ISSN 1682-296X (Print)
ISSN 1682-2978 (Online)

Bio Technology

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Biotechnology

ISSN 1682-296X
DOI: 10.3923/biotech.2017.1.9

Research Article
Optimization of Biodiesel Production from Selected Waste Oils Using Response Surface Methodology

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Abstract

Background and Objective: Converting waste cooking oils to biodiesel with favorable environmental implications is a major route to sustainable energy, pollution control and quality biodiesel production. **Methodology:** This study investigates the trans-esterification of Waste Groundnut Oil (WGO), Soybean Oil (WSO) and Waste Palm Kernel Oil (WPKO) catalyzed with potassium hydroxide (KOH). **Results:** Evaluating with ASTM standards, WGO, WSO and WPKO biodiesel generated were of good quality. The optimal conditions for biodiesel yielded are 10.67 methanol per oil mole ratio, 0.86 w/w oil catalyst concentration, 60°C reaction temperature and 71 min reaction time for WGO, 9.76 methanol per oil mole ratio, 1.04 w/w oil catalyst concentration, 60°C reaction temperature and 70 min reaction time for WSO and 9.51 methanol per oil mole ratio, 1.24 w/w oil catalyst concentration, 62°C reaction temperature and 80 min reaction time for WPKO. **Conclusion:** Waste cooking oils constitute ready feedstock for high volume, good quality and sustainable production of biodiesel as well as a realistic means of eliminating the pollution resulting from the indiscriminate disposal of waste oils common to both household and industrial users.

Key words: Trans-esterification, waste groundnut oil, waste palm kernel oil, waste soybean oil, biodiesel, response surface methodology, environmental pollution, cheap fuel

Received: September 05, 2016 Accepted: November 14, 2016 Published: December 15, 2016

Citation: Ayodele A. Ayoola, K.F. Hymore and C.A. Omonhinmin, 2017. Optimization of biodiesel production from selected waste oils using response surface methodology. Biotechnology, 16: 1-9.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The global economy depends heavily on energy generation from coal, petroleum and natural gas[1], albeit amidst an increasing rise in cost and environmental concerns regarding the emissions responsible for climate change, alongside other harmful substances such as SO_X, NO_X and methane released during fossil fuel production and utilization as well as the secondary pollution resulting from unguided disposal of materials. The consequences of inadequate energy supply could be severe and this has prompted global efforts to seek alternative and complimentary energy sources that are sustainable and of less negative environmental impact. Energy production from biomass, such as crop oils, woody and waste materials have great advantage over fossil fuels in this direction[2].

In most developing countries, biodiesel seems to offer a greater likelihood for a good complement to fossil fuels. This is because, most of such economies are largely agrarian, the crops required for biodiesel production are cultivated in large quantity and the biodiesel technology involves simple and practical procedures that can be practiced, even by rural dwellers. In addition, the resultant fuel is favorably environmentally friendly, sustainable and does not require petroleum-diesel engine modification. Biodiesel production also promises to address the issues of poor electricity generation in rural areas, recurrent fuel scarcity and environmental pollution through recycling of generated materials[1,3,4].

Biodiesel is produced from trans-esterification process, which involves chemical reaction between plant oil and alcohol in the presence of preferable hydroxides of alkali earth metals as catalyst to generate biodiesel and glycerol[5,6]. Waste vegetable oils are ideal feedstock for biodiesel production because the practice is cost effective and also offers a solution to the pollution challenges that result from the wrong disposal of waste oils[7]. However, aside converting the huge waste cooking oils generated on a regular basis to biodiesel, of greater importance is the need to produce quality biodiesel at established optimum conditions, through a clean technology.

Oils from palm, groundnut and soybean are the most common brands of industrial, commercial and household cooking oils in Nigeria. Large amounts of waste oils resulting from such uses can become ready feedstock even in the rural areas for biodiesel production[8]. High yield and high quality biodiesel can be obtained through scientific assessment of the various factors of production, such as yields and quality of the different feedstock and the establishment of optimum conditions for biodiesel production. Oils of more than 2% Free Fatty Acids (FFA) are not considered suitable feedstock for biodiesel production[9] and several techniques such as acid esterification with methanol and sulphuric acid, esterification with ion-exchange resins, neutralization with alkalis followed by soap removal and extraction with polar liquids along with acid esterification and distillation of FFA have been proposed to reduce the high FFA content in feedstock oils[10]. The present study seeks to adopt trans-esterification of waste oils as a reliable way to generate energy products like biodiesel as well as curb the unregulated disposal and pollution caused by waste oils and thus evaluates the optimum conditions for biodiesel production from three common waste oils in Nigeria, Waste Groundnut Oil (WGO), Waste Soybean Oil (WSO) and Waste Palm Kernel Oil (WPKO).

MATERIALS AND METHODS

Waste oils and chemicals: The WGO and WSO were obtained from the Covenant University cafeteria, WPKO was obtained from a local factory in Ota, Nigeria. The oils were stored at room temperature for 7 days before the commencement of trans-esterification. All chemicals used (products of Sigma-Aldrich UK and J.T. Baker, USA) were of Analytical Reagent (AR) grade.

Determination of molecular weights of WGO, WSO and WPKO: Gas chromatography/mass spectrometry (GC/MS) was used for the analysis of triglycerides in the oils, through the identification of the fatty acid profiles. Agilent technologies 7890A GC system USA (gas chromatography equipment) was used to separate oil triglycerides into the fatty acid components. This involved three stages:

- Injecting a sample into the GC
- Separating samples into constituent components
- Detecting/identifying compounds present in the sample

Oil samples were introduced at an initial oven temperature of 60°C. The column temperature was programmed to increase to 200°C at the rate of 10°C min^{-1}. The injector and the Flame Ionization Detector (FID) temperatures were set at 220°C.

The GC analysis of WGO, WSO and WPKO generated the fatty acid profiles and mass fraction of the fatty acids that constituted the oil triglycerides (Table 1). The analysis of fatty acids was recorded as peaks on a chromatogram. And the molecular weights of the biodiesel were determined.

Table 1: Molecular weights of the biodiesels generated from the waste oils

Oil type	Fatty acid	Weight (%)	Fatty acid (Molecular weight)	Biodiesel (Molecular weight)
WGO	$C_{18}H_{34}O_2$ (C18:1)	90.21	282.4688	
	$C_{18}H_{32}O_2$ (C18:2)	0.42	280.4455	885.4251
WSO	$C_{12}H_{24}O_2$ (C12:0)	10.39	200.3228	
	$C_{18}H_{34}O_2$ (C18:1)	39.14	282.4688	842.4501
	$C_{18}H_{32}O_2$ (C18:2)	34.86	280.4455	
WPKO	$C_{12}H_{24}O_2$ (C12:0)	2.58	200.3228	
	$C_{14}H_{28}O_2$ (C14:0)	0.64	228.3768	
	$C_{16}H_{32}O_2$ (C16:0)	38.34	256.4308	840.3933
	$C_{18}H_{34}O_2$ (C18:1)	49.39	282.4688	

Table 2: Properties of the treated waste oils

Oil	Flash point (°C)	Viscosity (mm sec^{-1} at 40°C)	Density (g cm^{-3})	Acid value (mg KOH g^{-1})	Sap. value (mg KOH g^{-1})	Water content (%)
WGO	243	32.64	0.9090	0.561	1220.0	0.63
WSO	232	31.67	0.9110	1.843	240.1	0.67
WPKO	230	36.72	0.9100	1.106	203.7	0.56

Pre-treatment of oils

Removal of impurities from waste oils: Impurities, such as sand, sticks and plant/animal debris were removed to improve yield of biodiesel[11]. Large particles were removed through sedimentation and smaller particles removed through filtration, using a 70 µm diameter pore industrial sieve.

Elimination of FFA from waste oils: The removal of high level of FFA is essential to prevent soap formation during trans-esterification[12]. To obtain this, 10 mL of 0.125 M NaOH solution is added to every 100 g of waste oil, the mixture is continuously stirred at a temperature of 40°C for 15 min to allow the FFA in oil to react with NaOH. Thirty minutes gravitational settling results in two distinct layers: A top layer of less viscous waste oil lean of FFA and a bottom layer of soap emulsion. The waste oil is separated from the soap emulsion. The offensive odor of the waste oil disappeared at this stage. The suitability indices of the 3 oils are generated (Table 2).

Experimental design: MINITAB 16 (PA, USA) was employed for the design of experiments, plotting of response surfaces, establishment of optimal conditions for biodiesel production and statistical analysis of variation (ANOVA) of the response model. Box-Behnken (BB) fractional factorial designs with four factors and 1 response variable (biodiesel yield) at 3 levels (Table 3) was applied for the study.

The BB (4) allows 3 evenly spaced levels for each of the factors considered and the choice of values of the 3 levels is based on earlier results on waste oil biodiesel production[13-15]. The BB (4) allows for the establishment of the interactions among methanol per oil mole ratio (X_1), catalyst concentration (X_2), reaction temperature (X_3) and reaction time (X_4) through a valid model that relates these factors (conditions) to biodiesel yield (regression analysis), as well as the justification of the optimum conditions for biodiesel production (Table 4).

Table 3: Statistical BB (4*) for biodiesel yields showing factors and levels

		Levels		
Factors	Symbol coded	-1	0	+1
Methanol per oil (mole ratio)	X_1	6:1	9:1	12:1
KOH catalyst concentration (% w/w oil)	X_2	0.7	1.2	1.7
Reaction temperature (°C)	X_3	48	55	62
Reaction time (min)	X_4	50	70	90

*BB (4): Box-Behnken fractional factorial designs with four factors

Trans-esterification: The KOH catalyst was dissolved completely in the required amount of methanol as specified in the experimental design to form a clear solution of potassium methoxide. The solution was transferred to 100 g pre-treated oil heated to 50°C. The mixture was enclosed, maintained at the specified temperature and continuously stirred at 400 rpm on a "7.25×7.25" Cimarec Digital Magnetic Stirring Hotplate (USA).

The products obtained were transferred to separating funnel and allowed to stand for 24 h. The products separated into two distinct layers, a light yellow top layer (biodiesel) and a reddish brown bottom layer (glycerol). Biodiesels generated were cleansed of impurities, such as unconverted methanol, catalyst, soap and traces of glycerol by washing with several charges of warm distilled water and dried afterward at 120°C in an oven for 30 min to eliminate residual moisture (Fig. 1).

Table 4: BB (4) design of experiment of four variables in coded and natural units with the observed responses

Parameters								Biodiesel yield (%)		
X_1	X_2	X_3	X_4	CH_3OH per oil (mole ratio)	KOH conc. (w/w oil)	Rxn temp (°C)	Rxn time (min)	WGO	WSO	WPKO
1	1	0	0	12	1.7	55	70	91.33	90.79	86.63
1	-1	0	0	12	0.7	55	70	92.78	92.82	89.04
-1	1	0	0	6	1.7	55	70	88.90	87.51	84.10
-1	-1	0	0	6	0.7	55	70	90.98	89.12	85.43
0	0	1	1	9	1.2	62	90	99.00	97.90	98.52
0	0	1	-1	9	1.2	62	50	91.61	92.31	93.12
0	0	-1	1	9	1.2	48	90	92.43	91.88	90.24
0	0	-1	-1	9	1.2	48	50	92.78	93.54	89.62
0	0	0	0	9	1.2	55	70	95.02	94.06	94.57
1	0	0	1	12	1.2	55	90	92.08	92.83	91.01
1	0	0	-1	12	1.2	55	50	91.00	90.91	90.39
-1	0	0	1	6	1.2	55	90	88.81	89.45	87.22
-1	0	0	-1	6	1.2	55	50	91.90	88.40	85.03
0	1	1	0	9	1.7	62	70	95.78	94.82	95.35
0	1	-1	0	9	1.7	48	70	88.74	89.57	91.23
0	-1	1	0	9	0.7	62	70	93.33	92.80	93.07
0	-1	-1	0	9	0.7	48	70	94.11	90.84	90.84
0	0	0	0	9	1.2	55	70	95.56	94.21	94.50
1	0	1	0	12	1.2	62	70	92.94	93.03	93.11
1	0	-1	0	12	1.2	48	70	93.93	91.08	90.33
-1	0	1	0	6	1.2	62	70	95.16	91.13	89.09
-1	0	-1	0	6	1.2	48	70	87.69	88.42	86.77
0	1	0	1	9	1.7	55	90	91.11	92.77	91.89
0	1	0	-1	9	1.7	55	50	93.12	92.02	90.03
0	-1	0	1	9	0.7	55	90	93.85	92.98	91.53
0	-1	0	-1	9	0.7	55	50	90.09	91.61	90.01
0	0	0	0	9	1.2	55	70	95.10	94.18	94.52

Rxn temp: Reaction temperature

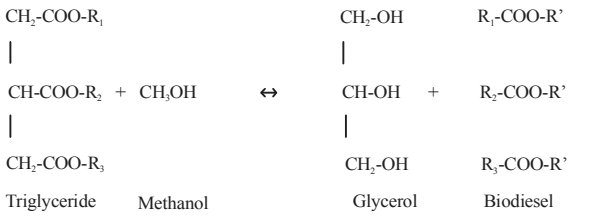

Fig. 1: Trans-esterification reaction of triglyceride (WGO, WSO and WPKO) in the presence of methanol (CH_3OH) to produce glycerol and biodiesel

RESULTS AND DISCUSSION

Biodiesel from vegetable sources offer complementary contributions to the global energy solution in technical, economic and environmental terms, particularly in developing countries where the energy crisis is further exacerbated by the poor level of technical knowhow, poor economic power of a large proportion of the population and the resultant environmental impoverishment that the continued energy crisis in such regions will bring[16].

The results of the present study offers an inexpensive, easy and low-tech means of converting waste oils into viable economic energy products, while eliminating a secondary pollutant generated across a wide range of the society from household to eateries, hotels and related establishments, highlights the potential of such energy sources and further expand the opportunities inherent in the adoption of such methodologies for the generation of energy products.

Biodiesel yield: Figure 2-4, show the effects of the variation in 4 parameters (methanol per oil mole ratio, catalyst concentration, reaction temperature and reaction time) on biodiesel yields obtained during the transesterification reactions of biodiesel production. Generally, it can be said that the 4 parameters have both the main and interactive effects on the biodiesel yields. The effects of each of the four parameters can be explained largely in terms of the reversible nature of the reaction between the oils and the methanol to form biodiesel.

Main and interactive effects of reaction temperature: Increase in reaction temperature (within the specified temperature range) resulted in increase in the biodiesel yields in each case of the oils used (Fig. 2b,d,f, 3b,d,f, 4b,d,f). That is increase in reaction temperature favored forward reaction for biodiesel production. The increased temperature caused the reactants (methanol and oil triglycerides) to react completely with increase reaction rate.

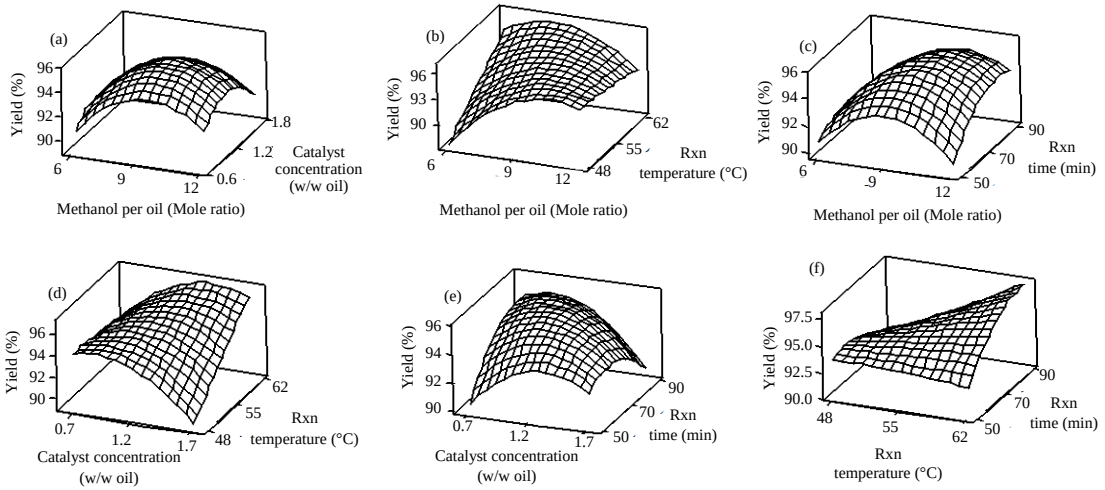

Fig. 2(a-f): Response surface diagrams of the four varied parameters and biodiesel yields obtained from WGO, Rxn: Reaction

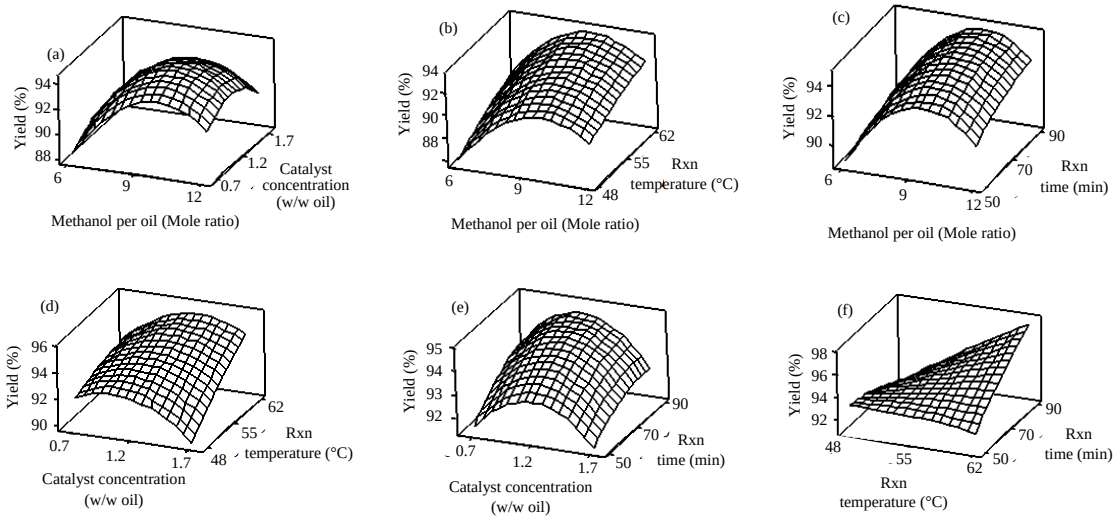

Fig. 3(a-f): Response surface diagrams of the four varied parameters and biodiesel yields obtained from WSO, Rxn: Reaction

It is important to note that the interactive effect of reaction temperature and methanol per oil mole ratio (as well as reaction temperature and catalyst concentration) on the yields is positive. That is biodiesel yield increased when these parameters were increased but with an exception at the catalyst concentration of 1.7 w/w oil and 48°C reaction temperature (Fig. 2d, 3d, 4d).

As reported earlier, increase in biodiesel yield with increase in reaction temperature is consistent with Arrhenius equation, which indicates increase in rate of reaction with increase in temperature[17-19]. High biodiesel yields were obtained at reaction temperature of (60-62°C) and this is supported by earlier studies[18,20-22].

Main and interactive effects of methanol per oil mole ratio: High biodiesel yield was obtained from the three oils when the methanol per oil mole ratio used was within (9-10) mole ratio (Fig. 2a-c, 3a-c, 4a-c). This implies that incomplete reaction occurred when the methanol oil mole ratio was less than 9 and a reverse reaction at mole ratio above 10, as equally reported by earlier researchers[12,23].

The interactive effect of methanol per oil mole ratio and catalyst concentration on biodiesel yield indicates that catalyst concentration should be kept at 1.2 w/w oil (Fig. 2a, 3a, 4a). The interactive effect of increase in the methanol per oil mole ratio and increase in reaction time (as well as increase in reaction temperature) showed an increase in biodiesel yield

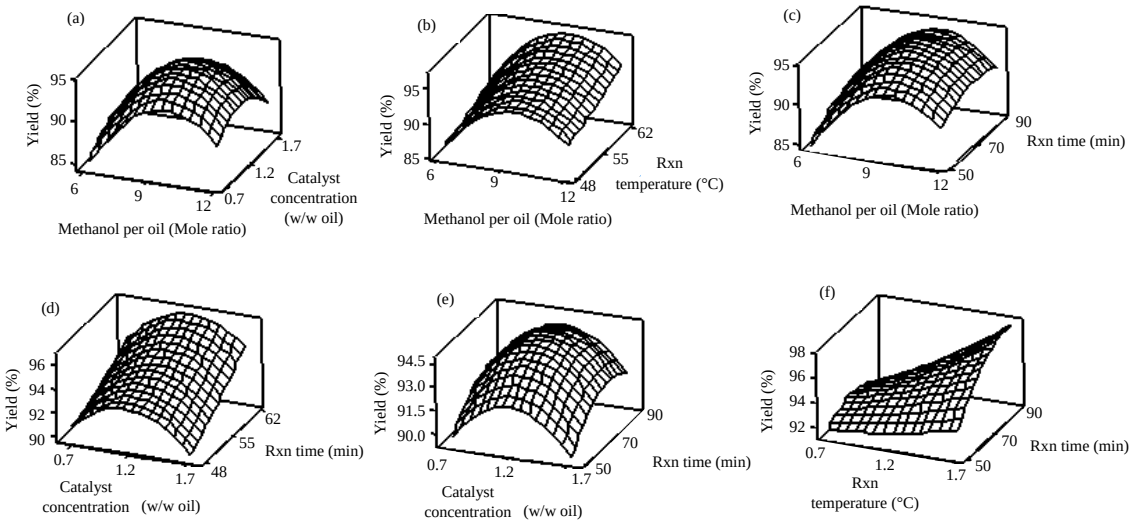

Fig. 4(a-f): Response surface diagrams of the four varied parameters and biodiesel yields obtained from WPKO, Rxn: Reaction

(Fig. 2b,c, 3b,c, 4b,c), an indication that the complete forward reaction of biodiesel production was favored by increase in the reaction time and temperature. In addition, literatures reveal that the low yield of biodiesel at excess methanol per oil of greater than 10 mole ratio during transesterification increases the polarity of the reaction mixture, thus increasing the solubility of glycerol and this promotes the reversible reaction between glycerol and biodiesel, thereby reducing biodiesel yields[23,24].

Main and interactive effects of catalyst concentration: In each case with the three waste oils employed in the present study, increase in catalyst concentration up to 1.2 w/w oil levels, increased biodiesel yield (Fig. 2a,d,e, 3a,d,e, 4a,d,e). As reported earlier, catalyst concentration of 1.2 w/w oil is regarded as optimum level. Beyond this concentration, decrease in biodiesel yields (due to saponification reaction) sets in, resulting mainly from the reaction between the excess catalyst and methanol to form soap, which inhibits biodiesel yield[20,21,25].

The interactive effect of catalyst concentration and the reaction time reveals that the reaction time should be kept at 80 min to promote the forward reaction and thus ensure favorable biodiesel yield.

Main and interactive effects of reaction time: Increase in reaction time favors the forward reaction for biodiesel production. In the present study, the main effect of reaction time on biodiesel yield showed biodiesel yield increased with reaction time. Earlier reports showed that providing sufficient time during transesterification reaction drive the reaction forward into completion for biodiesel production[12,18,20,25]. Also, the interactive effect showed high yield of biodiesel at methanol per oil mole ratio of 9, catalyst concentration of 1.2 w/w oil and reaction temperature of 62°C (Fig. 2c,e,f, 3c,e,f, 4c,e,f).

Biodiesel yield models: The general response (biodiesel yield) models, as function of the four parameters, are second-order polynomials, which can be represented in the form Eq. 1:

$$Y = \alpha_0+\alpha_1X_1+\alpha_2X_2+\alpha_3X_3+\alpha_4X_4+\alpha_{1,1}X_1X_1+\alpha_{1,2}X_1X_2+\alpha_{1,3}X_1X_3+\alpha_{1,4}X_1X_4+\alpha_{2,2}X_2X_2+\alpha_{2,3}X_2X_3+\alpha_{2,4}X_2X_4+\alpha_{3,3}X_3X_3+\alpha_{3,4}X_3X_4+\alpha_{4,4}X_4X_4 \quad (1)$$

The responses (biodiesel yields) designated as, α_0, α_1, α_2, α_3, α_4, $\alpha_{1,2}$ ..... $\alpha_{4,4}$ are the regression coefficients, X_1, X_2, X_3 and X_4 are the four factors, X_1X_1, X_1X_2, X_1X_3, X_1X_4 are the interactions of the variables, while X_1X_1, X_2X_2, X_3X_3 and X_4X_4 are the squared factor.

From the regression analysis, the most fitted models obtained are as shown in Eq. 2-4:

$$(\text{WGO biodiesel yield})_{KOH} = 38.5074+10.8486\ X_1-0.2922\ X_1X_1-0.1171\ X_1X_3+0.0164\ X_1X_4-7.1928\ X_2X_2+0.4836\ X_2X_3-0.1479\ X_2X_4+0.0099\ X_3X_4-0.0034\ X_4X_4 \quad (2)$$

$$\text{R-Sq} = 90.29\% \qquad \text{R-Sq (adj)} = 85.16\%$$

$$(\text{WSO biodiesel yield})_{KOH} = 73.9378+6.5672\ X_1-0.5116\ X_4-0.3379\ X_1X_1-5.9666\ X_2X_2+0.2520\ X_2X_3-0.0089\ X_3X_3+0.0125\ X_3X_4-0.0010\ X_4X_4 \quad (3)$$

Table 5: Analysis of variance of the factors for biodiesel yield from WGO, WSO and WPKO

		Coefficient			SE coefficient			f-value			p-value		
Term	Biodiesel	WGO	WSO	WPKO	WGOB	WSOB	WPKOB	WGOB	WSOB	WPKOB	WGOB	WSOB	WPKOB
Linear	Constant	38.5074	73.9378	28.5989	6.33702	6.11326	6.0791	17.5727	35.169	37.44	0.0000006	0	0
	X_1	10.8486	6.5672	11.0532	1.42639	0.55554	0.84301	57.8455	139.744	171.914	0.0000007	0	0
	X_2	-	-	24.6909	-	-	4.06234	-	-	36.942	-	0.0000076	-
	X_3	-	-	0.3862	-	-	0.15879	-	-	5.916	-	0.025059	-
	X_4	-	-0.5117	-	-	0.15424	-	-	11.006	-	0.003831	-	-
Square	X_1X_1	-0.2922	-0.3379	-0.5788	0.04372	0.03065	0.0465	44.6725	121.552	154.888	38	0	0
	X_2X_2	-7.1928	-5.9667	-10.3358	1.40493	1.00819	1.67418	26.2114	35.025	38.114	0.0000854	0.000013	0.0000062
	X_4X_4	-0.0034	-0.001	-0.0034	0.00076	0.00069	0.00086	20.9299	2.132	15.383	0.000269	0.161516	0.000915
Interaction	X_1X_3	-0.1172	-	-	0.01645	-	-	50.7454	-	-	0.0000017	-	-
	X_1X_4	0.0165	-	-	0.00773	-	-		-	-	0.04794	-	-
	X_2X_3	0.4837	0.2521	-	0.06856	0.04434	-	49.7775	32.314	-	0.0000019	0.000022	-
	X_2X_4	-0.1479	-	-	0.04275	-	-	11.9679	-	-	0.00299	-	-
	X_3X_4	0.0099	0.0125	0.0095	0.0018	0.00232	0.00218	30.5811	29.144	18.782	0.0000367	0.00004	0.0003577

WGOB: Waste groundnut oil biodiesel yield, WSOB: Waste soybean oil biodiesel yield, WPKOB: Waste palm kernel oil biodiesel yield

$$R\text{-}Sq = 93.99\% \quad R\text{-}Sq\ (adj) = 91.31\%$$

$$(\text{WPKO biodiesel yield})_{KOH} = 28.5989+11.0532\ X_1+24.6909\ X_2-0.3862\ X_3-0.5787\ X_1X_1-10.3358\ X_2X_2+0.0094\ X_3X_4-0.0033\ X_4X_4 \quad (4)$$

$$R\text{-}Sq = 93.99\% \quad R\text{-}Sq\ (adj) = 90.75\%$$

Analysis of variation using p and f-values: The ANOVA for the three regression models of biodiesel yields obtained indicates that the models fit well in describing the relationship between the predictor (biodiesel yields) and the factors. This is evident from the calculated high f-values and low p-values (Table 5). Large f-values imply that most of the variations in the responses can be explained by the regression model equations while the low p-values (of $\leq$0.05 for the main effects, two-factor interactions and squared terms) justifies the significance of each term of the models. Each model has high values of R^2 and R^2 (adjusted) and these values show the suitability of the models by describing the extent to which responses are reflected.

Equation 2 indicates the significance of the effect of methanol per oil mole ratio and also the interactions of the four parameters on WGO biodiesel yield. This was justified by the low p-values and high f-values obtained (Table 5). Methanol per oil mole ratio and reaction time, as well as the squared terms of the four parameters have significant effects on WSO biodiesel yield model (Eq. 3). In addition, the effects of the interactions of both the catalyst concentration with reaction temperature with reaction time are significant for WSO biodiesel yield as reflected by the low p-values and high f-values of the coefficients of the model equation (Table 5). The high f-value and low p-value that resulted in the omission of reaction time in Eq. 4, shows the significance of the effects of methanol per oil mole ratio, catalyst concentration and reaction temperature on WPKO biodiesel yield. In addition, low p-values and high f-values of these interactions and squared reaction temperature term indicates their significance.

Optimal conditions for biodiesel production: Table 6 shows the optimal conditions for biodiesel production from the three waste oils. The WGO and WSO generated optimal yield of 98.5% each, while WPKO recorded optimum yield of 97.7%. Considering the three waste oils employed, the optimum methanol per oil mole ratio range was 9.51-10.67 and this results are supported by the findings of earlier workers[18,26,27], that reported optimum methanol per oil mole ratio value of 9.9, when waste oils were trans-esterified to biodiesel. From the table, optimum value range obtained for biodiesel production from waste oils are, 0.86-1.24 w/w oil catalyst concentration, 60-62°C reaction temperature and 70-80 min reaction time.

Properties of the biodiesel obtained: In the present study, biodiesel properties obtained were within the ASTM standards, indicating that high quality biodiesel were obtained from the three oils[28-30] (Table 7).

The biodiesels generated from the waste oils recorded flash points above the ASTM minimum standard value of 130°C. The flash points recorded were 208°C (WPKO biodiesel), 204°C (WSO biodiesel) and 180°C (WGO biodiesel). Similarly, the viscosity range (at 40°C) for the biodiesels fell within the standard range of 1.9-6.0, as with the characterization values obtained for methyl ester generated from *Jatropha carcus*[31]. Water content determined in all the cases were of insignificant levels, making the biodiesels of good quality.

Table 6: Optimal conditions for biodiesel production from the three waste oils

Source of biodiesel	Methanol per oil (Mole ratio)	Catalyst concentration (w/w oil)	Rxn temp (°C)	Rxn time (min)	Optimum yield (%)	Optimum desirability
WGO	10.67	0.86	60	71	98.5	1.0000
WSO	9.76	1.04	60	70	98.5	0.9256
WPKO	9.51	1.24	62	80	97.7	1.0000

Rxn temp: Reaction temperature

Table 7: ASTM standards and properties of biodiesel generated from the waste oils

			Biodiesel		
Properties	ASTM standard (ASTM Mtd)	Units	WGO	WPKO	WSO
Density at 25°C	0.8600-0.9000 (ASTM D4052)	g cm^{-3}	0.8903	0.8760	0.8820
Pour point	(-12)-(+6) (ASTM D97)	°C	-9	-6	-6
Flash point	130 min (ASTM D93)	°C	180	208	204
Water content	0.005 min (ASTM D2709)	%	0.005	0.004	0.006
Viscosity at 40°C	1.9-6.0 (ASTM D445)	mm^2 sec^{-1}	(4.30-4.70)	(4.70-5.00	(4.55-4.85)
Cetane number	47.0 min (ASTM D613)		(49.4-51.0)	(51.7-53.2)	(50.6-52.8)

min: Minimum

CONCLUSION

This study shows that:

- High yield of quality biodiesel obtained from the KOH catalyzed trans-esterification process confirms treated waste cooking oils as good feedstock for the production of biodiesel
- Generated biodiesel properties from waste oils are congruent with the methanol per oil mole ratio, catalyst concentration, reaction temperature and reaction time regimes for the cost effective conversion of waste oils to biodiesel
- The properties of biodiesel yield from the three waste oils were consistent with ASTM standards for diesel of non-petroleum origin
- Generated biodiesel have higher cetane number, better engine ignitability, negligible sulphur content and poses lesser pollution problems than petroleum diesel
- Generating biodiesel from waste oils rather than costly virgin oils promise to improve livelihood by reducing the cumulative cost of acquiring energy and recycling generate wastes into economically viable energy products

SIGNIFICANCE STATEMENT

In this study, high quality biodiesels consistent with ASTM standards for non-petroleum diesel, with higher cetane number and better engine ignitability were generated from three waste oils by transesterification process using KOH as catalyst. Biodiesel conversion from waste oils will reduce use of virgin oils for biodiesel, reduce pollution and the cumulative cost of acquiring energy, improved recycling and improve livelihood.

ACKNOWLEDGMENTS

The authors acknowledged the Covenant University Centre for Research Innovation and Discovery (CUCRID) for the financial support through the doctorate programme grant (CUCRID 0.12.13./PGCU) and the Covenant University Cafeterias and Ojo factory for the waste oils.

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