



ORIGINAL RESEARCH ARTICLE

PRODUCTION AND EVALUATION OF AFRICAN STAR APPLE (*CHRYSOPHYLLUM ALBIDUM*) SEED OIL AS A NON-EDIBLE FEEDSTOCK FOR BIODIESEL PRODUCTION

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ABSTRACT

The ever-increasing demand for sustainable and renewable energy has intensified research into non-edible oil feedstocks for the production of biofuels. This study investigates the production of biodiesel using African Star Apple (*Chrysophyllum albidum*) seed oil as feedstock. The seeds were processed to remove the seedcoat while oil was extracted from the cotyledon by superheated solvent extraction at varying seed particle sizes of <0.5, 2.0 and 4.0mm respectively. The extracted oil was subjected to physical (density, colour, odour) and chemical characterisation (free fatty acid and acid value, iodine tests). Biodiesel was produced using the two-step reaction process (acid esterification and transesterification) and was tested for its physicochemical properties (density, kinematic viscosity and cetane number) and microstructural properties following the established ASTM and EN standards. The results show that the oil yield varied significantly across particle sizes, with the highest yield obtained from <0.5mm particle size, with an overall average yield of 8.37%. It was observed that the extracted oil contained 3.948% free fatty acid (FFA) content with saponification value of 201.8 mg KOH/g. Furthermore, the biodiesel properties (Density at 0.88g/cm, Kinematic Viscosity at 4.2mm/s, and Cetane Number at 52) were found to be in compliance with the established fuel standards, thus validating the use of *C. albidum* seed oil as a potential viable biodiesel feedstock. Overall, the physicochemical profile of *C. albidum* seed oil proves its effectiveness as a viable, alternative biodiesel feedstock.

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1.0 Introduction

The need for sustainable and renewable energy sources has led to an increase in studies aimed at establishing alternative sources of fuels that reduce reliance on fossil fuels and degradation of the environment (El-Araby, 2024). Biodiesel is a suitable renewable energy source due to its degradability, low toxicity and its ability to be used in existing diesel engines (Zhang *et al.*, 2022; Suhara *et al.*, 2024). Biodiesel is gaining prominence as a renewable fuel because it markedly reduces greenhouse gas emissions and toxic air pollutants such as unburned hydrocarbons, and particulate matter relative to conventional fossil diesel and supporting the global efforts to decarbonise the energy sector and improve air quality (Zhang *et al.*, 2022). However, the mass production of biodiesel is still constrained by the high cost of feedstock and food vs fuel concerns in cases where edible oils are used as feedstock (Suhara *et al.*, 2024). Currently, biodiesel is produced from first-generation feedstocks, mainly edible vegetable oils such as soybean, palm, rapeseed, and sunflower oils, due to their availability and established processing technologies (El-Gharbawy *et al.*, 2021; Suhara *et al.*, 2024).

Conversely, non-edible oil feedstocks have been considered as a sustainable and economically viable alternative source of oil for biodiesel production (Shaah *et al.*, 2021; Sujin *et al.*, 2024). Other non-edible oils such as Jatropha, Neem, Castor and Rubber seed oils have been found to be suitable in making biodiesel when proper processing methods are used (Shaah *et al.*, 2021). Although promising, most of these feedstocks are characterised by issues such as high free fatty acid (FFA) content, fluctuating oil yields, and required

pretreatment before transesterification (El-Gharbawy *et al.*, 2021; Shaah *et al.*, 2021). Such constraints facilitate the necessity to explore other underutilised oilseed sources with promising fuel characteristics and local availability.

Chrosophyllum albidum is a native tree that is common to West Africa, especially in Nigeria. Although the fruit pulp is usually eaten, most of the seeds are abandoned as waste (Adekanmi and Olowofoyeku, 2020). Previous studies have indicated that *C. albidum* seeds do have significant amounts of oil with a fatty acid composition, rich in oleic and linoleic acids (Aladekoyi *et al.*, 2016; Abel *et al.*, 2020). However, the systematic studies evaluating the efficiency of oil extraction, biodiesel production, and meeting the international fuel standards are scarce, especially with seeds obtained from Nigeria (Onukwuli *et al.*, 2021; Dzarma *et al.*, 2022).

In oil extraction, the size of seed particles is found to have a great impact on the oil yield and the efficiency of the extraction process (Anang *et al.*, 2019; Dzarma *et al.*, 2022). Additionally, transesterification is the prevailing and standardized method for producing biodiesel due to its efficiency in converting triglycerides into fatty acid methyl esters (Pedzisai *et al.*, 2025). Physicochemical characteristics that are often used to determine the quality of biodiesel include density, kinematic viscosity, flash point, cetane number, and fatty acid content of free samples, and the benchmarks used are ASTM D6751 and EN14214 (EN, 2019; ASTM International, 2023; Boichenko *et al.*, 2025). In addition, Fourier Transform Infrared (FTIR) spectroscopy is commonly used to identify characteristic ester functional groups and verify the successful conversion of triglycerides into fatty acid methyl esters in biodiesel samples (Verma *et al.*, 2024).

This paper examines the valorisation of agricultural waste through the use of *Chrosophyllum albidum* seeds, which are readily available but currently lack commercial application. By repurposing these seeds as a non-edible biodiesel feedstock, this study addresses food-versus-fuel competition associated with first-generation feedstocks, expands the renewable energy base, and contributes to a circular economy.

2. Materials and Method

2.1 Materials and Equipment

The African star apple (*C. albidum*) seeds, used as the feedstock in this study, were collected as post harvest waste from Bodija market in local sources Ibadan, Nigeria. The seeds were visually examined to rule out those with any sign of damage or contamination before any further processing. To produce biodiesel, methanol (analytical grade) was used as an alcohol reagent and sodium hydroxide (NaOH) was used as the alkaline reagent during transesterification. Chemicals and reagents used include sulphuric acid (H₂SO₄), potassium hydroxide (KOH), sodium hydroxide (NaOH), phenolphthalein indicator, iodine reagent, hydrochloric acid (HCl), n-hexane, and methanol.

The apparatuses used in this study included a Soxhlet extractor (J-SIL Scientific Industries, India), rotary evaporator (SM-52CS-I, Surgifield Medical, England), heating mantle with magnetic stirrer (SM-E1000S, Surgifield Medical, England), analytical balance (ME204, Mettler Toledo, USA), mesh sieves (Soiltest Inc., USA), desiccator (PYREX, USA), viscometer (NDJ-I Analog, HINOTEK, USA), density metre, pH metre (HI-9829, Hanna Instruments, UK), Fourier Transform Infrared (FTIR) spectrometer (PerkinElmer Spectrum 2, PerkinElmer Inc., UK) and standard laboratory glassware (PYREX, USA).

2.2 Seed Preparation and Oil Extraction:

The *C. albidum* seeds were thoroughly washed with warm water to remove dirt and other foreign particles and sun-dried for a period of 21 days. The seeds were then decorticated to extract the cotyledons which had been then crushed and milled to different particle sizes of 0.5 mm, 2.0 mm and 4.0 mm. The particular sizes were chosen so as to create an efficient base of oil recovery and a enough yield to proceed with biodiesel production. Although the existing literature proved that the decrease in the size of the particles tends to promote the mass transfer and extraction efficiency (Shejawale *et al.*, 2022), there was a need to identify the practical limits of the operational conditions of *C. albidum* seeds. This range enabled the determination of the optimum extraction point between full penetration of the solvent and the occurrence of agglomeration which was found to restrict the flow of the solvent and limit porosity at too small particle sizes.

The seed oil extraction was performed using a Soxhlet apparatus with n-hexane as the solvent. 150 g of milled seed sample was loaded into the extraction thimble and extracted at 65°C for over 6 hours. After extraction,

the solvent was recovered by rotary evaporation, leaving behind the crude oil. This was performed as per AOAC (2023) standards. The gravimetric determination of the oil yield was made as follows:

$$Y(\%) = \frac{W_{oil}}{W_{seed}} \times 100 \quad 1$$

where W_{oil} is the mass of extracted oil (g) and W_{seed} is the mass of dry seed sample (g)

2.3 Physicochemical Characterisation of Extracted Oil

To determine the suitability of the extracted oil for producing biodiesel, the physicochemical characteristics of the extracted oil were analysed using standard ASTM and AOAC test methods. Acid value was determined using standard NaOH solution to titrate and the free fatty acid (FFA) content (as oleic acid) was determined using Equation (2). The saponification value was determined by titrating the oil sample with alcoholic KOH and then back titration with HCl whereas the iodine value was determined through iodometric titration as the degree of unsaturation was estimated. Kinematic and density viscosity were also determined at standard temperatures to determine the base oil characteristics before the transesterification process.

$$\text{FFA (\% as Oleic Acid)} = \frac{V \times N \times M}{W_{oil}} \times 100 \quad 2$$

where V is the volume of NaOH used (mL), N is the normality of NaOH (mol/L), M is the molar mass of oleic acid (282 g/mol) and W_{oil} is the mass of oil sample (g).

2.4 Acid Esterification (Pretreatment)

Due to the presence of free fatty acids, the extracted oil was subjected to acid esterification to lower the FFA content to acceptable values of < 2% (Shaah et al., 2021). 50 mL of extracted oil was preheated to about 60°C and subjected to 1 wt.% of sulphuric acid (H_2SO_4) in proportion to mass of the oil. 8.5 mL of methanol, equivalent to 6:1 methanol-to-oil molar ratio was added and the mixture stirred with constantly for 1 hour. The mixture was left to settle after the reaction, and the top aqueous layer was removed (Kasirajan, 2021). The acid value of the pretreated oil was retested to make sure that the FFA reduced to below 2% before transesterification.

2.5 Biodiesel Production by Transesterification

The production of biodiesel was done through base-catalysed transesterification as described by Kasirajan (2021). A methoxide solution was prepared by dissolving 1 wt.% NaOH in methanol in a ratio of 6:1, methanol-to-oil. The pretreated oil was heated and then reacted with the methoxide under stirring at 60°C. At the end of the reaction, the mixture was moved into a separatory funnel and left to settle at 48 hours to facilitate phase separation. The upper biodiesel layer was separated from the glycerol phase, washed with warm distilled water to remove residual catalyst and impurities, and dried to eliminate moisture.

2.6 Physicochemical Characterization of Biodiesel

The obtained biodiesel was defined in accordance with ASTM D6751 and EN 14214 standards. Densitometer was used to determine density, while kinematic viscosity was determined at 40°C by ASTM D445 and EN ISO 3104 methods. An empirical correlation between the densities and viscosities was used to estimate the cetane number (Equation 3).

$$CN = 56.7 - 0.48\rho - 0.25v \quad 3$$

where CN is the Cetane number of biodiesel, ρ is the Density of biodiesel (kg/m^3), and v is the Kinematic viscosity at 40°C (mm^2/s)

2.7 FTIR Instrumentation and Procedure

A PerkinElmer Spectrum Two FTIR Spectrometer with a Universal Attenuated Total Reflectance (UATR) Two accessory was used to perform a functional group analysis. A drop of the biodiesel was directly applied on the ATR crystal lens. A standard pressure of 85% was used to provide uniform optical contact with the integrated

pressure arm. The spectral data were taken at the mid infrared wavenumber of 4000 to 400 cm^{-1} . The spectrometer displayed the attenuated reflected infrared light on the surface of the sample, generating the transmittance spectra used for subsequent functional group identification.

3. Results and Discussion

3.1 Oil Extraction Yield

The oil yield obtained at different particle sizes is presented in Table 1.

Table 1: Oil yield at different particle sizes

Particle Size	Mass (g)	Oil (mL)	Yield (%)
Powdered (0.5 mm)	390	45.9	11.77
2.0 mm	730	68.8	9.42
4.0 mm	1464	57.4	3.92

In the extraction of oil from *C. albidum* seeds, a strong relationship was evident between the particle size and the extraction yield. The total oil recovery recorded in this study was about 7.8%, lower than the 14.92% reported by Abel *et al.*, (2020) and 11.6% recorded by Anang *et al.*, (2019). The low oil yield could be attributable to long period of storage of seeds before use. Also, sun-drying prior to decortication may have impacted the oil content in the seeds.

Particle size had significant effect on extraction efficiency. Extraction was greatest with finely milled seeds (<0.5mm) yielding 11.77%, with 9.42% and 3.92% as the respective yields of 2.0mm and 4.0mm respectively. These results imply that, coarse particles do not allow penetrating of the solvent and mass transfer during Soxhlet extraction. These outcomes align with a previous study (Dzarma *et al.*, 2022), which suggest that a smaller size of particles positively influences oil yield by increasing the surface area as well as solvent accessibility.

Despite this enhancement, the quantitatively low oil production indicates that *C. albidum* seeds may be more applicable to small-to-median scale biodiesel production or for integrated waste-to-energy systems rather than large-scale oil extraction.

3.2 Physical and Chemical Properties of Extracted Oil

3.2.1 Physical Properties

The physical properties of the extracted *C. albidum* seed oil are presented in Table 2.

Table 2: Physical properties of extracted *C. albidum* seed oil

Property	Measured Value	Literature*
Density (kg/m^3)	910	850–940
Specific Gravity	0.91	0.85–0.94
Colour	Amber	Yellow to deep red
Odour	Pleasant to sweet	Pleasant
Physical State (28 °C)	Liquid	Liquid

*Anang *et al.*, 2019; Abel *et al.*, 2020; Izuakor *et al.*, 2024

The oil obtained had a density of 910 kg/m^3 and a specific gravity of 0.91, which falls within the same range of values as previous literature on *C. albidum* seed oil. Anang *et al.*, (2019) reported specific gravity of 0.92, Abel *et al.*, (2020) reported a value 0.896, and Mohammed *et al.*, (2023) reported a value of 0.94. The oil was amber in colour, had a mild sweet smell and was liquid at ambient temperature (around 28°C), implying a favourable flow behaviour, with the process devoid of intense thermal or oxidative degradation during extraction. These physical properties favour the oil use in biodiesel production.

3.2.2 Chemical Properties

The chemical properties of the extracted *C. albidum* seed oil are presented in Table 3.

Table 3: Chemical properties of extracted *C. albidum* seed oil

Property	Measured Value	Literature*
Free Fatty Acid (%)	3.948	2.6–3.2
Acid Value (mg KOH/g)	7.896	5.2–7.7
Saponification Value (mg KOH/g)	201.8	178–202
Iodine Value (mg I ₂ /100 g)	41	34–70

* Anang *et al.*, 2019; Mohammed *et al.*, 2023; Izuakor *et al.*, 2024

Chemical properties of the oil are very important measures of its potentials for biodiesel. An acid value of 7.896 mg KOH/g was calculated which translates to 3.948% free fatty acids (FFA) content, which is higher than the recommended 2% for direct base-catalysed transesterification. Related studies indicate lower acid values (Abel *et al.*, 2020; Igbafe *et al.*, 2020), and the high FFA in this case could be explained by differences in the seed maturity, handling after harvest, storage, and/or procedures to extract the seed oil. Further studies by Aladekoyi *et al.*, (2016) and Kasirajan (2021) on the free fatty composition of *C. albidum* seed oil indicated the presence of acids such as palmitic acid, oleic acid and linoleic acid which further confirm its suitability as a biodiesel feedstock.

The saponification value (201.8 mg KOH/g) is in the normal range for vegetable oils (178 - 202 mg KOH/g) (Mohammed *et al.*, 2023; Izuakor *et al.*, 2024) and therefore indicates a predominance of medium-chain fatty acids, which are preferred for efficiency of biodiesel combustion and viscosity (Izuakor *et al.*, 2024; Nithyananda *et al.*, 2024). The iodine value (41 mg I₂/100 g) reflects moderate unsaturation and suggests a balance between oxidative stability and cold flow performance. Taken together, these characteristics suggest that *C. albidum* seed oil is a good feedstock of biodiesel, though, proper pretreatment is needed.

3.3 Effect of Acid Esterification Pretreatment

Due to the presence of FFAs, acid esterification was done before transesterification. The pretreatment lowered the FFA percentage of 3.948% to about 1.213%, which is less than the critical threshold of 2% for soap formation during base-catalysed transesterification (Suzihaque *et al.*, 2022). This decrease is comparable with the values obtained in similar experiments and proves the usefulness of acid esterification to precondition high-FFA oils (Kasirajan, 2021). The positive outcome of the FFA reduction indicates that *C. albidum* seed oil, although being rather acidic, can be prepared to yield biodiesel using a two-step reaction process.

3.4 Biodiesel Yield

After transesterification, separation, washing and drying of the pretreated oil, about 15ml of biodiesel was obtained out of 25ml of pretreated oil, resulting in about 60% conversion rate. This yield is comparable but lower than values (68-90%) reported by Kasirajan, (2021) and Onukwuli *et al.*, (2021) under optimised conditions. This may be due to variations in some reaction parameters such as non-optimisation, purification losses, and residual FFA, which led to the formation of minor soaps. The above reasons are well discussed in the literature on biodiesel and can be overcome by further optimisation of the oil-methanol ratio, concentration of catalysts, and reaction conditions (Attahiran *et al.*, 2024; Suhara *et al.*, 2024). However, the yield is within the range of laboratory-scale production.

3.5 Physicochemical Characteristics of Biodiesel Produced

The physical properties of the produced biodiesel are presented in Table 4. The resulting biodiesel had a density of 0.88 gcm⁻³ at 15°C (Table 4), which falls within the acceptable ranges of the ASTM D6751 and EN 14214 standards. The kinematic viscosity at 40°C was measured as 4.2 mm²/s, which is within both ASTM (1.9-6.0 mm²/s) and EN (3.5-5.0 mm²/s) specifications. These values show that there is good atomisation of the fuel, sufficient lubrication and they are compatible with compression-ignition engines (Nithyananda *et al.*, 2024). Comparable viscosities have been reported for biodiesel derived from *C. albidum* and similar non-edible oils (Awogbemi *et al.*, 2021; Kasirajan, 2021).

The cetane number was determined empirically to be approximately 52, which exceeds the minimum requirements of ASTM D6751 (47) and EN 14214 (51). This implies a good ignition quality, low ignition delay and very smooth combustion behaviour (Nithyananda *et al.*, 2024). The same cetane values have been mentioned with respect to biodiesel obtained using *C. albidum* and other non-edible seed oils (Awogbemi *et al.*, 2021; Kasirajan, 2021).

Table 4: Physical properties of produced biodiesel

Property	Measured Value	Literature*	ASTM D6751 Standard	EN 14214 Standard
Density (g/cm ³)	0.88	0.89	0.86–0.90	0.86–0.90
Kinematic Viscosity (mm ² /s)	4.2	2.97	1.9–6.0	3.5–5.0
Cetane Number	52	40.1	≥47	≥51

*Olafimihan *et al.*, 2019; Awogbemi *et al.*, 2021; Kasirajan, 2021

When the measured biodiesel properties are compared with the ASTM D6751 and EN14214 standards as in Table 4, it is observed that all the assessed parameters are within the limits of the standards. This proves that the two-step reaction procedure that was utilised; acid esterification followed by base-catalysed transesterification, was effective in obtaining a good-quality biodiesel from *C. albidum* seed oil.

3.6 Fourier Transform Infrared (FTIR) Spectroscopy

FTIR spectroscopy was used to verify the successful conversion of triglycerides to fatty acid methyl esters. The spectrum (Figure 1) had typical absorption bands, such as ester carbonyl (C=O) at 1743 cm⁻¹, aliphatic C-H stretching vibrations at 2923 and 2853 cm⁻¹, and C-O stretching bands between 1164 and 1237 cm⁻¹. These functional groups are in line with the typical biodiesel spectra in literature and proves successful transesterification (Verma *et al.*, 2024).

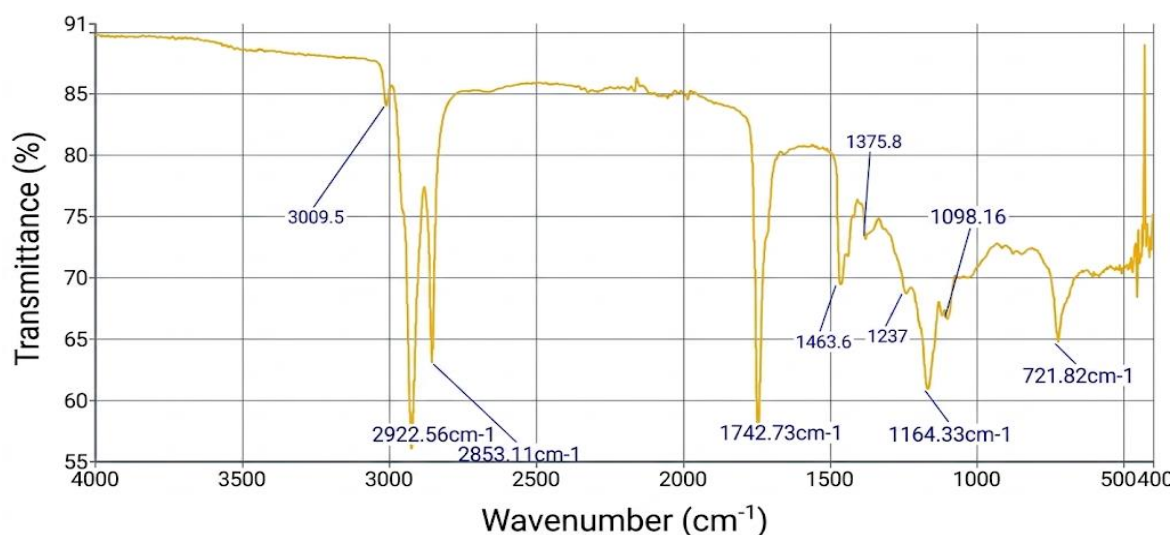


Figure 1: FTIR Spectrum of *C. albidum* Biodiesel

A strong absorption band observed around 2922.56 cm⁻¹ corresponds to aliphatic hydrocarbon C-H stretching vibrations which indicate the presence of long-chain fatty acid methyl esters in the biodiesel. Also, the peak at 2853.11 cm⁻¹ shows symmetric C-H stretching and thus confirms the presence of methyl and methylene groups typical of fatty acid methyl esters. The absorption band at 1742.73 cm⁻¹ is attributed to ester carbonyl C=O stretching, thus indicating ester formation during transesterification. The weak peak at 3009.5 cm⁻¹ is indicative of the presence of long-chain fatty acid methyl esters and is attributed to aliphatic hydrocarbon (C-H) stretching vibrations. The peak at 1463.6 cm⁻¹ attributes to C-H bending (scissoring) vibrations of CH₂ groups, which reflects the hydrocarbon chain structure of the biodiesel. The peak at 1375.8 cm⁻¹ corresponds to symmetric C-H bending vibrations and methyl group deformation, confirming the presence of methyl ester groups which is a characteristic of fatty acid structure. The peaks at 1164.33 cm⁻¹ and 1237 cm⁻¹ attribute to ester C-O stretching vibrations which is evidence of ester linkage in the biodiesel. The peak at 1098.16 cm⁻¹ corresponds to methoxy group C-O stretching which confirms the conversion of triglycerides to methyl esters. The absorption band observed around 721.82 cm⁻¹ corresponds to (CH₂)_n rocking vibrations from long-chain aliphatic hydrocarbons characteristic of biodiesel.

4. Conclusion

The current study indicates that the synthesis of biodiesel using *C. albidum* seed oil as a non-edible feedstock is possible. Although, the seeds produced low yield of oil, it was effectively converted to biodiesel through a sequential acid-catalysed esterification and a subsequent base-catalysed transesterification. It was found that

the extraction efficiency was also significantly influenced by the particle size; smaller milling resulted in a higher yield, hence highlighting the importance of pre-processing. Physicochemical results showed that the obtained biodiesel was within the requirements of the ASTM D6751 and EN 14214 standards, whereas FTIR spectroscopy indicated the existence of fatty acid methyl esters, which supports the success of conversion.

In addition to the technical attributes, the use of *C. albidum* seed oil can provide a sustainable approach to biodiesel production through alleviating food-fuel competition and allowing the marginalisation of previously neglected agricultural wastes. These findings highlight the possibility of this endemic resource to improve the diversification of renewable energy, particularly where the species is abundant. Overall, *C. albidum* seed oil has positive qualities as a biodiesel feedstock and provides a strong scientific base to carry out additional optimisation and scale up studies.

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