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Physicochemical Characterization of Waste Vegetable Oil as a Potential Feedstock for Biodiesel Production

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ABSTRACT

The increasing global demand for a renewable transportation fuels has motivated the search for alternatives such as biodiesel. The focus of this work was to completely characterize waste vegetable oil and evaluate its potentials as a feedstock for biodiesel production. The waste vegetable oil was extensively characterized to determine its key properties and chemical composition such as acid value, viscosity, iodine value, saponification value, fatty acid composition etc. The results showed that the waste vegetable oil exhibited desirable properties, such as a low free fatty acid value of 5.28%, a kinematic viscosity of 38.03 mPas, and iodine value of 82.90 mg I_2/100g oil and a saponification of 207.10 mg KOH/g oil, indicating its suitability for biodiesel production. Furthermore, its fatty acid profile showed a blend of saturated and unsaturated fatty acids which play important role in the quality of biodiesel. This work has shown that waste vegetable oil is a potential feedstock for biodiesel production.

1. INTRODUCTION

Sustainable energy has been identified as one of the very important ingredients of development of a country and its generation and consumption levels have been taken as an indication of the level of economic development and growth of that country (Zaman and Abd-el Moemen, 2017). Global demand for energy has been on a progressive increase in recent times and this has been linked directly to the increasing global population and level of industrialisation (Edelenbosch et al., 2017).

As it stands, the global demand for energy is mostly met from fossil-based sources mainly petroleum or crude oil. However, recent evidence has shown that continued utilisation of petroleum-based fuels is not sustainable for a number of reasons (Ajala et al., 2015). For instance, the available reserve of crude oil is finite, and it has been projected to run out within the next couple of decades (Shafiee and Topal, 2009). Furthermore, the combustion of petroleum-based fuels like diesel, kerosene, gasoline etc has been shown to have seriously negative environmental implications (Venkatesh et al., 2011).

The sustainable development goals (SDGs) advocates protection of the environment and energy security. Thus, it has become imperative to seek out alternative energy sources that are sustainable and environmentally friendly. The deployment of biofuels which are fuels derived from plant and animal sources has been identified as one way of achieving this goal and one important example of biofuel identified in this regard is biodiesel (Correa et al., 2019). Biodiesel is renewable, biodegradable, non-toxic and environmentally friendly (Osorio-Tejada et al., 2017). Its emissions are not toxic, and it has lower levels of unburnt hydrocarbons, carbon monoxide and particulate matter compared to petrodiesel and it does not contain sulphur eliminating the problems of sulphur emissions (Hasan and Rahman, 2017).

One of the important aspects of biodiesel production is the selection of an appropriate feedstock. Because of the food vs fuel debate and other sustainability issues, edible feedstocks are no longer encouraged for biodiesel production. Nonedible feedstocks are now favoured and an important example is waste vegetable oil.

Waste vegetable oil (WVO) refers to refined edible vegetable oil that has been used up for several domestic purposes and is no longer useful for human consumption. It was estimated that the total WVO generated in North America, Europe and some Asian nation was around 17 Mton (Gui et al., 2008). Considering the fact that the demand for biodiesel at the same time was around 11 Mton, WVO could have served as a sustainable feedstock to meet the biodiesel demand (Azocar et al., 2010). Using waste vegetable oil as feedstock could potentially reduce the cost of biodiesel production since its cost is about three to four times cheaper than fresh vegetable oil. Furthermore, the use of waste vegetable oil will potentially reduce the environmental problems caused by their inappropriate disposal in rivers and landfills.

Thus, the aim of this study was to characterize waste vegetable oil and assess its properties with the intention of using it as a feedstock for biodiesel production.

2. MATERIALS AND METHODS

2.1. Waste Vegetable Oil Collection and Characterization

The waste vegetable oil used as feedstock was obtained from a local eatery in Benin City, Edo State, Nigeria. Prior to use, it was filtered to remove solid impurities. The suitability of the collected waste vegetable oil as a feedstock for biodiesel production was examined by determining its physical and chemical properties via appropriate characterisation methods (AOAC 1990). The properties examined include moisture content, acid value, saponification value, peroxide value, iodine value, and viscosity, density, specific gravity, etc.

3. RESULTS AND DISCUSSION

3.1. Physical Properties of Waste Vegetable Oil

To assess the suitability of waste cooking oil for biodiesel, a comprehensive characterization was carried out, examining various properties of the oil such as acid value, free fatty acids (FFA) content, viscosity, saponification value, average molecular weight, density, specific gravity, and iodine value and the results are shown in Table 1. Table 1 shows that the acid value of the waste vegetable oil was determined to be 10.52 mg KOH/g oil, indicating the presence of free fatty acids. This suggests a certain degree of hydrolysis and oxidation, which could hinder the efficiency of biodiesel production (Vieitez et al., 2014). The FFA content, was obtained as 5.28%, and this further confirmed the presence of free fatty acids. Higher levels of FFA are not desirable as it can result in the formation of soap during biodiesel production via transesterification, thus, reducing both the quality and yield of biodiesel (Maheshwari et al., 2022). To address this, pretreatment methods such as acid esterification may be necessary to reduce the FFA content and enhance the efficiency of biodiesel production. This is usually necessary when homogeneous basic catalysts are used. However, for the case of this study, a heterogeneous solid catalyst was used, and the doping carried out on it introduced acidic sites in addition to the basic sites provided by the calcium-based precursors. The combination of the acidic and basic sites ensured that the catalyst is able to carry out simultaneous esterification and transesterification (Lau et al., 2022).

The oil's moisture content was determined to be 0.61%. This is very close to the 0% recorded by Younis et al. (2014) and the 0.62% recorded by Sirisomboonchai et al. (2015). Moisture content is very important because excessive moisture level promotes microbial proliferation during storage of oil and may interfere with biodiesel synthesis during transesterification (Banerjee and Chakraborty, 2009). Viscosity, an important parameter for biodiesel production, was found to be 38.03 mPas at 40 °C. This value is close to those reported by previous researchers in the field such as Sabarinath et al. (2020) (35.9 mm^2/s) and Younis et al. (2014) (33.6 mm^2/s). High viscosity values indicate increased resistance to flow, and this can influence the reaction kinetics during transesterification. The saponification value, measured at 207.10 mg KOH/g oil, provides insights into the oil's potential for biodiesel production. Higher saponification values suggest a larger proportion of higher molecular weight fatty acids, which can contribute to improved energy content and enhanced cold flow properties in the resulting biodiesel (Folayan et al., 2019). The saponification value obtained in this work is very close to the value of 207.83 mg KOH/g oil reported by Gopinath et al. (2009) showing conformity with trends.

Both the density and specific gravity were obtained as 931 kg/m^3 and 0.931 respectively. Both properties of oil play an important role in the separation and purification processes of biodiesel production. These properties can influence phase separation and the removal of glycerol and impurities from biodiesel (Thirumarimurugan et al., 2018). Understanding the density characteristics of waste vegetable oil enables the design of appropriate separation techniques to obtain high-quality biodiesel. Similar values of density such as 892.5 kg/m^3 (Sahu et al., 2021) and 941 kg/m^3 (Ali and Ali 2014) have been reported.

The iodine value (82.90 mg I_2/100g oil) is a measure of the oil's level of unsaturation. Unsaturated fatty acids contribute to the oxidative stability and cold-flow properties of biodiesel. Waste vegetable oil with a higher iodine value demonstrates a greater potential for blending with other feedstocks to optimize the final biodiesel properties. In comparing with previous work, it is seen that the iodine value of the oil used in this study was less than those reported previously such as the 113 mg I_2/100 oil obtained by Dim et al. (2013). The average molecular weight of the waste cooking oil was obtained as 856.09 g/mol, reflecting the distribution and size of its fatty acid constituents. Similar values have also been reported by other researchers such as 886 g/mol by Cetinkaya and Karaosmanoğlu, (2004).

Table 1: Properties of waste vegetable oil

Property	WCO
Acid value (mg KOH/g oil)	10.52
FFA (%)	5.28
Moisture content (%)	0.61
Dynamic viscosity @ 40 °C (mPa.s)	38.03
Saponification value (mg KOH/g oil)	207.10
Average molecular weight (g/mol)	856.09
Density @ 40 °C (kg/m^3)	931.00
Specific gravity	0.931
Iodine value (mg I_2/100g oil)	82.90

3.2. Chemical Composition of Waste Vegetable Oil

For any oil feedstock and in particular, waste vegetable oil, the fatty acid composition is a crucial factor that can influence its suitability as a feedstock for biodiesel production. In the current study, an assessment of the fatty acid profile of the waste vegetable oil used was carried out by conducting a chemical composition analysis using GC-MS analysis. The results presented in Table 2 shows the percentages of the various fatty acids, including oleic acid (43.33%), palmitic acid (36.01%), and linoleic acid (11.85%) which accounted for the major components of the feedstock. Other fatty acids were present in smaller proportions such as stearic acid (3.88%), myristic acid (1.1%), arachidic acid (1.1%), lauric acid (0.20%), and palmitoleic acid (0.47%). These results provide valuable insights into the oil's potential for biodiesel production and its overall quality. Oleic acid, which accounts for 43.33% of the total composition, is a monounsaturated fatty acid. Its composition in waste vegetable oil is beneficial for biodiesel manufacturing. Oleic acid improves fuel properties like cetane number and cold flow properties like viscosity. Overall, oleic acid enhances the quality of biodiesel and its performance in diesel engines (Lanjekar and Deshmukh, 2016). The second most abundant fatty acid, palmitic acid is a saturated fatty acid and accounted for 36.01% of the total composition. Like oleic acid, it also positively impacts the fuel properties of biodiesel made from waste vegetable oil (Ni et al., 2020). Linoleic acid is a polyunsaturated fatty acid and accounted for 11.85% of the fatty acid composition of the oil. Its presence in waste vegetable cooking oil suggests a high degree of unsaturation, which might impact the oxidative stability of the resultant biodiesel.

Table 2: Fatty acid composition of waste vegetable oil

Fatty acid	Chemical formula	Nature	Composition (%)
Linoleic acid	$C_{18}H_{32}O_2$	Unsaturated	11.58
Myristic acid	$C_{14}H_{28}O_2$	Saturated	1.10
Oleic acid	$C_{18}H_{34}O_2$	Unsaturated	43.33
Lauric acid	$C_{12}H_{24}O_2$	Saturated	0.20
Palmitic acid	$C_{16}H_{32}O_2$	Saturated	36.01
Palmitoleic acid	$C_{16}H_{30}O_2$	Unsaturated	0.47
Stearic acid	$C_{18}H_{36}O_2$	Saturated	3.88
Arachidic acid	$C_{20}H_{40}O_2$	Saturated	1.10
Others			2.33
Total			100

Unsaturated fatty acids increase cold flow properties and oxidation stability, making linoleic acid an important component of oils for biodiesel production (Kumbhar et al., 2022). Stearic acid is a saturated fatty acid with an 18-carbon chain length that accounts for 3.88% of the composition of the waste vegetable oil. Its presence in the oil may have a little effect on the fuel qualities of the resultant biodiesel, particularly raising viscosity and cloud point. Transesterification process optimization and alternative blending solutions can help buffer these impacts. Myristic acid is a saturated fatty acid with a composition of 1.1%. While the presence of saturated fatty acids is not ideal for biodiesel synthesis, the comparatively low content of myristic acid in waste vegetable oil indicates minimal impact on the properties of the produced biodiesel. The remaining fatty acids, lauric, and arachidic acid are saturated while palmitoleic acid is unsaturated and they are all in low proportion. They also contribute to cold flow properties of biodiesel. Summarily, the fatty acid composition of waste vegetable oil as presented in Table 2 revealed a combination of saturated and unsaturated fatty acids. The presence of oleic acid, as well as appropriate amounts of linoleic acid and comparatively lower quantities of saturated fatty acids, implies that waste vegetable oil has the potential to yield biodiesel with excellent fuel characteristics.

4. CONCLUSION

The focus of this study was to characterize waste vegetable oil and evaluate its potential as a feedstock for biodiesel production. At the end of the study, it was found from the characterization of the waste vegetable oil used in this study that it had a low free fatty acid value (5.28%), kinematic viscosity (38.03 mPas). The iodine (82.90 mg I_2/100 oil) and saponification (207.10 mg KOH/g oil) value ensured it had oxidative stability. The results of the GC-MS analysis supported this as there were some saturated fatty acids present in the waste vegetable oil. These findings contribute to the development of sustainable and economically viable biodiesel production processes using waste vegetable oil as a sustainable feedstock.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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