International Research Journal of Multidisciplinary Scope (IRJMS), 2024; 6(2): 1282-1297

Original Article | ISSN (O): 2582-631X DOI: 10.47857/irjms.2025.v06i02.03948

Optimization of Foraha Oil Biodiesel Production throgh Transesterification: A Comparative Study of Response Surface Methodology and Artificial Neural Networks

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Abstract

Biodiesel is an environmental free and substitute for diesel fuel it's derived from different seeds and vegetable oil it contains long-chain mono alkyl esters. Crude Foraha oil (FO) was assessed in this study as a suitable fuel for the production of biodiesel. At 57.30 mg KOH/g, foraha oil has a high acid value. In order to lower the acid value to 0.85 mg KOH/g, degumming, esterification, and transesterification procedures were carried out. To enhance the yield of biodiesel, the RSM tool optimizes the following parameters: temperature, catalyst amount, reaction time, methanol to oil ratio, and stirrer speed. A quadratic response surface regression model was employed to predict the yield. With a predicted biodiesel yield of 97%, the ideal parameters were found to be a methanol-to-oil ratio of 1:3, catalyst concentration of 2wt% stirring speed of 500 rpm, and reaction duration of 110minutes.Response surface methodology (RSM) and artificial neural networks (ANN) are used to compare the expected biodiesel yield. RSM data was used to train the artificial neural network. Sensitivity analysis was used to assess each in-dependent variable's impact on the reaction. R^2values of RSM and ANN is 97 and 98 respectively. Furthermore, the methyl ester properties of the produced biodiesel meet the fuel specifications outlined in the ASTM D6751 and EN 14214 standards.

Keywords: Biodiesel Production, Degumming, Forahaoil (FO), Optimization Process and Physicochemical Properties, Transesterification.

Introduction

The growing interest in alternative fuels is driven by increasing energy demands and the dwindling reserves of fossil fuels. Fossil fuel consumption has contributed significantly to environmental challenges, including climate change, air pollution, and fluctuating fuel prices. As a result, finding economically feasible alternative fuels is crucial for sustainable development, which has led to a greater focus on biodiesel. Due to its high molecular weight, biodiesel has a low volatility and experiences minimal viscosity variation with temperature (1). This renewable, clean-burning fuel can be derived from both virgin and used vegetable oils, whether edible or non-edible (2). Biodiesel production typically involves converting oils, primarily triglycerides, through a transesterification process with various oil-rich vegetable sources (3). However, using edible oils raises concerns about competition with food resources over the long term (4). Non-edible oil sources are now being explored extensively worldwide, particularly in regions with wastelands unsuitable for food production (5). Because they are readily available in many regions of the world, particularly wastelands unsuitable for food crops, non-edible oil resources are thus attracting interest on a global scale (6). Biodiesel usage in diesel engines helps reduce emissions, including particulate matter, carbon monoxide, and unburned hydrocarbons. Non-edible feedstocks commonly used for biodiesel include *Ricinus communis* oil, *Madhucaindica* raw seeds, raw Pongamiapinnata oil, and *Jatrophacurcas* seeds, with *Calophyllum inophyllum* and Jatrophacurcas seeds standing out due to their high oil content and non-food status. Transesterification is a commonly used technique in biodiesel production, consisting of three sequential reactions: triglycerides first convert to diglycerides, then to monoglycerides, and finally to glycerol, with esters formed as by-products at each stage. Typically, biodiesel production utilizes either acid or alkaline catalysts,

(Received 28th January 2025; Accepted 23rd April 2025; Published 30th April 2025)

with the choice depending on the acid value or free fatty acid (FFA) content in the different feed stock oil. For example, Acid esterification was performed by alkali transesterification on *karanja* oil with an FFA content of 2.53% (5.06 mg KOH/g) using H_2SO_4. It was also indicated by the use of oils with high FFA require a two-step process—acid esterification followed by alkaline transesterification—to achieve high biodiesel yields (7-9). One promising biodiesel feedstock is *Calophyllum inophyllum*, a versatile tree from the Clusiaceae family, related to the mangosteen. *C. inophyllum* is native to regions such as East Africa, India, Southeast Asia, Australia, and the South Pacific (10, 11). It thrives in areas with annual rainfall between 1,000–5,000 mm and at altitudes ranging from sea level up to 200 m. This species is a slow-growing, low-branching tree that thrives in sandy, well-drained soils and has the potential to be a sustainable source of biodiesel.

For large-scale biodiesel production, it is essential to conduct an optimization analysis of the production process (12). Using Design of Experiments (DOE) for biodiesel optimization helps identify the key parameters that affect transesterification conditions and measure the resulting biodiesel yield (13). Response Surface Methodology (RSM) is commonly applied to evaluate the effects of multiple process parameters. RSM employs multiple regression and correlation analyses to examine the influence of two or more independent variables on dependent outcomes. A mathematical model was developed through Central Composite Design (CCD) within the RSM framework to explore various process parameters (14). Key parameters for each trial were selected to predict optimal conditions, while Analysis of Variance (ANOVA) was used to analyze parameter effects and establish relationships between factors and outcomes (15).

In recent years, Artificial Neural Networks (ANNs) have become widely recognized as powerful modeling tools for complex problems (16). ANN offers several advantages over traditional modeling approaches, as it does not rely on assumptions about the nature of the process or require a deep mathematical understanding of underlying mechanisms. Instead, ANNs can learn both linear and nonlinear relationships directly from data examples (17). With efficient algorithms, ANNs can overcome modeling challenges and produce enhanced results, making them suitable for predicting and optimizing the transesterification process of vegetable oils (18). Therefore, ANN serves as an effective technique for forecasting and optimizing complex process parameters.

Various researchers have explored different methods to optimize biodiesel production from *Calophyllum inophyllum* oil. A two-step process utilizing acid-catalyzed esterification with modified phosphoric acid, followed by KOH-catalyzed transesterification was used for optimizing the esterification phase using response surface methodology and then the biodiesel was subsequently tested for fuel properties (19). Also, by using zirconia catalyst effectively for the raw pinnai oil esterification, a substantial decrease in free fatty acids from 39 mg to 1.7 mg KOH/g oil under optimized conditions (63.2°C reaction temperature, oil to methanol ratio of 1:12, with catalyst 0.5%) were achieved (20). A four-stage production process like degumming, esterification, a two-step transesterification process, and neutralization is used for biodiesel synthesis from crude tamunu oil, reaching a 98.82% yield with a methanol-to-oil molar ratio optimized catalyst (NaOH) as 1 wt% at temperature of 50°C for two hours. This biodiesel blend exhibited favorable engine performance, aligning with ASTM specifications (21). In the present outline a new seed crew and oil removal machine is used for achieving bio-diesel production using a methanol molar ratio of 8:1, KOH catalyst 1 wt%, at reaction heating point 65°C over 95 minutes, later the testing confirmed the compliance with ASTM 6751 standards, underscoring the suitability of *C. inophyllum* oil for biodiesel (22). Finally, a three-stage transesterification process started with, first acid esterification, second step transesterification, and finally post-treatment process, for optimizing key variables in a biodiesel output process. Although research on using alkali catalysts like KOH for *C. inophyllum* biodiesel has been limited, these catalysts are noted for their cost-effectiveness and high catalytic efficiency (23).

The previous study proved that very less research work has been completed on the bio-diesel production from raw crude *C. inophyllum* oil (Foraha oil) using a KOH catalyst, by optimizing biodiesel conversion and green chemistry parameters through response surface

methodology (RSM), additionally using artificial neural networks (ANN) in estimating fatty acid methyl ester quality, comparing RSM and ANN prediction accuracy in bio-diesel methyl ester production, for which a polynomial equation (quadratic) was developed to assess the effect of different variables such as raw oil to methanol ratio, concentration of catalyst, reaction interval, and temperature on biodiesel efficiency. Optimization was conducted with DOE10 software. Additionally, this research investigates the predictive capabilities of the models' performance was statistically analyzed using the r-squared and also mean square error.

Methodology

Extraction of *Calophyllum inophyllum* oil

Foraha oil seeds were gathered from perendurai, Tamilnadu as they are abuduntly available. The seeds were then allowed to dry in the sun until they turned reddish-brown. The oil from the Foraha seed is extracted using a hydraulic machine. Following extraction, the leftover seed cake has significant commercial potential and can be applied to both industrial and agricultural settings. Numerous contaminants and chemical compounds were discovered in the extracted Foraha oil as shown in Figure 1. Therefore, before turning crude Foraha oil into biodiesel, it is crucial to go through a degumming procedure.

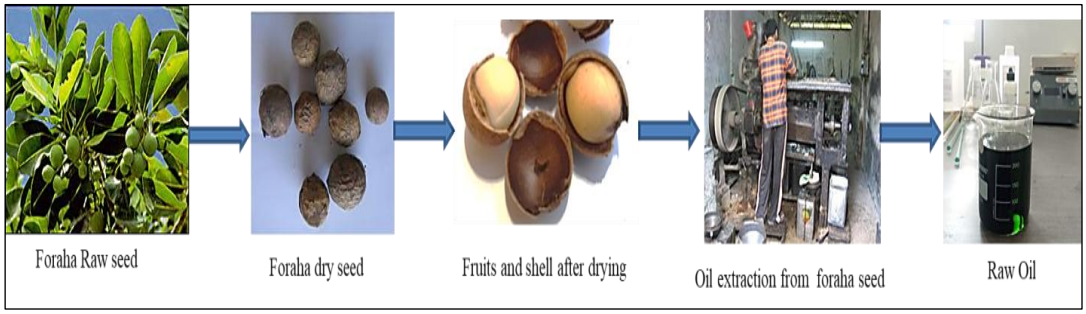

Figure 1: Extraction Process of Foraha Oil

Degumming Process

Foraha oil gum contains various impurities, including phosphates, proteins, carbohydrates, water residues, and resins. To enhance the oxidative stability of the final product, these gums are removed through a degumming process. The crude oil is first heated to 70°C and stirred at 900 rpm. Next, 0.5 volume of phosphoric acid (20% H_3PO_4) is added to the heated oil. Stirring continues, maintaining a 70°C temperature for 30 minutes. Following this, the mixture undergoes a density separation process using a separating funnel upto 6 hours, allowing phosphate compounds to settle at the bottom. The separated gums are washed number of times with refined water at 50°C. Finally, residual water is vanished by heating and stirring the oil for 30 minutes

Estrification Process

Degummed Foraha oil has a more free fatty acid (FFA) content and viscosity, greater than the recommended FFA limit of 2 wt.%. Therefore, an acid-catalyzed esterification pretreatment is needed before transesterification. Hydrochloric acid (HCl) is used in this step to lower the FFA content to below 2 wt.%. Thus, a two-step catalyzed esterification with acid followed by transesterification-is employed to produce metyel esters from Foraha oil with high FFA levels. Initially, crude Foraha oil is placed in a preheated reactor at 60°C. Methanol (in a 9:1 ratio to oil) and 1 vol.% HCl catalyst are mixed and supplementary to the reactor. The mixture is stirred continuously at 500 rpm with an overhead stirrer for 1.5 hours, while 60°C maintaining a constant temperature. After esterification, the esterifed oil is shifted to a separation process -funnel for 6 h to allow aquatic and additional methanol to settle. The esterified oil forms the upper layer, while water and excess methanol settle below. Esterified oils is mixed with condensed water at 50 degrees.

Transesterification Process

Following the esterification procedure, the FFAvalue was decreased to below 2wt/wt %. The esterified Foraha oil was then measured and transferred to a bottom flask. This oil was preheated to 50°C using a heating circulator. A 1 wt.% KOH and a 9:1 methanol ratio were combined

until the KOH was completely dissolved. The resulting methanol-KOH mixture was then added to the warmed Foraha oil. During the transesterification process, the blend was agitated continuously at 500 rpm using an overhead stirrer, with the temperature held at 50°C for 1.5 hours. Figure 2 shows the biodiesel production process and separating funnel.

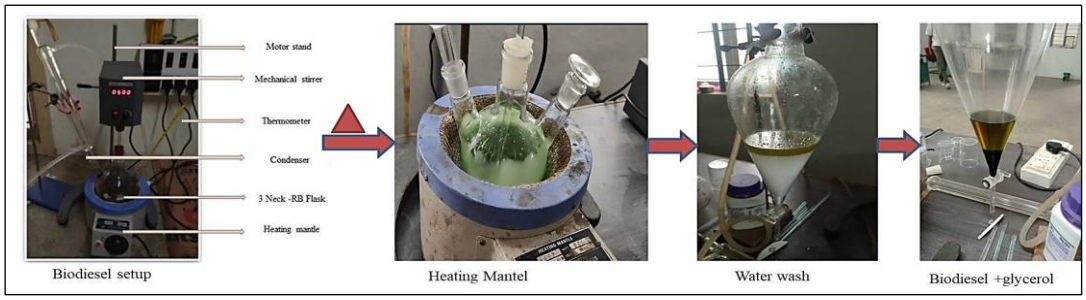

Figure 2: Biodiesel Production Process with Transestrification Process

Results and Discussion

Optimization of Process Parameters on Biodiesel Production

The optimization of biodiesel production using a KOH was carriedout through design of experts with Response Surface Methodology tool (RSM). Key parameters for methyl esters productionincluding catalyst weight, oil ratio, time duration, and temperature of reactionwere examined using a Central Composite Design (CCD) approach. A survey of pertinent literature was used to identify the process parameters and their ranges. Table 1 lists the chosen parameters along with their five levels. A total of 30 experiments were conducted in a randomized order to reduce potential errors. The CCD matrix for the experimental design is displayed in Table 2, and a quadratic equation was applied to represent methyl ester conversion, as shown in Equation [1].

$$Yield\ (\%) = \beta_{\circ} + \sum_{i=1}^{K} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1} \sum_{j=i+1} \beta_{ij} X_i X_j + \varepsilon \qquad [1]$$

Here, βo represents the intercept, while βi, βii, and βij correspond to the linear, quadratic, and interaction coefficients of the process variables, respectively. Xi and Xj denote the independent variables, and k indicates the total number of these variables.

Table 1: Experimental Variables

Parameters	Representation	Level	
		Lower value	Higher value
Temperature (°C)	A	40	60
KOH Catalyst (wt. %)	B	1	2
Time duration for reaction (minutes)	C	60	110
Methanol to molar ratio	D	3	9

Notes: Stirrer Speed= 500 rpm

Table 2: Optimizing Reaction Variables through Experimental Design

S.no	Temperature (°C)	KOH (wt.%)	Time duration for reaction (minutes)	Methanol: oil (molar ratio)	Biodiesel yield (%)	RSM Predicted values
1.	40	2	110	9	90	90
2.	60	1	110	3	90	87
3.	40	1	110	3	91	93

4.	60	2	110	9	97	96
5.	50	2	90	6	93	93
6.	50	1.5	90	3	96	96
7.	60	2	60	9	82	82
8.	50	2	60	9	94	94
9.	60	1	60	3	93	96
10.	40	1.5	90	6	70	71
11.	50	1.5	90	6	93	92
12.	50	2	90	6	93	93
13.	50	1.5	90	6	93	92
14.	40	2	60	3	60	61
15.	40	1	110	9	94	93
16.	50	1.5	90	6	92	93
17.	50	1.5	90	6	94	92
18.	60	2	110	3	97	99
19.	50	1.5	90	6	92	92
20.	60	1	110	9	75	76
21.	40	1	60	9	90	90
22.	50	1.5	90	6	92	92
23.	50	1.5	60	6	97	98
24.	60	2	60	3	90	87
25.	50	1.5	90	6	90	92
26.	50	1.5	90	6	96	92
27.	40	2	110	3	85	83
28.	60	1	60	9	84	83
29.	40	1	60	3	94	92
30.	50	1.5	90	6	94	92

Single Parameters Effecting on Biodiesel Yield

Influence of the Oil to Methanol Ratio: Figure 3 illustrates the effect of the methanol ratio on biodiesel yield. A ratio of 1:3 methanol to oil, with a catalyst concentration of 2 wt%, time of 110 min, and a temperature of 60°C, produced the highest yield of 97%. Ideally, triglyceride should react with methanol; however, a greater-than-stoichiometric amount is required for complete methyl conversion. As shown in Figure 3, increasing the ratio of Foraha oil-to-methanol from 3:1 to 9:1 enhances biodiesel yield. However, further increases up to 1:9 reduce yield. This decrease may be due to the reversible nature of transesterification, where excess methanol can deactivate the catalyst and shift the reaction backward, thus lowering conversion efficiency.

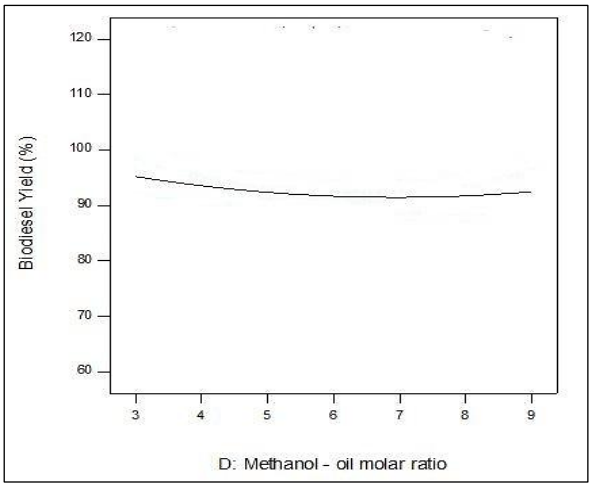

Figure 3: Biodiesel Yield vs. Methanol: Oil Ratio

Effects of KOH Catalyst Amount: Among the process variables, the amount of KOH plays a crucial role in biodiesel production from Foraha oil. Increasing the catalyst concentration from 1 to 2% by weight enhances the yield, as more active sites become available for the reaction. However, as shown in Figure 4, further increases in catalyst concentration lead to a decrease in biodiesel output. This reduction occurs because excess catalyst reduces the availability of active sites and triggers saponification. The soap produced during this reaction emulsifies glycerol and methyl ester, making separation more difficult and ultimately lowering biodiesel yield.

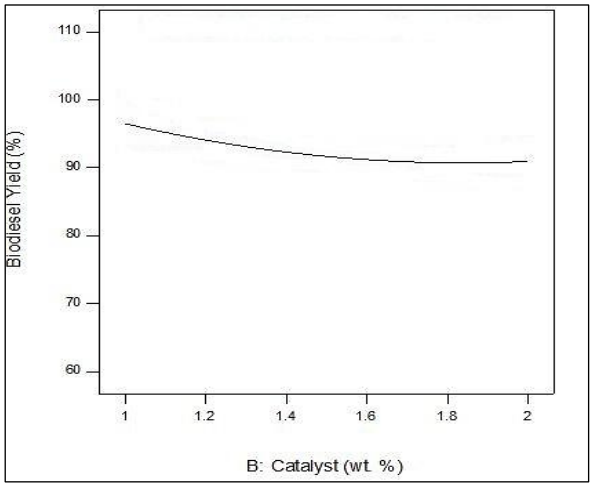

Figure 4: Biodiesel Yield vs. Catalyst

Effect of Temperature: Figure 5 depicts how reaction temperature influences methyl ester biodiesel production. This study investigated biodiesel yield by adjusting the temperature between 30°C and 60°C. Increasing the temperature improves the solubility and mass transfer of oil and methanol while also decreasing oil viscosity. However, temperatures above the optimal range increase soap formation, leading to higher ester losses and more difficulty in separation during the settling phase. As shown in Figure 5, higher temperatures also cause greater methanol evaporation, which reduces methyl ester conversion by limiting the availability of methanol for reaction with the catalyst and oil.

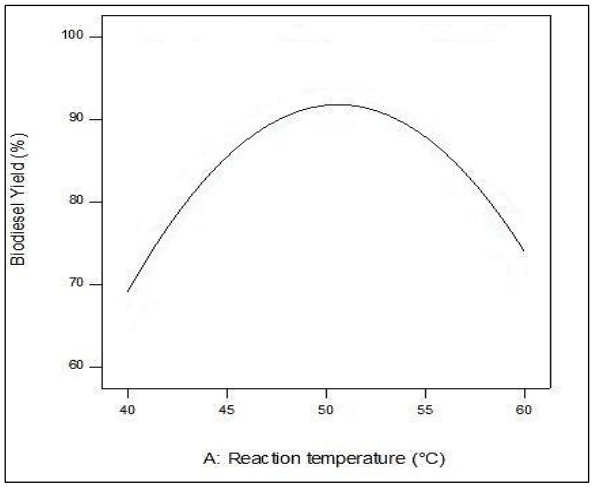

Figure 5: Biodiesel Yield vs. Reaction Temperature

Effect of Time Duration for the Reaction: Figure 6 demonstrates the effect of reaction time on ester production. Under the conditions of 60°C process temperature, 2 wt% catalysts, and a 1:3 oil to methanol molar ratio, the biodiesel yield increases with longer reaction times. Conversion Time is necessary for the esterified oil and methanol to interact effectively. Thus, identifying the optimal reaction time is essential for efficient methyl ester production.

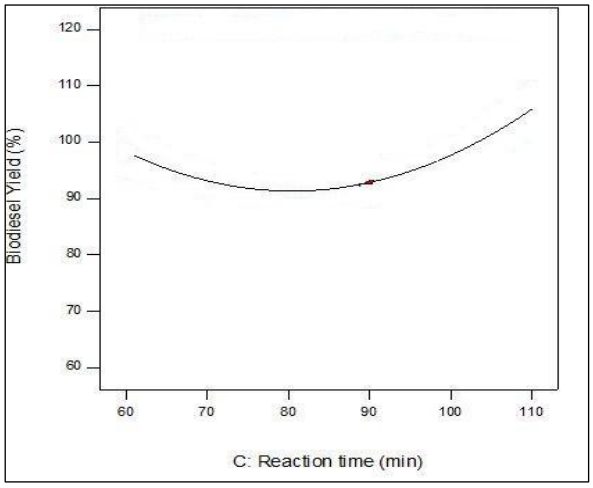

Figure 6: Biodiesel Yield vs. Reaction Time

Effects of Interaction Variables: To investigate how process factors interact to affect the yield of biodiesel, independent variables were varied while keeping others constant. Figure 7 illustrates how different parameters interact to affect biodiesel yield. It shows that increasing both catalyst concentration and reaction temperature boosts biodiesel yield due to their synergistic effect. The collision between oil and methanol molecules is enhanced by higher catalyst concentration and temperature, providing more active sites for the reaction, which drives it forward. Nevertheless, the yield of biodiesel rose with temperature and catalyst concentration up to 60°C and 2 weight present, respectively, before starting to fall. The relationship between the catalyst and methanol showed a similar pattern. However, the yield of biodiesel was adversely affected by the interplay between reaction duration and the methanol molar ratio. Although yield was somewhat increased by raising both parameters, subsequent increases resulted in a decline. Excess methanol and a protracted reaction time that resulted in a reverse reaction were the causes of this drop. Furthermore, excessive methanol decreased catalyst efficacy, which further decreased yield. Longer reaction durations have the potential to turn methyl ester back into triglycerides since transesterification is a reversible process. Consequently, a 1:3 oil-to-methanol ratio and a 60-minute reaction period were determined to be the ideal parameters for the manufacture of biodiesel.

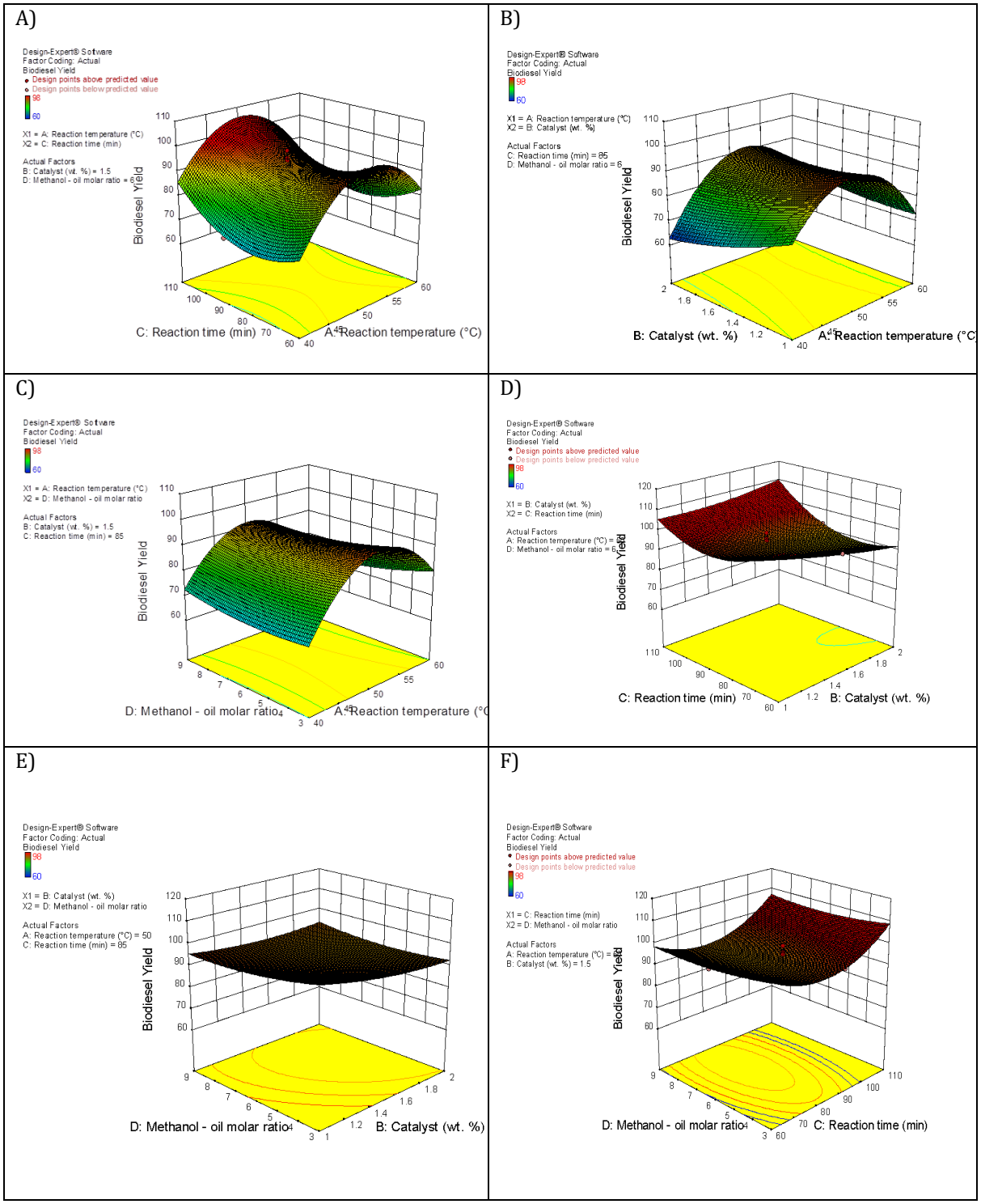

Figure 7: Surface Plots (A) Reaction Time and Temperature (B)Catalyst and Reaction Temperature (C) Methanol: Oil and Reaction Temperature (D) Reaction Time and Catalyst (E) Methanol: Oil and Catalyst (F) Methanol: Oil and Time

Table 3: ANOVA Analysis

Source	Sum of Squares	Df	Mean Square	F- Value	p-value Prob > F	Significant
Model	1955.44	14	139.67	26.89	< 0.0001	Significant
A-Reaction temperature (C)	85.67	1	85.67	16.49	0.0010	
B-Catalyst (wt. %)	114.50	1	114.50	22.04	0.0003	
C-Reaction time (min)	211.79	1	211.79	40.77	< 0.0001	
D-Methanol - oil molar ratio	29.07	1	29.07	5.60	0.0319	
AB	455.37	1	455.37	87.66	< 0.0001	
AC	83.95	1	83.95	16.16	0.0011	
AD	96.99	1	96.99	18.67	0.0006	
BC	396.32	1	396.32	76.29	< 0.0001	
BD	45.38	1	45.38	8.73	0.0098	
CD	3.92	1	3.92	0.76	0.3985	
A2	711.78	1	711.78	137.02	< 0.0001	
B2	8.26	1	8.26	1.59	0.2265	
C2	128.71	1	128.71	24.78	0.0002	
D2	6.72	1	6.72	1.29	0.2732	
Residual	77.92	15	5.19	Residual	77.92	
Std. Dev.	2.28			R-Squared	0.9617	
Mean	89.77			Adj R-Squared	0.9259	

The model's significance is demonstrated by its F-value of 26.89, with only a 0.01% probability that such a high value is due to noise (Table 3). A "Prob> F" value below 0.0500 indicates significant model terms, while values above 0.1000 suggest insignificance. In this case, A, B, C, D, AB, AC, AD, BC, BD, A^2, and C^2 are identified as significant terms. If the model includes numerous insignificant terms, reducing them may improve its performance. The "Lack of Fit F-value" of 2.40 suggests that the lack of fit is not significant compared to pure error, with an 11.52% likelihood of occurring due to noise. Since a non-significant lack of fit is preferable, this result indicates a well-fitting model.

$$\text{Biodiesel Yield} = 91.68+2.40*A-2.78*B+3.78*C-1.37*D+5.73*AB-2.47*AC-2.64*AD+5.13*BC+1.74*BD+0.51*CD-20.19*A^2+2.04*B^2+10.39*C^2+2.17*D^2 \quad [2]$$

Predictions about the reaction can be made for specific quantities of each component using an equation [2] based on coded factors. In this equation, the high and low levels of the components are represented by +1 and -1, respectively. By analyzing the factor coefficients, the coded equation helps assess the relative significance of each element. Based on the model signification Figure 8 shows the predicted yield with respective experimental values.

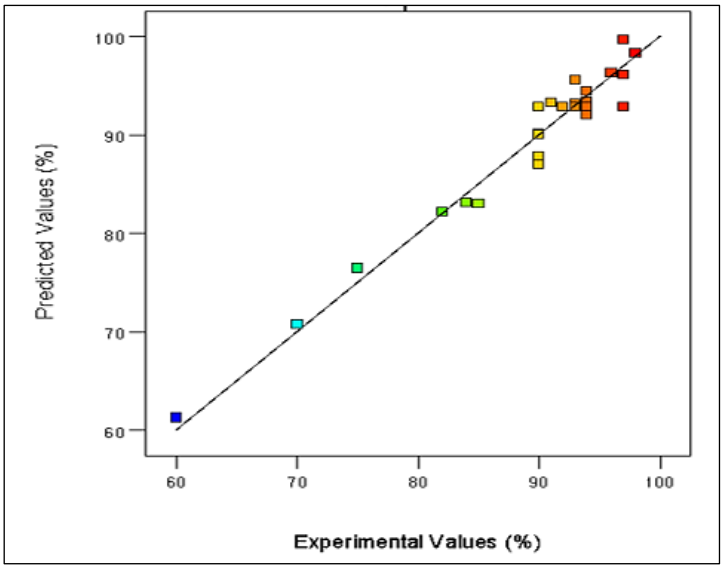

Figure 8: Experimental Biodiesel Yield vs. RSM Predicted Yield

Artificial Neural Network Analysis

Analysis, Experimental Validation, and ANN Modeling: The damped least-squares were chosen for this investigation due of its shown ability to produce precise predictions. Using the criterion of maximizing the coefficient of determination and decreasing mean squared error (MSE), the ideal number of neurons was found through optimization within the range of 2 to 16. According to earlier studies, Kolmogorov's theorem served as guidance when choosing the number of neurons in the hidden layer. As the regression coefficients for training, testing, validation, and overall were 0.95, 0.99, 0.98, and 0.97, respectively, as illustrated in Figure 10. The optimal encapsulation for validation was found at epoch 6 with a minimum MSE of 0.05, as shown in Figure 11. The model performed well, as evidenced by r squared of 0.99. Figure 9 displays the ANN model's prediction capabilities, demonstrating the model's accuracy in forecasting the output data.

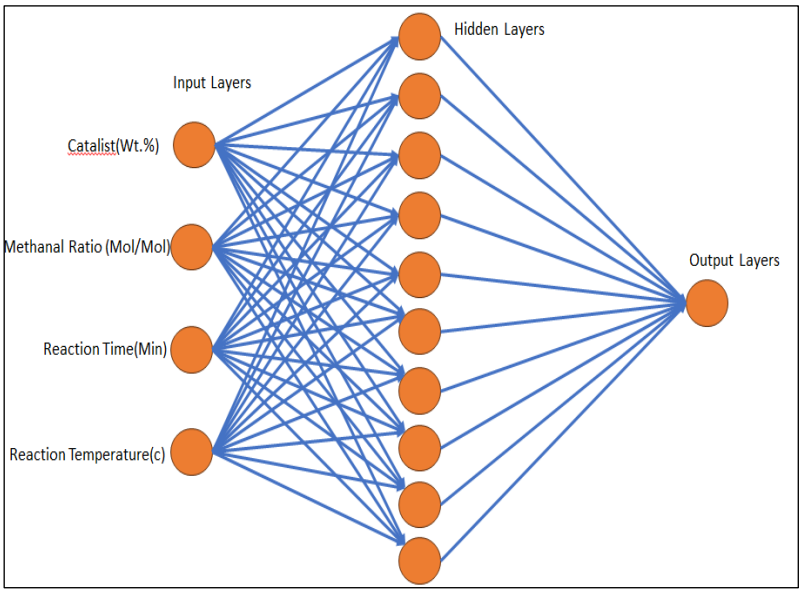

Figure 9: The ANN Model Developed for Predicting Biodiesel Yield

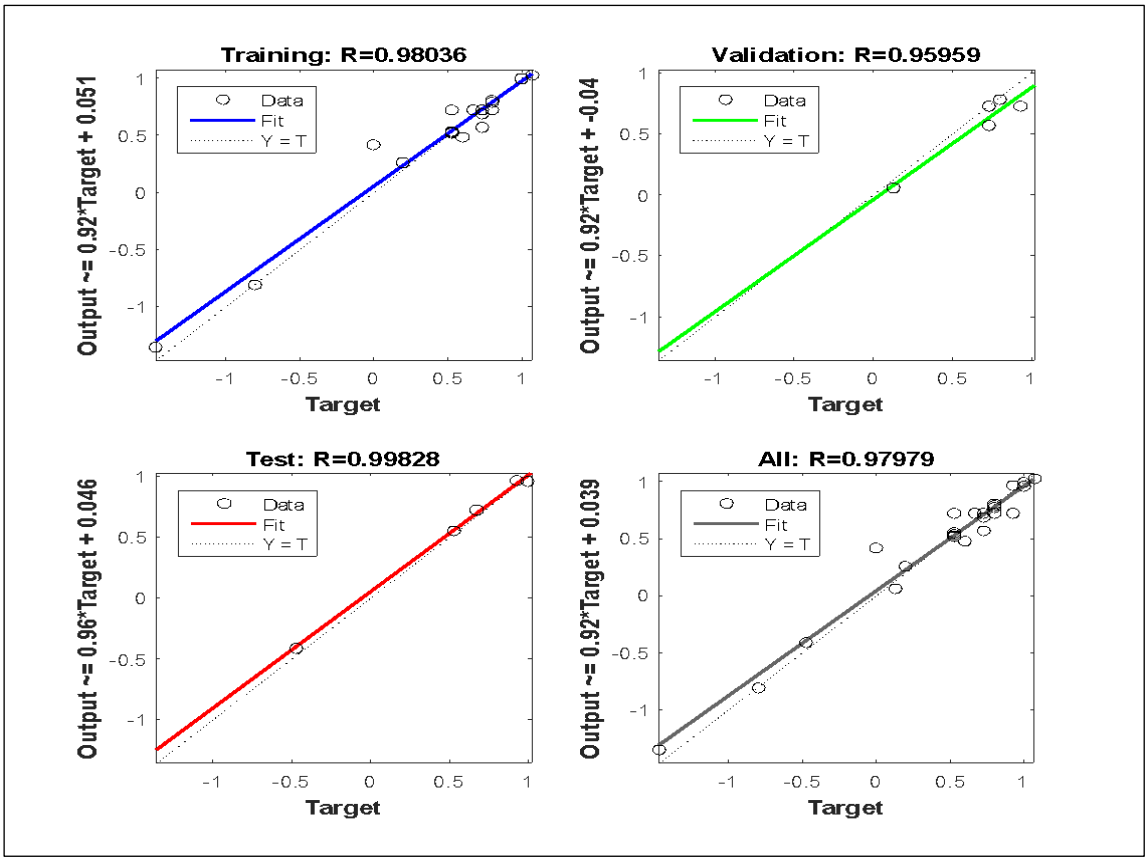

Figure 10: Regression Plot of Training, Validation, Testing, and ANN Outcomes

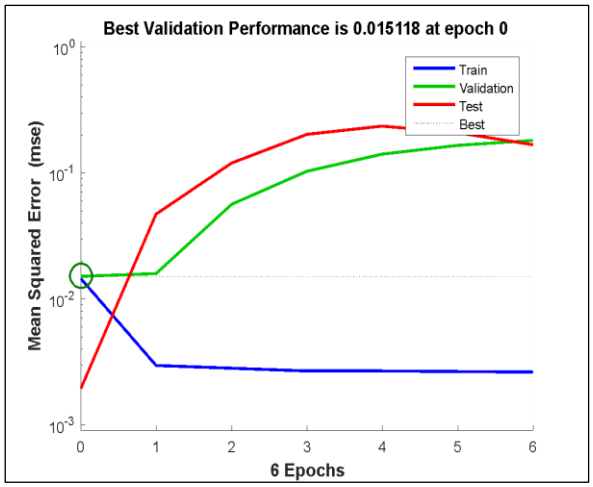

Figure 11: ANN Model Performance

Comparison of RSM and ANN: The predictive capabilities of RSM and ANN models were evaluated by comparing their results with experimental data and shown in the Figure 12. Model performance was assessed using statistical metrics such as the coefficient of determination (R^2) and mean squared error (MSE). The R^2 values were 0.97 for RSM and 0.98 for ANN, while the MSE values were 0.01511 for RSM and 0.0315 for ANN. Table 4 provides both experimental and predicted values for each model. As illustrated in Figure 9, ANN predictions aligned more closely with experimental data than RSM predictions. Additionally, Table 4 indicates that ANN had a lower overall error, demonstrating its superior accuracy in predicting biodiesel yield with minimal deviation.

Table 4: Predicted Values from RSM and ANN

S.no	Temperature (°C)	Catalyst (wt.%)	Reaction Time (min)	Methanol: oil (molar ratio)	Biodiesel yield (%)	RSM Predicted values	ANN predicted values
1.	40	2	110	9	90	90	93
2.	60	1	110	3	90	87	92
3.	40	1	110	3	91	93	92
4.	60	2	110	9	97	96	96
5.	50	2	90	6	93	93	93
6.	50	1.5	90	3	96	96	96
7.	60	2	60	9	82	82	92
8.	50	2	60	9	94	94	95
9.	60	1	60	3	93	96	94
10	40	1.5	90	6	70	71	82
11	50	1.5	90	6	93	92	94
12	50	2	90	6	93	93	93
13	50	1.5	90	6	93	92	94
14	40	2	60	3	60	61	77
15	40	1	110	9	94	93	95
16	50	1.5	90	6	92	93	94
17	50	1.5	90	6	94	92	94
18	60	2	110	3	97	99	96
19	50	1.5	90	6	92	92	94
20	60	1	110	9	75	76	85
21	40	1	60	9	90	90	93
22	50	1.5	90	6	92	92	94
23	50	1.5	60	6	97	98	97
24	60	2	60	3	90	87	93
25	50	1.5	90	6	90	92	94
26	50	1.5	90	6	96	92	94
27	40	2	110	3	85	83	90
28	60	1	60	9	84	83	89
29	40	1	60	3	94	92	95
30	50	1.5	90	6	94	92	94

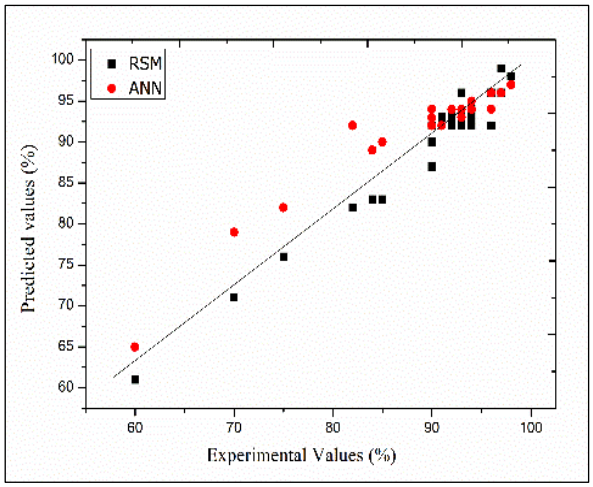

Figure 12: Comparison of Predicted and Experimental Output from ANN and RSM

Physical Properties of Foraha Oil-Based Biodiesel

The Physicochemical properties of Foraha oil bio-diesel were analyzed according to the ASTM D6751 standard, with detailed results presented in Table 5. Viscosity is a critical parameter for fuel used in engines, as high viscosity impacts on fuel injection system and requires additional energy to transfer fuel from the tank to the engine cylinder. The kinematic viscosity of Foraha oil, initially around 37.89mm^2/s, is significantly decreased to 3.45 mm^2/s after transesterification, making it only marginally higher than conventional diesel but within the limits of ASTM D445. Foraha oil biodiesel has a flash point of 145°C and a fire point of 155°C, about three times higher than diesel, ensuring safer processing, storage, and transport. Its pour point, or the temperature below which fuel solidifies, is 2°C, suitable for low-temperature applications. The calorific value, representing the fuel's heat energy upon combustion, is 42.05 MJ/kg, which is slightly lower than diesel. Table 5 provides a summary of the physicochemical properties of this biodiesel.

Table 5: Physico-Chemical Properties of the Diesel, Foraha Oil and Biodiesel

Properties	ASTM limits	Testing procedure	Diesel	Foraha oil	Biodiesel
Flash point (°C)	>130	ASTM D93	49	210	145
Fire point (°C)	-	ASMT D92	55	235	155
Density (kg/m^3)	860-900	ASTMD1298	828	915	877.9
Acid value (mg KOH/g)	0.8	EN14104	0	59.2	0.34
Cloud point (°C)	-3 to 12	ASTM D2500	-15 to -35	-	10
Pour point (°C)	-15 to 10	ASTM D97	10 to -20	-	4.3
Viscosity (mm^2/sec) at 40 °C	1.9-6	ASTM D445	2.5	37.89	3.45
Calorific value (MJ/kg)	NS	ASTM-D240	45.1	-	42.05

H NMR and GC–MS analysis

Figure 13 displays the Proton NMR spectrum of WSO biodiesel. The successful conversion to methyl esters is indicated by the presence of two specific peaks: a singlet at 3.6 ppm representing the methoxy protons and a triplet at 2.3 ppm for the alpha methylene protons. Additional peaks at 0.85, 1.26, and 1.58 ppm correspond to the terminal methyl protons, the methylene protons in the carbon chain, and the beta carbonyl methylene protons, respectively. These NMR characteristics enable the calculation of the methyl ester conversion percentage using the equation [3].

$$\text{Methyl esters conversion (\%)} = 100 \times \frac{2X_{ME}}{3X_{\alpha-CH2}} \quad [3]$$

Where, X_{ME} = Methoxy protons' integration value in methyl ester, Xα−CH2 = value of α-methylene protons' integration.

GC–MS analysis was employed to determine the chemical composition of FO methyl ester, with all primary peaks identified in the chromatogram. Table 6 lists the fatty acid methyl esters detected in FO biodiesel, indicating that it contains approximately 30% unsaturated fatty acids and 40% saturated fatty acids.

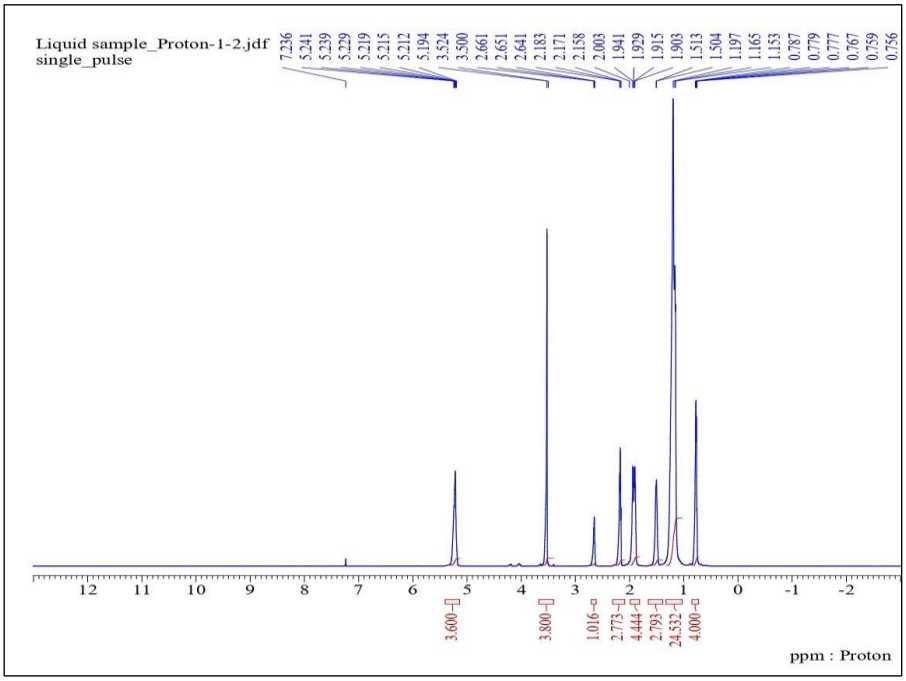

Figure 13: H NMR Spectra Analysis for Biodiesel (X-Axis is in ppm (Proton) and Y-Axis is Signal Pulse Generated)

Table 6: Fatty Acid Composition of Foraha Oil Biodiesel

S.No	Structure	Molecular formula	% Weight	Nature of fatty acid
1	Palmitic acid methyl ester	$C_{17}H_{34}O_2$	6.08	Saturated
2	Oleic acid methyl ester	$C_{18}H_{34}O_2$	49.93	Mono unsaturated
3	Stearic acid, methyl ester	$C_{19}H_{38}O_2$	2.96	Saturated
4	Linoleic acid methyl ester	$C_{18}H_{32}O_2$	40.94	Poly unsaturated
5	Myristic acid methyl ester	$C_{15}H_{30}O_2$	0.09	Saturated

Conclusion

This experimental study used RSM to examine the effects of different process factors on the production of biodiesel. Thirty trails were conducted successfully using a tiny factorial CCD, and the results were evaluated with confidence (R^2= 0.9617). The following were determined to be the ideal conditions for producing biodiesel from Foraha oil (FO): a methanol to Foraha oil (FO) molar ratio of 3:1, 2 weight percent catalyst amount, 110 minutes reaction duration, 60 degrees Celsius reaction temperature, and a constant stirrer speed of 500 rpm. Both the expected and experimental biodiesel yields were 97% and 99%, respectively. The mean square error of both models' predictions for the biodiesel yield was quite small. ANN, on the other hand, has a substantially smaller error between predicted and experimental values than RSM. It has been demonstrated that the regression model works well for predicting the yield of biodiesel under all conditions within the analysis range. When compared to the RSM model, the findings showed that the constructed ANN model has a great prediction capacity. Future research can focus on the use of heterogeneous catalysts for producing biodiesel from Foraha oil. Developing biocatalysts could help in evaluating the economic viability and overall profitability of the biodiesel production

process. Furthermore, with the aid of optimized process parameters, large-scale biodiesel production could be implemented commercially in India.

Abbreviations

None.

Acknowledgement

The authors sincerely thank his guide Dr. A. Pannirselvam for his feedback that led to critical adjustments and improvements in the work and Dr. B. Durga Prasad who provided the infrastructure at JNTUACEA Ananthapuramu, to carry out this research work.

Author Contributions

PS Bharadwaj: Conceptualization, preparation material, validation of ANN analysis, writing—original draft preparation, review, and editing, and data correction, A Pannirselvam: Helped during the project, provided feedback that led to critical adjustments and improvements in the work, B Durga Prasad: Helped by providing the infrastructure at JNTUACEA Ananthapuramu.

Conflict of Interest

The authors have no conflicts of interest to declare.

Ethics Approval

Not applicable.

Funding

This research received no external funding.

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