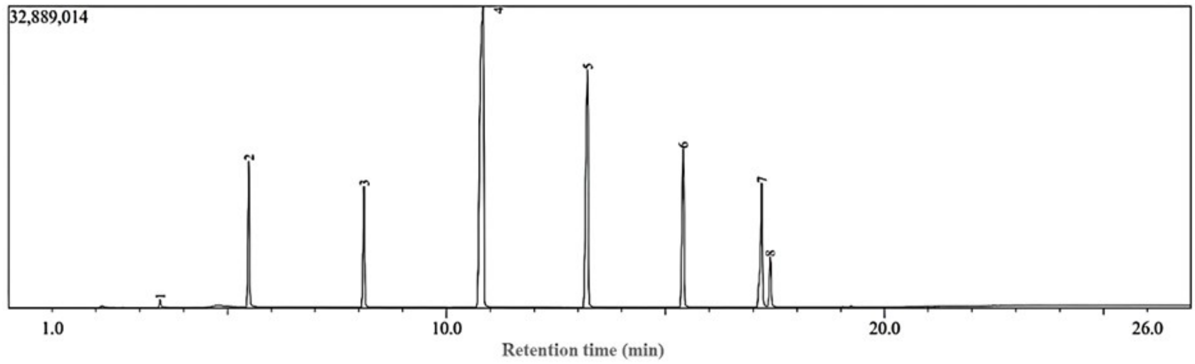

Figure 6. Chromatogram of the biodiesel sample representative.

Table 5. Composition of coconut oil derived biodiesel produced.

Peak Number	Retention Time (min)	Molecule Formula	Name	Relative Presentation
1.	3.461	$C_7H_{14}O_2$	Methyl caproate	0.40
2.	5.486	$C_9H_{18}O_2$	Methyl octanoate	7.76
3.	8.116	$C_{11}H_{22}O_2$	Methyl caprate	6.91
4.	10.838	$C_{13}H_{26}O_2$	Methyl laurate	41.37
5.	13.219	$C_{15}H_{30}O_2$	Methyl myristate	20.18
6.	15.405	$C_{17}H_{34}O_2$	Methyl palmitate	10.75
7.	17.195	$C_{19}H_{36}O_2$	Methyl oleate	9.60
8.	17.391	$C_{19}H_{38}O_2$	Methyl stearate	3.04

presented in Table 4. As seen in Table 4, the optimized model suggested that the maximum oil conversion (100%) was achieved from the experiment using CL of 2.5% catalyst, M/O ratio of 5, and reaction time (t) 1 h. To validate the optimization result, three experiments were undertaken and it was found that the average oil conversion of 98% was obtained, or a 2% deviation from the predicted maximum value (100%). This slight overestimation of the model is commonly observed in RSM-based models due to their reliance on idealized mathematical assumptions. In our case, the model does not fully account for minor experimental factors which can subtly reduce the actual conversion efficiency. Moreover, this very small deviation (2%) indicates that the model has high predictive accuracy and confirms the robustness of the optimization strategy for biodiesel production.

3.4. GC-MS Analysis

To confirm that the biodiesel was successfully produced, a GC-MS method was applied to analyze a sample resulting from the experiment with the highest %OC, producing GC-chromatogram presented in Figure 6. With reference to the standard data available in NIST12 MS Library System Software (NIST12), the components of the sample were identified and listed in Table 5. Chemical composition of the transesterification products, listed in Table 5, which is composed of fatty acid methyl esters (FAMEs), confirms successful conversion of coconut oil treated into biodiesel as expected. In addition, methyl laurate exists as the main component of the biodiesel (41.37%), which is in agreement with the relative percentages of fatty acids commonly found in coconut [19][43].

Previous workers have reported transesterification of coconut oil with different zeolite as catalyst, such as KNO_3/KL zeolite with oil conversion of 77.2% [44]. Other workers have reported application of various types of catalyst for production of biodiesel from different feed stocks, such as hierarchical zeolite for production of biodiesel from waste frying oils [45] and waste vegetable oil [39], ZSM-5 for biodiesel production from *Ricinus communis* oil [12], bifunctional catalyst for biodiesel production from coconut oil [27], and acid/base bifunctional catalyst for production of biodiesel from waste cooking oil [46]. In this current study, the composition of triglycerides composing the oil was not determined, however it is reasonable to assume that the composition of triglycerides is reflected by the composition of biodiesel produced, with respect to the oil conversion achieved (98%).

4. CONCLUSIONS

In this work, zeolite-A catalyzed transesterification reaction of coconut oil was studied using RSM-CCD statistical technique in order to establish optimum conditions based on catalyst load (CL), methanol to oil (M/O) ratio, and reaction time (t) parameters on the percentage of the oil converted into biodiesel (%OC). Based on the polynomial model established, it was found that the predicted and the experimental data are in good agreement, as indicated by the values of the R^2 = 0.9475 and the adj R^2 = 0.9002. Analysis of the variance of the data indicates that the optimum conditions were the CL of 2.5%, the M/O volume ratio of 5:1, and 1 h reaction time (t), resulting in oil conversion (OC) of 98% or only 2% error from the maximum value of 100% as predicted by the model.

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Conflicts of Interest

The authors declare no conflict of interest.

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REFERENCES

[1] W. N. A. Wan Osman, M. H. Rosli, W. N. A. Mazli, and S. Samsuri. (2024). "Comparative review of biodiesel production and purification". *Carbon Capture Science & Technology*. **13**. 10.1016/j.ccst.2024.100264.

[2] P. Varma, J. Otageri, and B. Kandasubramanian. (2024). "Biodiesel from fats: Fatty acid feedstock as a circular economy solution". *International Journal of Green Energy*. **21** (11): 2530-2550. 10.1080/15435075.2024.2319219.

[3] S. Pandey, I. Narayanan, R. Selvaraj, T. Varadavenkatesan, and R. Vinayagam. (2024). "Biodiesel production from

microalgae: A comprehensive review on influential factors, transesterification processes, and challenges". *Fuel.* **367**. 10.1016/j.fuel.2024.131547.

[4] G. Perumal. (2023). "Assessing biodiesel feedstocks and production techniques: a comprehensive review". *Petroleum Science and Technology.* **42** (25): 4556-4571. 10.1080/10916466.2023.2268148.

[5] S. Khanam, O. Khan, S. Ahmad, A. F. Sherwani, Z. A. Khan, A. K. Yadav, and Ü. Ağbulut. (2024). "A Taguchi-based hybrid multi-criteria decision-making approach for optimization of performance characteristics of diesel engine fuelled with blends of biodiesel-diesel and cerium oxide nano-additive". *Journal of Thermal Analysis and Calorimetry.* **149** (8): 3657-3676. 10.1007/s10973-024-12918-x.

[6] M. R. Hossain, M. A. Islam, and M. N. A. Siddiki. (2024). "Analysis of Compression Ignition Engine Performance of a Produced B20 Flaxseed Biodiesel". *American Journal of Pure and Applied Biosciences.* 152-159. 10.34104/ajpab.024.01520159.

[7] M. Elkelawy, E. A. El Shenawy, H. A. Bastawissi, M. M. Shams, V. E. P, D. Balasubramanian, V. Anand, and M. Alwetaishi. (2024). "Predictive modeling and optimization of a waste cooking oil biodiesel/diesel powered CI engine: an RSM approach with central composite design". *Scientific Reports.* **14** (1): 30474. 10.1038/s41598-024-77234-8.

[8] N. A. Fathurrahman, K. Ginanjar, R. D. Devitasari, M. Maslahat, R. Anggarani, L. Aisyah, A. Soemanto, M. D. Solikhah, A. Thahar, E. Wibowo, and C. S. Wibowo. (2024). "Long-term storage stability of incorporated hydrotreated vegetable oil (HVO) in biodiesel-diesel blends at highland and coastal areas". *Fuel Communications.* **18**. 10.1016/j.jfueco.2024.100107.

[9] I. Ullah Khan. (2024). "Review, Biodiesel Production from Basic to Advance Level Through Using Different Mechanism, Techniques, Approaches and How to Make It Commercialized". *Progress in Petrochemical Science.* **6** (1). 10.31031/pps.2024.06.000629.

[10] M. Ali Ijaz Malik, S. Zeeshan, M. Khubaib, A. Ikram, F. Hussain, H. Yassin, and A. Qazi. (2024). "A review of major trends, opportunities, and technical challenges in biodiesel production from waste sources". *Energy Conversion and Management: X.* **23**. 10.1016/j.ecmx.2024.100675.

[11] H. I. Mahdi, N. N. Ramlee, J. L. da Silva Duarte, Y. S. Cheng, R. Selvasembian, F. Amir, L. H. de Oliveira, N. I. Wan Azelee, L. Meili, and G. Rangasamy. (2023). "A comprehensive review on nanocatalysts and nanobiocatalysts for biodiesel production in Indonesia, Malaysia, Brazil and USA". *Chemosphere.* **319** : 138003. 10.1016/j.chemosphere.2023.138003.

[12] K. D. Pandiangan, W. Simanjuntak, S. Hadi, I. Ilim, and H. Amrulloh. (2021). "Physical characteristics and utilization of ZSM-5 prepared from rice husk silica and aluminum hydroxide as catalyst for transesterification of Ricinus communis oil". *Materials Research Express.* **8** (6). 10.1088/2053-1591/ac0365.

[13] K. Angassa, E. Tesfay, T. G. Weldmichael, S. Kebede, and C. Kordulis. (2023). "Response Surface Methodology Process Optimization of Biodiesel Production from Castor Seed Oil". *Journal of Chemistry.* **2023** : 1-12. 10.1155/2023/6657732.

[14] C. O. Asadu, B. N. Ekwueme, C. A. Ezema, T. O. Onah, I. S. Ike, J. O. Ugwuele, C. C. Aka, O. I. Maxwell, E. O. Umeagukwu, and C. C. Ogbonna. (2024). "Recycled waste groundnut oil: A potential feedstock for green energy/biodiesel synthesis". *Unconventional Resources.* **4**. 10.1016/j.uncres.2024.100081.

[15] R. Djayasinga, A. Setiawan, A. Purnomo, A. Z. Amien, and H. Hartanti. (2022). "Utilization of Breed Chicken Eggshells for Biodiesel Preparation from Waste Cooking Oil". *Journal of Multidisciplinary Applied Natural Science.* **2** (1): 41-46. 10.47352/jmans.2774-3047.90.

[16] K. D. Pandiangan, H. Satria, Z. Sembiring, W. Simanjuntak, D. I. Alista, N. Bramanthio, and R. N. Putra. (2024). "High-Performance

CaO/SiO2 Composite Prepared From Limestone And Pumice Silica As Catalyst For Rubber Seed Oil Transesterification". *Rasayan Journal of Chemistry*. **17** (01): 14-20. 10.31788/rjc.2024.1718684.

[17] D. T. Oyekunle, E. A. Gendy, M. Barasa, D. O. Oyekunle, B. Oni, and S. K. Tiong. (2024). "Review on utilization of rubber seed oil for biodiesel production: Oil extraction, biodiesel conversion, merits, and challenges". *Cleaner Engineering and Technology*. **21**. 10.1016/j.clet.2024.100773.

[18] K. D. Pandiangan, W. Simanjuntak, I. Ilim, D. I. Alista, and E. Noviana. (2025). "The Effect of MgO Loads on Catalytic Activity of MgO/SiO2 in Coconut Oil Transesterification". *Journal of Multidisciplinary Applied Natural Science*. **5** (2): 446-455. 10.47352/jmans.2774-3047.257.

[19] N. Widiarti, H. Bahruji, H. Holilah, Y. L. Ni'mah, R. Ediati, E. Santoso, A. A. Jalil, A. Hamid, and D. Prasetyoko. (2021). "Upgrading catalytic activity of NiO/CaO/MgO from natural limestone as catalysts for transesterification of coconut oil to biodiesel". *Biomass Conversion and Biorefinery*. **13** (4): 3001-3015. 10.1007/s13399-021-01373-5.

[20] A. Alabbsi. (2025). "Biodiesel Produced from Sunflower Oil via Heterogeneous Catalysts of Calcium Oxide Prepared from Eggshells Loaded on Barium Oxide". *Journal of the Turkish Chemical Society Section B: Chemical Engineering*. **8** (1): 59-72. 10.58692/jotcsb.1531152.

[21] K. D. Pandiangan, W. Simanjuntak, S. Hadi, I. Ilim, D. I. Alista, and D. A. Sinaga. (2023). "Study on the Reaction Parameters on Transesterification of Rubber Seed Oil Using MgO/zeolite-A Catalyst". *Trends in Sciences*. **20** (8). 10.48048/tis.2023.6480.

[22] S. Elfina, K. D. Pandiangan, N. Jamarun, F. Subriadi, H. Hafnimardiyanti, and R. Roswita. (2023). "Transesterification of Palm Oil Catalyzed by CaO/SiO2 Prepared from Limestone and Rice Husk Silica". *Journal of Multidisciplinary Applied Natural Science*. **4** (1): 49-57. 10.47352/jmans.2774-3047.185.

[23] M. Rahimi, B. Aghel, M. Alitabar, A. Sepahvand, and H. R. Ghasempour. (2014). "Optimization of biodiesel production from soybean oil in a microreactor". *Energy Conversion and Management*. **79** : 599-605. 10.1016/j.enconman.2013.12.065.

[24] K. D. Pandiangan, K. Nisa, W. Simanjuntak, D. I. Alista, E. Noviana, and S. A. Hasan. (2023). "Application of Response Surface Methodology (RSM) to Study Transesterification of Palm Oil in the Presence of Zeolite-A as Catalyst". *Journal of Multidisciplinary Applied Natural Science*. **4** (1): 146-157. 10.47352/jmans.2774-3047.201.

[25] N. H. Zabaruddin, L. C. Abdullah, N. H. Mohamed, and T. S. Y. Choong. (2020). "Optimization Using Response Surface Methodology (RSM) for Biodiesel Synthesis Catalyzed by Radiation-Induced Kenaf Catalyst in Packed-Bed Reactor". *Processes*. **8** (10). 10.3390/pr8101289.

[26] N. Hidouri and M. Mouftahi. (2022). "Response surface methodology (RSM) for biodiesel production from waste cooking oil: Study of fatty acid methyl ester (FAME) yield". *Journal of Renewable Energies*. **25** (1). 10.54966/jreen.v25i1.1071.

[27] F. O. Ifeanyi-Nze, C. O. Omiyale, M. M. Asugu, O. J. Adeleke, S. B. Lanade, I. A. Odumah, I. B. Idrees, G. A. Adebayo, A. G. Sherif, I. U. Okonkwo, P. A. Josiah, B. N. Chukwu, B. C. Iheanacho, and N. N. Chimezie. (2024). "Optimization of biodiesel production from coconut oil using a bifunctional catalyst derived from crab shell and coconut shell". *European Journal of Sustainable Development Research*. **8** (1). 10.29333/ejosdr/14188.

[28] S. B. Aryasomayajula Venkata Satya Lakshm, N. Subramania Pillai, M. S. B. Khadhar Mohamed, and A. Narayanan. (2020). "Biodiesel production from rubber seed oil using calcined eggshells impregnated with Al2O3 as heterogeneous catalyst: A comparative study of RSM and ANN optimization". *Brazilian Journal of Chemical Engineering*. **37** (2): 351-368. 10.1007/s43153-020-00027-9.

[29] O. D. Samuel, G. C. M. Patel, L. Thomas, D. Chandran, P. Paramasivam, and C. C. Enweremadu. (2024). "RSM integrated GWO, Driving Training, and Election-Based Algorithms for optimising ethylic biodiesel from ternary oil of neem, animal fat, and jatropha". *Scientific Reports*. **14** (1): 21289. 10.1038/s41598-024-72109-4.

[30] S. M. Asaad, A. Inayat, C. Ghenai, and A. Shanableh. (2024). "Response Surface Methodology in Biodiesel Production and Engine Performance Assessment". *International Journal of Thermofluids*. **21**. 10.1016/j.ijft.2023.100551.

[31] W. Simanjuntak, K. D. Pandiangan, Z. Sembiring, A. Simanjuntak, and S. Hadi. (2021). "The effect of crystallization time on structure, microstructure, and catalytic activity of zeolite-A synthesized from rice husk silica and food-grade aluminum foil". *Biomass and Bioenergy*. **148**. 10.1016/j.biombioe.2021.106050.

[32] C. Aseibichin, W. C. Ulakpa, I. Omenogor, E. Doyah, A. A. Olaseinde, O. C. Anakpoha, M. Keke, and S. Karuppannan. (2024). "Modeling and optimization of transesterification of Jatropha oil to fatty acid methyl ester: application of response surface methodology (CCD) and Taguchi orthogonal method". *RSC Advances*. **14** (17): 11784-11796. 10.1039/d4ra01149j.

[33] A. M. M. Saeed, S. Sharma, S. Z. Hassan, A. M. Ghaleb, and G. P. Cao. (2023). "Intensification and Optimization of FAME Synthesis via Acid-Catalyzed Esterification Using Central Composite Design (CCD)". *ACS Omega*. **8** (29): 26206-26217. 10.1021/acsomega.3c02434.

[34] S. Oza, P. Kodgire, and S. S. Kachhwaha. (2022). "Analysis of RSM Based BBD and CCD Techniques Applied for Biodiesel Production from Waste Cotton-Seed Cooking Oil via Ultrasound Method". *Analytical Chemistry Letters*. **12** (1): 86-101. 10.1080/22297928.2021.2019611.

[35] S. B. L. Ngomade, R. D. T. Tchuifon, R. F. T. Tagne, M. L. T. Ngueteu, H. M. Patai, G. N.-A. Nche, S. G. Anagho, and G. Liu. (2022). "Optimization by Response Surface Methodology of Biodiesel Production from Podocarpus falcatus Oil as a Cameroonian Novel Nonedible Feedstock". *Journal of Chemistry*. **2022** : 1-14. 10.1155/2022/3786602.

[36] W. Nzodom Djozing, S. Valange, S. I. Nikitenko, and T. Chave. (2024). "Sonohydrothermal synthesis of zeolite A and its phase transformation into sodalite". *Dalton Transactions*. **53** (39): 16407-16421. 10.1039/d4dt01943a.

[37] J. Madhu, A. Santhanam, and D. Velauthapillai. (2024). "Synthesis of "Ice Cube" Shaped Zeolite A Type and Cu(2+) Ion-Exchanged Zeolites and Study of Their CO(2) Adsorption Performance". *ACS Omega*. **9** (46): 45926-45942. 10.1021/acsomega.4c05487.

[38] H. E. (2017). "Synthesis of Phase-Pure Zeolite Sodalite from Clear Solution Extracted from Coal Fly Ash". *Journal of Thermodynamics & Catalysis*. **08** (02). 10.4172/2157-7544.1000187.

[39] M. A. Sayed, S. A. Ahmed, S. I. Othman, A. A. Allam, W. Al Zoubi, J. S. Ajarem, M. R. Abukhadra, and S. Bellucci. (2022). "Kinetic, Thermodynamic, and Mechanistic Studies on the Effect of the Preparation Method on the Catalytic Activity of Synthetic Zeolite-A during the Transesterification of Waste Cooking Oil". *Catalysts*. **13** (1). 10.3390/catal13010030.

[40] Y. Tao, H. Kanoh, and K. Kaneko. (2005). "Synthesis of mesoporous zeolite a by resorcinol-formaldehyde aerogel templating". *Langmuir*. **21** (2): 504-7. 10.1021/la047686j.

[41] K. Sun, J. Lu, L. Ma, Y. Han, Z. Fu, and J. Ding. (2015). "A comparative study on the catalytic performance of different types of zeolites for biodiesel production". *Fuel*. **158** : 848-854. 10.1016/j.fuel.2015.06.048.

[42] B. Sangeetha, S. Mohana Priya, R. Pravin, K. Tamilarasan, and G. Baskar. (2023). "Process optimization and technoeconomic assessment of biodiesel production by one-pot transesterification of Ricinus communis seed oil". *Bioresource Technology*. **376** : 128880. 10.1016/j.biortech.2023.128880.

[43] U. S. P. R. Arachchige, K. A. V. Miyuranga, D. Thilakarathne, R. A. Jayasinghe, and N. A. Weerasekara. (2021). "Biodiesel-Alkaline Transesterification Process for Methyl Ester Production". *Nature Environment and Pollution Technology*. **20** (5). 10.46488/NEPT.2021.v20i05.013.

[44] J. Jitputti, B. Kitiyanan, P. Rangsunvigit, K. Bunyakiat, L. Attanatho, and P. Jenvanitpanjakul. (2006). "Transesterification of crude palm kernel oil and crude coconut oil by different solid catalysts". *Chemical Engineering Journal*. **116** (1): 61-66. 10.1016/j.cej.2005.09.025.

[45] E. G. Fawaz, D. A. Salam, S. R. S, and T. J. Daou. (2021). "Hierarchical Zeolites as Catalysts for Biodiesel Production from Waste Frying Oils to Overcome Mass Transfer Limitations". *Molecules*. **26** (16). 10.3390/molecules26164879.

[46] M. Mulyatun, J. Prameswari, I. Istadi, and W. Widayat. (2024). "Synthesis Method Effect on the Catalytic Performance of Acid–Base Bifunctional Catalysts for Converting Low-Quality Waste Cooking Oil to Biodiesel". *Catalysis Letters*. **154** (8): 4837-4855. 10.1007/s10562-024-04643-9.