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Original Research Article

Production and Characterization of Sustainable Biodiesel and its Blends from Pumpkin (*Cucurbita moschata*) Seed Oil in Sudan

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Abstract

In this study, pumpkin seed oil extracted by the Soxhlet solvent method was converted into biodiesel using the transesterification process. This process involved the reaction between the extracted oil and alcohol (methanol) in the presence of a catalyst (NaOH) at an ideal temperature of 60 °C. The reaction resulted in the production of mono-alkyl esters (Biodiesel) and glycerol as byproducts. The functional groups of biodiesel were identified using the FTIR technique. The properties assessed included density, viscosity, color, flash point, cloud point, water content, pour point, total acid number, copper strip corrosion, and sulfur content. The properties were compared with the properties of fossil diesel according to ASTM D 6751 standard. Biodiesel was blended with fossil diesel (B20) as well as with fossil diesel and ethanol in different proportions. These blends were studied and compared with ASTM D 7467 standard. The results showed that biodiesel met all the requirements to be an alternative fuel. Moreover, its blends substantially complied with the standard.

Keywords: Biodiesel, Pumpkin seed oil, Transesterification, Catalyst, Blends.

INTRODUCTION

Recently, increased population and growing energy demand have led to higher rates of unsustainable diesel fuel consumption, and consequently this is expected to cause an increase in air pollution and global warming due to CO_2 and other greenhouse gas emissions (Ahmed *et al.*,2023). The utilization of petroleum diesel generates primary air pollutants like sulfur oxides, nitrogen oxides, carbon monoxide, carbon dioxide, hydrocarbons, and suspended particulate matter, posing significant risks to environmental and human health (Tavella *et al*., 2025). The rise in environmental awareness and the depletion of petroleum-based diesel have led to the search for alternative and sustainable fuel options. One of the most promising alternatives available is biodiesel. It is renewable and serves as a clean replacement for fossil diesel. In addition, Biodiesel is eco-friendly, minimizes sulfur pollutants in exhaust gases, improves lubricity, offers a positive energy balance, and is less harmful to the environment in case of spills compared to fossil diesel (Farokhi *et al*., 2023).

Biodiesel can be produced from a wide variety of resources such as vegetable oils, animal fats, waste oils, and algae (Talapatra and Ghosh, 2022). The direct use of vegetable oils as an alternative fuel in engines negatively affects performance due to their high viscosity, poor combustion, oxidation and thermal degradation, and poor cold flow properties, which make them unsuitable for use in pure form. Therefore, they must be converted into biodiesel through appropriate methods (Shereena and Thangaraj, 2009). Researchers have proposed different techniques to produce biodiesel from vegetable oils, such as micro-emulsions, thermal cracking (pyrolysis), and transesterification. The most prominent and widely used of these techniques is transesterification, where alcohol is used with a catalyst to form biodiesel and glycerol. The overall process is normally a sequence of three consecutive steps, which are reversible reactions (Meher *et al.,* 2006). Lipase can also be used as a catalyst for transesterification in non-aqueous media when the feedstock contains a high amount of free fatty acid (Abdelaziz *et al.*, 2025). Studies have shown that biodiesel and fossil diesel are similar in many properties, but biodiesel helps to reduce environmental pollution. Thus, it can be used alone or blended with fossil diesel in various proportions, most commonly B20 (20% biodiesel) and B5 (5% biodiesel) (Palani *et al.*, 2022).

The aim of this research is to produce biodiesel from pumpkin seed oil as a renewable feedstock, evaluate its physicochemical properties and compatibility with ASTM D 6751 standards, and prepare diesel-biodiesel and diesel-biodiesel-ethanol blends at different proportions to assess their effectiveness in enhancing performance and efficiency.

MATERIALS AND METHODS

Materials

- Pumpkin seed oil was extracted previously by using the Soxhlet solvent extraction technique.
- Chemicals used for all experiments were of analytical grade and purchased from trusted suppliers.

Methods

Transesterification Process

Mixing of Alcohol and Catalyst

In a high-temperature-resistant glass beaker, 0.5 g of sodium hydroxide pellet was carefully mixed with 30 mL of methanol. The mixture was gently heated at a temperature lower than the methanol boiling point to accelerate the dissolution process, resulting in the formation of a chemical solution known as methoxide (NaOCH3). Excess alcohol was added to ensure complete conversion of fats or oils to their esters (Ogunwole, 2015).

Transesterification Reaction

500 mL of pumpkin seed oil was placed into 1 L beaker and heated to 60 °C, 100 mL of freshly prepared methanolic Sodium Hydroxide was added under stirring at 3000 rpm for two hours. The mixture was transferred to a separating funnel and kept for 24 hours. Then the lower glycerol layer was drained, and the upper biodiesel layer was washed three times with warm distilled water to remove soap, methanol, and remaining glycerol (Okullo *et al*., 2006).

Preparation of Biodiesel Blends

Diesel-Biodiesel Blend

For superior blend quality, the biodiesel must be free from moisture and sediments. Biodiesel and fossil diesel were retained at the same temperature to achieve uniform blends. The B20 blend, containing 20% biodiesel and 80% fossil diesel, was prepared volumetrically in 500 mL batches using 250 mL and 50 mL graduated cylinders. The blending process involved stirring the mixture at 2500 rpm for 30 minutes to ensure thorough homogenization. (Jamrozik *et al.,* 2017).

Diesel-Biodiesel-Ethanol Blends

Diesel-biodiesel-ethanol blends were prepared following the same method as the biodiesel-diesel blend. Then the blends were kept in sealed bottles safely to prevent ethanol evaporation. Three blends with varying ratios were prepared and shown in Table 1.

Table 1: Diesel-Biodiesel-Ethanol blends ratios

Blend	Diesel	Biodiesel	Ethanol
D60B20E20	60%	20%	20%
D80B10E10	80%	10%	10%
D80B15E5	80%	15%	5%

Physical and Chemical Properties

The study of the physicochemical characterization of the produced biodiesel and its blends is essential for evaluating the quality of fuel and its compliance with international specifications.

Determination of Viscosity

The viscosity was determined by using a viscometer according to ASTM D 445. The time was measured for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer. The viscosity was the product of the measured flow time and the calibration constant of the viscometer.

Determination of Density

The density of the samples was determined by using a density bottle at 15 °C. The bottle was cleaned and dried in the oven at a temperature of 105 °C and kept in a desiccator to cool. The empty weight of the density bottle was taken, weighed when it was filled with water, and when it was filled with the sample (along with the stopper). The density was calculated using the following formula:

$$p = \frac{w_3 - w_1}{v}$$

P = density in units of g/ml

W3 = Weight of the bottle with the sample

W1 Weight of the empty bottle

V = volume of the bottle was calculated.

Fourier Transform Infrared Spectroscopy (FTIR)

The principal functional groups present in pumpkin biodiesel were detected and identified by the Fourier Transform Infrared Spectroscopy (FTIR) technique.

The FT-IR spectra were recorded on FTIR-8400S instrument (Shimadzu, Japan). This instrument is designed for precise molecular characterization through infrared absorption analysis. It operates across a spectral range typically from 4000 to 400 cm^{-1} with a maximum resolution of 0.85 cm^{-1} and is controlled via IR Solution software.

RESULTS AND DISCUSSIONS

Biodiesel Properties

The key physical and chemical properties of the biodiesel and fossil diesel were determined and presented in Table 2. Total acid number is a parameter used to determine the amount of free fatty acids (FFA) or other acidic compounds present in a biodiesel sample. The total acid number of pumpkin biodiesel was found to be 0.322 mg KOH/g, which is close to 0.35 mg KOH/g of watermelon waste oil biodiesel determined by Ketema B *et al.,* (2022) and higher than that of coconut biodiesel (0.18 mg KOH/g) reported by Musa *et al.* (2016).

Table 2: Physical and chemical properties of pumpkin biodiesel and fossil diesel in comparison with ASTM D6751

Parameter	ASTM D 6751	Biodiesel	Fossil diesel
Total Acid Number, mg KOH/g	Max 0.50	0.322	-
Density at 15ºC, g/ml	-	0.914	0.877
Kinematic Viscosity at 40ºC, cSt	1.9-6.0	2.5	1.9
Color	-	1.4	1.3
Water Content, wt%	Max 0.05	0.01	0.01
Cloud Point, °C	report	4.2	4
Pour point, °C	-	2	1
Copper Strip Corrosion (3 Hours at100ºC)	Max 3	1A	1A
Sulfur Content, % mass	Max 0.05	0.004	0.008
Flash Point, °C	Min 93	184	-

The density of pumpkin biodiesel was found to be 0.914 g/ml, which is slightly higher than that of fossil diesel (0.877 g/ml) and the density of coconut biodiesel (0.800 g/ml) determined by Musa *et al.* (2016), but it is very close to the density of sesame biodiesel (0.913 g/ml) reported by Olowosile (2014).

Viscosity is an important factor, as it directly affects the flow behaviour and efficiency of the biodiesel. The viscosity of pumpkin biodiesel was found to be 2.5 cSt. It is slightly higher than the viscosity of fossil diesel (1.9 cSt) but falls within ASTM standards. Thus, pumpkin biodiesel can be used as an alternative to diesel fuel in terms of its viscosity. In addition, its value is lower than (2.7 cSt) of coconut methyl ester reported by Musa *et al.,* (2016) and (3.3 cSt) of sesame methyl ester reported by Olowosile (2014).

The water content in biodiesel was found to be 0.01%, identical to that measured in fossil diesel, and lower than that of sesame biodiesel (0.08%) reported by Olowosile (2014). All values are within the limits specified in the standard. A high water content can reduce the heating value, cause damage to the fuel system and promote microbial growth. During the production process of biodiesel, some water may remain after the washing steps. Therefore, it is important to use effective drying techniques.

The cloud point is one of the cold-flow properties that must be considered when using diesel fuel in cold environments. The cloud point of fuel refers to the temperature at which wax crystals begin to form (Akhil *et al*., 2017). The biodiesel examined in this study exhibited a cloud point of 4.2°C, which is close to the cloud point of the fossil diesel (4°C) and higher than that of coconut biodiesel (0°C) reported by Musa et al. (2016).

The pour point of pumpkin biodiesel was found to be 2 °C, which differs from the pour point of fossil diesel (1°C), coconut biodiesel (-3 °C) reported by Musa et al. (2016) and sesame biodiesel (6.2 °C) reported by Olowosile (2014), reflecting the differences between them. The pour point is an important parameter that helps in the assessment of the cold-flow properties of liquid fuels at various temperatures. In general, feedstock oils have a higher pour point than the biodiesel produced from them. Alptekin and Canakci (2011) reported that the pour point of biodiesel is independent of the catalyst used and the reaction conditions but depends on the quantity of saturated fatty acids present in the oil.

The color of pumpkin biodiesel was found to be 1.4, and that of fossil diesel was 1.3. The color property is used to assess the purity of biodiesel and its compliance with the standards.

The copper strip corrosion test is an important indicator of biodiesel quality. Corrosion levels are influenced by multiple factors, including sulfur content, alkaline substances, and acidity levels (Sarin, 2012). This study showed that biodiesel derived from pumpkin seed oil achieved a corrosion rating of 1A, confirming the high quality of the final product.

The results showed that the sulfur content values of pumpkin biodiesel and fossil diesel were 0.004% and 0.008%, respectively, and both values fall within the ASTM D6751 standard.

The flash point is a measure of fuel flammability. In this study, the flash point of pumpkin biodiesel was found to be 184°C, which is higher than that of fossil diesel (68 °C) and sesame biodiesel (134°C) reported by Olowosile (2014). Biodiesel with a high flash point is safer for storage and handling.

Fourier Transform Infrared Spectroscopy FTIR of Pumpkin Biodiesel

The spectrum of biodiesel in Figure 1 shows an absorption at 2856.81 cm^{-1} due to the stretching of C-H in the methylene group (CH_2). A strong and clear peak at 1747.21 cm^{-1} is attributed to the stretching vibration of C=O (carbonyl) group in fatty acid methyl esters. The peak at 1452.54 cm^{-1} ascribed to the bending vibration of C-H methyl groups in the biodiesel. The peak at 1171.34 cm^{-1} corresponds to C-O stretching vibration of the ester functional group. It can also indicate the vibration of O-CH_3 in the spectrum (Oyerinde and Bello, 2016). The absorption band at 722.05 cm^{-1} indicates the presence of rocking vibrations of -CH_2 – groups in the long-chain aliphatic structure of biodiesel (Oyerinde and Bello, 2016).

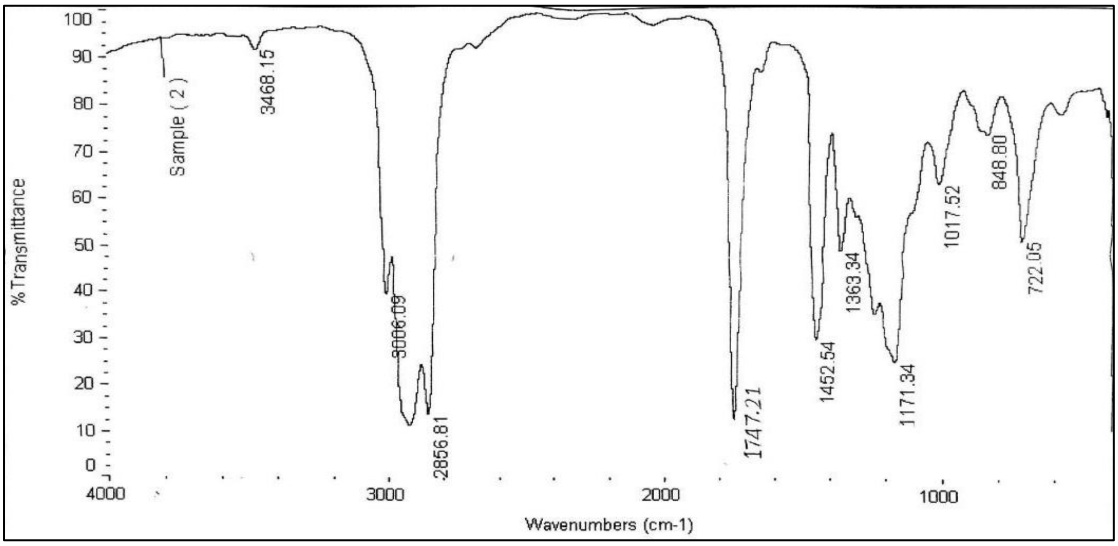

Fig. 1: FTIR spectrum of pumpkin seed methyl ester

Biodiesel Blends Characterizations

Table 3 shows the physical and chemical characterizations of Biodiesel blends in comparison with ASTM D 7467 standard. B20 blend met all the requirements of the standard without exception.

Table 3: Physicochemical properties of pumpkin biodiesel blends

TESTS	ASTM D 7467	B 20	D60B20E20	D80B10E10	D80B15E5
Total Acid Number, mg KOH/g	Max 0.3	0.20	0.26	0.29	0.28
Density at 15ºC, g/ml	-	0.884	0.880	0.870	0.881
Kinematic Viscosity at 40ºC, cSt	1.9-4.1	2.1	1.6	1.8	1.7
Water Content, wt%	0.05	<0.05	<0.05	<0.05	<0.05
Color	-	1.1	1	1	1.2
Cloud Point, °C	-	9.8	5.5	4	+3
Pour point, °C	-	9	1	1	+2
Copper Strip Corrosion (3 Hours at 100ºC)	NO 3	1A	1A	1A	1A
Sulfur Content, % mass	MAX 0.05	0.007	0.005	0.007	0.006
Flash Point, °C	Min 52	85	14	15	17

Ethanol blends met the standard requirements for total acid number, copper strip corrosion, and sulfur content.

The results indicate a slight variation in the total acid number among the blends. The acid value of B20 was found to be 0.20 mg KOH/g, representing the lowest value, followed by D60B20E20 (0.26 mg KOH/g), then D80B15E5 (0.28 mg KOH/g) and D80B10E10 (0.29 mg KOH/g). All values fell within the standard and were lower than the total acid number value of B100.

The density of the biodiesel and biodiesel blends was measured at 15 °C. The density values of all blends decreased noticeably compared to that of pure biodiesel (0.914 g/ml). Furthermore, the differences in density values among the blends are very slight. The maximum value was found to be 0.884 g/ml for the B20, followed by (0.881 g/ml) for D80B15E5, then (0.880 g/ml) for D60B20E20, and the minimum value (0.870 g/ml) for D80B10E10.

Viscosity is an important physical property of biodiesel and blends because it directly affects engine performance. The results illustrate the variation in viscosity values for biodiesel, biodiesel-diesel, and biodiesel-diesel-ethanol blends. The highest viscosity was recorded for B20 (2.1 cSt), while D60B20E20 (1.6

cSt) showed the lowest viscosity value among all tested samples. The viscosity of D80B10E10 and D80B15E5 was found to be 1.8 cSt and 1.7 cSt, respectively. Generally, these results indicate that blending biodiesel with diesel and pre-heating the biodiesel improves the viscous characteristics significantly. Moreover, the addition of ethanol plays an effective role in decreasing the viscosity of biodiesel blends.

The water content values of B20, D60B20E20, D80B10E10, and D80B15E5 were found to be below the limit specified in the standard. Remaining within the allowable water content range demonstrates strong fuel quality control, indicating that these blends are suitable for engine applications with minimal risk of moisture-induced degradation.

Color is an important feature, as it is one of the most noticeable characteristics for users and serves as a key indicator of product quality in the manufacturing of blends (Jimoh, 2004). The color values of B20, D60B20E20, D80B10E10 and D80B15E5 were found to be 1.1, 1, 1, 1.2 respectively.

Cold flow properties were determined for all biodiesel blends under study. The B20 blend exhibited a cloud point of 9.8°C and a pour point of 9°C. The D60B20E20 blend recorded a cloud point of **5.5°C** and a pour point of 1°C. The D80B10E10 blend showed a cloud point of 4°C and a pour point of 1°C. Finally, the D80B15E5 blend exhibited a cloud point of 3 °C and a pour point of 2°C. The cold flow properties do not have specification limits in the standard testing method (ASTM), as they depend on several factors such as operating conditions, equipment design, and weather situation in the country which uses the fuel. In most cases, additives are utilized to maintain the required limits (Murphy *et al.,* 2013).

Copper strip corrosion results for all blends were found to be 1A, which indicates the biodiesel blends are safe in terms of sulfur compounds, free acids, and any impurities that cause corrosion. This reflects their high quality, purity, and suitability for use in metal fuel systems.

The flash point is an essential and indispensable parameter because it ensures the safety of fuel handlers and provides a measure of the quality of biodiesel blends. The flash point of B20 was found to be 85°C, indicating that the addition of fossil diesel to biodiesel reduces the flash point value, yet it remains within the permissible range in the standard. The flash point values of D60B20E20, D80B10E10 and D80B15E5 were found to be 14 °C, 15 °C and 17 °C respectively. From these results, it can be noted that the flash point of ethanol–biodiesel blends decreases sharply even with small ethanol additions, which requires further treatment.

CONCLUSION

- Biodiesel was efficiently produced from pumpkin seed oil using the transesterification process in the presence of methoxide.
- The functional groups characteristic of biodiesel were identified using FTIR analysis.
- The physical and chemical characteristics of biodiesel were studied and found to be in accordance with the ASTM D6751 standard.
- Several blends were prepared (biodiesel-diesel, biodiesel-diesel-ethanol), and their physical and chemical properties were examined and compared with ASTM D7467 standard. The results showed that all blends were compatible with these specifications, except for the flash point values in diesel-biodiesel-ethanol blends.

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