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Evaluation of Nigerian *Gmelina arborea* Seed Oil as a Sustainable Industrial Bio-resource

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Abstract

A comprehensive characterization of *Gmelina arborea* seed oil was conducted to appraise its prospects as a sustainable industrial bioresource. The oil was extracted via Soxhlet method using n-hexane. Extraction at 60 °C for 50 minutes yielded 35.85% crude *Gmelina arborea* seed oil (GASO), light brown in color, with a specific gravity of 0.942. The characterization presented the oil with a kinematic viscosity of 75.813 $mm^2 s^{-1}$ at 40 °C, a refractive index of 1.4648 at 33 °C, and an acid value of 18.700 mg KOH/kg, corresponding to a free fatty acid value of 9.35 mgKOH/kg. The iodine value was 53.29 meq/100 g, the saponification value was 179.614 mgKOH/kg, and the molecular weight was 1045.90 g/mol. Proximate analysis of the oil revealed ash content of 0.018% and moisture content of 0.287%, indicating high storage stability. These properties are closely aligned with those specified in ASTM D6751, suggesting that *Gmelina arborea* seed oil could serve as a non-edible substitute for conventional vegetable oils. Gas Chromatography-Mass Spectrometry (GC-MS) analysis identified a robust fatty acid profile dominated by oleic acid (50.17%), n-hexadecanoic acid (19.20%), and octadecanoic acid (17.26%). The presence of high-value components such as squalene (1.18%) and beta-sitosterol (0.39%), which provide a balance between oxidative stability and low-temperature fluidity, further highlights the oil's multi-industrial potential. Fourier Transform Infrared (FTIR) spectroscopy confirmed the structural purity of the triacylglycerols, with a characteristic ester carbonyl (C=O) peak at 1742.5 cm^{-1} and a notable absence of oxidative degradation. FTIR also confirmed the presence of characteristic triglyceride ester linkages at 1745 $cm^{-1.}$ These results provide a fundamental baseline for developing *Gmelina arborea* seed oil based industrial feedstock, demonstrating that *Gmelina arborea* seeds which is presently regarded as residues can be transitioned from forest waste to a high-value and sustainable industrial bioresource

Keywords: *Gmelina arborea*, GC-MS, FTIR, Soxhlet Extraction, Bio- resource.

Introduction

Rapid growth of the global population, with its consequent increasing demand for energy and industrial materials, is driving an unprecedented depletion of fossil resource deposits. This has made it imperative to pursue global alternatives, with a preference for renewable energy and sustainable industrial feedstocks (Ezidinma, et al., 2025; Walgama, et al., 2026). This global shift from fossil fuels to renewable biological alternatives has made vegetable oils essential to the developing bio-economy. As industries seek to grow sustainably without negatively impacting the environment, demand for sustainable feedstocks such as biodiesel, biolubricants, and oleochemicals has increased (Narayana, and Vinu., 2022; Akanksha, et al., 2025). However, "food versus fuel" concerns remain a significant challenge, since using edible oils such as palm, soybean, and sunflower for industrial uses can threaten food security and raise commodity prices. As a result, research has turned toward non-edible oils from forest residues such as *Canarium schweinfurti* kernels, *Gmelina arborea* seeds and other underutilized plant species that do not compete with food supplies.

Gmelina arborea, also referred to as *Gmelina* or Beechwood, a fast-growing tree in the family *Lamiaceae* is widely distributed across Nigeria's forests, and known for its adaptability and rapid biomass production. Besides its predominance in wild forests, it is extensively cultivated in plantations for pulp, paper, and timber production (Akeem et al., 2016; Mohammed et al., 2024). In addition to its wood, *Gmelina arborea* bears numerous smooth, yellow drupes containing seeds that are largely underutilized. These seeds serve as a strong biological precursor (Ibrahim, and Ali., 2023; Obinna, and Dim., 2026). While the tree's leaves and bark are used in traditional medicine, and its wood vinegar is also studied for bio-based chemicals (Bhattacharyya et al., 2025; Wadasinghe et al., 2022), the oil-rich seeds are shed annually in large quantities and often neglected and abandoned on the forest floor as unmanaged waste.

The attraction for *Gmelina arborea* seed oil (GASO) as an industrial bio-resource is well supported by both economic, sustainability and environmental reasons. From a sustainability perspective, utilizing these seeds leverages a non-edible forest residue, avoiding competition with food-producing agricultural land. Since *Gmelina arborea* already exists in large plantations across Nigeria for pulpwood, the infrastructure to access these trees is already in place, thus making seed collection a cost-effective method for local forest communities. Chemically, the seeds are rich in complex oils and bioactive compounds, including phytosterols and squalene, which are highly stable even at elevated temperatures (Zhao, et al., 2025; Ibrahim and Ali, 2023). Therefore, converting this abundant forest waste into a usable liquid feedstock provides an excellent opportunity for local waste valorization while supplying a renewable oil for further industrial applications.

Gmelina arborea seed oil (GSO) was extracted using the Soxhlet extraction method, a leading technique for oil recovery that maximizes oil yield through continuous high-temperature solvent recycling. Previous studies frequently employed this method to evaluate the oil potential of various seeds. For example, Uzoh et al, (2014) studied the kinetics and optimization of Soxhlet extraction of *Gmelina arborea* seed oil and recorded a 49.50% oil yield at an extraction temperature of 60 °C, an extraction time of 60 min, a seed particle size of 150 µm, and a solvent volume of 150 mL. They observed that oil yield increased with higher temperature, longer time, and greater solvent volume, but decreased with larger seed particle size. Ogbeide et al. (2018) also optimized the Soxhlet extraction of *Gmelina* seed oil using response surface methodology with a Box-Behnken design and achieved a 52.09% oil yield at the optimum process conditions of a seed particle size of 150 µm, a solvent volume of 150 mL, and an extraction time of 60 mins. They concluded that, based on oil content, *Gmelina arborea* seed oil would be highly suitable for industrial applications. Similarly, Ofori et al. (2023) utilized Soxhlet extraction alongside mechanical pressing to examine *Adansonia digitata* seeds, noting that while mechanical methods preserve some heat-sensitive compounds, Soxhlet extraction provides higher and more complete oil recovery, suitable for industrial applications.

While extensive studies on the extraction of *Gmelina arborea* seed oil have been conducted and documented, and the transesterification profiles have also been well studied and documented to evaluate its potential as a fuel (Ameh et al., 2025; Umeuzuegbu et al., 2020; Mohammed et al., 2024), detailed analyses of its structure and properties remain scarce. For example, the literature lacks an established link between the oil's molecular composition, such as Gas Chromatography-Mass Spectrometry (GC-MS) peak profiles and Fourier-Transform Infrared (FT-IR) functional group fingerprints, and its physicochemical properties relating to thermal stability and kinematic transport, which are crucial for defining the oil's suitability for specialized applications beyond fuels, such as biolubricants and cosmetic ingredients. This study directly addresses this gap by conducting Soxhlet extraction of Nigerian *Gmelina arborea* seed oil and performing comprehensive physicochemical and multi-instrumental analyses, thereby providing information that contributes significantly to the transformation of *Gmelina arborea* seeds, which are presently forest waste, into a high-value and sustainable industrial bioresource.

2.0 Materials and Methods

2.1. Materials

Drupes of *Gmelina arborea* were collected from the *Agu-alu and Owele-abo forests in Umueshim, Umubo,* Nachi, Udi Local Government Area, Enugu State, Nigeria. Reagents and chemicals used in the research experiments include methanol (99 % assay, Merch, Germany), n-hexane (99% assay), phenolphthalein (Merk Germany), distilled water, Sodium hydroxide (99% Sigma-Aldrich), Potassium hydroxide (85% assay, Loba Chem, gmbH), Potassium bromide (99% Sigma-Aldrich) , Acetone (85% assay, Loba Chem, gmbH), Methylene chloride (99% Sigma-Aldrich) Phosphuric acid (85% assay, Vetec), Sulphuric acid (98% assay., Sg 18300 BDH), Hydrochloric acid (98% assay., Sg 18300 BDH), and Ammonia (99% assay). The chemicals and reagents were of analytical grade and sourced from Conraws scientific equipment and chemicals Limited Enugu, Enugu State, Nigeria. They were used as received without further treatment.

2.2 Methods

2.2.1 Sample Pre-treatment

The *Gmelina arborea* drupes were cut open, and the nuts were collected and washed several times with clean water, to remove remnants of the pulp. They were subsequently dried in the sun for six (6) hours per day for five (5) days. The nuts were cacked and the seeds manually separated from the shell washed several times with clean water, and then rinsed repeatedly with distilled water to remove contaminants before they were dried in the sun for another six hours each day for 5 days, then dried in an oven at 110 °C for six hours to ensure a moisture content below 5%. The dried seeds were decorticated, and dried again in an oven for another 6 hours at 105 °C, milled and sieved to obtain samples with particle size of 150 µm, and kept in an air tight container to await extraction.

2.2.2 Oil Extraction

Oil was extracted from the decorticated seeds by direct leaching with n-hexane as the solvent, following AOAC 2003.06 (2006) and the Randall/Soxtec extraction procedure according to Anderson (2019). An isomantle heating mantle on an adjustable platform facilitated easy removal and adjustments, with a three-neck round-bottom flask placed on it. A vertical reflux condenser with water hoses on each arm was fitted securely onto the flask, with the lower arm connected to the water faucet and the upper arm draining into the sink. The flask vent was sealed to prevent vapor loss, and a thermometer was inserted through a rubber bung fitted tightly into one of the inlets to monitor temperature. Another rubber bung sealed the inlet for adding the solvent and samples. The setup was stabilized with a retort stand, with clamps at the flask's main neck and the condenser. For each sample, 1.5 mL of n-hexane per gram of sample was measured using a measuring cylinder and funnel, then added to the flask. Water was filled into the reflux condenser, which drained into the sink as the heating mantle was turned on. The temperature was maintained at 60 °C and monitored with the thermometer. Once the temperature was stabilized, 2 g of the sample was added to the solvent to initiate oil extraction by leaching. The addition time marked the start, and extraction continued for 50 minutes at 60 °C. Afterward, the heating mantle was turned off, and the apparatus was carefully disassembled. The mixture was filtered under vacuum through a Millipore glass base and funnel, and the resulting solution was poured into a pre-weighed flask. The oil was separated from n-hexane using a rotary vacuum evaporator (Labora 4000), collected in a receiving flask, and weighed and recorded. The oil yield was calculated as per Equation (1).

$$Y = \frac{Wo}{w} \times 100 \qquad (1$$

where Y = the oil yield (%), Wo = the weight of pure oil extracted (g), and W = the weight of the sample of milled *Gmelina* seed used in the experiment.

2.2.3 Oil Characterization

I. Physicochemical characterization

The physicochemical properties of the extracted *Gmelina arborea* seed oil were analyzed using standard test methods presented in Table 1.

Table 1: Standard Test Methods for Physicochemical Characterization of the Extracted Oil.

Oil property	Test methods	Oil property	Test methods
Moisture contents	AOCS CA 2C-25 (2017b)	Saponification value	AOAC 920. 160 (2000a)
Specific gravity (s.g)	AOAC 920.212 (2000c)	Peroxide value	AOCS Cd 8-53 (1996)
Refractive index	ASTM D7483-21 (2021a)	Acid value	AOAC 920-159 (2000b)

Dynamic and kinematic viscosity	AOCS CC7-25 (2009b)	Iodine number or value	AOCS CD 3D-63 (2009a)
Melting point	ASTM DS5440 (2017a)	Free fatty acid (FFA) value	AOCS Ca Sa-40 (1989)
Pour point	ASTM D97 (2019c)	Calorific value	ASTM D240-19 (2019a)

II. Proximate analysis of *Gmelina arborea* seed oil

The ultimate composition of the extracted *Gmelina arborea* seed oil, including carbon, hydrogen, nitrogen, sulfur, and oxygen, and the proximate analysis, including moisture content, volatile matter, fixed carbon, and ash contents (wt%), were determined using modified ASTM standard procedures as shown in Table 2.

Table 2: Standard Test Methods for Ultimate and Proximate Characterization of GS

Ultimate		**Proximate**	
Property	Standard testing method (ASTM/ISO)	Property	Standard testing method (ASTM/ISO)
Carbon (wt. %)	ASTM D5291 / ISO 12902	Volatile matter (wt. %)	ISO 662:2016
Hydrogen (wt. %)	ASTM D5291 / ISO 12902	Ash (wt. %)	ASTM D482
Nitrogen (wt. %)	ASTM D4629 / ASTM D5291	moisture (wt. %)	ISO 662:2016
Sulphur (wt. %)	ASTM D4294 / ASTM D5453	fixed carbon (wt. %)	ASTM D5142
Oxygen (wt. %)	O % = 100 - (C % + H % + N % + S % + Ash %)		

III. GC-MS analysis

The fatty acid profile of *Gmelina arborea* oil samples was determined using GC-MS analysis according to AOAC 969.33 and .22 (2000d). The analysis was conducted on a Thermo Finnigan Trace GC/Trace DSQ IA1300 (E. 1 Quadrupole) equipped with an SGE-BPX5 MS fused silica capillary column (0.25 µm) for GC-MS detection, utilizing an electron ionization system with an ionization energy of 70 eV. Helium at a flow rate of 10 mL/min served as the carrier gas. The injector and transfer line temperatures were set at 220 °C and 290 °C, respectively, while the oven temperature was programmed to increase at 3 °C/min from 50 °C to 150 °C, then maintained isothermally for 10 min, and finally raised to 250 °C at 10 °C/min. Diluted samples (1/100, vv, in methylene chloride) of 1.00 µL were manually injected in slitless mode. Individual components were identified by comparing their relative retention times with those of authentic samples on an SGE-BPXS capillary column, matching their mass spectral peaks to those of authentic samples or to the Wiley 7N and TRLIB libraries, and referencing published data.Then, the molecular weight of the triglyceride in the oils (Mw) was determined from the fatty acid profile obtained through gas chromatography analysis using Equation 2.

$$Mw = 3 \times Mav + 38.049. \qquad (2)$$

Where, Mw = molecular weight of a triglyceride (g/mol), Mav = average molecular weight of the oil (g/mol), 3 = number of chains of each fatty acid in a triglyceride, 38.049 = molecular mass of glycerol in the triglyceride (the glycerol backbone) (g)

IV. FTIR spectroscopy

Functional group identification of *Gmelina arborea* seed oil was carried out using Fourier Transform Infrared (FTIR) spectroscopy. Spectra were recorded in the mid-infrared range (4000-650 cm^{-1}). The FT-IR spectra of the oil were obtained with a SHIMADZU FT-IR-8400 equipped with a 45° ZnSe HATR crystal, a deuterated triglycine sulfate (DTGS) detector, and potassium bromide (KBr) as the beam splitter. The instrument was operated with Omnic software (Version 6.0, Thermo Nicolet). The instrument, particularly the sample holder (die), was cleaned with acetone and dried with tissue paper to prevent contamination and ensure accurate results. In each case, oil samples were placed directly on the HATR surface at a controlled room temperature of 20 °C, covering the mid-IR region from 650 to 4000 cm^{-1}, with 40 scans averaged at a resolution of 4 cm^{-1}. The background of the spectra was corrected by removing the air reference spectrum collected from the cleaned blank HATR crystal before measurement. Each spectrum was collected three times, and the averages were taken. After each scan, the HATR crystal surface was cleaned twice with hexane, dried with soft tissue, cleaned with acetone, and dried again. Peak fitting and smoothing were performed using OPUS 2000 software on the Shimadzu 8400S over the 4000-650 cm^{-1} range.

V. Energy Dispersive X-ray Spectroscopy (EDS) analysis

Energy Dispersive X-ray Spectroscopy (EDS) Analysis of the *Gmelina arborea* seed oil was performed in accordance with ASTM E1508, using an Energy Dispersive X-ray Spectroscope (EDS) system integrated with a Scanning Electron Microscope (SEM). A microdroplet of the oil was spread to form a thin film on a conductive carbon tape. The oil was degassed under vacuum to prevent bubbling, then coated with a 20-nm-thick carbon film to provide a path for electron flow. An electron beam was let in to strike the oil, displacing inner-shell electrons and causing the emission of characteristic X-rays. The EDS detector measures the energy of these X-rays to identify the elements, while the Scanning Electron Microscope (SEM) captures the morphology.

VI. Acid esterification of *Gmelina arborea* seed oil

In the base-catalyzed transesterification of high-FFA oils (*Gmelina arborea* seed oil), the FFA content must be reduced to below 2 mg KOH/g or 0.1 wt% to prevent soap formation. This was achieved through acid-catalyzed esterification, following a modified method outlined by Ezidinma et al. (2025). The oil sample was dehydrated by heating to 105 °C for 20 minutes to remove trace moisture that could interfere with esterification. An acid-methanol mixture was prepared separately by adding a calculated amount of H_2SO_4 (98% assay), corresponding to 1 w/w% of the oil, to the measured alcohol at a 6:1 alcohol-to-oil ratio. This mixture was then added to the oil in a reactor equipped with a reflux condenser. The reaction was maintained at 65 °C for 90 minutes with constant stirring at 600 rpm. Afterward, the mixture was allowed to settle in a separating funnel for 2 hours. The top layer, containing methanol, acid, and water, was separated. The bottom layer (pre-treated oil) was withdrawn and washed with warm distilled water at 50 °C to remove residual Sulphuric acid. Washing was repeated until the wash water reached a neutral pH. The oil was dried in an oven set to 105 °C, and its weight was recorded at 10-minute intervals. The oil was considered dry when the weight remained constant. The free fatty acid (FFA) value of the oil was confirmed to be less than 2 mg KOH/g (1 wt%). The yield of low FFA oil was calculated, and the oil was characterized accordingly.

3.1 Physicochemical Properties.

The physicochemical characteristics of the extracted *Gmelina arborea* seed oil, presented in Table 3, indicate that the extraction process yielded 35.85 wt% of oil. The yield aligns with the 27%-40% range reported for *Jatropha curcas* seeds (Meher et al., 2013) and with the 35.1% w% reported by Agu et al. (2022) for *Gmelina arborea* seed oil, but it disagrees with the 49.90 w% reported by Uzoh (2014). The oil yields of *Gmelina arborea* seed is highly suitable and economical for industrial applications, since a 30 wt% oil yield is considered suitable for industrial application (Ude and Onukwuli, 2019b). The oil's light-brown color deviates slightly from the golden-yellow hues reported by Uzoh and Onukwuli (2016) and Uzoh et al. (2019) for *Gmelina arborea* seed oil. The minor color variation, suspected to be influenced by extraction process variables, suggests a need for pre-treatment to ensure the oil's purity prior to application. The moisture content of 0.287% recorded in the present study is significantly lower than the 7.5% reported by Uzoh and Onukwuli (2016) for *Gmelina arborea* seed oil and aligns with the <1.0 wt% limit specified in ASTM D6751, and is therefore suitable for direct transesterification for methyl ester production. The kinematic viscosity at 40°C, recorded in the present research, was 45.813 mm^2/s and closely aligns with 46.57 mm^2/s reported for *Gmelina arborea* seed oil by Onyinye and Tagbo (2023), but differs significantly from 29.22 mm^2/s for cottonseed oil (Ezidinma et al., 2015). It is also outside the 1.9–6.0 mm^2/s biodiesel range as stipulated by ASTM D6751 and EN 14214. This high viscosity, due to long hydrocarbon chains, is evidenced by FT-IR spectra and GC-MS analysis, which benefits applications such as biolubricant productions but necessitates transesterification, during which the glycerol backbone observed in the FT-IR ester regions (1742.5 cm^{-1}) is broken down, thereby lowering the viscosity to meet ASTM standards. Specific gravity of the *Gmelina arborea* seed oil, 0.942 obtained in this study is significantly high compared to 0.892 reported by Uzoh etal., (2014), 0.914 reported for *Gmelina arborea* seed oil by Onyinye and Tagbo (2023) and also higher than the 0.86 – 0.90 (ASTM D6751) standard for triglycerides. It is also appreciably higher than the 0.868 reported for *Gmelina arborea* seed oil, which Gea, et al. (2023) used to produce biodiesel with a specific gravity that presented with of 0.812 which is within the ASTM D6751standard. The indication is that the specific gravity of biodiesel generally comes out to be lower than the precursor triglyceride oil (Gea, et al., 2023; Nomanbhay et al., 2018). The implication is that the *Gmelina arborea* seed oil of the present study could be effectively used to produce biodiesel and biolubricants that would meet ASTM D6751 standards.

The measured Flash Point of 205 °C, which correlates with the absence of volatile contaminants indicated by GC-MS analysis, is significantly higher than the 130 °C reported by Ogbonnaya et al. (2018) for *Gmelina Arborea* seed oil and also greater than 200 °C for biolubricants, as specified in ASTM D6751. This indicates that the extracted oil is both environmentally friendly and safe for industrial handling as industrial feedstock (Sazzad et al., 2024; Rafiq et al., 2020).

The measured cloud point of 10.50 °C is significantly lower than the 14.0 °C reported by Yusuf et al. (2015) for castor seed oil and the 19 °C reported by Viswanathan (2018) for neem seed oil. This moderate cloud point is consistent with the oil's low melting point of 2.5 °C, and both reflect the C=C alkene bending at 721–723 cm^{-1} in FT-IR and with the identification of unsaturated fatty acids (such as oleic acid) in GC-MS (Omoyemi, 2025; Mekonnen, 2023). This makes *Gmelina arborea* seed oil a versatile industrial feedstock that remains fluid under various climatic conditions (Dymińska et al., 2022).

The refractive index is a property that indicates the oil's quality and purity. Analysis of the extracted crude *Gmelina arborea* seed oil reveals a refractive index of 1.4648, which aligns with the 1.44 reported by Uzoh and Onukwuli, (2016) and 1.44–1.48 (ASTM D6751) standard. The oil's quality is therefore confirmed for industrial applications.

The measured acid value of the extracted *Gmelina arborea* seed oil, 18.70 mgKOH/kg, is significantly higher than the values reported by Uzoh and Onukwuli (2016) and Umeuzuegbu et al. (2020) for *Gmelina arborea* seed oil, namely 3.92 mgKOH/kg and 3.08 mgKOH/kg, respectively. The considerably high acid value is a reflection of the sharp, intense peak at 1742.5 cm^{-1}in the FT-IR spectrum representing the C=O stretching vibration, which is further confirmed by the specific acidic components indicated in the GC-MS analysis and corresponds to the free fatty acid (FFA) value of 9.35 mgKOH/kg, which is significantly higher than the 2-4 mgKOH/g, (ASTM D6751) standard. This renders the oil unsuitable for direct alkaline transesterification because high FFA levels cause saponification, emulsion formation, reduced ester yield, and catalyst poisoning (Farouk, et al., 2024). However, this oil can still be modified for alkaline transesterification by first subjecting it to an acid-catalyzed esterification step (section 2.4.2) to reduce FFA levels to below 2.0 mg KOH/g before proceeding with alkaline transesterification.

The measured iodine value of the extracted *Gmelina arborea* seed oil, 53.29 $gI_2/100g$, is higher than the 34.9 $gI_2/100g$ reported by Uzoh and Onukwuli, (2016) for *Gmelina arborea* seed oil but significantly lower than 104 $gI_2/100g$ for neem seed oil and 98 $gI_2/100g$ for moringa seed oil reported by Garba et al. (2024). The moderate iodine value, implying moderate unsaturation and indicating viability for biodiesel and biolubricant productions, is chemically reflected in the high concentration of oleic acid (C18:1), identified in the GC-MS at RT 19.420 and confirmed by the peak at 3006.1 cm^{-1} (=C-H stretching) in the FT-IR spectroscopy. The presence of these monounsaturated fatty acids makes *Gmelina arborea* seed oil highly preferred for biodiesel production, as they improve the cold-flow properties and oxidative stability of the oil and of the industrial products synthesized from it (Kumar et al., 2024).

The saponification value, defined as the milligrams of KOH required to saponify one gram of oil, remains a crucial property of industrial oils. The saponification value of the extracted *Gmelina arborea* seed oil (179.614 mg KOH/kg) is significanty lower than the 181.31 mg KOH/kg reported for *Gmelina arborea* seed oil by Umeuzuegbu et al, (2020) and the 184.6 mg KOH/kg reported for castor seed oil by Omotehinse et al, (2019). However, when considered alongside the calculated molecular weight (1045.90 g/mol), this saponification value indicates that the extracted *Gmelina arborea* seed oil consists of long-chain fatty acids, as supported by the GC-MS profile, which identifies Oleic acid (50.17%), Palmitic acid (19.20%), and Stearic acid (17.26%) as the main components. The presence of these long hydrocarbon chains shows that nearly 90% of the crude oil is chemically suitable for high-efficiency conversion in industrial transesterification processes, such as biodiesel and biolubricant production (Farouk et al., 2024; Gul et al., 2020).

Table 3: Physicochemical Properties of Extracted *Gmelina Arborea* Seed Oil

Parametters	Value	Literature values
Yield (%)	35.85	27 – 40%[a], 35.1%[b], 49.9%[c]
Colour	Light brown	(golden-yellow)[d], (golden-yellow)[e]

Moisture (%)	0.287	7.5%[d], (<1.0 wt%)[h]
Kinematic viscosity @ 40^{0}c (mm^{2}s^{-1})	75.813	46.57 mm^2/s[f], 29.22 mm^2/s[g] (1.9–6.0 mm^2/s)[h] ,(1.9–6.0 mm^2/s)[i]
Refractive index @ 33^{0}c	1.4648	1.44[d], (1.44–1.48)[h]
Acid value (mgKOH/kg)	18.700	**3.92** mgKOH/kg[d], 3.08 KOH/kg[x]
Free fatty acid value (mgKOH/kg)	9.35	1-2%[h], (about 2-4 mgKOH/g)[h]
Iodine value (meq\100g)	53.29	34.9 gI$_2$/100g[d] ,104 gI$_2$/100g[v], 98 gI$_2$/100g[v]
Saponification (mgKOH/kg)	179.614	181.31 mg KOH/kg[x], 184.6 mg KOH/kg[y]
Specific gravity	0.942	0.914[f], (0.86 – 0.90)[h], 0.868[j], 0.892[c]
Flash point ^{0}C	205	130 °C[m], 200 °C[h]
Cloud point ^{0}C	10.50	14.0 °C[p], 19 °C[q]

Subscripts represent source for the values; [a]Meher et al., (2013), [b]Agu et al. (2022), [c]Uzoh, et al., (2014), [d]Uzoh and Onukwuli, (2016), [e]Uzoh, et al. (2019), [f]Onyinye and Tagbo (2023), [g]Ezidinma et al., (2015), [h]ASTM D6751, [i]EN 14214 [j]Gea, et al. (2023), [l]Nomanbhay et al., 2018, [m]Ogbonnaya et al. (2018), [n]Sazzad et al., (2024), [o]Rafiq et al., (2020), [p]Yusuf et al., (2015) [q]Viswanathan (2018), [r]Omoyemi, (2025), [s]Mekonnen, (2023, [t]Dymińska et al., (2022), [u]Farouk, et al., 2024, [v]Garba et al. (2024), [w]Kumar et al., (2024), [x]Umeuzuegbu et al, (2020), [z]Gul et al., (2020).

3.2 **Ultimate and Proximate Analysis of Crude *Gmelina arborea* Seed Oil**.

Ultimate composition refers to the weight percentage (wt%) of the oil, detailing the percentages of elements such as carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O), controlling heating value and emission potential of the oil, while proximate analysis provides information on the moisture content, volatile matter, fixed carbon, and ash content (wt%), describing thermal stability and behavior in industrial thermochemical processes. Both are routinely combined to evaluate oils for combustion, gasification, pyrolysis, and emissions, and to describe the thermal stability of the oil, which determines its behavior during industrial processing (Thiru et al., 2024; Qian et al., 2020).

3.2.1 Ultimate Analysis of *Gmelina arborea* Seed Oil

The ultimate and proximate analyses of the extracted *Gmelina arborea* seed oil are presented in Table 4. The analysis indicates that carbon constitutes 7.52 wt% of the biogenic elemental composition of the extracted *Gmelina arborea* seed oil. Although this value is relatively low compared to some bio-oils, such as sawdust oil from *Ficus exasperata*, which Anguruwa and Oluwadare (2019) reported with a carbon content of 77.42 wt%, the presence of biogenic elemental carbon in *Gmelina arborea* seed oil indicates the oil's potential to contribute to renewable energy generation while reducing net greenhouse gas emissions compared to fossil sources. The measured hydrogen content (52.32 wt.%), which is significantly higher than the 4.77 wt% reported by Anguruwa and Oluwadare (2019) for *Ficus exasperata* oil, is a significant indicator of the oil's potential energy density (Tang et al., 2020). Since higher hydrogen-to-carbon ratios typically correlate with better combustion characteristics and higher heating values (Bhasker and Porpatham, 2017), *Gmelina arborea* seed oil is considered a sustainable feedstock for the biofuel industry.

The presence of oxygen (40.14 wt.%), confirms the polar nature of the triglycerides within the oil (Chen, et al., 2021). Inasmuch as high-oxygen fuels have slightly lower energy density than pure hydrocarbons, they improve lubricity and can lead to more complete combustion in fuel applications (Mirea, 2025). The measured nitrogen content is insignificant (0.0018 wt.%), and the sulfur concentration is zero**.** The near-absence of nitrogen and the total absence of sulfur are major advantages for environmental sustainability. This ensures that the conversion of *Gmelina arborea* seed oil will not release significant SO_2 or NOx emissions, thus making it an eco-friendly "green" feedstock (Malik, 2019).

3.2.2 Proximate Analysis of *Gmelina arborea* Seed Oil

The results showed that Fixed Carbon is the dominant component of *Gmelina arborea* seed oil, constituting 99.625 wt.%. High fixed carbon in oils indicates a high concentration of non-volatile organic compounds (Onwudili et al., 2024). This suggests that the oil from *Gmelina arborea* seeds is highly stable and has high energy potential for conversion to biodiesel or biolubricants (Barbera et al., 2024; Bhukya & Kaki, 2024). The extremely low volatility (Volatile Matter 0.11 wt. %) suggests that the oil is stable at ambient temperatures and has a high flash point (Santos et al., 2020; Abdelkhalik et al., 2018). This is evidenced by the high flash point of 205 °C reported in the physicochemical analysis. This property is beneficial for the safe storage and transport of *Gmelina arborea* seed oil and industrial products derived from it (Ameh et al., 2025; Ezigbo, 2019). The low moisture content (0.287 wt.%) of the oil is crucial for preventing hydrolysis and oxidation during the storage of *Gmelina arborea* seed oil and its inherent industrial products (Adewale et al., 2022; Lawal et al., 2025). In biodiesel production (transesterification), low moisture content prevents catalyst poisoning and the formation of unwanted soap, thereby increasing the final yield (Chanakaewsomboon et al., 2020; Soni, 2025). The ash content (0.018 wt. %) is negligible, indicating very low levels of inorganic impurities or minerals (Kukuruzović et al., 2023; Stratulat et al., 2023). This is ideal for industrial machinery, as it minimizes the risk of engine deposits, corrosion, or catalyst poisoning during chemical processing (Dula and Kraszkiewicz, 2025; Nunes et al., 2016).

Table 4: **Ultimate and Proximate Analysis of Crude *Gmelina arborea* seed oil**

Ultimate analysis		Proximate analysis	
Property	**Value**	**Property**	**Value**
Carbon (wt. %	7.52	Volatile Matter (wt. %)	0.11
Hydrogen (wt. %)	52.32	Ash (wt. %)(wt. %)	0.018
Nitrogen (wt. %)	0.0018	Moisture (wt. %)	0.287
Oxygen(wt.%)	40.14	Fixed Carbon (wt. %)	99.625
Sulfur (wt.%)	0.00		

3.3 Fatty Acid Profile Analysis (GC-MS)

The total ion chromatogram of *Gmelina arborea* seed oil is shown in Figure 1, while the analysis is presented in Table 5. The Gas Chromatography-Mass Spectrometry (GC-MS) analysis of the raw *Gmelina arborea* (GM) seed oil provides definitive insights into its chemical composition, revealing a profile dominated by long-chain fatty acids. The chromatogram identifies Oleic acid (Peak 20, RT 19.420) as the primary constituent, accounting for a substantial 50.17% of the total relative area. This high concentration of monounsaturated fatty acids is crucial for industrial applications, as it balances fluid mobility with thermal resilience (Herrera, et al., 2024; Mehany, et al., 2025). The oil also exhibits a high degree of saturation, characterized by significant proportions of n-Hexadecanoic acid (Palmitic acid; Peak 15, RT 15.938) at 19.20% and Octadecanoic acid (Stearic acid; Peak 21, RT 19.822) at 17.26%. Collectively, these three major fatty acids account for approximately 86.63% of the total fatty acid profile, establishing *Gmelina arborea* seed oil as a highly concentrated and predictable feedstock.

Moreover, beyond the primary fatty acids, the analysis identified high-value minor components, such as Squalene (Peak 35, RT 33.744) at 1.18%. Notably, Squalene is a triterpene with significant antioxidant properties in the oil (Lozano-Grande, et al., 2018; Bose, 2022), thus, introducing a "wealth" dimension to the oil for potential cosmetic or pharmaceutical valuation (Martirosyan et al., 2022; Micera et al., 2020). In addition, the presence of plant sterols such as beta-Sitosterol (Peak 44, RT 43.452) and Stigmasterol (Peak 43, RT 42.285) was confirmed in the higher retention time range, further validating the wealth potential of this forest-derived residue (Bose, 2022; Terzieva., 2025)

Table 5: Major Chemical Constituents of *Gmelina arborea* Seed Oil

Peak #	Retention Time (min)	Area (%)	Compound Identity	NIST Qual Score	Chemical Class
20	19.420	50.17	Oleic acid	99	Monounsaturated Fatty Acid
15	15.938	19.20	n-Hexadecanoic acid (Palmitic acid)	99	Saturated Fatty Acid
21	19.822	17.26	Octadecanoic acid (Stearic acid)	99	Saturated Fatty Acid
31	30.828	2.35	9,17-Octadecadienal, (Z)-	90	Aldehyde
35	33.744	1.18	Squalene	99	Triterpene/Antioxidant
29	27.482	0.81	Bis(2-ethylhexyl) phthalate	91	Plasticizer/Ester
28	26.676	0.47	1-Heptadecene	38	Alkene
44	43.452	0.39	beta-Sitosterol	97	Phytosterol
43	42.285	0.21	Stigmasterol	91	Phytosterol

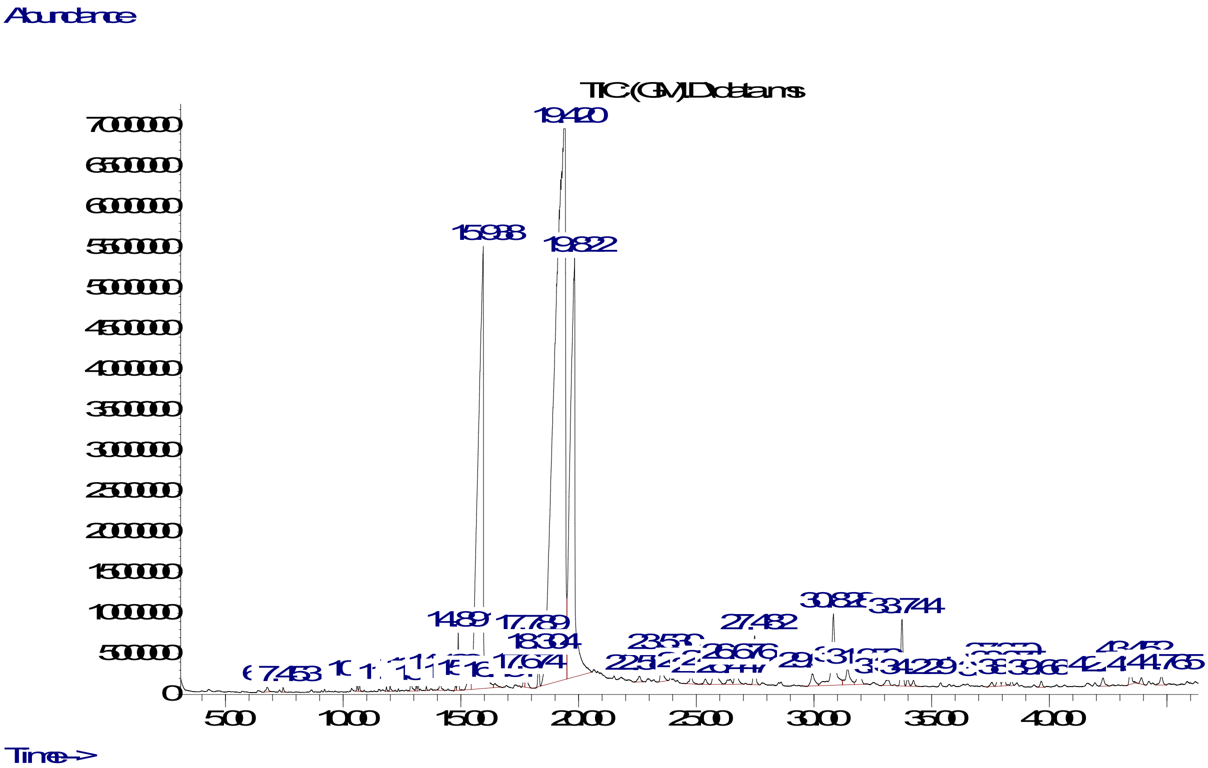

Figure 1: Total Ion Chromatogram of *Gmelina arborea* Seed Oil.

3.4. Fourier Transform Infrared (FTIR) Spectroscopic Analysis

The structural and functional group distribution of the extracted *Gmelina arborea* seed oil (GSO) was surveyed using FTIR spectroscopy in the mid-infrared region of 4000–650 cm^{-1}. The resulting spectrum (Figure 2) provides a molecular dactylogram confirming the functional group composition of the oil as shown in Table 5. The most prominent feature of the spectrum is the sharp, intense absorption band at 1742.5 cm^{-1}, which corresponds to the C=O stretching vibration of the ester carbonyl group. This peak is a definitive indicator of the oil's triglyceride nature (Mekonnen, 2023; Stanciu, 2026). The aliphatic nature of the feedstock is further supported by strong peaks at 2922.2 cm^{-1} and 2853.3 cm^{-1}, corresponding to the asymmetric and symmetric C-H stretching vibrations of methylene groups in long-chain fatty acids (Stanciu, 2026). A small but distinct peak at 3006.1 cm^{-1} was observed, corresponding to the =C-H stretching of cis-olefinic double bonds. This structural feature provides spectroscopic corroboration for the 50.17% Oleic acid (monounsaturated) identified in the GC-MS analysis (Dominguez-Candelaet al., 2023; Nikolaevich, et al., 2025). Notably, the absence of a broad absorption band in the 3200–3600 cm^{-1} region indicates low concentrations of hydroperoxides and moisture, suggesting that the Soxhlet extraction process preserved the oil's chemical integrity without significant oxidative degradation (Dąbrowski, et al., 2017; Zhu, et al., 2025).

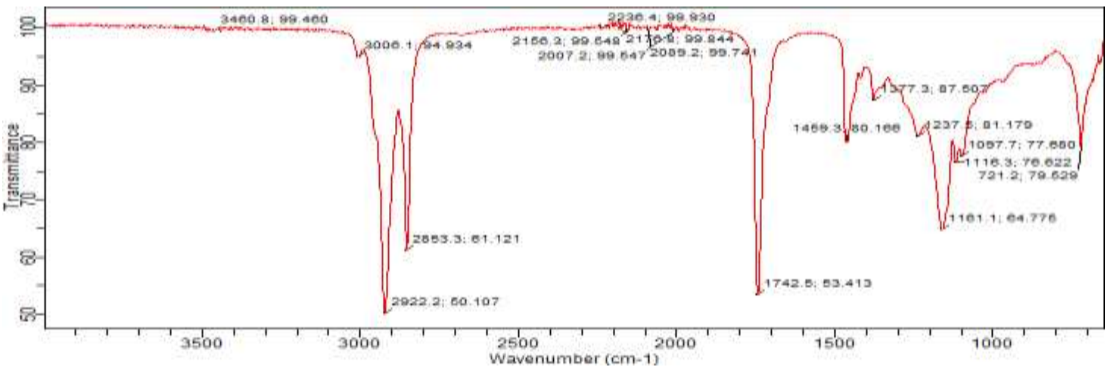

Figure 2: FTIR spectrum of the *Gmelina arborea* seed oil

Table 6: FTIR Functional Group Assignments for *Gmelina arborea* Seed Oil

Wavenumber (cm−1)	Functional group	Vibrational mode	Structural significance
3006.1	=C-H	Stretching	Unsaturation (Oleic acid)
2922.2	C-H (CH_2)	Asymmetric Stretching	Aliphatic backbone

2853.3	C-H (CH_2)	Symmetric Stretching	Aliphatic backbone
1742.5	C=O	Stretching	Ester (Triglyceride)
1459.3	C-H	Bending (Scissoring)	Methylene groups
1161.1	C-O	Stretching	Ester linkage
721.2	CH_2	Rocking	Long-chain hydrocarbon

3.4 Energy Dispersive X-ray Spectroscopy (EDS) Analysis of *Gmelina arborea* Seed Oil

The Energy-Dispersive X-ray Spectroscopy (EDS) testing of the crude *Gmelina arborea* seed oil performed in accordance with ASTM E1508 identified and quantified the elements present in the oil as Carbon (C) and Oxygen (O) and also detected trace contaminants as Silicon (Si) Iron (Fe), Chromium (Cr), Nickel (Ni) and copper (Cu) as shown in Table 7 and Figure 3, respectively. The analysis showed that *Gmelina arborea* seed oil contained significant concentrations of oxygen and carbon, reflecting the elemental composition of its triglyceride structure (Beims et al., 2018). The high oxygen content (40.14 wt.%) confirms the highly oxygenated nature of this forest-residue-derived oil. The oxygen provide inherent oxidizers which improve combustion efficiency of the oil (Zhao, et al., 2024; Vellaiyan, 2025). The analysis also revealed that *Gmelina arborea* seed oil has asignificant concentration of Chromium that can influence the catalytic properties of the oil if used in the synthesis of bio-based resins or specialty chemicals (Murthy, et al., 2023 ; Xia, et al., 2025) and combustion emission properties of the oil (Senthur, et al., 2022; Tang, et al., 2022), while ash fouling and slagging may be observed in industrial boilers due to the presence of silicon in the oil (Dai, et al., 2015; Vamvuka, et al., 2018).

Iron (27.77 wt.%) is the most prominent metal detected in the analysis. Even though iron can contribute to the thermal stability of certain industrial products (Bai, and Zheng, 2016), its high concentration in fuel feedstocks can act as a pro-oxidant, potentially accelerating the oxidative degradation of the oil during storage (David, and Kopac, 2023; Musakhanian, et al., 2022). Similarly, copper and nickel as transition metals can catalyze autoxidation reactions in triglycerides (Oh, Kim. and Lee., 2023). Their presence suggests that the *Gmelina arborea* seed oil may require the use of metal deactivators or antioxidants to maintain long-term stability in industrial applications (Afonso et al., 2023; Randhawa and Mukherjee, 2025).

Various industrial processes such as degumming, bleaching, filtration and sometimes chelating are used to remove such metals before fuel or lubricant synthesis (Shah, and Soylak., 2022). Non-edible seed oils such as neem, *jatropha curcas*, rubber seed, and Hevea have been successfully converted to biodiesel and biolubricants once their free fatty acids and impurities (including metals) are managed (Ifeanyi-Nze and Akhiehiero, 2023; Utono et al., 2024). In light of these considerations, *Gmelina arborea* seed oil can be a viable industrial feedstock, provided similar refining and upgrading are applied.

Table 7: Energy Dispersive X-ray Spectroscopic (EDS) Result of *Gmelina arborea* Seed Oil

Element	Symbol	Wt. (%)	Element	Symbol	Wt. (%)
Oxygen	O	44.14	**Cromium**	Cr	10.34
Carbon	C	7.52	**Nickel**	Ni	2.12
Silicon	Si	4.46	**Cupper**	Cu	3.20
Iron	Fe	27.77			

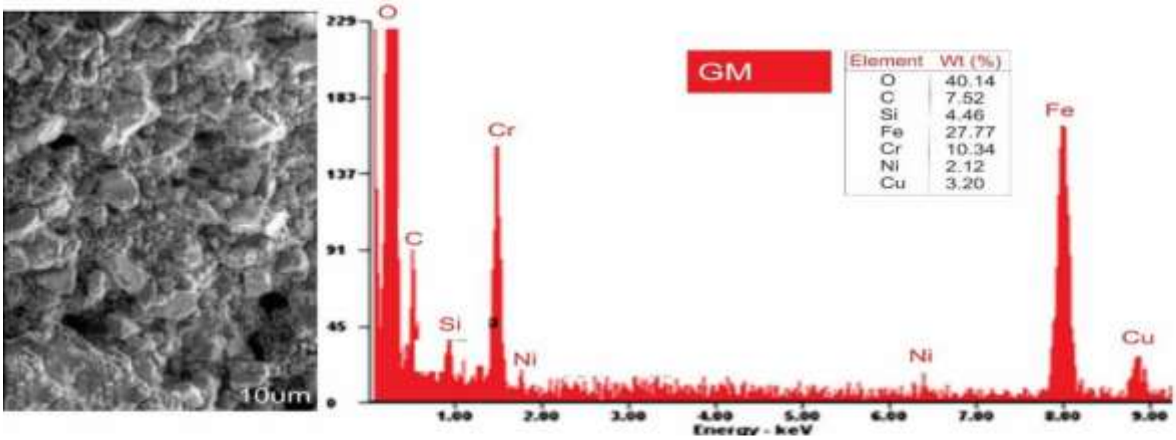

Figure 3: Energy Dispersive X-ray Spectroscopy (EDS) of *Gmelina arborea* seed oil: Analysis of Elemental Composition

4. Conclusion

This research conducted a comprehensive characterization of oil extracted from seeds to confirm its high potential as an industrial bioresource. The study was motivated by the neglect and abandonment of seeds as forest residue, despite the oil's distinctive chemical composition, which makes it a promising sustainable industrial bioresource. The research reports an oil yield of 35.85%, identifying the seed as a viable source for large-scale extraction. Chemically, the oil is dominated by oleic acid (50.17%), and its high flash point of 205 °C suggests that it is well-suited for biodiesel and biolubricant production. However, the acid value of 18.700 mg KOH/kg and the FFA content of 9.35% indicate that a two-step transesterification process is required for fuel conversion. In addition, the detection of bioactive compounds such as squalene (1.18%), beta-sitosterol (0.39%), and stigmasterol (0.21%) highlights the oil's significant value for pharmaceutical and cosmeceutical applications. FT-IR analysis also confirms the oil's triglyceride nature, specifically through the strong ester carbonyl peak at 1742.5 cm^{-1}.

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