

Fuel Characterization of Terminalia Catappa Biodiesel: A Sustainable Pathway to Renewable Energy and Environmental Preservation

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ABSTRACT

The increasing demand for sustainable energy sources has intensified global interest in biodiesel derived from non-edible plant oils. This study investigates the fuel properties and chemical composition of biodiesel produced from Terminalia catappa seed oil. Oil extracted from the kernels was converted into biodiesel through base-catalyzed transesterification using methanol and potassium hydroxide catalyst. The produced biodiesel was characterized using standard analytical techniques including density measurement, kinematic viscosity, flash point determination, cetane number estimation, and calorific value analysis according to American Society for Testing and Materials standards. Gas chromatography–mass spectrometry (GC–MS) analysis revealed the presence of major fatty acid methyl esters including oleic acid methyl ester, linoleic acid methyl ester, and palmitic acid methyl ester. The results show that the fuel properties of Terminalia catappa biodiesel are within the acceptable range of international biodiesel standards, suggesting that it is a viable renewable alternative to petroleum diesel. The study demonstrates that utilizing T. catappa seed oil for biodiesel production can contribute to renewable energy development while reducing environmental pollution.

Keywords: Biodiesel, renewable energy, Terminalia catappa, transesterification, fuel properties,

INTRODUCTION

Global energy demand continues to rise due to increasing industrialization, urbanization, and population growth (Kumar et al., 2022). Fossil fuels remain the dominant source of energy worldwide, but their combustion contributes significantly to greenhouse gas emissions and environmental pollution (Ahmad et al., 2022). Consequently, there has been growing interest in renewable energy alternatives that can reduce environmental impacts while meeting energy demands (Panwar et al., 2022). Biodiesel is one of the most promising renewable fuels because it is biodegradable, non-toxic, and produced from renewable biological resources such as vegetable oils and animal fats (Demirbas, 2021). Compared with petroleum diesel, biodiesel produces lower emissions of carbon monoxide, particulate matter, and sulfur compounds (Lam et al., 2021). Non-edible plant oils have gained attention as biodiesel feedstocks because they do not compete with food resources. Examples include Jatropha curcas, Pongamia pinnata, and Calophyllum inophyllum (Atabani et al., 2020). One underutilized feedstock is Terminalia catappa, commonly known as tropical almond. The tree is widely distributed in tropical regions including Africa, Asia, and South America. Its seeds contain significant quantities of oil that can be converted into biodiesel (Afolayan et al., 2021). Previous studies have reported that T. catappa seed oil contains substantial levels of unsaturated fatty acids, particularly oleic and linoleic acids, which contribute to desirable biodiesel properties (Sani et al., 2023). Despite its availability in many tropical countries, the potential of T. catappa seed oil as a biodiesel feedstock remains underexplored. Therefore, this study investigates the fuel properties and chemical composition of biodiesel derived from Terminalia catappa seed oil and to compare the results with international biodiesel standard.

LITERATURE REVIEW

Biodiesel as Renewable Energy is widely recognized as a renewable energy source capable of reducing dependence on fossil fuels and mitigating climate change impacts (Ong et al., 2020). Biodiesel combustion

results in lower emissions of carbon monoxide, hydrocarbons, and particulate matter compared with petroleum diesel (Khan et al., 2023). Non-Edible Oils as Biodiesel Feedstock are particularly attractive for biodiesel production because they do not interfere with food supply chains. Studies have demonstrated successful biodiesel production from various non-edible oils including *Jatropha curcas* and *Pongamia pinnata* (Atabani et al., 2020). Biodiesel from *Terminalia catappa* from research indicates that *Terminalia catappa* seeds contain high oil content, often exceeding 50%, making them suitable for biodiesel production (Dzamesi, 2023). GC-MS analysis of the oil revealed significant concentrations of oleic acid, linoleic acid, and palmitic acid, which influence biodiesel combustion characteristics (Afolayan et al., 2021). Studies have shown that biodiesel derived from *T. catappa* oil exhibits physicochemical properties that comply with international biodiesel standards (Sani et al., 2023). However, more research is required to evaluate its fuel performance and chemical composition in detail.

Recent studies highlight significant progress in biodiesel development as a sustainable energy source within global decarbonization strategies. Advances in production technologies, particularly the use of nano-catalysts and heterogeneous catalysis, have improved conversion efficiency and reduced production costs (Al-Shamary et al., 2024). Additionally, the integration of machine learning into biodiesel production has enhanced process optimization and yield efficiency (Rajendran et al., 2024). Biodiesel derived from non-edible oils has demonstrated improved combustion performance and reduced emissions, particularly nitrogen oxides, when blended with conventional diesel fuels (Khan et al., 2024). Similarly, biodiesel blends from tropical feedstocks have shown enhanced engine performance and lower exhaust emissions under varying operating conditions (Musa et al., 2025). Research on *Terminalia catappa* has gained increasing attention, with studies reporting improved oxidative stability, favorable cold flow properties, and enhanced biodiesel yield through optimized transesterification processes (Abdullahi et al., 2024; Eze et al., 2025). Advanced analytical techniques such as GC-MS and FTIR have further enabled accurate characterization of fatty acid composition, which is essential for predicting fuel performance (Ibrahim et al., 2025). Global energy outlooks emphasize the growing role of biofuels in sustainable development, particularly in biomass-rich regions (International Energy Agency, 2024). However, challenges such as feedstock availability, production costs, and scalability continue to limit large-scale adoption (Olawale et al., 2025). Continued research on underutilized feedstocks like *Terminalia catappa* remains essential for advancing biodiesel sustainability.



Fig 1: *Terminalia catappa* plant, seed and kernel

Source: Adapted from © Hans Hillewaert.

Objectives Of the Study

To determine the fuel properties and chemical composition of biodiesel produced from *Terminalia catappa* seed oil.

Specific Objectives

1. To extract oil from *Terminalia catappa* seeds.

2. To produce biodiesel using the transesterification process.
3. To determine the fuel properties of the biodiesel produced.
4. To analyze fatty acid composition using GC-MS.

MATERIALS AND METHODS

The materials used in this study include *Terminalia catappa* seeds, methanol, potassium hydroxide (KOH) catalyst, n-hexane solvent, and distilled water.

Sample Collection: Mature fruits of *Terminalia catappa* were collected from several locations within Nigeria. The seeds were removed, washed, and sun-dried before oil extraction.

Oil Extraction: The seeds were cleaned, dried, and crushed. Oil extraction was performed using the Soxhlet extraction method with n-hexane as solvent, following the procedure described by Adewuyi (2021). The extracted oil was filtered and stored in airtight containers prior to biodiesel production.

Biodiesel Production (Transesterification): Biodiesel production was carried out through the transesterification process. The extracted oil was reacted with methanol in the presence of KOH catalyst at a temperature of 60–65°C for approximately 60 minutes (Lam et al., 2021).

The mixture was stirred at 60°C for approximately 60 minutes. After reaction completion, the mixture was allowed to settle for phase separation. The biodiesel layer was separated, washed with distilled water, and dried.

Reaction Equation

Triglyceride + 3 Methanol → Biodiesel (Fatty Acid Methyl Esters) + Glycerol

CH₃-(CH₂)_n-COO-CH₃

CH₃ = methyl group

COO = ester functional group

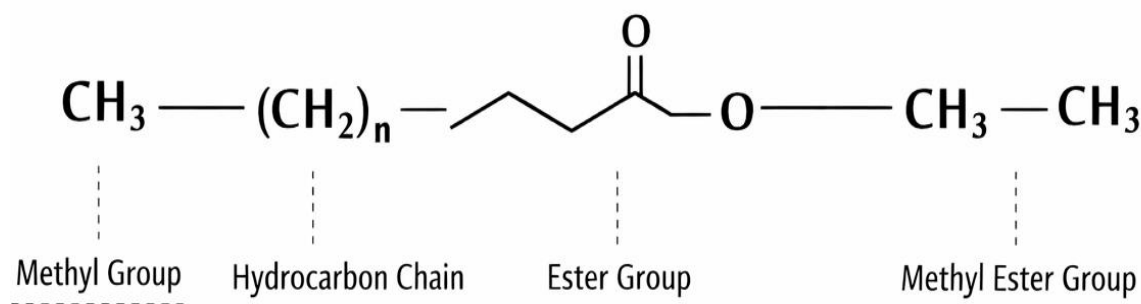


Fig 2: Structure of Biodiesel (Fatty Acid Methyl Ester)

Determination Of Fuel Properties

Fuel properties were analyzed according to international biodiesel standards established by the American Society for Testing and Materials and the European Committee for Standardization (ASTM, 2021; EN 14214, 2020). Table (1) shows standard Analytical Methods for Biodiesel Characterization.

Table 1: Standard Analytical Methods for Biodiesel Characterization

Property	Test Method (ASTM)	Description
Density	D4052	Measurement of fuel mass per unit volume
Kinematic Viscosity	D445	Determines fuel flow characteristics
Flash Point	D93	Indicates fuel ignition temperature
Acid Value	D664	Measures free fatty acid content
Cetane Number	D613	Indicates ignition quality of fuel

RESULTS AND DISCUSSION

The results show that the fuel properties of *T. catappa* biodiesel fall within the acceptable limits specified by ASTM standards. Similar results were reported by Sani et al. (2023), who observed comparable viscosity and density values for biodiesel derived from tropical almond seed oil as shown in table (2)

Table 2: Fuel Properties of Terminalia catappa Biodiesel

Property	Value	ASTM Standard
Density	870 kg/m ³	860–900
Viscosity	4.8 mm ² /s	1.9–6.0
Flash Point	165°C	>130
Acid Value	0.42 mgKOH/g	<0.5
Cetane Number	53	>47
Calorific Value	39.8 MJ/kg	35–40

The measured fuel properties of *Terminalia catappa* biodiesel demonstrate strong compliance with international biodiesel standards.

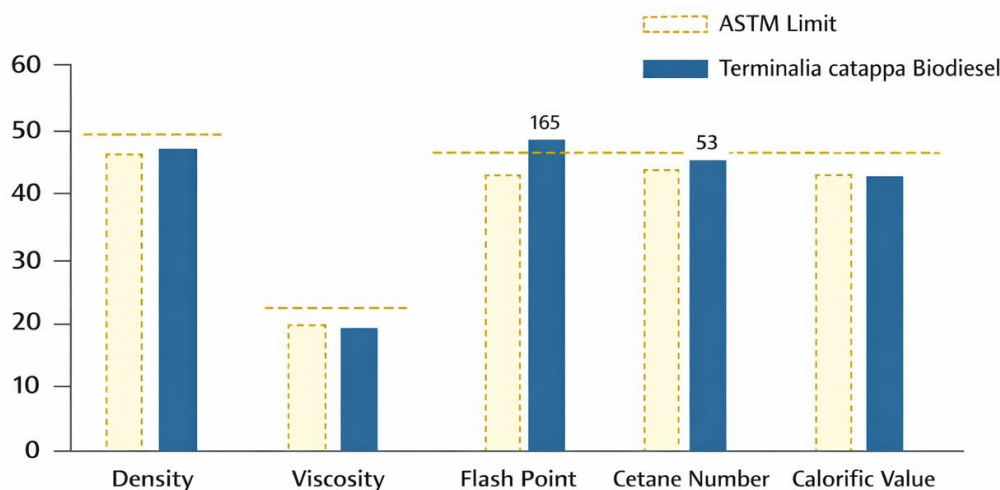


Fig 2: Comparism of fuel property with ASTM standard

From table (2), The density value of 870 kg/m³ falls within the acceptable range specified by ASTM standards. This indicates proper combustion characteristics in diesel engines. The viscosity of 4.8 mm²/s ensures efficient fuel injection and spray formation in diesel engines. Excessively high viscosity can cause engine deposits and poor atomization. The flash point of 165°C indicates excellent safety in handling and storage compared to conventional diesel fuel. The cetane number of 53 suggests good ignition quality, leading to smooth combustion and reduced engine noise. Using biodiesel derived from *Terminalia catappa* significantly reduces greenhouse gas emissions. Biodiesel combustion produces lower levels of sulfur dioxide and particulate matter, contributing to improved air quality. Furthermore, cultivating *T. catappa* trees for biodiesel production can support environmental conservation and rural economic development.

GC–MS Fatty Acid Composition

The GC-MS results indicate that unsaturated fatty acids dominate the composition of *T. catappa* biodiesel. High concentrations of oleic and linoleic acids improve biodiesel fluidity and combustion efficiency as shown in table (3)

Table 3: GC–MS Fatty Acid Composition

FATTY ACID	COMPOSITION (%)
Oleic acid (C18:1)	18.2
Linoleic acid (C18:2)	28.4
Palmitic acid (C16:0)	20.1
Stearic acid (C18:0)	12.7
Others	20.6

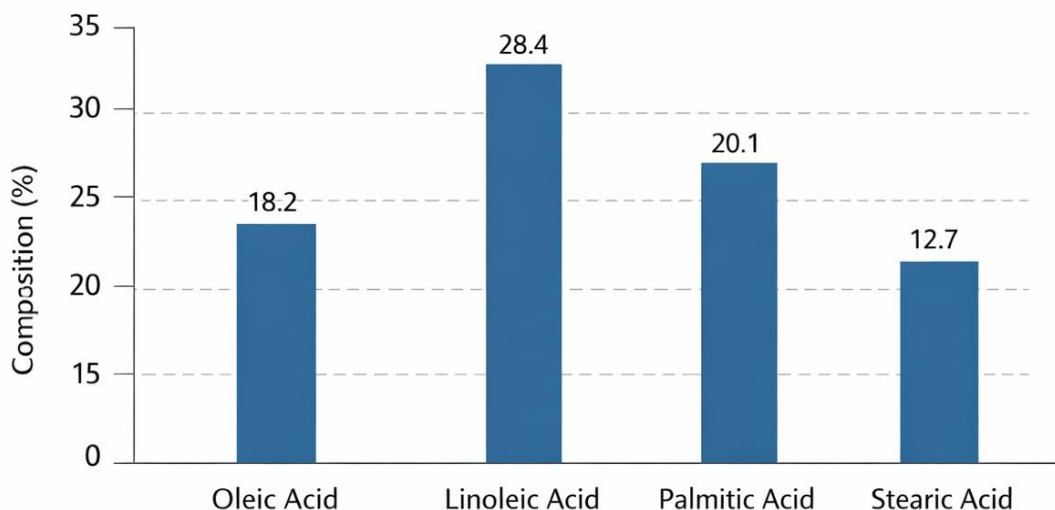


Fig 3: Fatty Acid Composition (GC-MS)

Environmental And Energy Implications

The use of biodiesel derived from *Terminalia catappa* provides several advantages:

- Reduction in fossil fuel dependence
- Lower greenhouse gas emissions

- Renewable and biodegradable fuel source
- Utilization of non-edible plant resources
- Promotion of sustainable agriculture

For countries like Nigeria with abundant tropical vegetation, large-scale production of *T. catappa* biodiesel could significantly contribute to national renewable energy strategies.

The use of biodiesel derived from *Terminalia catappa* offers several environmental benefits including reduced greenhouse gas emissions, lower sulfur content, and improved biodegradability compared with conventional diesel fuel (Ahmad et al., 2022). Additionally, cultivating *T. catappa* for biodiesel production can contribute to rural economic development and renewable energy sustainability (Panwar et al., 2022).

CONCLUSION

This study evaluated the fuel properties and chemical composition of biodiesel derived from *Terminalia catappa* seed oil. The results show that the biodiesel meets major international fuel standards and demonstrates suitable combustion characteristics for diesel engines; the findings confirm that *T. catappa* oil is a viable feedstock for biodiesel production. GC-MS analysis confirmed the presence of fatty acids suitable for biodiesel production. Therefore, *Terminalia catappa* seed oil represents a promising renewable feedstock for biodiesel production and could contribute significantly to sustainable energy and environmental preservation. The development of biodiesel from locally available plant resources such as *Terminalia catappa* offers a promising pathway toward renewable energy development and environmental preservation. Future research should focus on engine performance trials and test, emission analysis, and large-scale production feasibility.

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