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Comparative Analysis of Physicochemical Properties of Biodiesel Produced from Various Feedstocks

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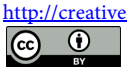

Abstract

This paper investigates the physicochemical properties of five distinct feedstocks (sunflower seed oil, Jatropha seed oil, beef tallow, pig lard, and used cooking oil) aiming to delineate their significance in biodiesel production. Methodologically, biodiesel production involved transesterification processes tailored to each feedstock's free fatty acid content. Subsequent property evaluations were conducted according to ASTM biodiesel standards, revealing substantial variations among the feedstock oils. Findings indicated significant differences in fuel density, energy content, flash point, and kinematic viscosity, highlighting the diverse characteristics influencing their suitability for biodiesel production. The highest and lowest values of fuel density differed by 1.15%, recorded for used cooking oil biodiesel and Pig Lard biodiesel, respectively. Meanwhile, pig lard biodiesel recorded the highest values of energy content and kinematic viscosity at 39.93 MJ/kg and 5.9 cSt, respectively. Lastly, the highest value of 176˚C (flash point) was recorded for Jatropha biodiesel. Statistical analysis revealed significant variations confirming the importance of feedstock selection for sustainable biodiesel production. The study's findings contribute to a deeper understanding of the diverse properties of feedstock oils and their pivotal role in optimizing biodiesel production for enhanced sustainability and performance.

Keywords

Biodiesel, Feedstock, Physicochemical Properties, Transesterification, ASTM Standards

1. Introduction

Research on a variety of feed oils to produce biodiesel has increased because of the growing demand for environmentally friendly and sustainable energy sources worldwide. The physicochemical characteristics of feed oils are crucial in determining the effectiveness and environmental impact of the biodiesel production process, which is driven by the search for cleaner alternatives. This paper presents a physicochemical comparative study of selected feed oils namely, used cooking oil, pig lard, beef tallow, sunflower seed oil, and Jatropha seed oil. The paper also seeks to demonstrate the unique characteristics of these feed oils and their significance in producing sustainable biofuel through a thorough analysis of recent studies.

It is important to mention here that biodiesel feedstocks are classified according to their fatty acids' compositions [1]. That is, according to the presence or absence of double bonds as saturated fatty acids (without double bonds), monounsaturated fatty acids (with one double bond) and polyunsaturated fatty acids (with two or more double bonds) [2] [3]. They can be Monounsaturated Fatty Acids (MUFA), Saturated Fatty Acids (SFA) and Polyunsaturated Fatty Acids (PUFA) [4]. Authors have emphasized that an ideal biodiesel feedstock should contain a relatively higher percentage of MUFA than PUFA [5]. For the feedstocks used for the present investigations, the beef tallow and pig lard are saturated while the used cooking oil, sunflower oil and Jatropha seed oil are unsaturated.

As a result of its favorable fatty acid composition and high oil content, sunflower seed oil, which is derived from sunflower seeds has gained notice and grown in importance within the biodiesel industry [6]-[8]. Similarly, Jatropha seed oil, which is produced from the *Jatropha curcas* plant, has special benefits including resistance to arid environments and little rivalry with food crops, making it a promising option for a feedstock for biodiesel [9].

Similarly, beef tallow and pig lard, which are byproducts of the meat processing industry, provide twice as much benefit when it comes to using animal-based feedstocks [10] [11]. Recent research emphasizes the potential of animal-based feedstocks in biodiesel production, highlighting their role in waste management and sustainable energy generation [12] [13]. In addition, in Botswana, cooking oil that is collected from food chain stores is often regarded as a waste product. Emerges as a green option that encourages recycling and aids in the generation of sustainable energy [14] [15]. Optimizing the transesterification processes, a crucial chemical reaction in the production of biodiesel, requires a thorough understanding of the physicochemical characteristics of these different potential feed oils. To improve the overall efficiency and quality of biodiesel production from the feed oils under review, analysis of the free fatty acid composition, density, flash point, and energy content is essential [16]-[18].

By leveraging these physicochemical analyses, researchers and biodiesel producers can better understand the characteristics of feed oils and make informed decisions regarding process optimization, feedstock selection, and quality control.

This ultimately leads to improved efficiency, higher biodiesel yields, and higher-quality biodiesel that meets the biodiesel standards for commercial use. As a result, this paper seeks to add to the current discussions about biodiesel production by offering a thorough summary of current studies on the physicochemical properties of used cooking oil, pig lard, beef tallow, sunflower seed oil, and Jatropha seed oil. In the constantly changing field of renewable energy, the paper also sheds light on the unique characteristics of each feedstock and provides insightful information about their potential as sustainable sources for biodiesel production.

2. Materials and Methods

In this study, biodiesel was produced from 5 different feedstocks, each sourced and processed uniquely depending on the level of Free Fatty Acids (FFA). A two-stage is employed when the FFA content is above 3% while a single-stage process is used when the percentage of FFA level is below 3%. The beef tallow, sourced from Botswana Meat Commission (BMC), underwent production considering its FFA content of approximately 8%, necessitating a two-stage transesterification process to reduce the level of FFAs to below 3%. Used cooking oil, procured from the local waste oil management company Orera Proprietary Limited, typically contained the level of FFA content of approximately 6%, thus requiring to be processed using a two-stage process of producing biodiesel. Sunflower seeds and Jatropha seeds which were collected from National Agricultural Research and Development Institute (NARDI) located at (24.5649˚S, 25.9809˚E) and Mmadinare Village located at (21.8811˚S, 27.7514˚E), respectively, were pressed to extract oil using a Kern Kraft oil press GmbH 8 Co.KG machine. The machine, consumed approximately 1.6 kilowatts per hour of electrical power while operating with the following specifications, a production capacity of 40 kilograms per hours and an operating speed ranging between 15 to 70 revolutions per minute. These two feedstocks were processed using one stage transesterification process due to their relatively low levels of FFA of approximately 0.7% and 1.2%, respectively. Pig lard was collected from Botswana University of Agriculture and Natural Resources (BUAN), and a one stage transesterification process was used to produce biodiesel due to its relatively low level of FFA (0.6%). To perform the titration, approximately 8 grams of the cooking oil sample that was received was collected, and approximately 2 grams of the feed oil were measured into three conical flasks using a Drawell analytical balance. Specifications are included in Table 1.

Around 50 ml of 95% ethanol and toluene each was measured using a pipette and added to the conical flasks containing the feed oil. The contents were thoroughly mixed by swirling and left to settle. Approximately 5 drops of phenolphthalein (an indicator) were added to each conical flask using a 3 ml disposable syringe. The burette was securely fastened onto a support stand, and approximately 50 ml of potassium hydroxide solution was charged into the burette, and the initial volume was recorded. The conical flask with the feed oil mixture was positioned under the burette, and the potassium hydroxide solution was gradually

Table 1. Drawell digital analytical balance specifications.

Name	Specifications
Maximum weight	100 g
Minimum weight	10 mg
Repeat accuracy	±0.2 mg
Measurement Precision	±0.1 mg
Operation Temperature	17.5˚C - 22.5˚C
Stabilization Time	≤8 sec

added to the mixture until a colour change occurred, indicating the completion of the titration. This colour change was observed as a transition from a yellowish colour to a slightly pinkish or purplish. The process was repeated at least three times for accuracy. Figure 1 demonstrates the schematic arrangement of the titration processes.

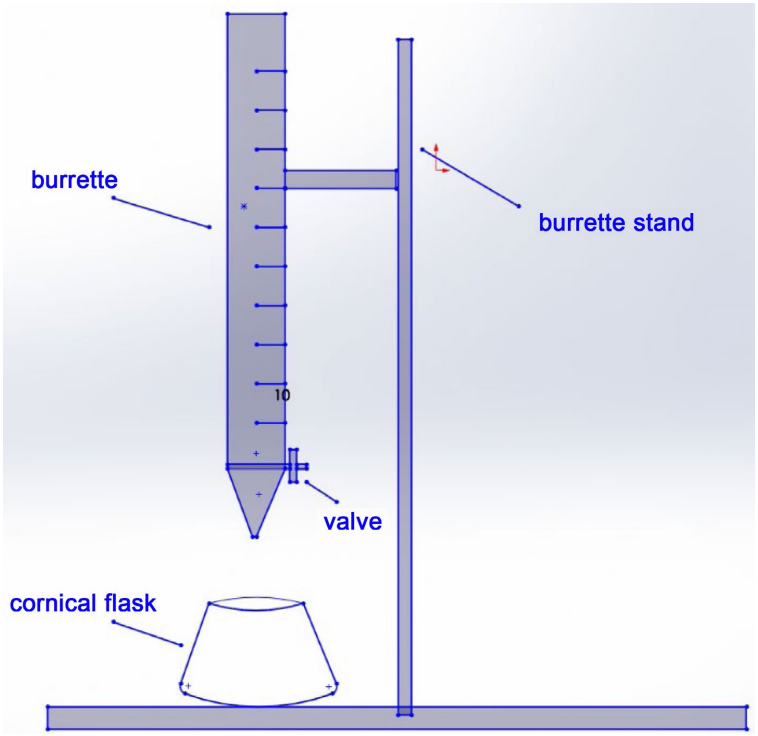

Figure 1. Schematics arrangement of the titration processes (*Sketched using SolidWorks Software*).

The final volume of potassium hydroxide used was then recorded. The level of free fatty acids was then calculated using Equation (1). This evaluation provided valuable information on the level of FFA present in the feed oil and enabled the determination of the appropriate processing procedure to be followed.

$$\text{Free Fatty Acids Levels} = \frac{V \times N \times MW_{KOH}}{W \times 1000} \quad (1)$$

where:

V = Volume of KOH solution consumed in the titration (mL)

N = Normality of the KOH solution (mol/L)

W = Weight of oil sample (g)

MW = Molecular weight (g/mol)

MW_{KOH} = 56.1 g/mol.

2.1. Transesterification

Transesterification is the pivotal process of converting fats into biodiesel, involving a chemical reaction between fats or oils and an alcohol, typically methanol or ethanol, catalyzed by an alkali or acid. This reaction results in the formation of fatty acid alkyl esters, known as biodiesel, and glycerol. The transesterification process was carried out using the experimental setup demonstrated in Figure 2.

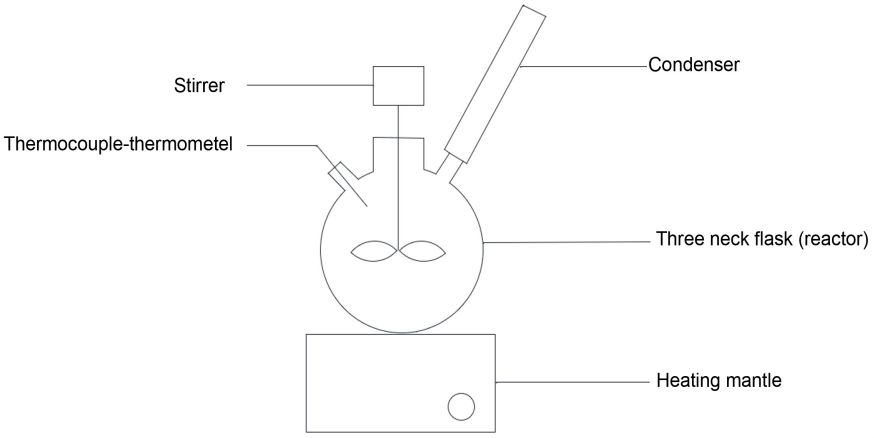

Figure 2. Schematic experimental set up of the transesterification process (Gandure *et al*., 2017).

2.1.1. Initial Esterification

The initial esterification stage was used to reduce the high levels of FFA recorded in feedstock, such as beef tallow and used cooking oil, to a level suitable for the subsequent transesterification reaction. The feedstock oil (2000 ml) was reacted with 1000 ml of methanol in the presence of 10 ml of a catalyst (sulfuric acid, H_2SO_4). This mixture was continuously stirred and heated at a maintained temperature of approximately 60˚C, for a reaction time of 1 hour. This reaction reduced the FFA content making the feedstock oil more amenable to the subsequent transesterification process, which is the main reaction for producing biodiesel.

2.1.2. Main Trans-Esterification

Following the initial esterification processes, the treated feedstock then undergoes the main transesterification reaction. During this stage, the esterified feedstock, methanol of 600 ml, and a catalyst of approximately 30 g (potassium hydroxide pellets, KOH) were added under the same reaction conditions as described in section 2.1.1. This reaction led to the formation of biodiesel, which is a mixture of

fatty acid alkyl esters, along with glycerol as a byproduct.

The two-stage transesterification process ensures that feedstocks with relatively high FFA levels, which might hinder a single-stage transesterification reaction, can be effectively converted into biodiesel by initially reducing the FFA levels and then proceeding to the main transesterification reaction. It is important to mention here that, sunflower oil, Jatropha seed oil and pig lard were produced employing a single stage as described above, and that the separation, methanol recovery and washing stages were the same across all biodiesels produced. Section 2.2 explains the separation stage.

2.2. Separation

2.2.1. Phase Separation

After the completion of the transesterification reaction, the mixture separated into two distinct layers as demonstrated by Figure 3 due to the differing densities of the components. The upper layer demonstrates the desired biodiesel, which is composed of fatty acid alkyl esters. The lower layer shows crude glycerol, which is denser and settles at the bottom due to its relatively high specific gravity.

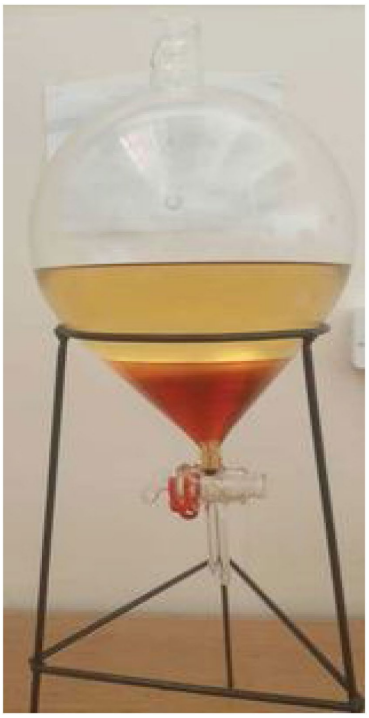

Figure 3. Separation of biodiesel and crude glycerol layers.

2.2.2. Glycerol Removal

The next step involved the separation of crude glycerol from the biodiesel layer. Various methods can be used for this purpose, including settling, decantation, or the use of separation equipment like centrifuges or gravity-based separators. In the present study a gravity-based separator was used to separate the two layers. Glycerol layer was then drained from the bottom, leaving behind the biodiesel in the upper layer.

2.3. Methanol Recovery

Simple distillation was used to recover unreacted methanol from the biodiesel-methanol mixture obtained after the transesterification process. The setup of this procedure is shown in Figure 4. The biodiesel-methanol mixture was heated in Flask A to approximately 65˚C, causing methanol to evaporate. The evaporated methanol was condensed and collected separately in Flask B, allowing for its reuse in subsequent biodiesel production batches, reducing costs, and minimizing environmental impact by limiting chemical waste release.

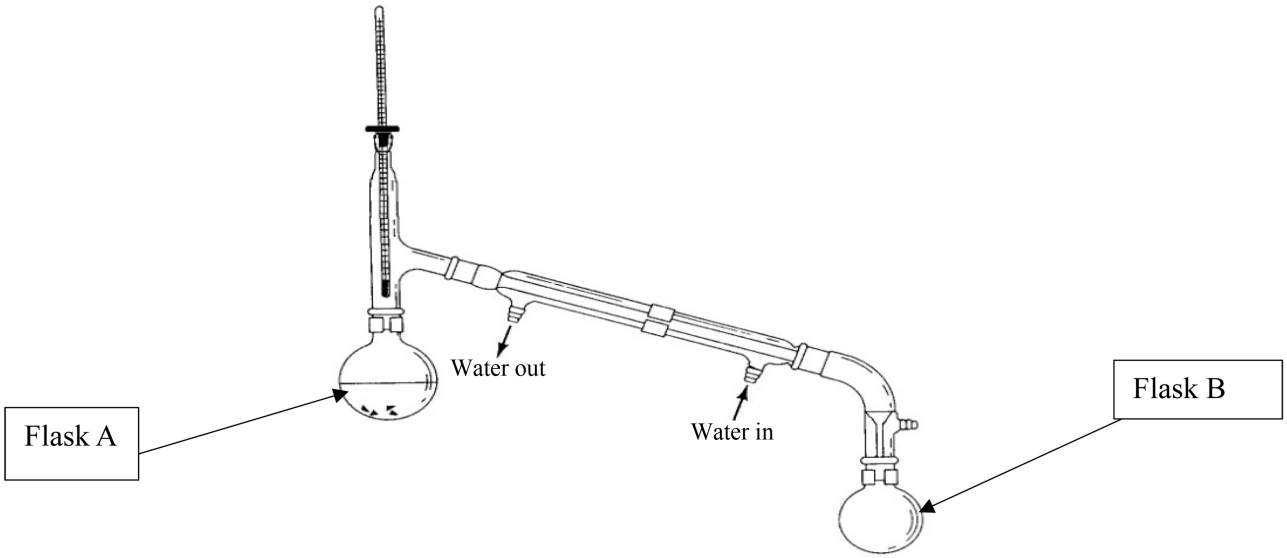

Figure 4. Methanol recovery set-up (Lopez, 2019).

2.4. Washing

To ensure the removal of any remaining impurities or traces of glycerol, the biodiesel was washed using hot water (80˚C), which helps to eliminate residual impurities. Water can remove all the impurities since it is a universal solvent; therefore, all the impurities can dissolve in water and be separated using a gravity-based separator. The washed biodiesel was then dried to remove excess water content, ensuring the final product meets quality standards of approximately 0.5 mg/g maximum allowable moisture content.

2.5. Testing Methods and Equipment Used

2.5.1. Fuel Density

A Kyoto Electronics density meter model DA-130N was used to measure the density according to ASTM D1298 standard which specifies the range of density of biodiesel as 0.86 - 0.90 g/cm^3. The meter has a precision of ±0.001 g/cm^3, a resolution of 0.0001 g/km^3 and a range from 0 to 2 g/m^3. The equipment is auto-calibrated, and the density of water at each temperature required for calibration of the measuring cell is pre-installed. The results were compared to ASTM D1298 standard.

2.5.2. Energy Content

The energy content was determined using CAL 3K-AP Combustion Calorimeter according to ASTM D240 standard which specifies the energy content to range from 39 to 43.3 MJ/kg. Samples of approximately 0.5 g were measured in the crucible basin using analytical balance, with a precision of 0.0001 g. The mass was entered into the system using the built-in keyboard. The testing vessel was then prepared by attaching the firing cotton thread to the firing wire. The crucible basin containing the sample was then placed on the holder and positioned properly making sure that the firing cotton thread was dipped into the sample. If the firing cotton thread does not touch the sample, it is unlikely that the sample fires. In that case the test fails or gives wrong results. The vessel was then gently closed and placed well in the calorimeter and the lid was then closed. The calorimeter automatically charges the vessel with oxygen and initiates the test run. At the end of the test, the results were then indicated on the display screen. The procedure was repeated five times for each sample and the average was calculated. The results of the energy content were compared to the ASTM D240 standard.

2.5.3. Flash Point

The Flash points were determined using Automated Pensky-Martens Closed Cup Flash Point Tester Model apm-8, following ASTM D93 standard which specifies the flash point as 130˚C minimum for biodiesel. The flash point tester has the measuring range from the ambient temperature to 370˚C. The expected flash point of the sample, sample ID, and test method were entered in accordance with ASTM D93 before running the test. The protective cover was removed first, and the arm release button was pressed to lift the arm automatically. The samples were then filled in the test cup to the filling mark as specified by the equipment manufacturer. The test cup was then placed in a test stove section and the arm was lowered gently into the test cup by pushing it downward until the latch was engaged and secured. Finally, the test was then initiated by pressing the start button. When the flash was detected, the flash point temperature was displayed on the screen. The tests were repeated five times for each sample and the average value was compared to ASTM D93 standard values.

2.5.4. Kinematic Viscosity

The viscosity analysis of biodiesel samples employed a Fungilab Premium Series digital electronic viscometer in accordance with ASTM D445 standards. The viscometer, equipped with specifications presented in **Table 2**, was linked to a Thermo-scientific Hake AC 150 water heater, maintaining precise sample temperatures by circulating water around the test cup. This method involved immersing a rotating spindle, calibrated with a spring, into 15 ml of the respective biodiesel sample within the test chamber, ensuring consistent sample depth for accuracy. Utilizing a low viscosity adaptor (LCP spindle) suitable for fluids as low as 1cp, rotational speeds between 2 to 60 rpm for seed oil and 50 to 200 rpm for

biodiesel were adjusted to maintain torque levels between 65% and 100%, based on the viscosity of the test samples. The temperature of the samples was carefully controlled, gradually increasing from approximately 20˚C to a maximum of 50˚C to prevent thermal degradation. Viscosity measurements were taken incrementally, noting the viscosity at 40˚C in line with ASTM standards. Each viscosity recording underwent five repetitions to derive the average value for precise analysis.

Table 2. Specifications for the Fungilab Premium digital electronic viscometer used for measuring viscosity.

Specifications
Precision: ±1% of full scale
Resolution: With low viscosity adapter: 0.01 For lower than 10.000 viscosity cP: 0.1 For viscosity equal to or above 10.000 cP: 1
Repeatability: 0.2%
Thermometer features: Temperature margins: 0˚C to +100˚C 32˚F to 212.0˚F Resolution: 0.1˚C/0.1722˚F Precision: ±0.1˚C Type of probe: PT100
Supplied at 100 - 240 VAC, 50/60 Hz
Measuring Range (cP): 1 - 106.000.000
Speed (r.p.m): 0.01 - 250

3. Results and Discussion

The authors performed a comparative analysis of selected biodiesel physical properties for biodiesel produced from four (4) oil feeds, namely, Jatropha oil, Sunflower oil, Beef tallow, and Pig oil. A statistical method (ANOVA) was also employed to analyze the data further. The results of the study are presented in **Figures 5(a)-(d)**, while the analysis of variance results is presented in **Tables 3(a)-(d)**.

The results in **Figure 5(a)** show that biodiesel produced from Used Cooking Oil (U-B) recorded relatively high density compared to the rest of the biodiesel produced from other feedstocks under review. However, the overall results reveal that there is a 95% level of confidence that the difference between densities of biodiesel produced from Sunflower seed oil, *Jatropha* Seed Oil and Used Cooking Oil is not statistically significant. Moreover, the same observation was made about the densities of biodiesel produced from Beef tallow, and Pig Lard. The results in

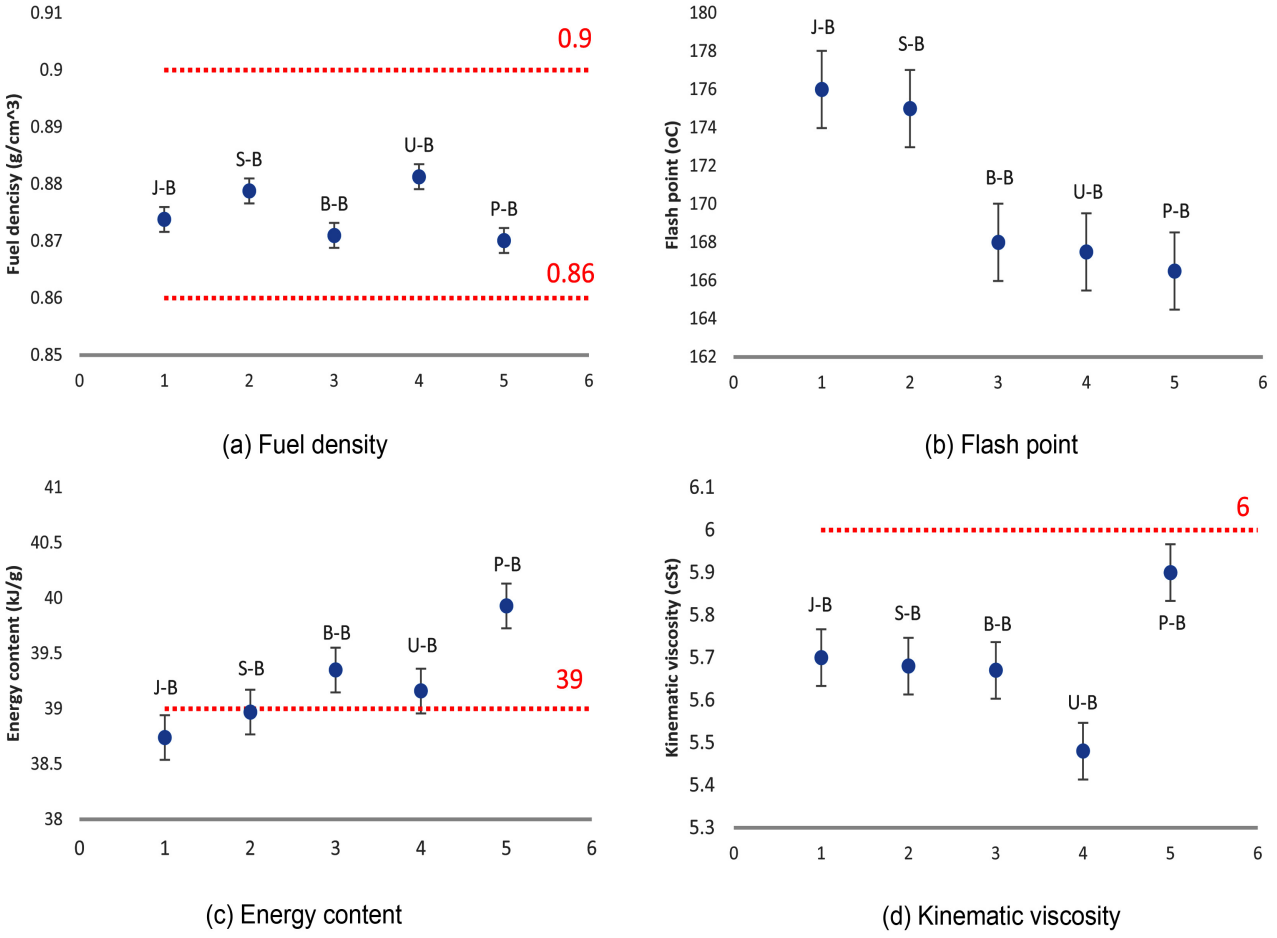

Figure 5. (a) to (d) Experimental results of the biodiesel samples (Note that J-B, S-B, B-B, U-B and P-B represent *Jatropha* seed oil biodiesel, sunflower seed oil biodiesel, beef tallow biodiesel, used cooking oil biodiesel and pig lard biodiesel, respectively).

Figure 5(a) show that there is 95% level of confidence that there is a significant difference between the densities of biodiesel produced from plant oils and animal fats. The results indicate that the biodiesel produced from plant oils recorded relatively high fuel densities as compared to the biodiesel produced from animal fats. For instance, Pig Lard biodiesel recorded the lowest density of 0.87 g/cm^3 followed by Beef Tallow biodiesel, Jatropha and Sunflower seed oil. Used cooking biodiesel recorded the highest density value as demonstrated by **Figure 5(a)** approximately 1.15% more than the value recorded for Pig Lard biodiesel. However, when comparing the recorded densities to the ASTM D6751, all the samples recorded fuel density values which are within the set range of 0.86 to 0.9 g/cm^3. A study by [19] reported that biodiesel density is dependent on the fatty acid composition, molar mass, purity and moisture content. The author revealed that biodiesel derived from plant oil and animal fats have fatty acid compositions of 50.18% and 49.81% respectively. As a result, biodiesel derived from plant oils has a higher density than animal fats because they have a relatively high fatty acid composition, approximately 0.37% more. This was supported by other authors, including [20], who reported that biodiesel from unsaturated fatty acid oils like Jatropha and sun-

flower seed oils tend to have higher densities than biodiesel produced from saturated oils. The authors further stated that these variations may affect storage and handling conditions. For example, biodiesel with higher fuel density may require different storage and transportation considerations due to its weight and volume characteristics. Meanwhile, **Figure 5(c)** shows that the energy content of biodiesel produced from animal fats is relatively higher than that of biodiesel produced from plant oils. For example, Pig Lard biodiesel recorded the highest value of 39.93 kJ/g while Jatropha biodiesel recorded the lowest value of 38.74 kJ/g. The result of this investigation further shows that Sunflower and Beef Tallow Biodiesels show a difference in energy content of 2.22% and 3.33% lower than that of Used Cooking Oil Biodiesel, respectively. The statistical analysis revealed that there is a 95% level of confidence that there is a statistical difference between the energy content of biodiesels produced from Jatropha and Sunflower seed oils. The same conclusion was drawn for biodiesels produced from Beef tallow and Used Cooking Oil. The results agree with the data reported by [21]-[24], who stated that biodiesel produced from saturated oils has a higher energy content than unsaturated oils. The results demonstrate the significance of assessing feedstock composition in the evaluation of biodiesel energy content. The information suggests that the type of feed oil used as a feedstock for biodiesel production can impact the energy content of the resulting biodiesel. This information is crucial for the strategic selection of feedstocks in biodiesel production, with a focus on enhancing energy efficiency and overall operational performance.

Furthermore, Jatropha Seed Oil and Sunflower Seed Oil Biodiesels exhibit a difference in energy content of approximately, 0.67% to 0.08% respectively, below the lower limit of 39 MJ/kg as specified by the ASTM D240 standard. The results distinguish them from other sources such as Used Cooking Oil, Pig Lard and Beef Tallow which were within the specified range of 39 to 43.3 MJ/kg in terms of potential energy efficiency. The variations in energy content among the biodiesel sources demonstrate the potential for different feedstocks to provide different levels of energy potential. **Figure 5(c)** further indicates that the energy levels for Beef Tallow and Pig Lard Biodiesels exceed Jatropha and Sunflower Biodiesel by 0.96% and 1.49%, respectively. This is due to the higher proportion of saturated fatty acids in Beef Tallow and Pig Lard compared to the unsaturated fatty acids present in Jatropha and Sunflower oils. Regarding flash points (ASTM D93 minimum value 130˚C), all-flash points recorded were above the minimum limit. Jatropha Biodiesel displays a flash point of approximately 35.38% higher than Pig Lard Biodiesel, which recorded the lowest flash point among the samples as demonstrated by **Figure 5(b)**. The results show that biodiesel from fresh seed oils such as Sunflower and Jatropha recorded relatively high flash points than biodiesel from Used Cooking Oil, Beef Tallow, and Pig Lard. The variation is believed to be due to the higher proportion of unsaturated fatty acids in fresh seed oils, which have higher flash points compared to the saturated fatty acids in Beef Tallow and Pig Lard. The overall results indicate that there is 95% level of confidence that the difference between the flash points of biodiesels produced from Beef tallow, Pig lard and Used cooking oil is not statistically significant. This was also observed for the difference between the flash points of biodiesels produced from

Jatropha seed oil and Sunflower seed oil. The results are inconsistent with finding by [22] [25] who reported that composition of the fatty acids is crucial as it affects the physiochemical properties of the biodiesel.

Figure 5(d) depicts that Used Cooking Oil Biodiesel shows a viscosity of approximately 8.67% lower than Sunflower Biodiesel, potentially affecting flow characteristics and engine performance. Meanwhile, **Figure 5(d)** also reveals that Jatropha, Sunflower, and Beef Tallow Biodiesels demonstrate viscosity levels within a 5.56% to 5.17% range from each other, indicating similarities compared to Used Cooking Oil and Pig Lard Biodiesel. The study demonstrated that Beef Tallow and Pig Lard had higher kinematic viscosity compared to fresh seed oils like Jatropha and Sunflower. The overall results show that there is 95% level of confidence that the difference between the viscosities of biodiesel produced from Jatropha seed oil, Sunflower seed oil and Beef tallow is not statistically significant. However, there is a statistical difference when comparing the viscosities of biodiesel produced from Pig lard and Used cooking oil. This was attributed to the higher molecular weights of saturated fatty acids in Beef Tallow and Pig Lard, resulting in higher kinematic viscosity. In contrast, unsaturated fatty acids in Jatropha, Sunflower, and Used Cooking Oil result in lower molecular weights, leading to lower kinematic viscosity. Furthermore, the results are consistent with previous studies conducted [26] [27] which also reported that biodiesel kinematic viscosity exhibits a positive correlation with the length of the carbon chain. As the number of carbon atoms increases, the viscosity increases. Conversely, kinematic viscosity decreases with a higher degree of unsaturation in fatty acids. These comparisons highlight the differences among the biodiesel samples in relation to ASTM D6751 standards, emphasizing their varying properties and potential implications for their performance in different applications.

Statistical Analysis

As mentioned earlier, Analysis of Variance (ANOVA) was employed to further analyze the level of significant differences among biodiesel sources. The results of the analysis are shown in **Tables 3(a)-(d)**.

The ANOVA results indicate statistically significant differences among the biodiesel samples for Fuel Density, Energy Content, Flash Point, and Kinematic Viscosity. This determination is based on comparing the calculated F-values with the critical F-values at a 5% significance level (alpha = 0.05). The F-values obtained (5.526, 22.083, 8.491, and 4.949) for Fuel Density, Energy Content, Flash Point, and Kinematic Viscosity, respectively, significantly exceed the critical F-value of 2.866 at alpha = 0.05 for all properties. These F-values are shown in **Tables 3(a)-(d)** respectively. This observation implies that the variations observed in these properties across the biodiesel samples are highly unlikely to have occurred due to random chance, indicating that the differences are statistically significant. Therefore, with high confidence, it can be stated that the differences observed among the biodiesel samples for these properties are not merely by random variability but are indeed significant, impacting the selection of feedstock for biodiesel production.

Table 3. (a) to (d) Analysis of Variance (ANOVA) results. (a) Fuel density; (b) Energy content; (c) Flash point; (d) Kinematic viscosity.

(a)

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-value	Critical F-value (alpha = 0.05)
Between Groups	0.0003181	4	0.00007953	5.526	2.866
Within Groups	0.0002876	20	0.00001438	-	-
Total	0.0006057	24	-	-	-

(b)

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-value	Critical F-value (alpha = 0.05)
Between Groups	0.286642	4	0.0716605	22.083	2.866
Within Groups	0.652748	20	0.0326374	-	-
Total	0.93939	24	-	-	-

(c)

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-value	Critical F-value (alpha = 0.05)
Between Groups	245.42	4	61.3549	8.491	2.866
Within Groups	144.75	20	7.2375	-	-
Total	390.17	24	-	-	-

(d)

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-value	Critical F-value (alpha = 0.05)
Between Groups	0.029584	4	0.007396	4.949	2.866
Within Groups	0.02992	20	0.001496	-	-
Total	0.059504	24	-	-	-

4. Conclusions

This study provides a comprehensive analysis of the physiochemical properties of biodiesel produced from Beef tallow, Pig lard, Jatropha oil and Sunflower oil through transesterification and property evaluation. The results reveal substantial variations in fuel density, energy content, flash point, and kinematic viscosity among the feedstock. The findings provide a broader understanding of optimal feedstock selection and utilization in biodiesel production.

Future research should explore:

1) A broader range of feedstocks including those with high free fatty acid content, to compare biodiesel yield and quality.

2) A more detailed analysis of how fatty acid profiles of animal fats and plant-based oils compare and demonstrate their relationship to the resulting biodiesel properties.

3) The effects of varying transesterification methods on biodiesel properties.

4) The quantity and cost-effectiveness of each feedstock by assessing factors such as availability, pricing, and lifecycle impacts.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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