



# Methanolysis of Africa Pear Seed Oil via Thermally Activated Empty Palm Fruit Bunch Ash (TAEPFBA) Catalyst, ANN Prediction and Sensitivity Analysis

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## Authors' contributions

This work was carried out in collaboration among all authors. Author OEU co-supervised, analyzed the data and prepared the manuscript. Author ODO conceptualized and supervised the study. Author CNU did experimental work, interpreted the results and proof read the manuscript. Author COA assisted in the experimental work. All authors read and approved the final manuscript.

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## ABSTRACT

This study investigated the catalytic effect of thermal modified empty palm fruit bunch ash (TAEPFBA) on the transesterification reaction of Africa pear seed oil (APSO) with optimization of the process variable, and relative contribution of each variable ascertained. The TAEPFBA was

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synthesized from empty palm fruit bunches while the APSO was extracted via solvent extraction. The oil and catalyst were characterized using American Standard for Testing of Material (ASTM) and analytical tools. The biodiesel was produced at optimal condition and the yield of biodiesel was predicted with artificial neural network (ANN). The methyl ester produced was characterized and compared with standard properties for its application. The results showed that the oil and catalyst had comparable properties with other oils and catalysts that have been used for transesterification. The optimal conditions for transesterification reaction are temperature of 60°C, reaction time of 3hrs, 10:1 methanol/oil molar ratio, 3wt % catalyst dosage and agitation speed of 300rpm with biodiesel yield of 75%. The biodiesel produced was within the acceptable standard. The ANN predicted the yield of biodiesel with a mean square error (MSE) value of 0.0214 less than 0.05 level of significant. The contributive impact of each process variable shows that the temperature has the highest relative impact on the yield of biodiesel while the methanol/oil molar ratio has the least contribution. The overall result shows that the catalyst (TAEPFBA) has the potential to convert the APSO to alkyl ester and the yield can be predicted with ANN tool.

**Keywords:** Africa pear seed oil; Thermal Activated Empty Palm Fruit Bunch Ash (TAEPFBA); biodiesel; ANN; sensitivity analysis.

## 1. INTRODUCTION

Biodiesel is considered a replacement for depleting conventional diesel because it is renewable, environmentally friendly, and non-toxic fuel and can be blended with conventional diesel. Biodiesel has remained vital because of its usage in diesel engines to convey heavy loads, which is impossible with other fossil fuels or bio-energy. Moreover, it contains oxygen, which enhances the combustion process in diesel engines and reduces the emission of harmful gases, soot, and unburnt hydrocarbons [1-3]. Hence, it is a potential substitute for diesel [4-7]. In the recent past, biodiesel production has promoted economic development in some European countries. Biodiesel is predominantly produced via the transesterification process.

Transesterification reactions have been carried out with many edible oils such as *cocos nucifera* oil, *elaeis guineensis*, groundnut oil, cashew oil, avocado oil e.t.c. However, the use of these oils to produce biodiesel was discontinued due to how it affects food availability and the cost of living, especially in developing countries. Various non-edible biomass such as castor [8], tamanu [9], rubber seed [10], *jatropha curcas* [11], neem [12], *pongamia pinnata* [13], rubber seed [14], cottonseed [15] etc. have been used to produce biodiesel. Non-edible seed oils of African pear seed oil (APSO) have been gaining the attention of researchers in recent times especially in Nigeria. It is an annual fruit, and contains 49–53% oil per seed, and a plantation can produce 8–9 tonnes of oil per hectare.

The nature of the catalyst determines the percentage conversion of oil (like APSO) to biodiesel. Onukwuli and Ude [16] used activated clay as a catalyst to produce 78%-80% biodiesel from APSO. Iloamaeke et al. [17] applied two-step transesterification using H<sub>2</sub>SO<sub>4</sub> and NaOH to have 69% APSO conversion to biodiesel. Isong et al. [18] used NaOH to synthesize biodiesel (87% yield) from *dacryodes edulis* while Bull and George [19] studied the transesterification of biodiesel with NaOH with a percentage yield of 80%. The research on the use of heterogenous catalysts in APSO conversion to biodiesel is limited and this has spurred the research on the use of EPFBA in raw and activated form as a catalyst in the methanolysis of APSO to biodiesel. From the literature review, there is no report on the percentage of APSO oil converted to biodiesel using raw and thermally activated empty palm fruit bunch ash (EPFBA). It is relevant to ascertain some vital physiochemical and thermal properties of biodiesel produced with thermal activated EPFBA in order to widen its application in biodiesel technology.

The EPFBA is a catalyst synthesized from empty palm fruit bunches (EPFB), which is the most abundant waste found in oil palm mills. Oil palm is one of the most essential edible oils that is readily available with high economic value. It is grown in large quantities in Nigeria. A palm tree harvested and processed could produce waste such as empty palm fruit bunches (EPFB), palm oil mill effluent, and palm kernel shell. This EPFB when not disposed properly blocks the drainage system. The use of the EPFB as a catalyst in

biodiesel production could minimize this challenge.

The EPFBA catalyst and other variables like time, catalyst, alcohol/oil ratio, speed, and temperature affect the biodiesel yield. It is difficult to optimize the process by one factor or two factors at a time approach. Alternatively, response surface methodology (RSM), RSM linked with genetic algorithm (GA), artificial neural network (ANN), and adaptive neural fuzzy interference system (ANFIS) are reliable techniques to use. Several researchers have identified these techniques as reliable optimization tools. Zabeti et al. [20] used response surface methodology to predict the biodiesel yield produced using alumina-supported calcium oxide. Onukwuli et al. [17] employed response surface methodology in the optimization of biodiesel production from crude cottonseed oil using sodium hydroxide as a catalyst. Therefore, this study focused on the transesterification of Africa pear seed oil using thermally activated EPFBA, optimization of the process, and the relative contribution of the input variables to the yield.

## 2. MATERIALS AND METHODS

### 2.1 Materials

The Africa pear seeds were purchased from Okigwe in Imo State, Nigeria, and the seeds were gathered after the edible parts had been consumed. The empty palm fruit bunch was collected from individuals that have a large oil plantation in Okigwe, Imo State, Nigeria. The reagents were procured from Kelechi Science Laboratory Ltd., Okigwe Market, Imo State, Nigeria, and they were of analytical grade.

### 2.2 Methods

#### 2.2.1 Extraction of oil and its characterization

The seeds were dried in sunlight for thirty days, deshelled, and the kernels were milled using a Kenwood electrical grinder KEFP580 prior to oil extraction. Solvent extraction as described by Zahira [21] was adopted in extracting the oil from the seed. The extraction was carried out by using a soxhlet extractor containing the milled kernel (particle size of 900µm), fitted with a round bottom flask (2 L capacity). The extraction was achieved on a water bath for 6 hrs, with n-hexane solvent (Bpt 40-60°C). The oil and n-hexane contained in the beaker are subjected to

a temperature above 70°C to vapourize and recover the n-hexane. The percentage mass of oil is determined using Equation 1. The Africa pear seed oil was characterized with ASTM to determine its physiochemical properties.

$$A = \frac{N_o}{N} * 100 \quad (1)$$

Where,

A represent the percentage of oil extracted from the seed

$N_o$  is the mass of pure oil extracted (g)

N is the mass of the seed prior to extraction

#### 2.2.2 Preparation and synthesis of catalyst

The raw empty palm fruit bunch (EPFB) was cut into small pieces and air dried. The dried EPFB was milled using a laboratory blender. The pulverized biomass was sieved through a 250 µm diameter sieve to get fine particles and submerged in distilled water for 12 hrs. It was decanted to remove impurities, then left to drain before being dried in a hot air oven at 104°C until it reached a consistent weight. The EPFB was then burned for 4 hrs at 800°C in a furnace to produce empty palm fruit ash, or EPFBA. The dried EPFBA was subjected to heat treatment in a muffle furnace until a temperature of 1000°C was reached for 1hr.

#### 2.2.3 Physiochemical properties of catalyst

The properties of the raw and thermally modified EPFBA samples were determined using various analytical instruments. The ASTM D4067 method, and multi-point Brunauer-Emmet-Teller BET (Nova station Quantachrome instrument version 11.3) were used to determine their physiochemical properties of the raw and activated EPFBA. The fourier transform infra-red spectrometer (FTIR) transmission method using KBr (BUCK model 500M) was employed to determine the functional group, while a Carl Zeiss sigma field emission scanning electron microscope (SEM) was used to determine the morphology of the EPFBA samples, and the group and the crystallographic structures of the EPFBA were recorded using an X-ray diffractometer (XRD). The x-ray diffraction measurements were performed in a Shimadzu diffractometer model XRD-7000 with Cu Ka X-ray source (40 kV, 30 mA,  $\lambda = 1.5418 \text{ \AA}$ ).

## 2.2.4 Transesterification reaction

The extracted oil from Africa pear seed react with methanol in the presence of raw EPFBA or thermal activated empty palm fruit bunch ash (TAEPFBA) to produce fatty acids methyl ester FAME, and glycerol. The flat bottom flask containing the oil, catalyst (3% weight of oil sample) and methanol (10:1 methanol/oil molar ratio) was placed on a hot magnetic stirrer at a constant temperature with a set agitation speed of 300 rpm during the reaction. The flask was removed after 3 hours, cooled, and the biodiesel in the upper layer was separated from the by-product (glycerol) in the lower layer by overnight settlement at room temperature. The catalyst was recovered by filtration using filter paper, and the excess methanol in the upper layer was recovered by rotary evaporation. The optimal percentage of biodiesel yield was calculated as shown in Equation 2.

$$\text{Biodiesel (\%)} = \frac{\text{weight of biodiesel}}{\text{weight of oil used}} \times 100 \quad (2)$$

## 2.2.5 Effect of process parameters on biodiesel yield

The effect of process variables on the yield of biodiesel was investigated experimentally. To study the effect of one parameter the other variables are kept constant. The variables considered were catalyst (raw and activated), methanol/oil ratio, temperature, reaction time, and agitation speed.

## 2.2.6 Statistical design and optimization approach

The multi-input-single-output (MISO) ANN model in Fig. 1 was adopted to model the performance of the input parameters and predict the optimal yield of alkyl ester. The input variables processed in the hidden layers are catalyst, methanol/oil ratio, temperature, reaction time, agitation speed, while biodiesel produced from APSO with thermal activated catalyst is the single-output. The ANN architectural neural network in Fig. 1 was designed to train 70% of the data of the process variables, validate 15% of the variables, and test 15% using the Levenberg-Marquardt training algorithm processed in the hidden layers with different neurons (10,17,20,23,30). The neuron with the least mean square error (MSE) was taken to be the best performing algorithm network, and the interactive effect of the process

variable on the output was significant and maximized at data processed with the number of neurons. The best algorithm network was adopted to predict the optimal yield of biodiesel. This was done on a feed-forward back propagation network. The mean square error (MSE) is represented in Equation 3. The correlation coefficient ( $R^2$ ) were determined.

$$MSE = \left( \frac{\sum_{i=1}^n (\text{Predicted value} - \text{Experimental value})^2}{n} \right) \quad (3)$$

Where,  $n$  = number of datasets used to train the network

## 2.2.7 Properties of biodiesel

The biodiesel produced at optimal conditions was characterized using ASTM method. Gas chromatography-mass spectrometer (GC-MS) and a fourier transform infra-red spectrometer (FTIR) were used to determine the fatty acid content and functional group of the biodiesel respectively

## 2.2.8 Sensitivity analysis of input variables

The impact of each process variable on the output in the MISO ANN model was ascertained using the connection weight model in MATLAB R2015a. The best processing neuron in the hidden layer having the least mean square error was used to process the data and train the network. The number of vertically connected weight layer from input and horizontally weight layer from output corresponds with the number of hidden neurons. The analysis algorithm is expressed as follows:

- Sum the vertically connected weights layer,  $A_{ih}$ , for each input and determine their average.  $A_{aih} = \sum_{h=1}^{15} (A_{ih})/h$  (4)
- Sum the horizontally connected weights layer for each output.  $B_{toh} = \sum_{h=1}^{15} (B_{oh})$  (5)
- Multiply  $A_{aih}$  and  $B_{toh}$  using matrix multiplication method;  $C_{AB} = [A_{aih1} \ A_{aih2} \ \dots \ A_{aih5}] [B_{toh1}]$  (7)
- Evaluate  $D_{io} = \sum C_{AB} / n$  (8)
- Absolute value of  $E_{io} = |A_{aih} - D_{io}|$  (9)
- Evaluate  $F_{io} = \sum |A_{aih} - D_{io}|$  (10)
- The relative impact (RI) in percentage

$$G_{io} = RI(\%) = \frac{E_{io}}{F_{io}} \times 100 \quad (11)$$

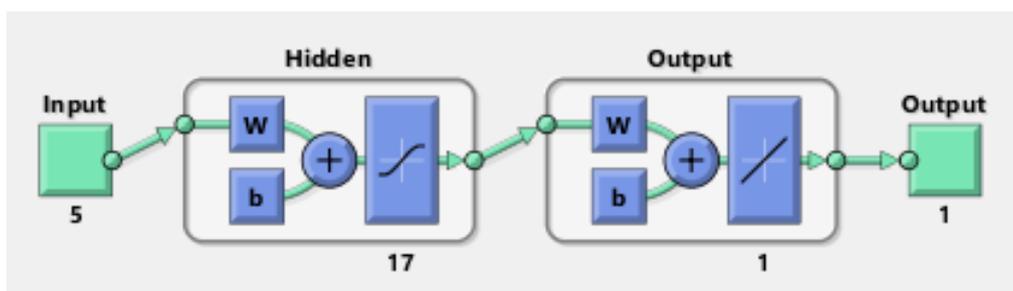


Fig. 1. ANN network architecture

### 3. RESULTS AND DISCUSSION

#### 3.1 Properties of Africa Pear Seed Oil

The physiochemical properties of the Africa pear seed oil (APSO) are presented in Table 1. The oil has less free fatty acid which could be catalyzed by homogeneous and heterogeneous catalysts and does not require any form of pretreatment prior to transesterification. The magnitude of other properties like viscosity and energy value could be compared favourably with other non-edible oils such as *prunus amygdalus* [22], lard oil [23] and avocado seed oil [24]. Some of the Physiochemical properties of the APSO in this research are in agreement with Ofoefule [25].

#### 3.2 Properties of Raw and Modified Catalyst

The physiochemical properties, thermal properties, and structure of raw and thermally activated catalyst were determined using ASTM,

BET, FTIR, SEM, and XRD analytical method/tools.

##### 3.2.1 Catalysts characterization

The properties of the raw catalyst change when modified with heat at temperature of 800°C, as shown in Table 2. The ASTM method was adopted to characterize the raw and activated EPFBA. The difference between the two catalysts was an indication of the effect of thermal activation, which is evident in high pore volume, low density, and low pore diameter.

##### 3.2.2 BET analysis of the catalysts

The Brunauer-Emmet-Teller (BET) analysis in Table 3 confirms the ASTM characterization of the two catalysts when the two catalysts are compared. The activated catalyst (TAEPFBA) has more pore volume and surface area than the raw EPFBA. Moreover, the TAEPFBA requires less adsorption energy to adsorb the reactants. This is as a result of the presence of more pores compared to raw EPFBA.

Table 1. The summary of characterization of Africa pear seed oil

Properties	Africa pear seed oil
Specific gravity	0.9195
Kinematic viscosity (centistoke) at 40°C	6.42
Refractive index	1.4715
Energy value (J/g)	30164
Flash point (°C)	176
Fire point (°C)	198
Acid value (mg KOH/kg)	5.01
Saponification value (mg KOH/kg oil)	135.26
Free fatty acid value (mg KOH/kg)	2.505
Peroxide value (meq/kg)	2.7421
Moisture content (%)	0.44
Molecular weight (g/mol)	880.87
Ester value (%)	94.46
Iodine value (mg I <sub>2</sub> /100g oil)	25.13

**Table 2. Properties of Catalysts by ASTM analysis**

Sample/Properties	Raw EPFBA	Modified EPFBA
Conductivity	2.74	114.8
Ash(%)	6.08	34.48
Bulk density(g cm <sup>-3</sup> )	0.8147	0.6541
Organic carbon (%)	0.26	0.2
Organic matter (%)	0.80	0.59
Fixed carbon (%)	53.60	47.81
Volatile matter (%)	39.93	17.71
Particle density(g cm <sup>-3</sup> )	1.0030	1.0024
Total porosity (%)	18.77	34.78
Moisture (%)	-	-

**Table 3. BET analysis of different catalysts**

Catalyst	Surface area (m <sup>2</sup> /g)	Pore-volume (cc/g)	Pore-diameter (nm)	Adsorption energy(kJ/mol)
Raw EPFBA	173.955	0.108	2.144	4.530
Activated EPFBA	210.528	0.117	2.133	4.165

### 3.2.3 Fourier transforms infrared (FTIR) analysis of the catalysts

The FTIR analytical technique was used to determine the functional group. The raw catalyst and activated catalyst have a wave number of 1028.7cm<sup>-1</sup> and 1006.7cm<sup>-1</sup>, respectively, confirming the presence of SiO<sub>2</sub> dominant around 1000cm<sup>-1</sup> as shown in Figs. 2a and 2b. The Si-O-Si bond was confirmed at a transmittance of 58 and 79 for raw and thermally treated catalyst. The spectra show the OH functional group at a wave number of 3257cm<sup>-1</sup> and 3552.6cm<sup>-1</sup> for raw and thermally modified EPFBA respectively, and at a transmittance of 82 and 90 respectively. The presence of OH and SiO<sub>2</sub> and having the alkali properties makes the catalyst a potential feedstock in the production of biodiesel via transesterification.

### 3.2.4 Scanning electron microscopes (SEM) of the catalysts

The morphology of the raw catalyst and TAEPFBA catalyst was investigated using the SEM analytical tool. The two catalysts were scanned with an electron microscope at a magnification of 300x and the pore sizes of the two catalysts were 889µm and 885µm for raw and activated catalysts, respectively, as shown in Fig. 3a and Fig. 3b. The result is similar to the analysis carried out using BET, with the thermally modified EPFBA having smaller pore sizes and a

greater number of pores and surface area when compared to the raw catalyst. The catalyst's surface area and pore volumes allow for greater internal diffusion of reactant molecules.

### 3.3 Effect of Process Variables on Biodiesel Yield

The effect of each process variable on the yield of biodiesel was determined experimentally. This was achieved by varying one process parameter while the other variables were kept constant. The constant values of the process parameters for catalyst, methanol/oil ratio, temperature, reaction time, and agitation speed are 3wt %, 10:1, 60°C, 3hrs, and 300 rpm, respectively.

#### 3.3.1 Catalyst effect on biodiesel yield

The yield of alkyl ester increased as the catalyst weight percentage increased for both catalysts and then decreased as the catalyst (wt %) was increased beyond 3 wt.% as presented in Fig. 4. This is as a result of insufficient reactants molecules needed to completely diffuse (mass transfer) into the pores of the catalyst and, as a result, inhibit the contact between the reactants. Fig. 4 shows that the yield of alkyl ester using TAEPFBA is significantly higher compared to the raw catalyst. This is attributed to having a large surface area and pores.

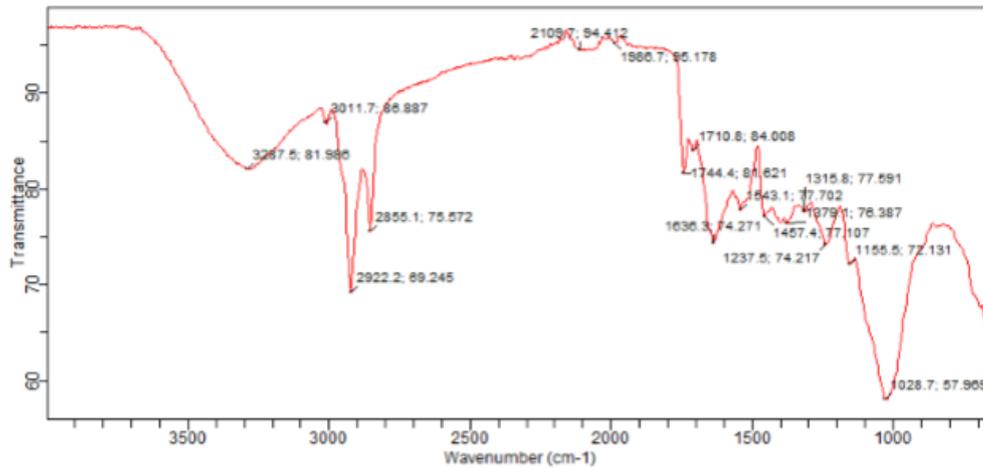


Fig 2a. FTIR spectrum of raw EPFBA

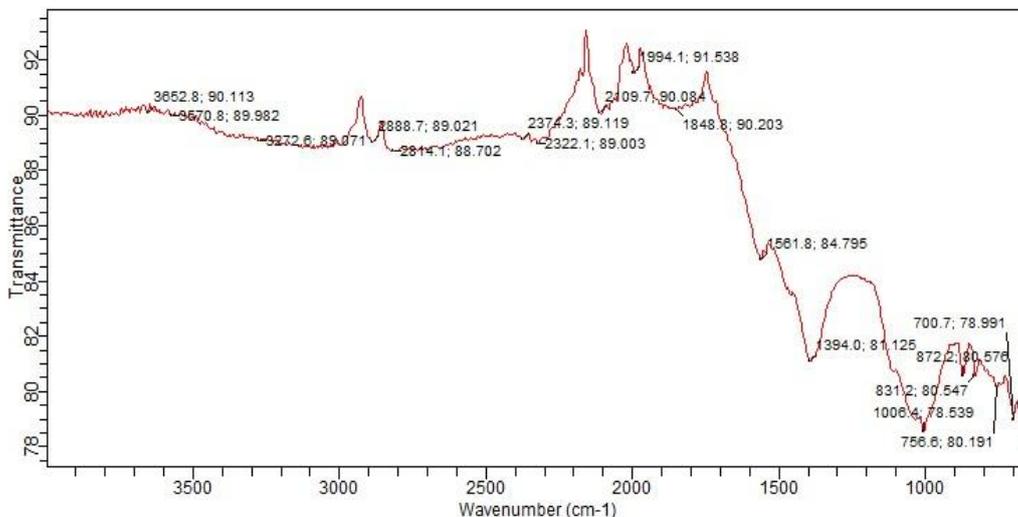


Fig 2b. FTIR spectrum of thermally modified EPFBA

### 3.3.2 Methanol/oil ratio effect on biodiesel yield

The yield of methyl ester to the different molar ratios indicated that methanol/oil molar ratio has a significant impact on biodiesel yield, as shown in Fig. 5. The maximum methyl ester yield was obtained at a methanol/oil molar ratio of 10:1 for the raw EPFBA and activated EPFBA. The yield reduced when the molar ratio was higher than 10:1. The reason may be that the catalyst is insufficient to completely catalyze the methanol and oil as they increase in volume and, hence, may lead to little formation of ester. The results obtained are in line with the reports of earlier works by Ude and Onukwuli [26].

### 3.3.3 Effect of temperature on biodiesel Yield

The plot of temperature as it affects the yield of alkyl ester as shown in Fig. 6 reveals that the optimal yield of biodiesel from APSO using raw and thermally activated catalyst is achievable at a temperature of 60°C in a period of 3 hrs and at a speed of 300 rpm. Further increases in reaction optimal temperature, as shown in Fig. 6, decreased the yield of biodiesel. This was attributed to the loss of methanol via vapourization since methanol's boiling point is below 66°C. Similar result was reported by Hoque et al. [27]. The results also recommended that EPFBA modified gave a higher yield of biodiesel.

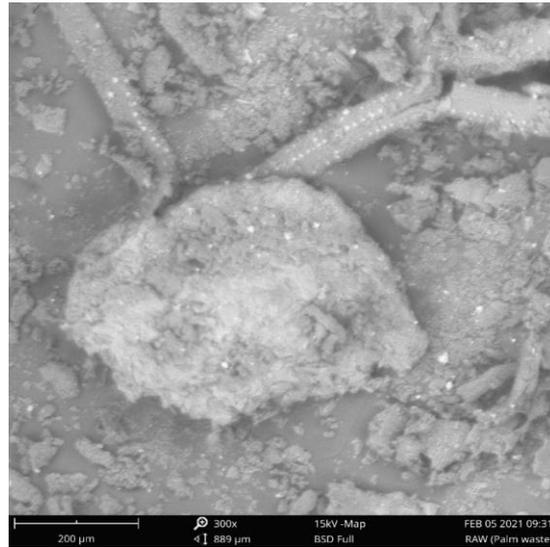


Fig. 3a. SEM for raw EPFBA catalyst at 300x magnification

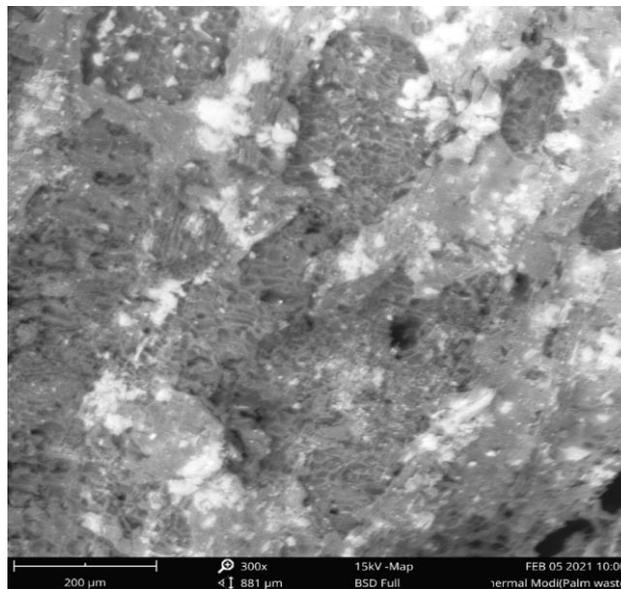


Fig. 3b. SEM for thermally activated EPFBA catalyst at 300x magnification

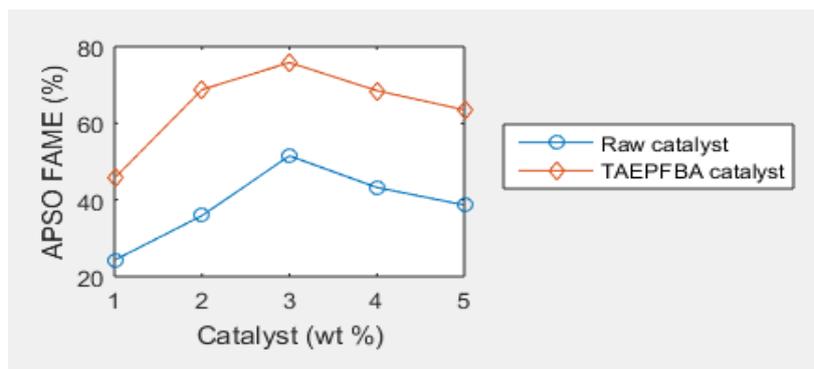
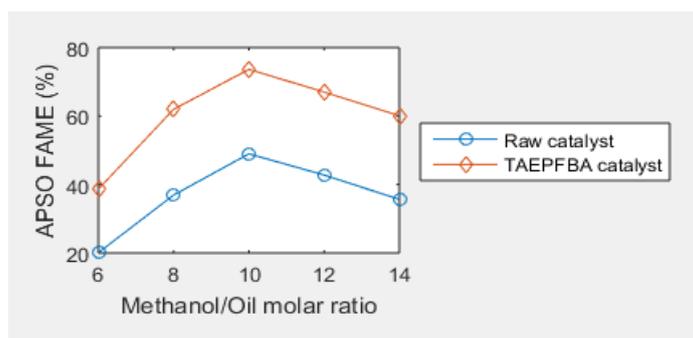


Fig 4. Effect of catalyst on FAME yield



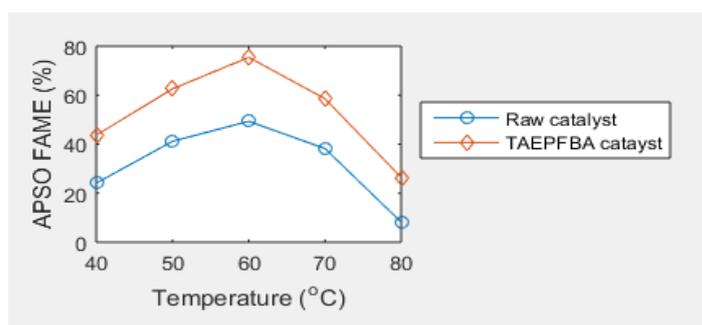
**Fig 5. Effect of methanol/oil molar ratio on FAME**

### 3.3.4 Effect of time on biodiesel yield

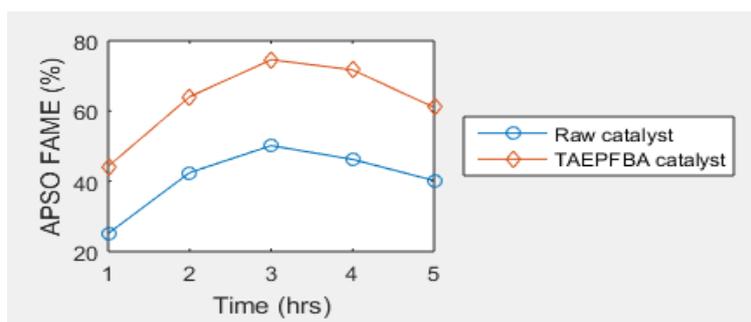
The plot in Fig. 7 shows that there was a significant difference between the yield of alkyl ester produced from APSO catalyzed with raw and TAEPFBA. This is in agreement with the result of Ude and Onukwuli (2019) that the yield of biodiesel increased as the clay (catalyst) was activated with alkaline. The effect of reaction time on biodiesel yield when using heterogeneous catalysts was ascertained and shown in Fig. 7. It was discovered that the optimal reaction time was 3 hrs and beyond that, the yield decreased. The decrease is due to a reversible reaction of transesterification resulting in the loss of esters.

### 3.3.5 Effect of stirring speed on biodiesel yield

The collision between reactants and catalyst can be promoted and more effective if the reaction is agitated with a stirrer. The yield of methyl esters at different rates of mixing is shown in Fig. 8. It was observed that the methanolysis reaction was practically complete at 300 rpm. The yield was observed to decrease as the stirring rate went above 300 rpm for raw EPFBA and modified EPFBA. This may be attributed to increase in pressure affecting the adsorption process, leading to soap formation. These results are in conformity with observations made by Chozhavendhan et al. [28].



**Fig. 6. Effect of temperature on biodiesel yield**



**Fig. 7. Effect of time on APSO FAME yield**

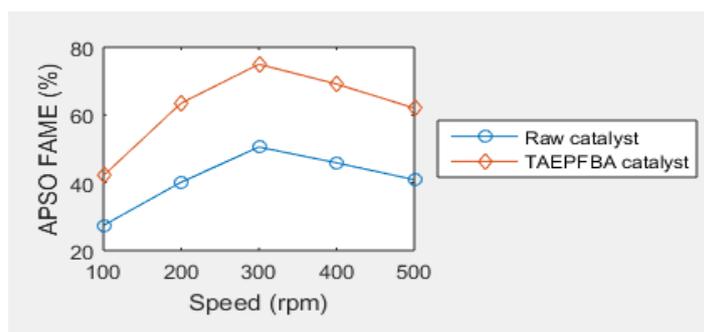


Fig. 8. Effect of speed on APISO FAME yield

### 3.4 Properties of Biodiesel

The physio-chemical and thermal properties of biodiesel presented in Table 4 show that biodiesel has the potential to be run in diesel engines and also when blended with diesel. The results show that the biodiesel produced has a higher cetane number than diesel, and Ude et al. (2021) obtained a similar result using Africa pear seed oil and clay as catalysts. The high cetane number is as a result of high oxidative stability and chemical activity with a low calorific value. The biodiesel advantage over diesel can be traced to variables like density, cetane number, and combustion. Biodiesel burns completely longer than diesel because of the oxygen content, making it a better lubricant. In addition, biodiesel is sulfur free and is one of the reasons diesel engines emit fewer toxic substances when operated with biodiesel.

### 3.5 GS-MS Result of Biodiesel

The methanolysis conversion of fatty acid of APISO catalysed with TAEPFBA to alkyl ester is

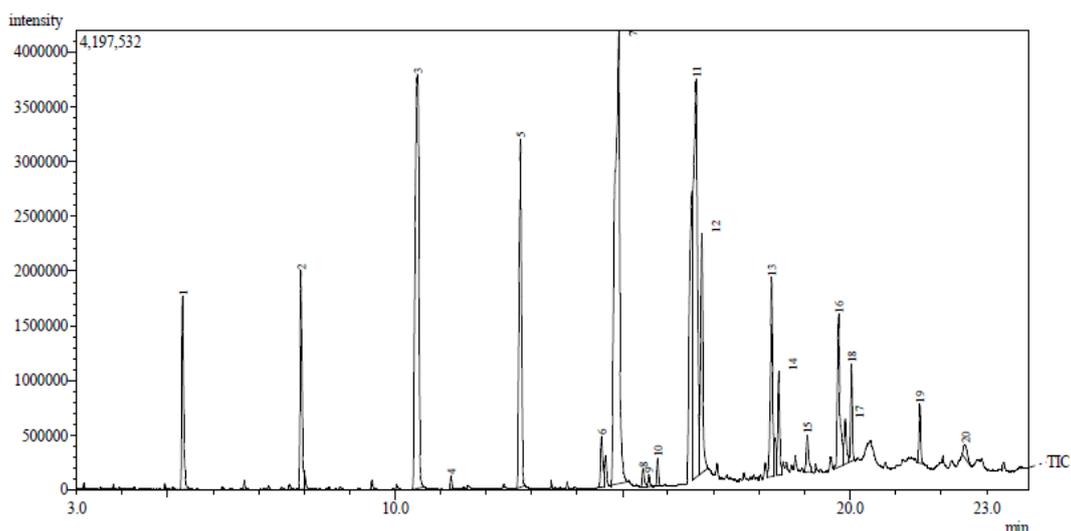
presented in Fig. 9. From the Figure, it is observed that the triglyceride was converted to methyl esters. The highest peaks indicate the presence of methyl esters, while the lower peaks on the right hand side indicate the presence of monoglyceride, diglyceride and unconverted triglyceride.

### 3.6 FTIR Characterization of Biodiesel

Fig. 10 shows the fourier transform infra-red spectrum for the conversion of triglyceride of APISO to methyl ester by TAEPFBA. From the figure, the IR peak at 3050-3900  $\text{cm}^{-1}$  is attributed to the stretching of hydroxyl (OH) groups in the biodiesel. The IR peaks at 1300–1600  $\text{cm}^{-1}$  are assigned to the peaks of bending vibration of O=C=O group. The two bands within the range of 2100–2890  $\text{cm}^{-1}$  and peak at 1750  $\text{cm}^{-1}$  on the IR spectra are ascribed to the C-H stretching of the alkyl group and the C=O stretching of the esters group, respectively. These bands occurred because of the unconverted triglyceride in the oils.

Table 4. Properties of Biodiesel and its Blends produced from Africa pear seed oil

Parameters	B <sub>0</sub>	B <sub>20</sub>	B <sub>40</sub>	B <sub>60</sub>	B <sub>80</sub>	B <sub>100</sub>
Viscosity@40°C (mm <sup>2</sup> /s)	1.189	1.270	1.908	2.092	2.871	3.577
Density ( g/cm <sup>3</sup> )	0.8283	0.8600	0.8712	0.8797	0.8897	0.8948
Flash point (°C)	56.00	96.00	103.00	121.00	139.00	171.00
Fire point (°C)	78.00	115.00	123.00	145.00	159.00	194.00
Cloud point (°C)	4.00	4.50	6.00	7.50	9.00	10.00
Pour point (°C)	2.00	2.50	3.50	4.50	5.00	6.00
Acid value ( mg KOH/g)	-	0.02	0.034	0.04	0.044	0.050
Free fatty acid (mgKOH/g)	-	0.01	0.017	0.02	0.022	0.025
Aniline Point (°C)	58.50	54.60	52.50	46.50	38.50	36.00
Diesel index	54.08	45.18	39.96	34.68	28.91	25.64
API Gravity	39.33	34.97	32.05	30.45	28.04	26.99
Cetane Number	53.55	57.48	64.98	68.89	71.91	73.94
Gross calorific value (J/g)	47074	46753	46491	46474	45823	45722



**Fig. 9. GC-MS of APSO FAME produced by TAEFBA catalyzed reaction at optimal condition**

### 3.7 Prediction of APSO FAME Yield Using ANN model

Table 5 shows that seventeen (neurons) in the hidden layer of the ANN neural network could effectively train the input data and maximize the data for maximum output. Hence, the number of neurons was used to predict the output. Figs. 11, 12, and 13 depict the error performance plot, error histogram, and regression plot respectively, of the seventeen training, validating, and testing neurons. As seen in Fig. 11, the MSE dropped from 1000 to 0.021365 at epoch 5. The training and testing of process variables were significantly achieved at epoch 5 at the best performance validation. The maximum number of epochs for performing the best validation was 6. The error histogram as shown in Fig. 12 shows that the errors fall between -0.01822 and 0.1258 (zero region), indicating a good performance. Fig. 13 shows the best fit between the target data and the output data. The correlation coefficient indicates that the best training, testing, and validation were carried out using the

MISO architectural neural network with seventeen neurons.

Table 6 shows the predicted yield of APSO FAME using the ANN model. The percentage errors between the experimental yield and the predicted optimal yield of APSO FAME with ANN model is 0.02% . The statistical indices confirm that the model can be used to predict the yield of biodiesel.

### 3.8 Sensitivity Analysis of Input Variables

The relative contribution of process parameters to the output train on the MISO ANN architectural network with 17 hidden neurons is presented in Fig. 14. The Figure shows that the temperature has the greatest contribution (40.7%). However, the methanol/oil ratio shows a small percentage contribution of less than 15%, and this is reflected in the RSM model, with the methanol/oil ratio having the highest negative coefficient and antagonistic interaction with other variables.

**Table 5. The MSE best performance and correlation coefficient**

Number of neuron	MSE	Epoch	R
10	0.1324	6	0.9972
17	0.0214	5	0.9977
20	0.2320	5	0.9977
23	0.0316	3	0.9672
30	0.0465	5	0.9968

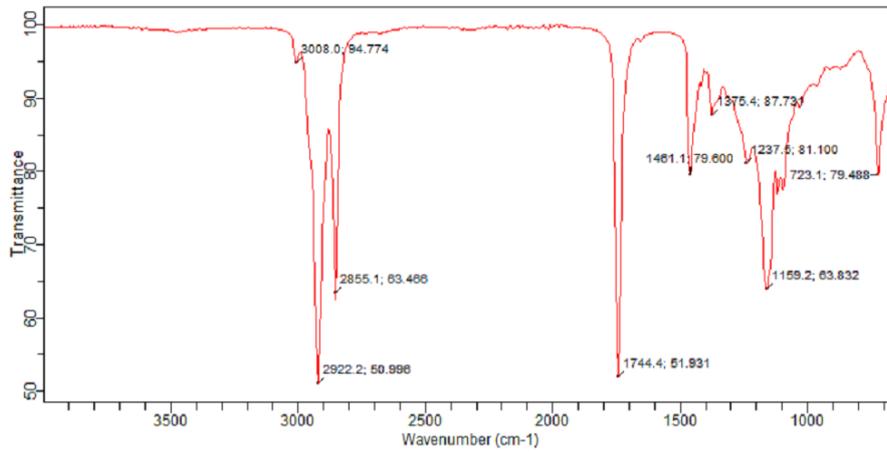


Fig. 10. FTIR of APSO FAME produced by TAEPFBA catalyzed reaction at optimal conditions

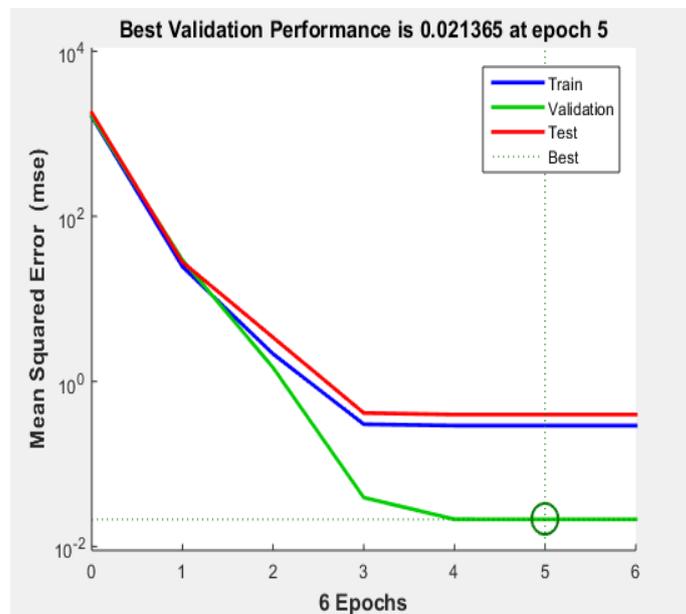


Fig 11. Validation performance error curve using seventeen neurons network

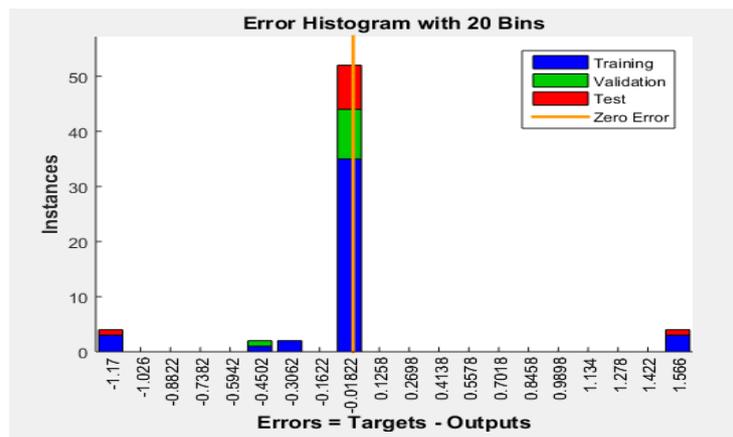


Fig 12. Error Histogram of experimented data and predicted data on MISO ANN model

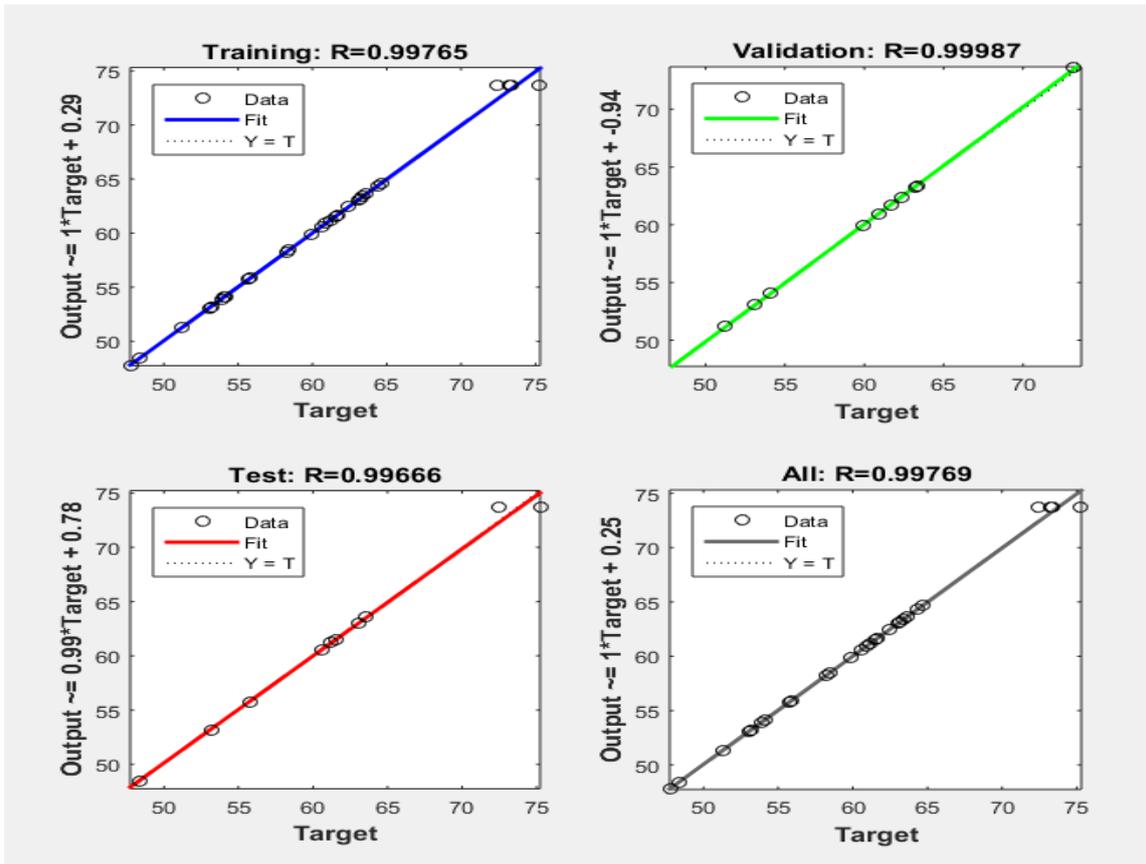


Fig. 13. ANN Regression plot analysis using seventeen neurons

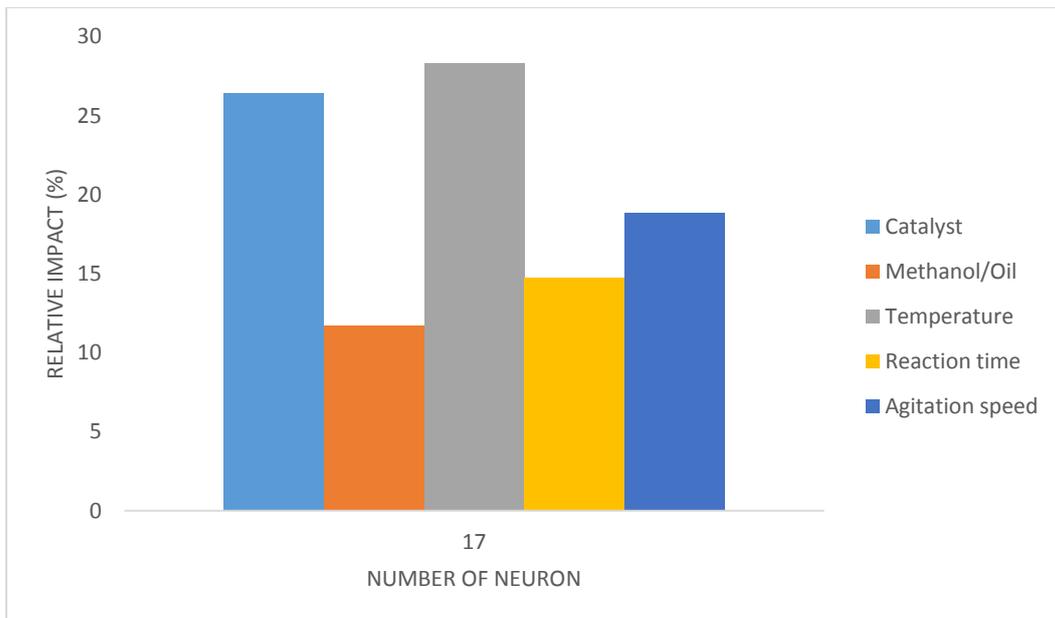


Fig. 14. Contribution of transesterification process variables in APSO FAME yield

**Table 6. Actual and predicted responses of APSO transesterification process using TAEPFBA catalyst**

Run order	Catalyst conc. (wt %) A	Methanol/Oil molar ratio B	Temperature (°C) C	Time (hrs) D	Agitation Speed (Rpm) E	Biodiesel yield from carbonized catalyst (vol. %) ANN	Biodiesel yield by TAEPFBA (vol. %) ANN
1	2	8	50	2	400	53.17	54.14
2	4	8	50	2	200	47.74	43.96
3	2	12	50	2	200	54.11	54.36
4	4	12	50	2	400	58.24	54.04
5	2	8	70	2	200	48.43	44.94
6	4	8	70	2	400	61.66	64.11
7	2	12	70	2	400	61.53	52.91
8	4	12	70	2	200	53.9	56.70
9	2	8	50	4	200	53.1	45.00
10	4	8	50	4	400	55.74	64.09
11	2	12	50	4	400	63.2	51.12
12	4	12	50	4	200	60.88	61.37
13	2	8	70	4	400	59.92	57.56
14	4	8	70	4	200	54.09	55.06
15	2	12	70	4	200	58.46	70.39
16	4	12	70	4	400	64.39	56.20
17	1	10	60	3	300	61.22	64.76
18	5	10	60	3	300	62.41	54.18
19	3	6	60	3	300	53.16	59.12
20	3	14	60	3	300	63.37	61.95
21	3	10	40	3	300	60.59	54.03
22	3	10	80	3	300	64.64	61.87
23	3	10	60	1	300	55.84	54.00
24	3	10	60	5	300	63.59	51.21
25	3	10	60	3	100	51.27	44.36
26	3	10	60	3	500	63.06	64.75
27	3	10	60	3	300	75.23	75.38
28	3	10	60	3	300	73.35	75.38
29	3	10	60	3	300	75.31	75.38
30	3	10	60	3	300	72.43	75.38
31	3	10	60	3	300	73.21	75.38
32	3	10	60	3	300	72.43	75.38

**Table 7. Model Summary Statistics and predicted APSO FAME yield**

Model (APSO FAME)	% error	MSE	R <sup>2</sup>	APSO FAME (%)
ANN model	0.20	0.0214	0.9977	75.38

#### 4. CONCLUSION

The production of biodiesel at optimal conditions from Africa pear seed oil using heterogeneous catalyst TAEPFBA, validation of the ANN model equation via process variables and the relative impact of the various process parameters were carried out. The transesterification method was adopted without treating the oil. The transesterification results show the yield of methyl ester increased significantly after the

EPFBA had been thermally activated. This is an indication that it is pertinent to calcine the catalyst (EPFBA) at 800°C. The process variables are relevant in biodiesel production, which was ascertained from the ANN equation analysis. Optimization of the reaction parameters for biodiesel production from Africa pear seed oil was carried out using ANN tools. Their predicted values certified the techniques to be recommended for predicting the biodiesel yield. The optimal values of the parameters were:

catalyst concentration of 3wt%, methanol/oil ratio of 10:1, temperature of 60°C, time of 3 hrs, and reaction speed of 300 rpm. The percentage yield of biodiesel from APSO oil using TAEPFBA shows that the catalyst has the potential to be used as a catalyst to transesterify edible and non edible oils to biodiesel. The sensitivity analysis carried out shows that the temperature has the highest relative impact and the methanol/oil ratio has the least relative contribution. The physiochemical properties of biodiesel produced under optimized conditions meet the ASTM standard and are within the recommended limits.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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