Automotive Experiences
Vol. 5 No.1 (2022) pp. 3-15
p-ISSN: 2615-6202 e-ISSN: 2615-6636

Research Paper

Elemental, Thermal and Physicochemical Investigation of Novel Biodiesel from Wodyetia Bifurcata and Its Properties Optimization using Artificial Neural Network (ANN)

Aditya Kolakoti[1], Bobbili Prasadarao[2], Katakam Satyanarayana[3], Muji Setiyo [4,5], Hasan Köten[6], Metta Raghu[1]

[1] Department of Mechanical Engineering, Raghu Engineering College, 531162, India
[2]Department of Electrical and Electronics Engineering, Vignan's Institute of Information Technology, 530049, India
[3]Department of Mechanical Engineering, ANITS Engineering College, 531162, India
[4]Department of Automotive Engineering, Universitas Muhammadiyah Magelang, Megelang, 56172, Indonesia
[5]Center of Energy for Society and Industry, Universitas Muhammadiyah Magelang, Megelang,56172, Indonesia
[6]Department of Mechanical Engineering, Istanbul Medeniyet University, 34730, Turkey

aditya.kolakoti@gmail.com

https://doi.org/10.31603/ae.6171

Check for updates

Published by Automotive Laboratory of Universitas Muhammadiyah Magelang collaboration with Association of Indonesian Vocational Educators (AIVE)

Article Info
Submitted:
15/10/2021
Revised:
11/11/2021
Accepted:
15/11/2021
Online first:
25/11/2021

Abstract

In this study, an unexplored oil from the wodyetia bifurcata fruit was used for biodiesel production. The transesterification process was implemented to convert the raw oil into wodyetia bifurcata methyl ester (WBME) and the influence of process variables on WBME yield was examined with the response surface method (RSM) assisted Box-Behnken optimization. The results of RSM show that a maximum biodiesel yield of 94.67% was achieved and reaction time was identified as an influencing process variable. The fatty acid composition (FAC) from chromatography reveals the presence of highly unsaturated in WBME and the significant fuel properties of thermal and molecular meet the required fuel standards (ASTM). The obtained fuel properties of WBME are compared with other popularly used biodiesels and observed low kinematic viscosity (3.87mm^2/sec) and moderated cetane number (53) for WBME. Furthermore, artificial neural network (ANN) tools are used for the prediction of WBME yield and show an improvement of 0.4% than RSM and low mean square error and a high coefficient of correlation was observed for ANN.

Keywords: Wodyetia Bifurcata, Biodiesel; Foxtail tree; Fuel properties; ANN; RSM

1. Introduction

In the last decade, the search for renewable and environmentally friendly fuels has become increasingly important due to reports of the crude oil crisis and the increase in global environmental air pollution. Therefore, renewable fuels, especially biodiesels, are considered feasible solutions to mitigate energy and air pollution crises [1]. Biodiesel is the strongest candidate to be widely implemented due to the availability of domestic raw materials and the maturity of technology readiness level for production that meet key properties of biofuel [2], [3]. The improved fuel properties in biodiesel, like negligible sulfur content, lubricity, high cetane index, presence of inbuild molecular oxygen and etc., made the biodiesel a promising alternative to conventional petro-diesel.

Biodiesel can be obtained from different oils of edible and non-edible categories. However, low cost and easily available oils are considered a better choice in biodiesel production. Therefore, the search for different oils that are less significant in food versus fuel conflict is considered as most significant for biodiesel production. All these potentials reinforce the motivation of some researchers to look for various oils for biodiesel production regardless of geographic location. For instance, Asia palm oil [4], Africa jatropha oil [5], America soybean oil [6], Europe rapeseed oil [7], Australia beauty leaf oil and castor oils [8] are widely used for biodiesel production. Apart from the mentioned oils, a wide variety of oils are identified for biodiesel production [9], [10]. Moreover, cooking waste oil is also a new potential in biodiesel production, with the addition of suitable catalysts and additives [11], [12].

In addition to equipment, additives, and catalyst [3], [9], [13], producing better-quality biodiesel with high yield can be possible with the advent of statistical optimization and artificial intelligence (AI) modeling tools. From the available literature, it was evident that the accurate prediction of biodiesel yield with limited usage of resource parameters can be achieved with the optimization tools of response surface method (RSM), Taguchi, screening and etc. [14], [15]. Similarly, maximum biodiesel yield can be predicted with AI modeling tools [16], [17]. From this fact, the search for unexplored oil for biodiesel production has an important meaning and at the same time, using modern tools such as AI results in high accuracy for quality optimization in biodiesel production.

One of the raw materials for biodiesel that has not been explored is wodyetia bifurcata (WB). So far, Wodyetia bifurcata has only been recognized for methylene blue removal [18], [19], candidate for pharmaceuticals [20], [21], and activated carbon material [22]. Wodyetia bifurcata is also known as foxtail tree (in **Figure 1**a). It is a species of palm in the family of Arecaceae native to Queensland, Australia. It consists of white color flowers stalk, and its foliage resembles in deep green to light green color, which appears to be in the shape of a fox's tail and hence it was called a foxtail tree [20]. It can be grown in a wide range of soils where the soil is well-draining and not highly acidic. The trunk of this tree is smooth and thin, and it can grow up to 2 to 3 feet per year under normal conditions and may reach a height of about 30 feet within 10 years. Its two-inch-long fruits appear to be in olive green to green color as shown in **Figure 1**b, and its color changed to orange as shown in **Figure 1**c when it is in the ripping stage. The germination may occur as quickly as one month to a three-month time frame, or it may take up to one year depends on the environmental conditions. WB prefers a humid environment which may be provided by fountains of pebble trays in the area where it can grow.

From the above discussions, it was evident that renewable and easily available fuels have a great demand as a petro-diesel replacement to combat the energy and environmental crisis. Therefore, the present study aims to produce biodiesel from wodyetia bifurcata oil which is a novel feedstock. Then the significant fuel properties related to elemental, thermal and physicochemical are investigated. The effect of reaction parameters like catalyst, alcohol, temperature and time on wodyetia bifurcata biodiesel is also investigated with the modern optimization tools of response surface method and artificial neural network using Minitab-18 and Matlab-R19 software.

2. Materials and Method

2.1. *Chemicals used*

Different analytical grade chemicals of methyl alcohol (CH_3OH), sodium hydroxide (NaOH), sulphuric acid (H_2SO_4), etc. were obtained from the Sigma Aldrich chemicals. Temperature-controlled magnetic stirrer, distilled water, filter papers, and different glassware of Borosil make are utilized from our fuel's laboratory.

Figure 1. Details of Wodyetia Bifurcata plant: a. Tree; b. Fruites; and c. Ripen fruites

2.2. Oil extraction process

The fully ripen fruits from the wodyetia bifurcata (WB) tree are collected (Figure 2a) and washed with distilled water to remove the mud and other attached impurities to the fruits (Figure 2b). Then they are dried under the sun for five days to remove the moisture content. The outer shells of dried fruits are removed (Figure 2c), and the seeds are kept in an electric dryer for 12 hours for further removal of any trace of moisture in it (Figure 2d). The finally dried seeds of measured quantity are sent to a local oil crushing unit (Figure 2e) where the WB oil was extracted to get WB oil as presented in Figure 2f.

2.3. Design of experiments

In order to achieve maximum biodiesel yield with the utilization of limited process parameters, a well-planned experiment is essential. For this purpose, response surface method (RSM) optimization was proposed in this current research. RSM techniques are widely used for biodiesel production optimization and better biodiesel yield was achieved (≥ 90%) with this technique as per the investigation from different authors [23], [24]. Therefore, RSM-based Box-Behnken design in Minitab version 18 software was used to design the number of experiments as per the four process parameters. A total of 30 experiments are conducted by varying the four process parameters of methyl alcohol to oil ratio (A), catalyst percentage(B), temperature (C), and time (D), as shown in Table 1. The mathematical Eq (1) was used to predict the output response yield by varying the input process parameters. Where, A_0 and A_i represents the intercept and regression of the first-order coefficient in RSM and A_{ii} and A_{ij} represents the regression quadratic coefficient for its factor and regression coefficient among the ith and jth input parameters. X_i and k denotes the input independent parameter and no of input parameters.

$$Yield = A_0 + \sum_{i=1}^{k} A_i X_i + \sum_{i=1}^{k} A_{ii} X_i^2 + \sum_{j=i+1}^{k} \sum_{i=1}^{k} A_{ij} X_{ij} \quad (1)$$

Figure 2. (a-f) Oil extraction process from wodyetia bifurcate

Table 1. Process parameters and their ranges

S.No	Process parameters	Units	Notations	Low	Medium	High
1	Methyl alcohol to oil ratio	-	A	30	45	60
2	Catalyst percentage (v/v)	%	B	0.5	1	1.5
3	Time	min	C	30	60	90
4	Temperature	°C	D	50	60	70

2.4. Transesterification process

To reduce the high viscosity in raw oils, a popular method that was followed by several researchers is the transesterification process [25]–[27]. This process has the highest success rate in converting the different category raw oils into low viscous biodiesel. Therefore, it was employed in this current investigation to convert wodyetia bifurcata (WB) oil into wodyetia bifurcata methyl ester (WBME). Experiments are conducted based on the design of experiments by varying the four process parameters as shown in **Table 1**. Initially, the filter raw oil (WB) of measured quantity was placed on a temperature-controlled, hot plate magnetic stirrer as shown in **Figure 3a**, and homogeneous catalyst sodium hydroxide (NaOH) and methanol were used to initiate the transesterification reaction. The reaction duration has maintained a minimum of 30 to a maximum of 90 minutes. Similarly, the maximum reaction temperature was maintained up to 70°C, and proper care was taken to control the escape of alcohol (CH_3OH) from the reaction. After achieving the desired reaction period, the mixture was shifted into a separating funnel, as shown in **Figure 3b** and allowed to settle for the whole night. As the transesterification process was successful, a clear separation of glycerol at the bottom and methyl ester at the top layer with distinct color will appear as shown in **Figure 3b**. The heavy mass glycerol was separated, and methyl ester was washed with lukewarm distilled water to remove the unwanted chemicals, and the washing process was stopped when a clear separation of methyl ester and water appears as shown in **Figure 3c**. The final samples of WBME were stored in an airtight glass beaker to test significant fuel properties. The same procedure was followed by varying the process parameters, and the experiments are conducted randomly. The finally obtained WBME yield was calculated from Eq. (2) and presented in the **Table 2**.

$$Biodiesel\ yield(\%) = \frac{Weight\ of\ the\ wodyetia\ bifurcata\ biodiesel}{Weight\ of\ the\ wodyetia\ bifurcata\ oil} \times 100 \tag{2}$$

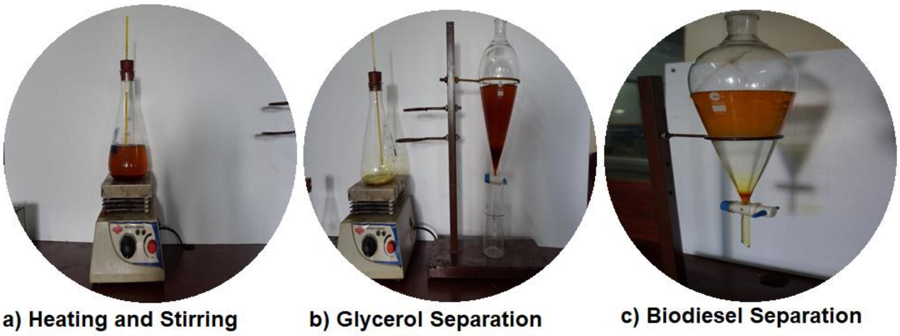


Figure 3. (a-c) Transesterification process of wodyetia bifurcata

Table 2. Design of experiments and biodiesel yield

Runs	A	B	C	D	Exp Yield (%)	RSM Yield (%)
1	45	0.5	90	60	92.47	92.77
2	45	0.5	30	60	88.05	87.88
3	60	1	60	50	94.74	94.67
4	30	1	30	60	89.94	89.85
5	45	1.5	90	60	90.74	90.91
6	45	1	60	60	93.41	93.68
7	60	1.5	60	60	89.42	89.53
8	45	1	30	70	91.14	91.32
9	45	0.5	60	70	90.17	90.26
10	60	1	60	70	90.97	90.81
11	45	1	90	70	94.19	94.03
12	45	1	60	60	93.98	93.68
13	45	1	30	50	91.95	92.10
14	30	1.5	60	60	90.82	90.97
15	45	0.5	60	50	90.85	90.88

Runs	A	B	C	D	Exp Yield (%)	RSM Yield (%)
16	60	1	90	60	93.54	93.61
17	45	1	60	60	93.63	93.68
18	30	1	90	60	92.35	92.13
19	30	0.5	60	60	87.37	87.25
20	30	1	60	50	89.47	89.63
21	45	1	60	60	93.52	93.68
22	60	1	30	60	91.18	91.37
23	45	1	60	60	93.58	93.68
24	45	1.5	60	70	91.38	91.33
25	45	1.5	30	60	91.58	91.28
26	30	1	60	70	92.78	92.85
27	60	0.5	60	60	91.86	91.70
28	45	1	60	60	93.98	93.68
29	45	1.5	60	50	91.48	91.36
30	45	1	90	50	94.09	93.90

2.5. AI modeling

Artificial Intelligence (AI) modeling is one of the popular techniques in the prediction of best output results. They are known for high prediction accuracy when compared to any other models. Available scientific literate reveals that [28]; Artificial Neural Network (ANN) models perform reasonably well when compared with statistical regression models. This was evident in our previous research when comparing the predictive ability of RSM and ANN in biodiesel production from low grade oils using heterogeneous catalysts [29]. Results show that ANN achieves the highest efficacy (R^2) and low mean square error than the RSM model. Similar results are observed from different scientific groups [30]. ANN techniques are successfully applied in predicting the optimum diesel biodiesel blends [31], biodiesel fueled engine performance and emissions analysis [32], biodiesel fuel property analysis [33] and etc. Due to these benefits, an attempt was made in this endeavor to employ the ANN model for the prediction of biodiesel yield from wodyetia bifurcata.

In a nutshell, ANN models are inspired by the biology of the human brain consist of a large number of neurons called processing units connected to each other [30], [34]. These units are responsible for estimating the linear and non-linear problems from a large network. The biodiesel yield results, as shown in table.3 are used for training the ANN network model. A popularly used feedforward backpropagation algorithm (Lavenberg) in MATLAB2019R software was used for this purpose. The network architecture consists of input, output and hidden layers as shown in **Figure 4**; the input layer was trained with the four process parameters and the output with biodiesel yield. The choice of the hidden layer was trial and error, and in this current investigation, the hidden layer was trained with 20 neurons. Similarly, the 100% experimental data was segregated as 70% for training, 15% for testing, and 15% for validation, and tan-sigmoid function (Eq.3) was used for input and hidden layers.

$$tansig(X) = \frac{e^X - e^{-X}}{e^X + e^{-X}} \tag{3}$$

2.6. Statistical correlation

The efficacy of chosen models (RSM and ANN) was estimated based on the coefficient of determination (R^2), mean square error (MSE), and root mean square error (RMSE) values. This highest R^2 and lowest MSE represent the best model, and they are computed by Eq. (4) to (7). Where, the terms n represents the number of experimental data, $X_{p,i}$, $X_{a,i}$ represents the estimated and experimental values, $X_{a,avg}$, $X_{p,avg}$ represents the average experimental and estimated values respectively.

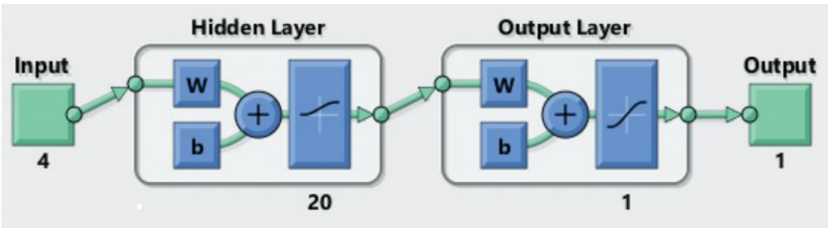


Figure 4. ANN network architecture

$$R = \frac{\sum_{i=1}^{n}(X_{p,i} - X_{p,avg})(X_{a,i} - X_{a,avg})}{\sqrt{[\sum_{i=1}^{n}(X_{p,i} - X_{p,avg})^2][\sum_{i=1}^{n}(X_{a,i} - X_{a,avg})^2]}} \tag{4}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(X_{a,i} - X_{p,i})^2}{\sum_{i=1}^{n}(X_{p,i} - X_{a,avg})^2} \tag{5}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(X_{p,i} - X_{a,i})^2 \tag{6}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{p,i} - X_{a,i})^2} \tag{7}$$

3. Results and Discussions

3.1. Fatty acid composition analysis

The presence of fatty acid compositions (FAC) in biodiesels like saturated, unsaturated play a significant role in altering the biodiesel fuel properties. Therefore, FAC levels are tested for wodyetia bifurcata methyl ester (WBME) using gas chromatography (Agilent-HP 6890 model). The results of fatty acid profiles are presented in the Table 3, that shows that WBME was identified with five major fatty acids, namely linoleic, oleic, arachidic, palmitic, and myristic acids. The two major unsaturated groups of mono-unsaturated and poly-unsaturated are observed as linoleic acid (Figure 5) and oleic acids (Figure 6) with a contribution of 29.27% and 33.12%. Following this, the total saturated and unsaturated FAC are observed as 32.63% and 63.96%. Saturated FAC in biodiesels helps in improving the performance of the engine with regulated exhaust emissions [35]. Similarly, high saturated FAC in biodiesel has a significant contribution in improving the fuel properties and engine performance characteristics [36]. Therefore, the FAC compositions of WBME are compared with three popularly used biodiesels of palm (POME), jatropha (JOME) and soybean (SOME) as shown in table.3 reveal that the total saturated FAC of WBME are observed higher than POME, JOME and SOME.

Table 3. Wodyetia bifurcata methyl ester (WBME) fatty acid compositions

S.No	Fatty acid name	POME(Wt.%) [35]	JOME(Wt.) [39]	SOME(Wt.%) [40]	WBME(Wt.%)
1	Palmitic Acid	40.2	13.0	15.07	7.12
2	Stearic Acid	0.04	5.8	12.09	3.65
3	Lauric Acid	2.69	0.1	0.21	2.31
4	Arachidic Acid	6.07	0.2	0.40	6.15
5	Behenic Acid	1.52	-	0.60	3.14
6	Lignoceric Acid	1.55	-	0.28	3.14
7	Myristic Acid	6.06	0.1	0.71	7.12
8	Linoleic Acid	-	35.4	4.39	29.27
9	Linolenic Acid	44.69	0.3	40.93	1.57
10	Oleic Acid	27.28	44.5	19.78	33.12
11	Other	5.18	-	2.95	3.41
12	Total Saturated	22.65	19.1	29.39	32.63
13	Monounsaturated	27.48	45.2	45.32	33.12
14	Polyunsaturated	44.69	35.7	22.34	30.84

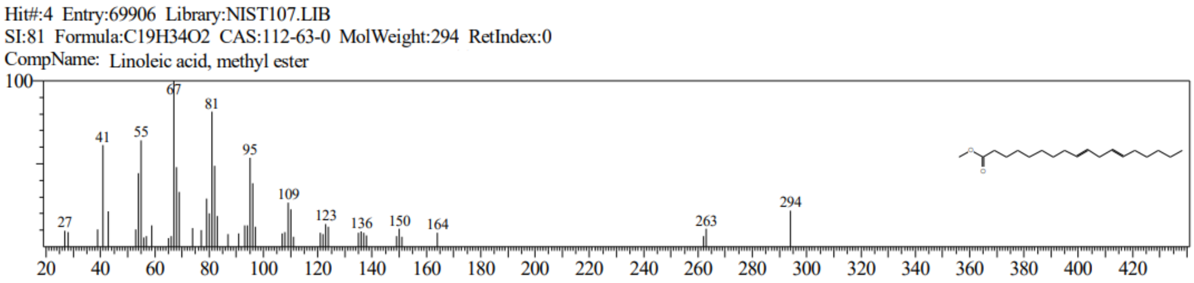


Figure 5. GCMS spectrum for linoleic acid

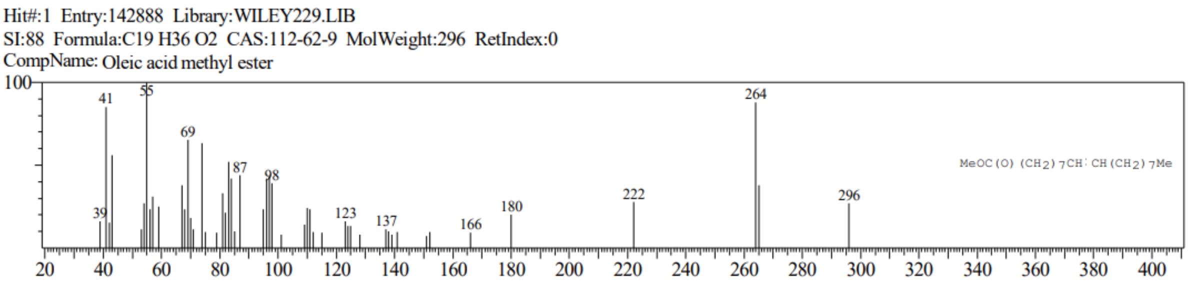


Figure 6. GCMS spectrum for oleic acid

3.2. *Specific fuel properties of WBME*

Biodiesel fuel properties play a significant role in commercialization and, at the same time to compete with diesel fuel. Therefore, the fuel properties of WBME, especially physiochemical, thermal and elemental compositions, are tested as per the ASTM standards are presented in **Table 4**. From the previous studies on biodiesel fuel properties showed that some thermal properties like flash point, fire point and cetane number have the edge over diesel fuel which can be considered as a good sign for storing the fuel and reduce the delay period during combustion. However, low calorific value, high density and viscosity have a negative impact on the engine performance. The variations in biodiesel fuel properties may also be related to the presence of saturated and unsaturated FAC. The fuel properties of WBME showed that density and kinematic viscosity was increased by 6.02% and 38.81% than mineral diesel fuel. This may acclaim for long-chain fatty acids, especially the presence of palmitic, stearic and myristic acids [37]. Due to high density and viscosity may results in higher fuel consumption, thereby results in low brake thermal efficiency. High flash and fire points are observed for WBME, which helps in safe handling during transportation and storage. Increased carbon number from long-chain saturated fatty acids like palmitic acids may be responsible for high flash and fire points [35]. High saturated FAC helps in improving the cetane number (CN) and it was observed for WBME that 8.16% higher than diesel fuel. Higher CN is always recommended for diesel engines which restricts the ignition lag (delay period) during the combustion. In contrast, a low calorific value was observed for WBME than diesel fuel which may occur due to the low hydrocarbon and zero sulfur content [38]. In general, biodiesels are known as oxygenated fuels and the same can be witnessed in WBME with the presence of 12.14% molecular oxygen, which may help in achieving complete combustion, thereby achieving low tailpipe emissions. Finally, the fuel properties of WBME meet the minimum criteria set by the international biodiesel standards of ASTM D6751. The obtained fuel properties of WBME are compared with the available literature [35], [39]–[41] as shown in **Table 5** reveals that low kinematic viscosity was recorded for WBME compared to other biodiesels.

Table 4. Significant fuel properties of wodyetia bifurcata methyl ester

S.No	Properties	Units	ASTM Standard	WBME	Diesel	Limits
1	Density	kg/m³	D1298	880	830	-
2	Kinematic viscosity	mm²/sec	D445	3.87	2.86	1.90-6.01
3	Pour point	°C	D7346-15	3.12	-13	-15 to 10
4	Cloud point	°C	D2500	2.16	-	-3 to 12
5	Flash point	°C	D93-16	149	87	130 min
6	Fire point	°C	D93-16	164	98	-
7	Calorific value	MJ/kg	D240	38	42.7	35 to 45
8	Cetane number	-	D613	53	49	47 (min)
9	Oxygen content	wt.%	D5291	12.14	-	-
10	Sulfur content	wt.%	D5291	0.006	0.134	-

Table 5. Comparison of WBME with other biodiesels

S.No	Properties	Units	POME [35], [41]	JOME [39], [41]	SOME [40]	WBME (Present study)
1	Density	kg/m³	860.6	838.8	874	880
2	Kinematic viscosity	mm²/sec	4.545	3.91	5.19	3.87
3	Pour point	°C	9	2.0	-	3.12
4	Cloud point	°C	16	3.0	1	2.16
5	Flash point	°C	164	161	160	149
6	Fire point	°C	-	181	182	164
7	Calorific value	MJ/kg	38.50	40.42	38.81	38.76
8	Cetane number	-	65	58.2	49	53
9	Oxygen content	wt.%	-	11.45	-	12.14
10	Sulfur content	wt.%	0.003	0.004	0.014	0.006

3.3. *Analysis of variance*

The transesterification of wodyetia bifurcata methyl ester (WBME) was successfully completed based on the design of experiments (**Table 1** and **Table 2**). Now the accuracy of the experiments and the influencing parameter on WBME was examined by ANOVA results, as shown in **Table 6**. The experimental WBME yield was analyzed with a second-order polynomial Eq. (1) which correlates the response variable to an independent variable. From table.6 significance of process parameters (A, B, C & D) can be identified with the F-test and probability of error P-vales. The significance of the individual coefficient was confirmed by the P-value (<0.05) at 95% confidence level and the lowest P-vale (<0.001) represents the highest significance and reliability of the chosen model in estimating the output results (biodiesel yield). From the ANOVA results, molar ratio (A), catalyst used (B), time (C) are significant in WBME yield. However, reaction time was identified as the most influential parameter based on P (<0.0001) and F (254.63) values. Lack of fit of the model was identified as insignificant (0.609) compared to the pure error (0.291). The model accuracy was determined by the coefficient of determination (R^2) which is 99.11%. This shows that more than 99% of the data were consistent with the observed values and the same can be witnessed in the predicted versus actual yield plot (**Figure 7**). High R^2 was desirable to ensure the better estimation between the chosen model and the experimental data which was attained in this current research. Finally, the biodiesel yield for further experiments can be conducted based on the regression Eq. (8).

$$WBME\ Yield = 12.77 + 1.5127\ A + 32.52\ B + 0.1536\ C + 0.795\ D - 0.006187\ A{*}A - 9.693\ B{*}B - 0.000605\ C{*}C - 0.002958\ D{*}D - 0.1963\ A{*}B - 0.000028\ A{*}C - 0.011800\ A{*}D - 0.08767\ B{*}C + 0.0290\ B{*}D + 0.000758\ C{*}D \tag{8}$$

Table 6. ANOVA results for significant process parameters

Source	DOF	Sum of Squares	Mean Square	F-Value	P-Value
Model	14	100.744	7.1960	119.94	<0.0001
Linear	4	24.116	6.0291	100.49	<0.0001
A- Molar Ratio	1	6.720	6.7200	112.00	<0.0001
B- Catalyst Used	1	1.802	1.8019	30.03	<0.0001
C- Time	1	15.278	15.2776	254.63	<0.0001
D- D- Temperature	1	0.317	0.3169	5.28	0.036
Square	4	48.215	12.0537	200.90	<0.0001
A*A	1	13.288	13.2884	221.48	<0.0001
B*B	1	40.269	40.2689	671.17	<0.0001
C*C	1	2.034	2.0336	33.89	<0.0001
D*D	1	0.600	0.6001	10.00	0.006
2-Way Interaction	6	28.413	4.7355	78.93	<0.0001
A*B	1	8.673	8.6730	144.55	<0.0001
A*C	1	0.001	0.0006	0.01	0.920
A*D	1	12.532	12.5316	208.87	<0.0001
B*C	1	6.917	6.9169	115.28	<0.0001
B*D	1	0.084	0.0841	1.40	0.255
C*D	1	0.207	0.2070	3.45	0.083
Error	15	0.900	0.0600		
Lack-of-Fit	10	0.609	0.0609	1.05	0.512
Pure Error	5	0.291	0.0582		
Total	29	101.644			
R^2 = 99.11%		R^2 (Adj) = 98.29%		R^2 (Pred) = 96.14%	

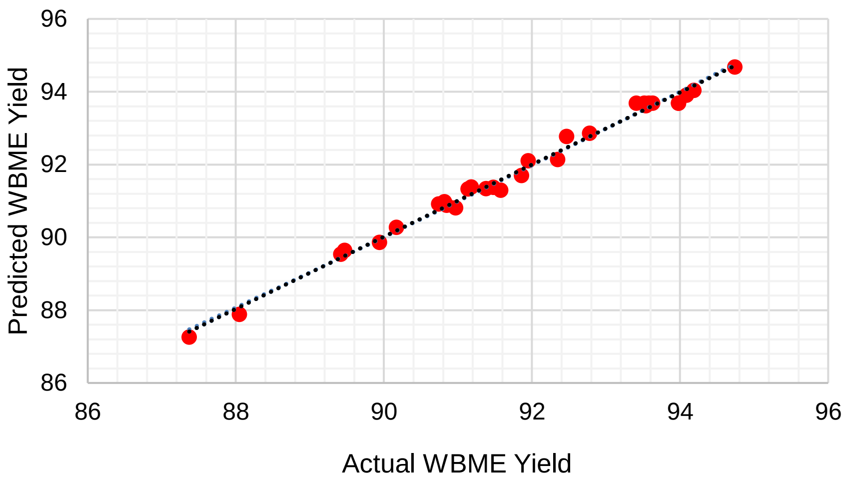


Figure 7. Comparison of actual and predicted WBME yield

3.4. *3.4 Process parameters influence*

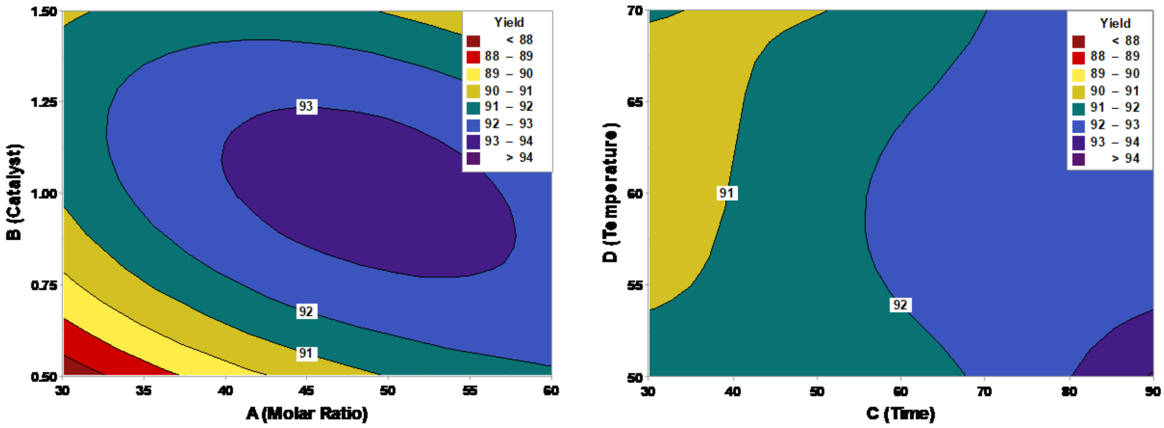
The effect of reaction parameters like temperature, time, catalyst usage and alcohol to oil ratio on wodyetia bifurcata methyl ester (WBME) yield was shown in **Figure 8a** and **Figure 8b**. These plots reveal the interaction effect of any two chosen parameters on WBME yield. For instance, the variation of molar ratio (v/v) versus catalyst usage (%) plot (**Figure 8a**) reveals that maximum biodiesel yield (>93%) was achieved at a molar ratio of 45 and catalyst usage of 1.25%. However, further increases in alcohol and catalyst reduce the WBME yield. This may due to a higher dosage of catalyst results in the formation of soap, thereby reduce the biodiesel yield. Soap formation not only decreases the yield but also consumes more time and water (distilled) for the purification process. Similarly, from time (min) versus temperature (min) plot, as shown in **Figure 8b** reveal that maximum WBME yield was achieved at 53°C and 80 minutes. High reaction temperatures may help the alcohol to escape from the reaction results in an incomplete transesterification process. From **Figure** 8b, it was evident that at high reaction temperatures (>60°C), there is a reduction in WBME yield (<90%).

3.5 Neural network modeling

The experimental WBME yield results from **Table 2** were used to train the artificial neural network (ANN) model and the training results are shown in **Figure 9**. Similar to the RSM model, the accuracy of the ANN model was determined by the coefficient of determination (R) and R^2 values. The high R values in training, validation and testing represent how close the chosen model predicts the output result. From **Figure 9**, it was evident that the high R-value in testing (0.99484) represents the good prediction accuracy of the ANN model. Similarly, the prediction accuracy for RSM and ANN models, as shown in **Figure 10**, reveals that both RSM and ANN are successful in estimating the WBME yield. However, ANN shows an improvement of 0.38% in WBME yield compared to the RSM model. Likewise, low mean square error (MSR) and high R^2 were achieved for the ANN model compared to RSM. The obtained results are in convergence with the finds of prior finding [28], [29]. The model accuracy based on R, R^2, MSE and RMSE (Eq.4-7) are shown in the **Table 7.** Comparison of RSM and ANN statistical results. reveal that ANN showed a better efficacy in achieving WBME yield.

2. Conclusions

From this study, Wodyetia bifurcata oil was successfully converted into biodiesel. Based on the significant fuel properties of thermal, elemental and molecular analysis, wodyetia bifurcata methyl ester (WBME) meet the requirements of recommended fuel standards (ASTM). High cetane number, molecular oxygen and moderate kinematic viscosity in WBME may improve diesel combustion and performance. Furthermore, a better yield from the raw oil was achieved with the expeditions of the latest tools of RSM (94.67%) and ANN (95.03%). Therefore, this novel biodiesel was recommended as diesel fuel replacement to combat energy and environmental crises.



(a) Molar ratio vs catalyst (b) Time vs tempeature

Figure 8. Interaction effect of process parameters on WBME yield

Table 7. Comparison of RSM and ANN statistical results.

S.No	Parameter	RSM	ANN
1	R	99.55	99.48
2	R^2	99.11	99.27
3	MSE	0.0301	0.0291
4	RMSE	0.1736	0.1705
5	WBME Yield	94.67	95.038

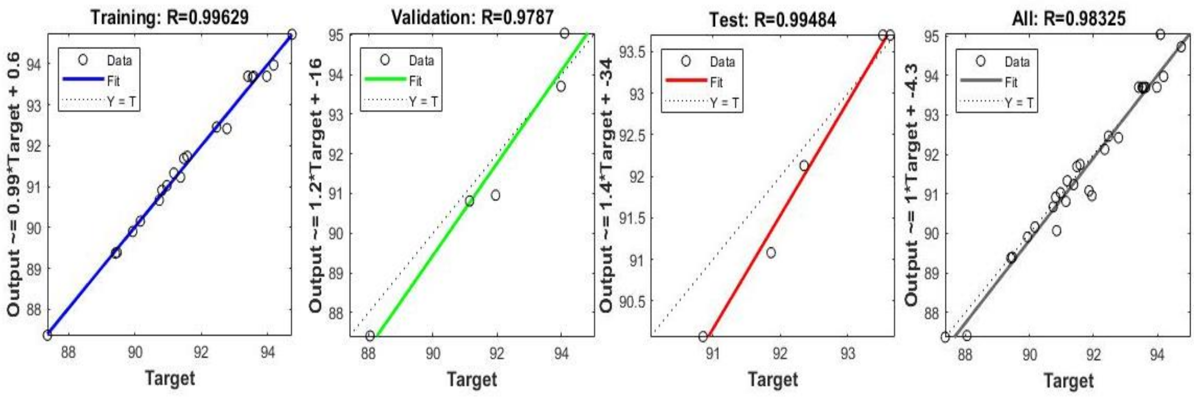


Figure 9. The coefficient of determination (R) for the ANN model

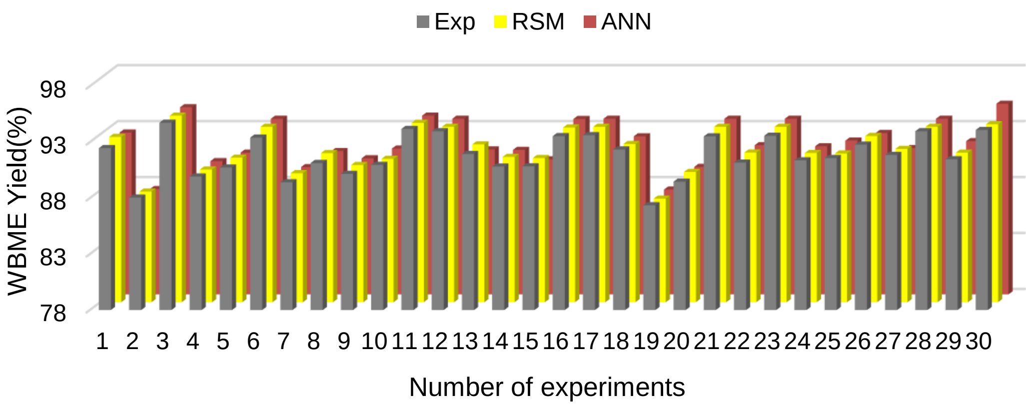


Figure 10. WBME yield for three methods

Future Scope

Shelf life and significant fuel properties of wodyetia bifurcata biodiesel after blending with petro-diesel, especially B5 to B20, have to investigate. Likewise, performance and emission tests have to be carried out with various blend ratios.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

Funding

No information funding from the authors.

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

References

[1] A. M. Liaquat, M. A. Kalam, H. H. Masjuki, and M. H. Jayed, "Potential emissions reduction in road transport sector using biofuel in developing countries," *Atmospheric Environment*, vol. 44, no. 32, pp. 3869–3877, 2010, doi: 10.1016/j.atmosenv.2010.07.003.

[2] M. Dehghani Madvar, A. Aslani, M. H. Ahmadi, and N. S. Karbalaie Ghomi, "Current status and future forecasting of biofuels technology development," *International Journal of Energy Research*, vol. 43, no. 3, pp. 1142–1160, 2019, doi: doi.org/10.1002/er.4344.

[3] T. M. I. Mahlia *et al.*, "Patent landscape review on biodiesel production: Technology updates," *Renewable and Sustainable Energy Reviews*, vol. 118, no. November 2019, p. 109526, 2020, doi: 10.1016/j.rser.2019.109526.

[4] I. Mukherjee and B. K. Sovacool, "Palm oil-based biofuels and sustainability in southeast Asia: A review of Indonesia, Malaysia, and Thailand," *Renewable and sustainable energy reviews*, vol. 37, pp. 1–12, 2014, doi: 10.1016/j.rser.2014.05.001.

[5] D. L. Kgathi, G. Mmopelwa, R. Chanda, K. Kashe, and M. Murray-Hudson, "A review of the sustainability of Jatropha cultivation projects for biodiesel production in southern Africa: Implications for energy policy in Botswana," *Agriculture, Ecosystems & Environment*, vol. 246, pp. 314–324, 2017, doi: 10.1016/j.agee.2017.06.014.

[6] W. Körbitz, "Biodiesel production in Europe and North America, an encouraging prospect," *Renewable energy*, vol. 16, no. 1–4, pp. 1078–1083, 1999, doi: 10.1016/S0960-1481(98)00406-6.

[7] P. Mihaela, R. Josef, N. Monica, and Z. Rudolf, "Perspectives of safflower oil as biodiesel source for South Eastern Europe (comparative study: Safflower, soybean and rapeseed)," *Fuel*, vol. 111, pp. 114–119, 2013, doi: 10.1016/j.fuel.2013.04.012.

[8] A. K. Azad, M. G. Rasul, M. M. K. Khan, S. C. Sharma, M. Mofijur, and M. M. K. Bhuiya, "Prospects, feedstocks and challenges of biodiesel production from beauty leaf oil and castor oil: A nonedible oil sources in Australia," *Renewable and Sustainable Energy Reviews*, vol. 61, pp. 302–318, 2016, doi: 10.1016/j.rser.2016.04.013.

[9] M. Setiyo, D. Yuvenda, and O. D. Samue, "The Concise Latest Report on the Advantages and Disadvantages of Pure Biodiesel (B100) on Engine Performance: Literature Review and Bibliometric Analysis," *Indonesian Journal of Science and Technology*, vol. 6, no. 3, pp. 469–490, 2021, doi: 10.17509/ijost.v6i3.38430.

[10] T. Issariyakul and A. K. Dalai, "Biodiesel from vegetable oils," *Renewable and Sustainable Energy Reviews*, vol. 31, pp. 446–471, 2014, doi: 10.1016/j.rser.2013.11.001.

[11] S. Özer, M. Akçay, and E. Vural, "Effect of toluene addition to waste cooking oil on combustion characteristics of a ci engine," *Fuel*, vol. 303, p. 121284, 2021, doi: 10.1016/j.fuel.2021.121284.

[12] A. Kolakoti, M. Setiyo, and B. Waluyo, "Biodiesel Production from Waste Cooking Oil : Characterization , Modeling and Optimization 2 . Material and Methods," *Mechanical Engineering for Society and*

Industry, vol. 1, no. 1, pp. 22–30, 2021, doi: 10.31603/mesi.5320.

[13] A. Hidayat, W. Kurniawan, and H. Hinode, "Sugarcane Bagasse Biochar as a Solid Catalyst: From Literature Review of Heterogeneous Catalysts for Esterifications to the Experiments for Biodiesel Synthesis from Palm Oil Industry Waste Residue," *Indonesian Journal of Science and Technology*, vol. 6, no. 2, pp. 337–352, 2021, doi: 10.17509/ijost.v6i2.34498.

[14] F. Ferella, G. M. Di Celso, I. De Michelis, V. Stanisci, and F. Vegliò, "Optimization of the transesterification reaction in biodiesel production," *Fuel*, vol. 89, no. 1, pp. 36–42, 2010, doi: 10.1016/j.fuel.2009.01.025.

[15] S. Satya, A. Kolakoti, and R. Rao, "Optimization of palm methyl ester and its effect on fatty acid compositions and cetane number," *Mathematical Models in Engineering*, vol. 5, no. 1, pp. 25–34, 2019, doi: 10.21595/mme.2019.20469.

[16] A. Garg and S. Jain, "Process parameter optimization of biodiesel production from algal oil by response surface methodology and artificial neural networks," *Fuel*, vol. 277, p. 118254, 2020, doi: 10.1016/j.fuel.2020.118254.

[17] Y. Sewsynker-Sukai, F. Faloye, and E. B. G. Kana, "Artificial neural networks: an efficient tool for modelling and optimization of biofuel production (a mini review)," *Biotechnology & Biotechnological Equipment*, vol. 31, no. 2, pp. 221–235, 2017, doi: 10.1080/13102818.2016.1269616.

[18] K. J. L. Dos Santos *et al.*, "Wodyetia bifurcata biochar for methylene blue removal from aqueous matrix," *Bioresource technology*, vol. 293, p. 122093, 2019, doi: 10.1016/j.biortech.2019.122093.

[19] F. A. Daud, N. Ismail, and R. M. Ghazi, "Response surface methodology optimization of methylene blue removal by activated carbon derived from foxtail palm tree empty fruit bunch," *J. Trop. Resour. Sustain. Sci*, vol. 4, pp. 25–30, 2016, doi: 10.47253/jtrss.v4i1.580.

[20] B. S. Abd ELnasser, M. Y. El Dina, M. R. Elgindi, and M. B. Elsaid, "Biological studies of isolated triterpenoids and phenolic compounds identified from Wodyetia bifurcata family Arecaceae," *Journal of Pharmacognosy and Phytochemistry*, vol. 3, no. 6, 2015.

[21] N. Naderali *et al.*, "'Candidatus Phytoplasma wodyetiae', a new taxon associated with yellow decline disease of foxtail palm (Wodyetia bifurcata) in Malaysia," *International journal of systematic and evolutionary microbiology*, vol. 67, no. 10, pp. 3765–3772, 2017, doi: 10.1099/ijsem.0.002187.

[22] N. S. Subki, N. M. Akhir, N. S. A. Halim, and N. R. N. Yusoff, "COD Reduction in Industrial Wastewater Using Activated Carbon Derived from Wodyetia Bifurcata Fruit," in *IOP Conference Series: Earth and Environmental Science*, 2020, vol. 549, no. 1, p. 12066, doi: 10.1088/1755-1315/549/1/012066.

[23] I. Noshadi, N. A. S. Amin, and R. S. Parnas, "Continuous production of biodiesel from waste cooking oil in a reactive distillation column catalyzed by solid heteropolyacid: optimization using response surface methodology (RSM)," *Fuel*, vol. 94, pp. 156–164, 2012, doi: 10.1016/j.fuel.2011.10.018.

[24] V. Singh, L. Belova, B. Singh, and Y. C. Sharma, "Biodiesel production using a novel heterogeneous catalyst, magnesium zirconate (Mg2Zr5O12): Process optimization through response surface methodology (RSM)," *Energy Conversion and Management*, vol. 174, pp. 198–207, 2018, doi: 10.1016/j.enconman.2018.08.029.

[25] J. Otera, "Transesterification," *Chemical reviews*, vol. 93, no. 4, pp. 1449–1470, 1993, doi: 10.1021/cr00020a004.

[26] U. Schuchardt, R. Sercheli, and R. M. Vargas, "Transesterification of vegetable oils: a review," *Journal of the Brazilian Chemical Society*, vol. 9, pp. 199–210, 1998, doi: 10.1590/S0103-50531998000300002.

[27] D. Ayu, R. Aulyana, E. W. Astuti, K. Kusmiyati, and N. Hidayati, "Catalytic Transesterification of Used Cooking Oil to Biodiesel: Effect of Oil-Methanol Molar Ratio and Reaction Time," *Automotive Experiences*, vol. 2, no. 3, pp. 73–77, 2019, doi:

10.31603/ae.v2i3.2991.

[28] M. A. Mujtaba *et al.*, "Ultrasound-assisted process optimization and tribological characteristics of biodiesel from palm-sesame oil via response surface methodology and extreme learning machine-Cuckoo search," *Renewable Energy*, vol. 158, pp. 202–214, 2020, doi: 10.1016/j.renene.2020.05.158.

[29] A. Kolakoti and G. Satish, "Biodiesel production from low-grade oil using heterogeneous catalyst: an optimisation and ANN modelling," *Australian Journal of Mechanical Engineering*, pp. 1–13, 2020, doi: 10.1080/14484846.2020.1842298.

[30] M. Rajendra, P. C. Jena, and H. Raheman, "Prediction of optimized pretreatment process parameters for biodiesel production using ANN and GA," *Fuel*, vol. 88, no. 5, pp. 868–875, 2009, doi: 10.1016/j.fuel.2008.12.008.

[31] A. Kolakoti, P. Jha, P. R. Mosa, M. Mahapatro, and T. G. Kotaru, "Optimization and modelling of mahua oil biodiesel using RSM and genetic algorithm techniques," *Mathematical Models in Engineering*, vol. 6, no. 2, pp. 134–146, 2020, doi: 10.21595/mme.2020.21357.

[32] A. Kolakoti, "An experimental based artificial neural network modeling in prediction of optimum combustion, performance, and emission from diesel engine operated with three biodiesels," *World Journal of Engineering*, 2021, doi: 10.1108/WJE-01-2021-0010.

[33] M. Agarwal, K. Singh, and S. P. Chaurasia, "Prediction of biodiesel properties from fatty acid composition using linear regression and ANN techniques," *Indian Chemical Engineer*, vol. 52, no. 4, pp. 347–361, 2010, doi: 10.1080/00194506.2010.616325.

[34] A. Kolakoti, "Optimization of biodiesel production from waste cooking sunflower oil by Taguchi and ANN techniques," *Journal of Thermal Engineering*, vol. 6, no. 5, pp. 712–723, 2020, doi: 10.18186/thermal.796761.

[35] A. Kolakoti and B. V. A. Rao, "Effect of fatty acid composition on the performance and emission characteristics of an IDI supercharged engine using neat palm biodiesel and coconut biodiesel as an additive," *Biofuels*, vol. 10, no. 5, pp. 591–605, 2019, doi: 10.1080/17597269.2017.1332293.

[36] G. R. Srinivasan *et al.*, "Influence of fatty acid composition on process optimization and characteristics assessment of biodiesel produced from waste animal fat," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, pp. 1–19, 2020, doi: 10.1080/15567036.2020.1771477.

[37] R. Fillières, B. Benjelloun-Mlayah, and M. Delmas, "Ethanolysis of rapeseed oil: Quantitation of ethyl esters, mono-, di-, and triglycerides and glycerol by high-performance size-exclusion chromatography," *Journal of the American Oil Chemists' Society*, vol. 72, no. 4, pp. 427–432, 1995, doi: 10.1007/BF02636083.

[38] A. Demirbas, "Effects of moisture and hydrogen content on the heating value of fuels," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 29, no. 7, pp. 649–655, 2007, doi: 10.1080/009083190957801.

[39] H. C. Ong, A. S. Silitonga, H. H. Masjuki, T. M. I. Mahlia, W. T. Chong, and M. H. Boosroh, "Production and comparative fuel properties of biodiesel from non-edible oils: Jatropha curcas, Sterculia foetida and Ceiba pentandra," *Energy conversion and management*, vol. 73, pp. 245–255, 2013, doi: 10.1016/j.enconman.2013.04.011.

[40] D. H. Qi and C.-F. Lee, "Influence of soybean biodiesel content on basic properties of biodiesel-diesel blends," *Journal of the Taiwan Institute of Chemical Engineers*, vol. 45, no. 2, pp. 504–507, 2014, doi: 10.1016/j.jtice.2013.06.021.

[41] A. Sarin, R. Arora, N. P. Singh, R. Sarin, R. K. Malhotra, and K. Kundu, "Effect of blends of Palm-Jatropha-Pongamia biodiesels on cloud point and pour point," *Energy*, vol. 34, no. 11, pp. 2016–2021, 2009, doi: 10.1016/j.energy.2009.08.017.