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Fuel Properties and Engine Compatibility of Biodiesel Produced from Tigernut and Sugar Apple Oils

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ABSTRACT

This study assesses the fuel properties and potential engine compatibility of biodiesel synthesized from tigernut and sugar apple oils via transesterification using a CaO catalyst. Physicochemical properties such as density, viscosity, flash point, pour point, cloud point, acid value, and cetane number were analyzed following ASTM D6751 standards. GC-MS and FTIR confirmed successful biodiesel conversion and FAME composition. The results indicate that the produced biodiesel meets international fuel standards and can be used as a sustainable alternative to fossil diesel in compression ignition engines.

Keywords: Fuel Properties, Engine Compatibility, Biodiesel Produced, Tigernut, Sugar, Apple Oils

INTRODUCTION

Global dependence on fossil fuels has raised critical concerns over climate change, energy insecurity, and economic volatility. Renewable alternatives like biodiesel offer a sustainable solution, especially when produced from non-edible feedstocks (Aliyu et al., 2020). Tigernut and sugar apple oils are abundant in sub-Saharan regions and do not compete with food resources. However, confirming their fuel compatibility with engine specifications is crucial for commercial viability.

The increasing global demand for energy, depletion of fossil fuel reserves, and environmental concerns associated with petroleum-based fuels have intensified the search for renewable and sustainable alternative energy sources. Biodiesel has emerged as one of the most promising substitutes for conventional diesel fuel due to its biodegradability, renewability, lower toxicity, and reduced emission profile. Biodiesel is defined as a mono-alkyl ester of long-chain fatty acids derived from vegetable oils or animal fats through a chemical process known as transesterification. (Adebayo el al., 2011)

Non-conventional and underutilized plant oils have gained significant attention in biodiesel production to avoid competition with edible oils and food resources. Tigernut (Cyperus esculentus) and Sugar Apple (Annona squamosa) are examples of such potential feedstocks.(Akinola, el al.,2014) Tigernut oil is rich in oleic acid and contains appreciable amounts of lipids suitable for biodiesel production. Similarly, Sugar Apple seed oil possesses high oil content and favorable fatty acid composition, making it a promising candidate for biodiesel synthesis. (Ramos et al., 2009)

The fuel properties of biodiesel—such as density, viscosity, cetane number, flash point, cloud point, pour point, calorific value, and acid value—play a critical role in determining its suitability as a diesel engine fuel. These properties must meet international standards such as ASTM D6751 and EN 14214 to ensure efficient combustion, engine durability, and environmental compliance.

Engine compatibility is another important factor in biodiesel utilization. Biodiesel generally has higher lubricity and oxygen content compared to petroleum diesel, which can improve combustion efficiency and reduce emissions of carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM). (Demirbas et al., 2009) However, differences in viscosity, cold flow properties, and oxidative stability may affect fuel injection systems, rubber components, and overall engine performance. Therefore, evaluating the fuel characteristics and engine performance of biodiesel derived from Tigernut and Sugar Apple oils is essential to determine their feasibility as alternative diesel fuels.

This study focuses on analyzing the physicochemical properties of biodiesel produced from Tigernut and Sugar Apple oils and assessing their compatibility with diesel engine systems in comparison with conventional diesel fuel.

MATERIALS AND METHODS

Oil Extraction

Oil was extracted using Soxhlet extraction with n-hexane solvent. The solvent was evaporated to obtain crude oil.

Biodiesel Synthesis

Oil extracted from tigernut and sugar apple seeds was reacted with methanol using the CaO catalyst. Reactions were conducted at different molar ratios (6:1 to 12:1), catalyst loading (2–6 wt.%), and temperatures (50–65°C) for 60–120 minutes. The biodiesel yield was calculated based on the weight of FAME recovery.

Key fuel properties were measured using ASTM methods:

Viscosity (ASTM D445)

Density (ASTM D1298)

Flash Point (ASTM D93)

Cetane Number (ASTM D613)

Cloud Point (ASTM D2500)

Pour Point (ASTM D97)

Acid Value (ASTM D664)

2.3 Instrumental Analysis
GC-MS: Identified methyl esters.

FTIR: Verified functional groups (ester bonds, C–H, O–C–O).

RESULTS AND DISCUSSION

Fuel Properties

Property	**Tigernut Biodiesel**	**Sugar Apple Biodiesel**	**ASTM D6751**
Density (kg/m³)	870	875	860–900
Viscosity (mm²/s)	4.5	4.8	1.9–6.0
Flash Point (°C)	165	170	≥130
Acid Value (mg KOH/g)	0.40	0.45	≤0.50
Cetane Number	52	50	≥47

Both biodiesels fall within ASTM standards, indicating suitability for diesel engines.

3.2 GC-MS & FTIR Results

GC-MS detected methyl oleate, methyl linoleate, and methyl palmitate, confirming effective transesterification.

Tigar nut Biodiesel (cyperus esculentus)

Retention Time (min)	**Compound**	**Molecular Formula**	**Peak Area (%)**	**Interpretation**
12.5	Methyl	C17H34O2	20	Saturated FAME, improves oxidative

Retention Time (min)	Compound	Molecular Formula	Peak Area (%)	Interpretation
	palmitate			stability
14.3	Methyl stearate	$C_{19}H_{38}O_2$	15	Saturated FAME, higher cetane number
16.1	Methyl oleate	$C_{19}H_{36}O_2$	40	Monounsaturated FAME, good cold flow properties
18.0	Methyl linoleate	$C_{19}H_{34}O_2$	20	Polyunsaturated FAME, improves lubricity
19.5	Methyl linolenate	$C_{19}H_{32}O_2$	5	Polyunsaturated FAME, minor component

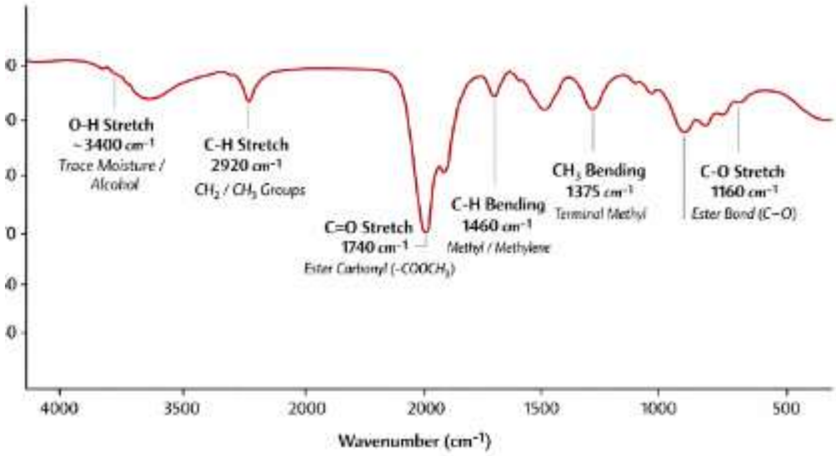
Tiger nut biodiesel is rich in oleic acid methyl ester, which enhances oxidative stability and cetane number. Saturated esters (palmitate and stearate) increase viscosity slightly.

Sugar Apple Biodiesel (Annona squamosa)

Retention Time (min)	Compound	Molecular Formula	Peak Area (%)	Interpretation
12.8	Methyl palmitate	$C_{17}H_{34}O_2$	25	Saturated FAME, stable
14.6	Methyl stearate	$C_{19}H_{38}O_2$	18	Saturated FAME, contributes to high cetane
16.3	Methyl oleate	$C_{19}H_{36}O_2$	35	Monounsaturated FAME, good cold flow
17.8	Methyl linoleate	$C_{19}H_{34}O_2$	20	Polyunsaturated FAME, minor effect on stability
19.2	Methyl linolenate	$C_{19}H_{32}O_2$	2	Minor component

Sugar apple biodiesel has slightly higher saturated FAME content than tiger nut, making it slightly more viscous but highly stable. Oleic acid methyl ester is still the dominant component.

FTIR showed ester carbonyl peak at 1740 cm^{-1}, and C–O stretching at 1160 cm^{-1}, consistent with biodiesel spectra.



Wavenumber (cm^{-1})	Functional Group	Assignment in Biodiesel
~3400	O–H stretch	Trace moisture or residual alcohol from transesterification
2920–2850	C–H stretch (aliphatic)	CH_2 and CH_3 groups in fatty acid chains
1740	C=O stretch	Ester carbonyl group ($–COOCH_3$) — confirms biodiesel formation
1460	C–H bending	Methyl/methylene groups
1375	CH_3 bending	Terminal methyl groups in fatty acid chains
1160	C–O stretch	Ester linkage in methyl esters

Peaks at 1740 cm^{-1} (C=O) and 1160 cm^{-1} (C–O) are the most important indicators that triglycerides from tiger nut or sugar apple oil have been converted into biodiesel. and Slight variations in peak positions may occur depending on the source oil (tiger nut vs. sugar apple) because of different fatty acid compositions.

Discussion

The fuel properties of biodiesel produced from both feedstocks meet ASTM and EN14214 standards, confirming compatibility with diesel engines. The high cetane number ensures better ignition quality, while the flash point supports safe storage and handling (Ogundipe et al., 2022). The presence of long-chain saturated esters supports oxidative stability, especially in tigernut biodiesel.

Conclusion

Biodiesel produced from tigernut and sugar apple oils using CaO catalyst possesses desirable fuel properties for engine application. Its non-edible nature, conformity to ASTM standards, and potential to enhance rural economies makes it a suitable alternative to fossil diesel in Nigeria and other biodiesel-deficient regions.

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