



ORIGINAL RESEARCH ARTICLE

BIODIESEL PRODUCTION FROM THE BLEND OF SUNFLOWER, AVOCADO SEEDS AND WASTE SOYBEANS

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ABSTRACT

The climatic, environmental, and health concerns of fossil fuels have spurred the development of biodiesel as an alternative fuel. Biodiesel production has transitioned from single lipid-based feedstock to hybrid lipid-based feedstock owing to the challenges related to the former. Unlike previous studies that focused on singular and binary feedstock, this study uniquely employed ternary oil blends to synthesize biodiesel via alkaline transesterification and measured selected oil and biodiesel fuel properties using standard test methods. The studied hybrid oils were extracted (using the Soxhlet method) from ternary feedstock (72%, 20%, and 8% by weight of soybeans, avocado seeds, and sunflower seeds) and characterized for the physicochemical properties: viscosity, moisture content, volatile content, ash content, higher heating value, free fatty acids, and density. The measured biodiesel fuel properties were kinematic viscosity, density, flash point, pour point, and lower heating value. Results revealed that the hybrid oil properties were observed to be within the range of values for individual feedstock that made up the oil. The biodiesel produced has a yield of 81% and exhibited a kinematic viscosity of 3.75 mm²/s, density of 893 kg/m³, flash point of 122 °C, pour point of -11 °C, and lower heating value of 34.96 MJ/kg. These fuel properties were observed to conform to biodiesel standards. Relatively low kinematic viscosity and pour point, and high lower heating value and flash point of the studied biodiesel were recorded due to the synergetic effect of oil hybridization. Therefore, selective mixing of different oils from existing feedstock for biodiesel production is recommended as this would further improve biodiesel fuel properties and consequently, enhance the performance, combustion, and emissions of biodiesel-fueled engines. Hybrid oil deployment will assist in addressing existing problems related to the use of single-feedstock based oil, with the ultimate view of promoting carbon neutrality in agreement with the Sustainable Development Goals.

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1.0 Introduction

Biodiesel is a green, neutral carbon, renewable, and sustainable liquid fuel proposed as an alternative to fossil diesel. It is synthesized from lipid-based resources such as oilseeds (edible and non-edible), animal oil, fats, waste seeds, waste cooking oil, algae, micro-organisms, etc. (Giwa et al., 2023). Prominent lipid-based feedstock used for biodiesel production include soybean, sunflower seeds, jatropha, canola, rapeseed, chicken wastes, waste cooking oil, animal fats, etc. (Giwa et al., 2023). Of the various methods of biodiesel production, the transesterification process is the most used, with alkaline-based transesterification being the most reported. Owing to the variation in the fatty acid compositions of the lipids (from diverse feedstock) utilized for biodiesel production, which appears unaltered after transesterification, different magnitudes of biodiesel fuel properties from diverse biodiesel feedstock have been reported in the literature (Giwa et al., 2024). This portends the strong connection between fatty acid compositions of biodiesel feedstock to their fuel

properties. However, the use of single feedstocks from edible and edible oils, waste oils, waste cooking oils, etc., are known for their respective shortcomings such as feedstock cost, availability, high viscosity, poor cold flow properties, high emissions, and low cetane number, which are relatively limiting their application in diesel engines in comparison to diesel (Giwa et al., 2024).

The concept of hybrid biodiesel, which involves the use of two or more feedstock for biodiesel production, is proposed to improve biodiesel fuel properties by synergizing the advantages and modifying the shortcomings of each biodiesel feedstock through the alteration of the fatty acid compositions. Aside from numerous studies (Ishola et al., 2020; Adekanmi et al., 2020; Dagde, 2019; Hayatudden et al., 2020) on biodiesel production from single feedstock, growing interest has been observed concerning the use of hybrid feedstocks for biodiesel production (Falowo and Betiku, 2022; Giwa et al., 2023; Brahma et al., 2023). The utilization of more than one feedstock (at different proportions) for biodiesel synthesis has demonstrated improved fuel properties compared to those of single-feedstock biodiesels.

Several studies have reported biodiesel production from hybrid feedstock at different ratios via the transesterification process (Adepoju, 2020; De Almeida et al., 2015; Balamurugan et al., 2022; Brahma et al., 2023). Adepoju (2020) optimized the production of hybrid biodiesel from pig fat oil and neem oil (at different ratios of 90:10 – 10:90) using biomass-derived calcium oxide (CaO) catalyst and measured the fuel properties. The lowest viscosity, which favours further application of this hybrid biodiesel, was produced using a 60:40 ratio of neem oil and pig fat oil at optimal values of 5.9:1 methanol/hybrid oil, 2.179 g of catalyst amount, 59.91 °C of reaction temperature, and 57.5 min of reaction time, yielding 98.03 (wt.%) of the hybrid biodiesel. De Almeida et al. (2015) measured the fuel properties of hybrid biodiesel produced from the mixtures of palm oil, waste frying oil, and waste fish oil via two-way transesterification. Induction period and completion of melt onset temperature were improved by 20% and 80% using 42.1 wt.% of the waste fish oil and 57.9 wt.% of waste frying oil to produce hybrid biodiesel. Balamurugan et al. (2022) studied the production of hybrid biodiesel from an equal volume of castor oil, Mahua oil, and processed dairy waste using the esterification and transesterification process. At 600 rpm stirring speed, 1 wt% catalyst, 60 min reaction time, and 55 °C reaction temperature, a yield of 96 vol% was achieved. Yunus et al. (2015) examined the fuel properties (calorific value, Kinematic Viscosity (KV), Oxidative stability (OS), flash point, cold filter plugging point, etc.) of biodiesel produced using oils from *Nigella sativa*, *Ceiba pentandra*, and their mixture (equal volume). The hybrid biodiesel revealed the augmentation of the cold filter plugging point, flash point, and KV of *Nigella sativa* oil biodiesel and the OS for both *Ceiba pentandra* and *Nigella sativa* oil biodiesel.

Kumar et al. (2023) improved the fuel properties of different hybrid biodiesels via binary mixtures of waste cooking oil, palm, Jatropha, and Karanja oil. Hybrid biodiesel produced from palm-Karanja (48.4:51.6% v/v) oil showed improvement in cetane number (4.2%), density, KV, and OS (21.47%), while the hybrid biodiesel from palm-Jatropha (65.2:34.8% v/v) oil recorded enhanced OS (46.9%), KV, cetane number (11.28%), and density. However, no optimal mix was established for hybrid biodiesels from other oil mixtures to satisfy biodiesel standards. Kumar et al. (2019) examined the suitability of synthesizing hybrid biodiesel from castor and Karanja oil (equal amount) using lipase derived from *Pseudomonas cepacia*. A higher flash point was obtained using the hybrid biodiesel compared to single-feedstock biodiesel and diesel. Kodgire et al. (2022) studied the production of hybrid biodiesel from castor oil and waste cooking oil (50:50, 70:30, and 90:10). The hybrid biodiesel produced from the 50:50 mixture demonstrated improved calorific value, density, and viscosity over that of castor oil biodiesel. Optimal reaction time (9.04 min), methanol/oil ratio (8.42:1), KOH loading (0.52 w/w %), RCO: WCO (61:39) ratio, and yield of 93.12% were achieved. Edo et al. (2022) studied the use of ternary oils (Jatropha curcas oil – 15 vol%, waste cooking oil – 50 vol%, and palm oil – 35 vol%) to produce hybrid biodiesel with the optimization of the reaction variables, all to improve the fuel properties. With optimal values of 0.78 wt%, 9.86:1, 10.5 min, and 478 rpm for catalyst concentration, methanol/oil molar ratio, reaction time, and stirring speed, respectively, achieving 96.9% biodiesel yield, improved OS, cetane number, and cold flow properties were recorded.

From the above research survey, it can be observed that studies have been mainly conducted using binary feedstock to produce biodiesel, with very few works published using ternary feedstock for biodiesel production, all toward improving the fuel properties of the synthesized biodiesel. This study intended to fill this research gap by producing biodiesel from ternary feedstock (avocado seeds, waste soybeans, and sunflower seeds), and examining the corresponding biodiesel fuel properties. The essence was to possibly improve the fuel properties of the hybrid biodiesel over those of individual biodiesels. In addition, the physicochemical properties of the extracted oil from the ternary feedstock were measured. This study valorized waste soybeans and avocado seeds as feedstock for biodiesel production against their discarded and worthless perception, which constitute a social nuisance as agricultural and solid municipal wastes. Oil-based

wastes provide more options as potential feedstock for biodiesel production by promoting waste management via waste-to-energy, therefore reducing and adding value to wastes.

2. Materials and Method

2.1 Materials

The raw materials (sunflower seeds and soybeans) used to produce the biodiesel were sourced from a local market at Osiele, Abeokuta, Ogun State. Similarly, the avocado seeds were obtained from a fruit waste disposal center. The chemicals (analytical grade) – NaOH (95% purity), methanol (99% purity), anhydrous sodium sulphate (98% purity), and n-hexane (99% purity) – used in this study were purchased from local chemical vendors. Other materials included the rotary vacuum evaporator, Erlenmeyer flask (as reactor), magnetic stirrer, oven, separating funnel, beakers, conical flasks, filters, personal protective equipment, and Soxhlet extractor.

2.2 Oil Extraction

The avocado seeds were washed in water to remove contaminants and were then sun-dried for 8 days to reduce their water content. The sunflower seeds were dehulled before being washed in water. Also, the waste soybean and sunflower seeds were oven dried (70 °C for 6 h) and ground before oil extraction. Before commencing with the production of biodiesel, the respective feedstocks for biodiesel production were ground into powder form and weighed. The weight of the ground soybeans, avocado seed, and sunflower seed was 1350 g, 363.3 g, and 153.41 g, respectively. The feedstock were mixed at a ratio of 72%, 20%, and 8% (by percentage weight) for soybean, avocado, and sunflower, respectively, before oil extraction. This mixing ratio was informed by the oil yield of individual feedstock. The oil in the mixed substrate was extracted using the Soxhlet extractor via a solvent extraction process using hexane. From the weighed soybean seed, avocado seed, and sunflower seed, a total of 748 mL of oil was extracted. The oil was collected and stored in a dirt-free beaker for further processing.

2.3 Physicochemical Properties of Hybrid Oil

The physicochemical properties of the extracted hybrid oil were determined in the laboratory using standard test methods (Dele et al., 2022). This was to confirm their suitability for the production of biodiesel. The analysis involved the moisture content, volatile content, ash content, and the higher heating value of the oil.

2.4 Biodiesel Production Procedure

The transesterification reactions are the most common method of converting triglycerides (contained oils) into methyl esters (biodiesel). This involved the displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis, except that an alcohol is used instead of water (Athar and Zaidi, 2020). A weighed quantity (150 g) of the hybrid oil was poured into the reactor and was heated to a temperature of 60 °C using a heater. An appropriate quantity of methanol (44.05 g; 1:6 oil/methanol molar ratio) was measured and discharged in a beaker containing the required amount of NaOH (1.5 g; 1% wt. oil) pellet added to it. The beaker content was manually stirred (slowly) until the NaOH was completely dissolved in the methanol, which gave a sodium methoxide mixture. This mixture was poured into the reactor containing the heated oil, and the whole content was stirred at the rate of 360 rpm (using a magnetic stirrer), and the temperature was maintained at 60 °C. The heating and stirring were halted after 60 min, and the formulated product was poured into a separating funnel and allowed to settle overnight.

The formulated mixture was observed to settle into two separate layers of glycerol (bottom layer) and pale-yellow soybean-sunflower-avocado oil methyl esters (upper layer). The separating funnel was opened to collect the glycerol while the crude soybean-sunflower-avocado oil methyl esters were collected in a separate container. The crude soybean-sunflower-avocado oil methyl esters were heated on a rotary vacuum evaporator (at 80 °C for 1 h) to remove the excess methanol in the content, after which it was gently washed with warm distilled water (three times with two drops of diluted hydrochloric acid at the first wash) to remove the soaps and residual catalyst. Thereafter, it was dried using anhydrous sodium sulphate and then filtered. The resulting product (purified soybean-sunflower-avocado oil methyl esters – hybrid biodiesel) was stored in a cool and dry place. This procedure was repeated three times, and the average yield was reported. Equation 1 was used to estimate the biodiesel yield achieved in this study.

$$Yield = \frac{\text{Volume of biodiesel produced (ml)}}{\text{Volume of extracted oil used for transesterification (ml)}} \times 100\%$$

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2.5 Characterization of Hybrid Biodiesel Fuel Properties

Fuel property characterization of the hybrid biodiesel produced was carried out using standard methods, as reported in the literature (Oni-Adimabua et al., 2024). The determined fuel properties included kinematic viscosity (ASTM D445), flash point (ASTM D93), density (ASTM D6751), pour point (ASTM 97-96a), and higher heating value (ASTM D2015), using standard testing methods (ASTM, 2002). Figure 1 shows the flow chart of the process for hybrid biodiesel production.

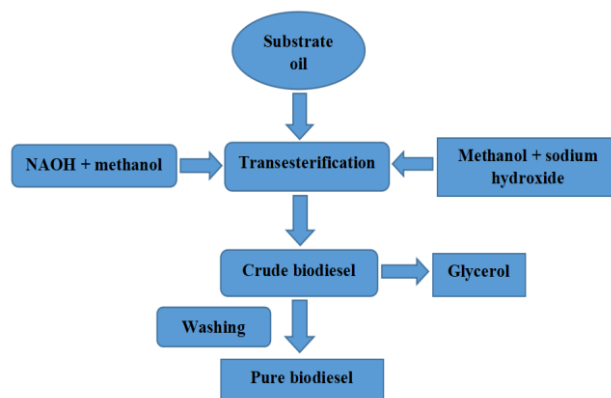


Figure 1: Process diagram for the production of biodiesel

2.5.1 Determination of density

The samples were brought to a specified temperature, and a test portion was transferred to a hydrometer cylinder that had been brought to approximately the same temperature. The approximate hydrometer, also with a similar temperature, was lowered into the test portion and allowed to settle. After the equilibrium temperature had been reached, the hydrometer scale reading and the temperature of the test portion were taken. The observed hydrometer reading was reduced to the reference temperature utilizing a petroleum measurement table. The hydrometer scale reading was recorded to the nearest 0.1 kg/m³ as the density.

2.5.2 Dynamic and kinematic viscosity

The viscosity of the oil was determined using the Brookfield Digital rotational viscometer. The sample was heated in the hot oil bath, and the spindle of the viscometer was fitted into the melted wax. The speed was selected, and the start button was pressed for the spindle to rotate and give the angle of rotation, including the viscosity measurement and the operating temperature on the display. The kinematic viscosity is the ratio of dynamic viscosity to the density, as expressed in Equation (2).

$$\text{Kinematic viscosity} = \frac{\text{Dynamic viscosity}}{\text{Density}}$$

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2.5.3 Determination of flash point

The flash point was determined using a small, strong heat-resistant glass cup and a heating mantle. The sample was poured into the cup and heated gradually while being stirred to distribute heat uniformly in the cup, and the temperature was monitored using a thermometer. At regular intervals, the cup was exposed to naked flame, the temperature at which the biodiesel increases the flame like a flash, but does not increase combustion, was recorded, which was the flash point of the sample.

2.5.4 Determination of pour point

5 mL of the sample was drawn into a capillary tube tied to a thermometer and placed in a 250 mL beaker containing distilled water, immersed together in a water bath for controlled heating. The temperature at which the oil just begins to move downward due to its weight is called the pour point.



Plate 1: Oil sample after extraction

2.5.5 Determination of higher heating value

A weighed sample of approximately 0.1 gram was placed inside the calibrated adiabatic bomb calorimeter with 1 millilitre of deionized water. A Chromel (chromium-nickel alloy) wire was connected to the two electrodes in the pressure vessel (bomb) and placed in contact with the sample. The bomb was then assembled, sealed, and purged twice by pressurizing to 0.5 MPa with pure (99.99%) oxygen, after which it was vented, which was later pressurized with pure oxygen to 2.0 MPa for the test and placed inside a bath containing 2 L of water in an insulated jacket. A motorized stirrer was placed inside the water bath to circulate the water around the bomb, creating a uniform temperature. The sample was then ignited by passing an electric current through the chromel wire, causing the sample to burn to completion in the high-pressure oxygen. The bomb and the bucket were then held in a calorimeter jacket that serves as a thermal shield. The result was displayed in the display unit in (MJ/Kg).

3. Results and Discussion

3.1 Hybrid Oil Properties

Physicochemical properties of the extracted hybrid oil were studied to ensure that it had comparable characteristics to oils used for transesterification. Plate 1 shows the extracted hybrid oil. Table 1 gives the physicochemical properties of the hybrid oil. The hybrid oil has viscosity, moisture content, volatile content, ash content, higher heating value, free fatty acids, and density of 46.6 mm²/s, 0.76%, 0.25%, 0.03%, 37 MJ/kg, 0.52%, and 924 kg/m³, respectively, and are found to agree with the oil properties of conventional oils (Verma and Sharma, 2016; Sajjadi *et al.*, 2016; Dagde, 2019). From Table 2, the viscosity of the hybrid oil was found to be slightly higher than that of soybean, sunflower, and avocado oil (measured at 40 °C). This is because the hybrid oil was measured at 28 °C. However, at higher temperatures, the viscosity is expected to reduce as the intermolecular forces are weakened, causing an increase in the flowability of the hybrid oil. At 40 °C, the viscosity of the hybrid oil is anticipated to reduce, making it closer to those of soybean, sunflower, and avocado oil used for comparison (in Table 2). Then, the density of the hybrid oil was found to be within the range reported for soybean, sunflower, and avocado oil, thus reflecting the blend of these oils.

The heating value of the hybrid oil was observed to be lower than that of the soybean and sunflower oils. With the hybrid oil measured for its lower heating value, it can be evaluated to be within the lower heating range of the soybean and sunflower oils. The measured free fatty acid value of the hybrid oil was found to be within the range of values measured for soybean, sunflower, and avocado oil. Therefore, the hybrid oil can be directly used for the transesterification process as the value is <1% (Agarwal, 2007; Monika *et al.*, 2023). This is supported by the relatively low moisture content of the hybrid oil, which prevents hydrolysis, reduces soap formation, and increases biodiesel yield, thus eliminating acid esterification before transesterification.

Table 1: Physicochemical properties of hybrid oil

Properties	Values
Viscosity (28 °C)	46.6 mm ² /s
Moisture content	0.76%
Volatile content	0.25%
Ash content	0.03%
Lower heating value	37 MJ/kg
Free fatty acid	0.52%
Density	924 kg/m ³

Table 2: Physicochemical properties of oils from existing studies

Feedstock	Kinematic viscosity (mm ² /s)	Density (kg/m ³)	Higher heating value (MJ/kg)	Free fatty acid (%)
Soybeans	28.08 ^a ; 31.83 ^b ;	890 ^{a,*} ; 916 ^b ;	39.6 ^b ;	0.35 ^a ; 0.14 ^b
Sunflower	33.4 ^a ; 34.01 ^b ;	922.2 ^{a,*} ; 918 ^b ;	39.56 ^b ;	0.25 ^a ; 0.15 ^b
Avocado	36.7 ^c	912 ^c		0.8 ^c

*Density @ 40 °C; ^aVerma and Sharma (2016); ^bSajjadi *et al.* (2016); ^cDagde (2019)

3.2 Hybrid Biodiesel Fuel Properties

The transesterification process was successful, giving two distinct layers of biodiesel and glycerin. The biodiesel yield from the oil was equally good ($81.07 \pm 0.45\%$) and comparable with the yield from other experimental production of biodiesel. This yield value was moderately higher than the 72.2% recorded with the use of soybean oil to produce biodiesel (Hossain and Mazen, 2010) and slightly better than the 78% reported concerning the production of biodiesel from avocado seed (Dagde, 2019). With 300 mL of oil (obtained from the extraction process) and 114 mL of methanol, 242 mL of biodiesel were produced. Visual inspection showed a darker color for the produced biodiesel compared to the color of the parent oil used for transesterification. Table 3 provides the results of the physicochemical properties of the hybrid biodiesel fuel produced from the hybrid oil, while Table 4 shows biodiesel standard values of the measured biodiesel fuel properties.

Table 3: Physicochemical properties of hybrid biodiesel fuel

Properties	Values
Density	893 kg/m ³
Kinematic viscosity (40 °C)	3.75 mm ² /s
Flash point	122 °C
Lower heating value	34.96 MJ/kg
Pour point	-11 °C

Table 4: Standard fuel properties of biodiesel (Mahmudula *et al.* 2017)

Property	ASTM D6751	EN14214
Density	880 kg/m ³	860 – 900 kg/m ³
Kinematic viscosity (40 °C)	1.9 – 6.0 mm ² /s	3.5 – 5.0 mm ² /s
Flash point	100 – 170 °C (minimum)	>120
Calorific value	-	35 MJ/kg
Pour point	-15 °C – (-16) °C	-

3.3 Comparison of Hybrid Biodiesel Properties with ASTM Biodiesel Standard

The biodiesel produced in this present study was compared with the ASTM biodiesel standards required to be satisfied before it can be safely used in the engine. Biodiesel that has too many outliers from this standard might need some further form of processing before it can be certified as being safe for usage in the diesel engine in terms of the fuel quality.

3.3.1 Density and kinematic viscosity

Density is a key fuel property that directly affects the engine performance characteristics concerning volumetric fuel economy and maximum power. It can be observed from Table 4 concerning the comparison of results obtained from this work to that of the ASTM standards that the produced biodiesel had a kinematic viscosity of 3.75 mm²/s at 40 °C, which was within the recommended range of 1.9 – 6.0 mm²/s (for the ASTM D6751 standard). This indicates better flow properties as required and does not contain any undissolved suspension. If the viscosity lies far away from the range prescribed by the standards, it might lead to clogging in the pipe and reduced pressure of fuel supply to the engine. The density was 893 kg/m³, which lied within the recommended range of 860 – 900 kg/m³ (for the EN14214 standard). Both the kinematic viscosity and density of the hybrid biodiesel are observed to satisfy biodiesel standards. Interestingly, an over 11-fold reduction in the kinematic viscosity of the hybrid oil and a 3.47% reduction in the density were observed after the synthesis of the corresponding biodiesel.

3.3.2 Flash point and calorific value

The flash point of the biodiesel produced in this study was within the values (100 – 170 °C) recommended by the ASTM D6751 standard and slightly higher than that of the EN14214 standard (> 120 °C). This implies that the produced biodiesel possesses the flammability requirement of the biodiesel standards. Hence, ignition could happen quicker in the engine, and it can be transported safely irrespective of the ambient temperature. In addition, the results revealed that the hybrid biodiesel fuels could be used as fuel in compression ignition engines after further engine and wear tests. The calorific value of the biodiesel recorded in this work was similar to that of the EN14214 standard. This implies that it can generate appropriate energy per unit mass compared with the biodiesel fuel with a standard calorific value, which invariably leads to a good rate of fuel consumption. Hence, its calorific value can be improved by blending it with petroleum diesel. It can be deduced that the flash point and calorific value of the produced hybrid biodiesel satisfied the biodiesel standards.

3.3.3 Pour point

The pour point represents the hybrid biodiesel fuel's ability to flow before it can be gelled. Therefore, this parameter indicates the temperature at which the hybrid biodiesel may cease to flow. The value recorded for the pour point of the hybrid biodiesel was slightly higher than the limit set by the ASTM D6751 biodiesel standard. However, for the tropics, this value of pour point and hybrid biodiesel is applicable as the atmospheric temperature of the tropics is higher than 0 °C (> 10 °C). This implies that no gelling of the hybrid biodiesel when used in diesel engines will be observed. Blending the biodiesel produced with diesel or the addition of additives can improve the fuel properties for better engine performance, combustion, and emissions, close to the case of diesel-fueled engines (Giwa *et al.*, 2023; Brahma *et al.*, 2023).

3.4 Comparison of Hybrid Biodiesel Properties with Biodiesel produced from Individual Feedstocks

The fuel properties of the hybrid biodiesel produced, such as density, kinematic viscosity, flash point, calorific value, and pour point, were compared with the properties of the biodiesels produced using single feedstocks of soybean, sunflower, and avocado, as shown in Table 5.

3.4.1 Density and kinematic viscosity

From Tables 3 and 5, it could be observed that the density of hybrid biodiesel was slightly higher than the range (860 – 885 kg/m³) reported for the density of single-feedstock biodiesels from soybean, sunflower seed, and avocado seed oils. The mixing of the feedstocks for hybrid biodiesel production was observed to have an insignificant influence on the density of the hybrid biodiesel. From Table 5, the kinematic viscosities (3.94 – 4.439 mm²/s) of single-feedstock biodiesels of soybean, sunflower, and avocado seeds were observed to be

higher than that of the hybrid biodiesel, which implies that the mixing of the feedstocks influenced this property. This can be connected to the lower kinematic viscosity of the avocado seed oil biodiesel compared to that of sunflower seed and soybean biodiesel.

Table 5: Biodiesel fuel properties from existing studies

Feedstock	Kinematic viscosity (mm ² /s)	Density (kg/m ³)	Flash point (°C)	Calorific value (MJ/kg)	Pour point (°C)
Soybean	4.039 ^a ; 4.5 ^b ; 4.15 ^c	884 ^a ; 885 ^b ; 882 ^c	178 ^a ; 178 ^b ; 140.1 ^c	37.75 ^a ; 33.5 ^{*b}	-7 ^b ; -3.7 ^c
Sunflower	4.439 ^a ; 4.6 ^b ; 4.26 ^c	880 ^a ; 860 ^b ; 869 ^c	183 ^a ; 183 ^b ; 180.3 ^c	33.5 ^a ; 33.5 ^{*b}	-2 ^c
Avocado	3.94 ^d	860 ^d	100 ^d	33.2	-15 ^d

^aAthar and Saidi (2020); ^bAgarwal (2007); ^cSajjadi *et al.* (2016); ^dDagde (2019); *lower calorific value. Note: average values from the literature are provided.

3.4.2 Flash point

Flash point is simply described as the temperature at which biodiesel burns when in contact with an ignition source. The flash point of the hybrid biodiesel was found to be within the flash point values (100 – 183 °C) published for the pure soybean, sunflower seed, and avocado seed biodiesels in the literature. This reveals an improvement in the flash point of the pure avocado seed biodiesel as the mixing of the feedstocks (avocado seed + soybean and sunflower seeds) influenced this property for the hybrid biodiesel produced in this work. The results reveal that the hybrid biodiesel fuels could be used as fuel in compression ignition engines after further studies concerning their performance, wear analysis, combustion, emissions, etc. In addition, the flash point of hybrid biodiesel and pure biodiesel fuels tends to be within the acceptable standard than that of conventional diesel, which has a range of 60 – 80 °C (Omonhinmin *et al.*, 2020). The high flash point of the hybrid biodiesel produced indicates that the fuels have higher fire safety during transportation, handling, and storage.

3.4.3 Pour point and the calorific value

From Table 5, it can be observed that the pour point of the hybrid biodiesel was within the range of values (-15 to -2 °C) reported for the individual biodiesels. This showed that the hybrid biodiesel exhibited a lower pour point value than the values for soybean and sunflower seed biodiesels, with the avocado seed biodiesel demonstrating the lowest pour point value. This is attributed to the synergetic mixing of the feedstocks for biodiesel production. The calorific value of the hybrid biodiesel was observed to be within the values published for individual biodiesels from soybean, sunflower seed, and avocado seed oils. These results agreed with those found in the literature (Mofijur *et al.*, 2015; Omonhinmin *et al.*, 2020). However, the calorific values of pure biodiesels and that of hybrid biodiesel fuel are generally lower than that of conventional diesel (44.8 MJ/kg) because of the presence of oxygen, which occupies space and contains a small heating value (Mofijur *et al.*, 2015; Omonhinmin *et al.*, 2020).

4. Conclusion

This research work has shown that by the transesterification of oil produced by solvent extraction of 72% weight of soybeans, 20% weight of avocado seed, and 8% weight of sunflower seed using NaOH as the catalyst and methanol, the reaction resulted in biodiesel with properties that conform to the ASTM D6751 and EN14214 biodiesel standards. The mixing of the feedstocks revealed reduced kinematic viscosity (compared to soybean and sunflower seed biodiesel) and improved flash point (compared to avocado seed biodiesel), pour point (compared to soybean and sunflower seed biodiesel), and lower calorific value (compared to avocado seed biodiesel). This work has sufficiently proven that biodiesel produced from the mixture of soybeans, sunflower seeds, and avocado seeds is a suitable fuel (considering its quality) for the diesel engine. The findings of this study provide a promising foundation for future research and development in the field of biodiesel production from agricultural waste. Blending of the obtained hybrid biodiesel with 20% diesel and further engine performance and wear test could practically promote its use as fuel. Additionally, this study could benefit from the use of different alcohols and catalysts and the optimization of the production process, which would further expand the field of biofuel production and improve the current database.

REFERENCES

- Adekanmi, AA., Cole, AT., Lawal, IK., Esho, EO. and Lawal, KA. 2020. Production of biodiesel from soybeans. International Journal of Academic Information Systems Research, 4: 2643-2660.
- Adepoju, TF. 2020. Optimization processes of biodiesel production from pig and neem (*Azadirachta indica* a.Juss) seeds blend oil using alternative catalysts from waste biomass. Industrial Crops and Products, 149: 112334. <https://doi.org/10.1016/j.indcrop.2020.112334>.
- Agarwal, AK. 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science, 33: 233–271.
- ASTM, 2002. “Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels”, American Society for Testing and Materials, D6751-02.
- Athar, M. and Zaidi, S. 2020. A review of the feedstocks, catalysts, and intensification techniques for sustainable biodiesel production. Journal of Environmental Chemical Engineering, 8(6): 104523. <https://doi.org/10.1016/j.jece.2020.104523>.
- Balamurugan, S., Saravanan, BA., Sundaravadivel, TA., Krishnan, PG. and Ramesh, B. 2022. Experimental investigation and performance evaluation of biodiesel production from non-edible mixed oil. AIP Conference Proceedings 2527: 030011. <https://doi.org/10.1063/5.0108125>.
- Brahma, S., Basumatary, B., Basumatary, SF., Das, B., Brahma, S., Rokhum, SL. and Basumatary, S. 2023. Biodiesel production from quinary oil mixture using highly efficient *Musa chinensis* based heterogeneous catalyst. Fuel, 336: 127150. <https://doi.org/10.1016/j.fuel.2022.127150> Received
- Dagde, KK. 2019. Extraction of vegetable oil from avocado seed for production of biodiesel. Journal of Applied Science and Environmental Management, 23(2): 215–221.
- De Almeida, VF., García-Moreno, PJ., Guadix, A. and Guadix, EM. 2015. Biodiesel production from mixtures of waste fish oil, palm oil and waste frying oil: Optimization of fuel properties. Fuel Processing Technology, 133: 152–160.
- Dele, O., Adeleke, AE., Oyelaran, OA. and Awotunde, WO. 2022. Analysis of physicochemical properties of biodiesel from the mixture of ackee and neem seeds. Equity Journal of Science and Technology, 9(1): 8–12.
- Edo, GI., Makinde, MG., Nwosu, LC., Ozgor E. and Akhayere E. 2022. Physicochemical and pharmacological properties of palm oil: an approach for quality, safety, and nutrition evaluation of palm oil. Food Analytical Methods. 15, 2290–2305. <https://doi.org/10.1007/s12161-022-02293-4>
- Falowo, OA. and Betiku E. 2022. A novel heterogeneous catalyst synthesis from agrowastes mixture and application in transesterification of yellow oleander-rubber oil: Optimization by Taguchi approach. Fuel, 312: 122999. <https://doi.org/10.1016/j.fuel.2021.122999>.
- Giwa, SO., Aasa, SA., Taziwa, RT. and Sharifpur, M. 2024. Deploying artificial neural network to predict hybrid biodiesel fuel properties from their fatty acid compositions, International Journal of Ambient Energy, 45(1): 2262466. DOI: 10.1080/01430750.2023.2262466.
- Giwa, SO., Taziwa, RT. and Sharifpur, M. 2023. Dependence of composition-based approaches on hybrid biodiesel fuel properties prediction using artificial neural network and random tree algorithms. Renewable Energy, 218: 119324. <https://doi.org/10.1016/j.renene.2023.119324>.
- Hayatudden, A., Hammari, AM., Adamu, U. and Abubakar, A. 2020. Biodiesel production using Helianthus Annuus(sunflower) seed oil by transesterification. Bioremediation Science and Technology Research. 8(2): 24-27. <https://doi.org/10.54987/bstr.v8i2.555>.

Hossain, ABM., Mazen and M.A. 2010. Effects of catalyst types and concentrations on biodiesel production from waste soybean oil biomass as renewable energy and environmental recycling process. Australian Journal of Crop Science. 4(7); 550-555.

Ishola, F., Adeleken D., Mamuda A., Abodunrin T., Aworinde A., Olatunji O. and Akinlabi S., 2020. Biodiesel production from palm olein: A sustainable bioresource for Nigeria. Heliyon, vol. 6(8): e03725. <https://doi.org/10.1016/j.heliyon.2020.e03725>.

Kodgire, P., Sharma, A. and Kachhwaha, SS. 2022. Biodiesel production with enhanced fuel properties via appropriation of non-edible oil mixture using conjoint ultrasound and microwave reactor: Process optimization and kinetic studies. Fuel Processing Technology, 230: 107206. <https://doi.org/10.1016/j.fuproc.2022.107206>.

Kumar, D., Das, T., Giri, BS., Rene, ER. and Verma, B. 2019. Biodiesel production from hybrid non-edible oil using bio-support beads immobilized with lipase from *Pseudomonas cepacia*. Fuel, 255: 115801. <https://doi.org/10.1016/j.fuel.2019.115801>.

Kumar, S., Singhal, MK. and Sharma, MP. 2023. Analysis of oil mixing for improvement of biodiesel quality with the application of mixture design method. Renewable Energy, 202: 809–821.

Mahmudula, HM., Hagosa, FY., Mamata, R., Adama, AA., Ishakb, WFW. and Alenezi, R. 2017. Production, characterization and performance of biodiesel as an alternative fuel in diesel engines – A review. Renewable and Sustainable Energy Reviews, 72: 497–509.

Mofijur, M., Masjuk, HH., Kalam, MA., Rasul, MG., Atabani, AE., Hazrata, MA. and Mahmudul HM. 2015. Effect of biodiesel blending on physicochemical properties of biodiesel produced from *Moringa Oleifera*. 6th BSME International Conference on Thermal Engineering (ICTE 2014) Procedia Engineering, vol. 105, pp. 665-669.

Monika, BS. and Pathak, VV. 2023. Biodiesel production from waste cooking oil: A comprehensive review on the application of heterogenous catalysts. Energy Nexus, 10: 100209. <https://doi.org/10.1016/j.nexus.2023.100209>.

Omonhinmin, C., Olomukoro, E., Ayoola, A. and Egwim, E. 2020. Utilization of *Moringa oleifera* oil for biodiesel production: A systematic review. Energy, 8(1): 102-121.

Oni-Adimabua, ON., Ifeanyi-Nze, FO., Abimbolu, AK., Opadokun, EO., Omolusi, AR., Ezeokolie, ED., Udoh, EA., Afuape, AR., Areola, MO., Wokoma, PTB., Odoh, EC., Aiso, S. U., Francis, CJ., Egbo, JO., Ayanleke, TA. and Ankomah, NO. 2024. Production optimization, and characterization of biodiesel from almond seed oil using a bifunctional catalyst derived from waste animal bones and almond shell. European Journal of Sustainable Development Research, 8(3): em0261. <https://doi.org/10.29333/ejosdr/14740>

Sajjadi, B., Raman, AAA. and Arandiyan, H. 2016. A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: Composition, specifications and prediction models. Renewable and Sustainable Energy Reviews, 63: 62–92.

Verma, P. and Sharma, MP. 2016. Review of process parameters for biodiesel production from different feedstocks. Renewable and Sustainable Energy Reviews, 62: 1063–1071.

Yunus, KT., Atabani, A., Badruddin, I., Ankalgi, R., Mainuddin, KT. and Badarudin, A. 2015. *Ceiba pentandra*, *Nigella sativa* and their blend as prospective feedstocks for biodiesel. Industrial crops and product, 65(1) 367-373.