Original Article

Development and characterization of biodiesel from obodoukwu palm kernel seed oil

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ABSTRACT

As a way of mitigating the depleting nature and environmental hazards of fossil diesel fuels, biodiesel was synthesized from Obodoukwu Palm kernel oil (PKO), which is the base oil for biodiesel. The process sequentially entails the crushing of the kernels, and extraction of the palm kernel oil (PKO) by the solvent extraction method using the Soxhlet apparatus with n-hexane, and the synthesis of the biodiesel by the transesterification of the oil, which involves converting the glycerol in the oil to methyl esters (diesel) in the presence of a base catalyst. The design for the optimization of this process was done using the Box Benkhen approach of the Response Surface Methodology (RSM) in the Design Expert 13 software. Physicochemical properties of the palm kernel oil and the developed biodiesel were determined using standard methods - American Society of Testing and materials (ASTM). Results indicate a yield of 46.73% of oil from seeds, and an optimum biodiesel yield of 85% at a temperature of 60°C for 30 minutes for a 6:1 ratio of methanol (solvent) to KOH (catalyst), and 4mm kernel particle size. The synthesized biodiesel was characterized by measuring its physical and chemical properties. The specific gravities, kinematic viscosities at 40 ∘ C, cloud point, pour and flash points of the biodiesel are:(0.873, 5.64cSt, 7.6 cSt, 6 ∘ C, −5 ∘ C, and 188 ∘ C) respectively. These, with the flash point of 188, density of 0.873, cloud point of 6, and specific gravity of 0.873 amongst others are in line with ASTM values for biodiesel, indicating that the biodiesel can be run on diesel internal combustion engines. Generally, eco-friendly and cost friendly biodiesel has been synthesized.

Keywords: Obodoukwu palm kernel oil, Soxhlet extraction, synthesis, biodiesel, characterize, transesterification, methyl esters

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INTRODUCTION

With consistent depletion of the crude oil reserves worldwide stemming from excessive consumption due to increase in population, and increased demand for fossil energy, there is a concern that the rate of fuel consumption may exceed the rate of natural decay and formation of crude deposits for fossil fuels [1]. This can lead to serious crises in the demand for energy if not mitigated with the discovery and application of alternative renewable energy sources [2]. One of such renewable alternatives are the bio-fuels – fuels derived from plant origin [3], usually from the seeds. . Findings indicate that these oils may be utilized as a substitute for mineral oils in large branches [4]. Compared to crude oil derivatives, bio-based oils are less toxic and eco-friendly. A lubricant formulated and prepared from plant or animal oils is called a biolubricant. One of such biolubricants is the biodiesel.

Biodiesel is a non-toxic, biodegradable and portable fuel produced from biomass of plant and animal products [5], and it is one of the technically and economically feasible options to tackle the fast depletion of fossil fuels and environmental pollution. It is free of lead, contains almost no sulfur or aromatics (toxic compounds such as benzene, toluene and xylene), and substantially reduces emissions of unburned hydrocarbons, carbon monoxide and particulate matter (soot), which have been linked to respiratory disease, cancer and other adverse health conditions [6].

Recent trends in alternative energy solutions have suggested the use of fuels from bio-based materials. Furthermore, the environmental issues created by pollutants emanating from much consumption of crude oil-based lubricants have re-awakened interest in exploring and using bio-based resources [7] and also provoked scientific and technological research on bio-based materials as alternative energy sources. for the following reasons: no sulphur, higher oxidative stability, coupled with its cleaner and more friendly exhaust emissions. In the long run, the solution to the impending energy crisis rests on the ability to develop environmentally friendly, renewable, and biodegradable fuels and lubricants that can sustainably be used totally, or in blends with the conventional fossil fuels, thus reducing the over-bearing dependence on fossil fuels [8]. The exhaustibility and the apparent environmental impacts of petroleum-based stock is a pressing cause for research in exploring the use of vegetable based lubricants. This is a major problem which needs to be solved. The use of vegetable-based oils will help improve this problem. These oils are non-toxic, they exhibit good lubricity, biodegradable and they are environmentally friendly [9]. In Europe during the 1980s, various mandates and regulations were placed on petroleum products necessitating biodegradable lubricants [10]. Due to increased environmental interest over the past two decades, a renewed interest in biodegradable lubricants, such as vegetable oil-based lubricants, arose [11]. Biochemical conversion methods are currently the most widely used for producing biofuels from biomass, accounting for approximately 80% of all biofuels produced worldwide [12].

With this additional evidence, it becomes necessary to find a better and environmentally friendly lubricant. In this work, Palm kernel oil was used for the production of the biodiesel based on its high abundance in the Eastern part of Nigeria, and as a means of reducing the waste of these kernels in dumps where they are mostly left to rot under the sun and in the rain in oil mills in the Eastern part of Nigeria. In terms of novelty, this work contributes to existing literature by documenting the properties of biodiesel specifically from palm kernel oil, a less commonly studied feedstock compared to palm oil or soybean oil. It fills a research gap by providing detailed physicochemical profiles and comparison with international standards, which can inform future research and industrial applications. The use of a region-specific raw material, namely palm kernel nuts from Obodoukwu in Nigeria, which has not been previously studied for biodiesel production, broadens the raw material base and scientific knowledge of local resources. Furthermore, the incorporation of the Box-Behnken Response Surface Methodology (RSM) for optimizing biodiesel production parameters adds significant methodological novelty to the work. It allows for a systematic, statistically robust investigation into the effects of process variables such as catalyst concentration, reaction time, temperature, and methanol-to-oil ratio, leading to optimized yields with minimal experimental runs. This approach enhances the precision and reliability of the process compared to traditional trial-and-error methods. Again, on the choice of palm kernel oil as base stock, the research also presents the characterization results of the produced biodiesel, in comparison with mineral-based biodiesel, and offers data for the potentials of the palm kernel oil based biodiesel for cold climate applications since the measured cold flow properties (pour point and cloud point) indicate the biodiesel's usability in temperate regions, which is a significant aspect considering biodiesel's general limitations in cold weather.

Premised on the above reasons, and the necessity for biodegradable and environmentally friendly bio-fuels as eco-friendly alternatives, this research dwells on the synthesis and production of biodiesel from palm kernel obtained from palm fruits that grow in abundance in Oboduukwu village of Ideato North Local government area of Imo state in Nigeria, where red cooking oil is notably produced from the palm fruit with the kernels as by-products of less value.

MATERIALS AND METHODS

The methods involve the crushing of the kernels, oil extraction, characterization of the oil, biodiesel synthesis, characterization of the produced biodiesel, and comparison of the results with ASTM values.

Palm Kernel Oil Extraction

The seeds were cracked with the use of a palm kernel crusher to extract the seeds from the hard shells, after which the seeds were oven dried at 60^{o}C for between 1 to 2 hours to reduce the moisture content.Preliminary investigations of experimental parameters was carried out using n-hexane of (300 – 500ml), particle size of (3 – 5mm), temperature of extraction of (80 – 100) ^{o}C and extraction time of (3 – 5 hours) using Soxhlet extraction method with n-hexane as a solvent due to its low boiling points (about 68.7 °C) which allows for easy removal of the solvent after the extraction process and its being relatively inexpensive compared to other solvents [13]. 100 g of crushed palm kernel seeds were placed in the thimble-holder in a 2L capacity Soxhlet extractor, and the results of preliminary investigations was then be used to continue the extraction process. After this, the oil became ready for the transesterification process. The oil yield is calculated using equation (1)

$$\% \text{ Oil yield} = \frac{Weight\ of\ extracted\ oil\ (g)}{Weight\ of\ dry\ seed\ (g)} \times 100$$

(1) [14]

Biodiesel synthesis

Biodiesel production was done in the WAFT Laboratory of Federal University of Technology, Minna. The transterification process was performed using a temperature-regulated heating mantle with a magnetic stirrer. The temperature of the oil was raised initially to 60°C to expel any moisture and n-hexane content that may still remain in the oil. After that a design of experiment was used to get the optimum values for the transesterification of the palm kernel oil using Response Surface Methodology in Design Expert 13 software. The Box Benkhen method of RSM as used. From the design table, (Table 1), the parameters from the "Run number 8" gave the highest yield in comparison with other runs, taking cognizance the other reaction parameters at a temperature of 60 °C for 30 minutes. Thus, a 6:1 ratio of methanol (solvent) to KOH (catalyst) in grams was added to a 100ml volume of oil. Then the reaction was carried out for 30 minutes on a hot plate at 60°C as the transesterification progressed. After this, the liquid in the vessel was poured into a separating funnel, wherein a clear distinction of methyl esters as the supernatant liquid was gradually seen in about 5 minutes as shown in Plate I.

Table 1: Experimental Design for Optimal Production Variables for the Biodiesel

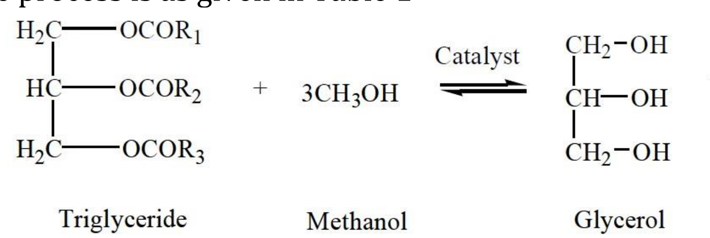
Run	Component	Mole ratio xr	Temperature	Catalyst con	Time	% yield
1	FACTORIAL	3:1	30	0.5	30	65
2	"	3:1	30	0.5	30	62
3	"	3:1	60	1.5	90	74
4	"	6:1	60	1.5	90	74
5	"	3:1	30	1.5	90	68
6	"	6:1	30	1.5	90	70
7	"	3:1	60	0.5	30	85
8	"	6:1	60	0.5	30	85
9	"	3:1	30	1.5	30	60
10	"	6:1	30	1.5	30	45
11	"	3:1	60	1.5	30	52
12	"	6:1	60	1.5	30	70
13	"	3:1	30	0.5	90	68
14	"	6:1	30	0.5	90	70
15	"	3:1	60	0.5	90	87
16	"	6:1	60	0.5	90	76
17	AXIAL	4.5:1	45	1	60	52
18	"	7.5:1	45	1	60	55

19	"	4.5:1	15	1	60	55
20	"	4.5:1	75	1	60	30
21	"	4.5:1	45	0	60	12
22	"	4.5:1	45	2	60	40
23	"	4.5:1	45	1	0	35
24	"	4.5:1	45	1	120	48
25	CENTRE	4.5:1	45	1	60	50
26	"	4.5:1	45	1	60	46
27	"	4.5:1	45	1	60	46
28	"	4.5:1	45	1	60	50
29	"	4.5:1	45	1	60	48
30	"	4.5:1	45	1	60	45

Plate I: Reaction set-up after the Transesterfication

By daybreak, the liquids have given a clear distinction to an upper methyl esters layer of amber colour with the glycerol below, consisting of excess methanol, impurities, and catalyst. The methyl esters were then separated and cleaned by washing off the soap with warm water, and drying in the dryer, after which the methyl ester yield was determined. These processes were repeated in batches to get the required amount of biodiesel as shown in Plates II and III.

The reaction for this process wherein the triglyceride is being converted to methyl esters is as shown in Equation 2, while the experimental design for the process is as given in Table 1



(Extracted oil) (FAME) (2)

Plate II: Biodiesel being washed

Plate III: The Synthesized Biodiesel after washing

The extracted oil was characterized to obtain its physicochemical properties, and compared with ASTM values, after which it is then placed in the transesterification set-up where it was converted to biodiesel through the transesterification of the oil to obtain biodiesel. The biodiesel was also characterized and compared with ASTM values of conventional fossil biodiesel.

Determination of the Physicochemical Properties of the Palm kernel oil and Biodiesel

The physical characterization methods used are as given in Table 2 below:

Table 2: Physicochemical characterization and adapted procedures

S/N	Parameters	Procedure
1	Viscosity index	ASTM D2270 - 10 [15]
2	Moisture content	AOAC 926.12[16]
3	Pour point	ASTM D97-17a)[17]
4	Flash point	ASTM D93-16[18]
5	Specific gravity	ASTM D1217-15[19]
6	Viscosity	ASTM D445-17a[20]
7	Iodine value	AOAC 993.20[21]
8	Saponification Value	AOCS method Cd 325[22]
9	Peroxide value	AOAC 965.33[23]
10	Yield	AOAC 920.85[24]

The physicochemical properties of the palm kernel oil and the biodiesel were determined according to the following procedures:

Determination of specific gravity

Having cleaned the specific gravity bottle with methanol and oven dried at 60 degrees Celsius, the weight of the empty bottle was noted, before filling it with 350cm^3 of the sample; covered and weighed using a weighing balance. It was then thoroughly cleaned, and the sample was taken out of the bottle, and distilled water was used to fill it, before the weight of the bottle containing the water was taken. The specific gravity was computed using the relationship in equation 3

$$Specific\ Gravity = \frac{W_1 - W}{W_2 - W}$$

[19]

where:

W = weight of empty bottle, W_1 = weight of the bottle and oil content, W_2 = Weight of bottle and water content

Viscosity

ASTM D445-17a[16] was used to determine the kinematic viscosities at 40^{o}C and 100^{o}C. A viscometer was used to conduct this test, ant the temperatures were maintained with an oil bath. In this procedure the visco-beaker was filled with the lubricant sample and placed on the horizontal support. The spindle of the viscometer was allowed to sink into the beaker containing the sample, and when the machine is turned on, the spindle rotates in the sample and gives a reading on the display screen in Cs proportionate to the viscosity of the sample.

Viscosity index measurements
Viscosity index was calculated using ASTM D2270 – 10[15]. This was obtained by interpolation of the kinematics viscosity values obtained at 100°C and 40°C using viscosity index chart/ with calculation.

Flash and fire point values
ASTM D93-16[18.] standard method was adopted in this test. The test was carried out as follows:

Into an evaporating dish was poured 3ml of thesample, and the temperature of the oil gradually increased. The temperature at which the oil began to flash (when flame was applied) without promoting combustion is known as the flash point, while the temperature at which the oil starts forming thick clouds of smoke is recorded as the fire point.

Saponification (SAP) value
The AOCS approach Cd 3-25 [22] was used. 50 cm^3 of 0.5 N ethanolic KOH (which had been left overnight) was added to 2g of the oil sample after it had been weighed and moved into a conical flask. After that, the mixture was heated to about 40°C in order to saponify the oil. Two to three drops of the phenolphthalein indicator were then used to back titrate the unreacted KOH with 0.5 M hydrochloric acid. Equation 4 was used to get the saponification (SAP) value of the examined samples:

$$\text{SAP value} = \frac{(\text{Titre value})(\text{Normality of NaOH})(56.1)}{(\text{Weight of sample})}$$

Pour point
ASTM D97-17a[17] was used to measure pour point. A glass test tube with a diameter of 26 mm was filled with a 25 ml oil sample. A thermometer was placed in the sample and the test tube was sealed with a one-hole stopper. After that, the sample-containing test tube was placed inside a 100 ml volumetric cylinder, which was thereafter placed in a refrigerator. The cooling media and the test tube did not come into close touch. The volumetric cylinder's sample test tube was removed. Beginning at 20°C, the test tube holding the sample was tilted to manually inspect it every 3°C as it cooled. By noting the temperature at which the sample would not flow if tilted for 5 seconds, the pour point was found.

RESULTS

The results of the extraction oil, biolubricant synthesis, and characterization are presented in the sections below. Table 2, Table 3, Table 4, and Table 5 show the physicochemical characterizations of the oil, biodiesel, and comparisons with ASTM standards

Characterization of Palm kernel Oil
The results and discussion of the result of the characterization of the Palm kernel oil are presented in the following subsections.

Physicochemical Properties of Palm kernel oil

The physiochemical properties Palm kernel oil are presented in Table 2. From the Table the palm kernel oil's pH was measured at 5.18, with a specific gravity of 0.901 and a viscosity of 32.54 at 40°C.The acid value was 5.18 mgKOH/g, free fatty acids were 10.36 mgKOH/g, saponification value was 222.58 mgKOH/g, peroxide value was 1.84 meq/kg and iodine value was 22.72 g/100g

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Table 2: Physicochemical properties of Palm kernel oil

S/N	Parameter	Results
1	Ph	5.18
2	Specific Gravity	0.901
3	Viscosity @ 40°C	32.54
4	Acid Value mgKOH/g	5.18
5	Free Fatty Acids mgKOH/g	10.36
6	Saponification Value mgKOH/g	222.58
7	Peroxide Value meq/kg	1.84
8	Iodine Value g/100g	22.72
9	Pour Point °C	13
10	Cloud Point °C	20
11	Fire Point °C	265
12	Flash Point °C	240
13	Yield	46.73

The comparison for the properties of both the Palm Kernel Oil and ASTM values for their physicochemical properties as shown in Table 3

Table 3: Comparison of physicochemical values of the extracted Palm kernel oil with ASTM values [25]

Item	ASTME	Extracted Palm Kernel Oil
Peroxide value	6.02 - 8.38	22.72
Moisture content	0.62 – 1.94	
Refractive index	1.453 – 1.455	
Density	0.90 – 0.91	0.901
Saponification value	216.02 – 248.16	222.58
Iodine value	17.52 – 19.65	22.72
Percentage of oil yield	39.64% - 52.26%	46.73
Acid value	6.37 – 8.54	5.18
Free fatty acid (FFA)	3.20 – 4.29	10.36
Insoluble impurities	0.06 – 0.09	

From Table 3, it is seen that the extracted palm kernel oil shows some similarities and differences when compared to ASTM standards. For properties such as the oil's density, saponification value, and percentage oil yield – these are all within ASTM standards, indicating not just that the oil is palm kernel oil, but that it is good quality oil suitable for biodiesel production. However, some differences can be observed in the peroxide value and iodine value. The extracted oil has a value of 22.72 meq/kg, which exceeds the ASTM recommended range of 6.02 – 8.38, indicating a higher level of initial oxidation or potential rancidity. The iodine value of the oil is 22.72 g/100g, slightly above the ASTM range of 17.52 – 19.65, suggesting a moderate degree of unsaturation. As for the acid and free fatty acid values, the acid value (5.18 mgKOH/g) is within the ASTM acceptable range, but the free fatty acids (10.36 mgKOH/g) are higher than typical values, which could impact oil stability and processing. Results from Table 3 also indicate a yield of 46.73 from the palm kernel. This is a bit lower than the value got by Hossain *et al.*[26], 49.2%, and far below the value of Yerima *et al*. [27], 51.35%. However, it is significantly closer to the value of Zaidul *et al.* [28], 47%, conforming with the report of Hossain *et al.* [26[, and Zaidul *et al.,* [28]. The origin of the seeds may have contributed to the little variation in the yields from the kernels, alongside operating parameters employed by Almeida da Costa*et al.* [29]

In summary, while many parameters are within acceptable ranges, higher peroxide and free fatty acid values suggest that the oil might be more oxidized or less refined, which could impact its stability and suitability for biodiesel production without further modification. Generally, results above, it is discovered that majority of the properties of the characterization result of the palm kernel oil fall in the range of the standard values and the few not in range are not so far away from standard values hence, there is a clear indication that the extracted palm kernel oil is actually palm kernel oil, and it can be used for its intended purpose, which is for the synthesis of biodiesel. From the comparisons, the value of the yield obtained from Obodoukwu palm kernel oil is good, and with better optimization, it can be increased, indicating the potentials of the Obodoukwu palm kernel oil as a veritable base stock for biodiesel synthesis.

Physicochemical Properties of Synthesized Palm Kernel Oil Biodiesel

The physicochemical properties of the synthesized biodiesel are presented in Table 4.

Table 4: Physiochemical Properties of the Synthesized Biodiesel

Serial no	Parameters	Results
1	Specific Gravity	0.873
2	Viscosity @ 40°C	5.64
3	Pour Point °C	-5
4	Flash Point °C	188
5	Cloud Point °C	6.0
6	Peroxide Value meq/kg	0.15
7	Iodine Value g/100g	96.72
8	Saponification Value	246.90
9	Acid Value mgKOH/g	0.544

From the table, the synthesized biodiesel had a specific gravity of 0.873 and a viscosity of 5.64 at 40°C.The pour point was -5°C, flash point was 188°C, cloud point was 6.0°C, peroxide value was 0.15 meq/kg, iodine value was 96.72 g/100g, saponification value was 246.90, and acid value was 0.544 mgKOH/g. These values for the physicochemical properties of the synthesized biodiesel were compared with ASTM values in Table 5

Table 5: Comparison of Physicochemical properties of produced Biodiesel with ASTM values[30]

Biodiesel properties	Measured values of Sample	ASTM Standard values (ASTM D6751)
Kinematic viscosity		19 – 60
Flash point	188	Less than/equal to 130
Density	0.873	0.876g/cm3
Moisture content		Less than 0.03
Iodine content	96.72	Less than 120
Free fatty acid (FFA)		0.42 maximum
Cloud point	6.0	-3 to 15
Cetane number		Greater than 47
Specific gravity	0.873	0.88
Boiling point	340	375

A comparison of the synthesized biodiesel with ASTM standards (Table 5) reveals that the measured values for the biodiesel are generally within acceptable limits. The measured flash point of 188°C indicates that the biodiesel has a high thermal stability and is safe to handle and store, aligning well with typical safety standards, as it exceeds the ASTM maximum requirement of 130°C. Conversely, the pour point of -5°C suggests the biodiesel remains liquid at relatively low temperatures, which is advantageous for cold weather performance. However, in colder climates, a lower pour point might be necessary to prevent gelling and flow issues, although -5°C is generally acceptable for moderate temperatures. Overall, these properties imply that the biodiesel is suitable for use in a range of operating conditions, with good safety and handling characteristics. Furthermore, in comparison with the ASTM biodiesel values, the measured value of Kinematic viscosity of the produced biodiesel is 5.64 cSt, which falls within the ASTM D6751 range of 1.9 – 6.0 cSt, indicating suitable flow properties for engine use, ensures good atomization, complete combustion, and avoids injector clogging. The flash point at 188°C exceeds the ASTM maximum of 130°C, suggesting good safety and thermal stability. This value also enhances safety during storage and handling, reducing fire hazards. For engine performance, a sufficiently high flash point is preferable to prevent pre-ignition, and auto-ignition. Although not directly compared with ASTM limits in the table, the peroxide value (0.15 meq/kg) and acid number (0.544 mgKOH/g) are low, indicating good stability. Furthermore, a low peroxide value (0.15 meq/kg) indicates minimal oxidation, ensuring the biodiesel's stability during storage and reducing the risk of engine deposits or corrosion. It is also seen that the pour point (-5°C) and cloud point (6°C) determine that cold-flow properties of the biodiesel are within the acceptable ranges. Low pour point helps the biodiesel flow at low temperatures, essential for cold weather start-ups, while the cloud point indicates the temperature at which wax crystals begin to form. The measured values suggest acceptable cold-flow performance in moderate climates but might pose challenges in colder environments without additives. The measured specific gravity/density is 0.873/0.873 g/cm^3, slightly below the ASTM value of 0.876 g/cm^3, but lies within acceptable limits. The specific gravity impacts fuel injection and atomization. A value close to the standard ensures proper spray characteristics in engine injectors. This closeness in values also indicates consistency. A close look at the saponification value of the palm kernel oil (246.90) (this relates to the average molecular weight of the fatty acids) shows that it falls within the acceptable range; higher saponification values usually indicate shorter chain fatty acids, influencing combustion characteristics and soap formation during processing. The Iodine value of the biodiesel is 96.72 g/100g, which is well below the maximum allowable of 120, indicating low unsaturation, leading to improved oxidative stability but potentially affecting cold flow and combustion properties.

The table also shows that there are some limitations which need to be improved upon. Such limitations include thermal, oxidative and hydrolytic instability and inadequate low temperature fluidity due to high pour points [31]. These limitations are due to the presence of the glycerol moiety which is a major component in vegetable oil. The susceptibility of this molecule to high temperature destruction is due to the presence of a β-hydrogen atom on the second carbon atom of the glycerol molecule [32], which is more acidic and unstable. Most of these shortcomings can be minimized by chemical modification through transesterification of vegetable oil with polyhydric alcohol [31].The yield of 85% is close to the 90.53% obtained by Ojolo *et al.*[33]. This further attests to the veracity of the production method and the product obtained.

Overall, the biodiesel's properties are generally within or close to ASTM specification ranges, particularly in viscosity, flash point, and cold-flow properties, indicating it is suitable for engine use with good safety and stability profiles. The high flash point adds a safety margin, and the low peroxide and acid values suggest good oxidative and storage stability. Based on the physicochemical properties presented, the produced biodiesel is suitable for use in diesel automobile engines, but for enhanced outputs, certain considerations are necessary, such as proper formulation and possible inclusion of additives to optimize cold-flow properties or stability in specific environmental conditions.

CONCLUSION

The synthesized biodiesel from palm kernel oil exhibits key properties such as a specific gravity of 0.873, a viscosity of 5.64 cSt, and a flash point of 188°C, which are generally within the acceptable ranges for biodiesel fuels. Its iodine value (96.72 g/100g) indicates a degree of unsaturation suitable for biodiesel. Also, the biodiesel's physicochemical properties, including viscosity, density, and flash point, meet or are close to ASTM D6751 standards, suggesting its suitability as a renewable alternative to fossil diesel. Again, the application of local content possibility of utilization of regional raw material) has been explored in this work; the use of palm kernel nuts from Obodoukwu in Nigeria has demonstrated, and showed that locally sourced, underutilized regional resources can effectively be converted into biodiesel. Furthermore, the application of the Box-Behnken Response Surface Methodology optimized the biodiesel production process, potentially leading to higher yields, cost-effectiveness, and process efficiency.

In conclusion, a bioldiesel with acceptable fuel qualities for diesel engine applications has been produced from Obodoukwu palm kernel oil. Characterization results indicate that the fuel can be employed in diesel automobile engines. However, further research is needed to improve on the yield of the biolubricant, its biodegradability, and emission characteristics in a diesel automobile engine.

Authors' Contribution

Nwizugbo, F. C. conceptualized the study, field work, and data collation. Ayo, S. A., Lawal, S. A., and Kovo, A. S. assisted in the design of the study. and the data analysis. Nwizugbo, F. C. prepared the first draft of the manuscript, which was reviewed by Ayo, S. A, Lawal, s. A., and Kovo, A. S. All authors contributed to the development of the final manuscript and approved its submission.

Disclosure of Conflict of Interest

None

Ethics Approval and Informed Consent

This study did not use human or animal subjects. Therefore, ethical consideration was not applicable.

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