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GC–MS CHARACTERIZATION AND FATTY ACID METHYL ESTER PROFILE OF BIODIESEL PRODUCED FROM *GLIRICIDIA SEPIUM* SEED OIL: IMPLICATIONS FOR FUEL QUALITY AND ENGINE APPLICATION

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Abstract
Biodiesel consists primarily of fatty acid methyl esters (FAME) derived from renewable lipids. Understanding its molecular composition helps predict fuel behavior and feedstock influence. This study used gas chromatography–mass spectrometry (GC–MS) to characterize biodiesel produced from Gliricidia sepium seed oil using a snail–egg–periwinkle shell-derived CaO catalyst. The GC–MS analysis identified nine major chromatographic peaks between 7.608 and 10.011 minutes. Three compounds were confidently identified as FAMEs, comprising 28.68% of the total chromatographic area namely Methyl linoleate (18.26%) – Polyunsaturated, Methyl palmitate (5.83%) – Saturated and Methyl stearate (4.59%) – Saturated. Within this confirmed fraction, polyunsaturated FAMEs made up 63.67% and saturated FAMEs accounted for 36.33%; no monounsaturated FAMEs were confidently identified. Additionally, ethyl palmitate and ethyl stearate were detected as non-FAME ethyl esters.Two major peaks at 8.414 and 10.011 minutes (representing 18.19% and 33.83% area) remained tentative library matches due to ambiguous structures like 9,12-octadecadienoic acid and 1-cis-vaccenoylglycerol ethyl linoleate. They require authentic standards for confirmation. The high concentration of methyl linoleate improves low-temperature flow but increases oxidative degradation risks. Ultimately, GC–MS is highly useful for qualitative profiling, but uncalibrated peak areas must not be misinterpreted as total FAME content or conversion efficiency.

Keywords
Gliricidia sepium; biodiesel; GC–MS; fatty acid methyl esters; methyl linoleate; FAME profile; molecular characterization

1. INTRODUCTION

The growing need for alternative fuel that is renewable and sustainable has made biodiesel to be a desirable alternative, coupled with the fact that it is biodegradable and burns cleaner than fossil fuel [1]. According to the International Energy Agency (IEA) report on world energy outlook of 2022, the industrial economy's reliance on fossil fuels may soon come to an end, with a substantial portion of the energy system of the future likely to be powered by clean energy sources [2].

The focal point of discussion on the global stage is to find ways of mitigating the effect of fossil fuel burning all over the world so as to reduce the global warming and its attendant effect on weather and environmental changes [3][4][5]. This discussion has taken a center stage on all major gatherings among the committee of nations with a view to finding a lasting solution. The resilient efforts have identified a closely knitted relationship between bioenergy production and climate change [6]. The justification for this work is that, although biodiesel from various non-edible feedstock has been investigated, detailed characterization of the individual FAME constituents of *G. sepium* seed-oil biodiesel and their relationship with important fuel-quality characteristics remains insufficiently documented, particularly for biodiesel produced using heterogeneous CaO-based catalytic systems.

The objective is to carry out a GC-MS characterization and fatty acid methyl ester profile of biodiesel produced from *gliricidia sepium* seed oil and evaluate the implications of its FAME profile on fuel quality.

Biodiesel consists mainly of fatty acid alkyl esters formed when triglycerides are converted through transesterification. The resulting ester structures retain the carbon-chain characteristics of the original fatty

acids while replacing the glycerol backbone with an alkyl group. The molecular distribution of the esters therefore provides useful information about the likely physical and chemical behaviour of the fuel [7] . The feedstock used for biodiesel production include edible and non-edible vegetable oils, animal fats, waste cooking oils and other lipid-containing biomass resources. The fuel produced is expected to contain characteristics that enable its application in compression-ignition engines either as a neat fuel or in blends with conventional diesel. Consequently, biodiesel has been investigated not only as an alternative fuel but also as a potential component of strategies for reducing the environmental burden associated with petroleum-based transportation fuels [8].

Gliricidia sepium seed (GSS), is a fast-growing leguminous tree that is commonly found in tropical regions, produces seeds rich in oil, making it a viable non-edible source for biodiesel production. It can be found in the tropical region of Nigeria, it is called *Agunmaniye* in Yoruba and southwestern part of Nigeria and Mother of Cocao in English language or Madre de cacao/ kakawate (in the Philippines). It is a small to medium-sized tree attaining 10-12 m in height. It is leguminous thus, fixes its own nitrogen and does not require nitrogen fertilizer. The utilization of GSS oil does not only addresses the feedstock availability and sustainability but also reduces the competition with food sources (food versus fuel), a predominant limitation associated with edible oil- based biodiesels such as soya beans and palm oils [9].

Previous work on *G. sepium* seed oil has identified C16–C18 fatty acids as important components, with linoleic acid being a notable constituent [10]. The molecular profile is important because conversion of these fatty acids to methyl esters produces a biodiesel whose cold-flow, oxidative and combustion-related characteristics are partly controlled by the degree of unsaturation of the resulting FAMEs.

Catalyst play a vital role in determining the efficiency and yield of biodiesel production. Conventional homogeneous catalyst such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) often lead to soap formation, difficult product separation, and environmental disposal challenges. Consequently, heterogeneous catalyst, which can be easily separated and reused, have gained considerable attention while shell wastes such as snail, egg, and periwinkle shells has an inherent abundance of calcium carbonate ($CaCO_3$), which, upon calcination, produces calcium oxide (CaO), a potent base catalyst for transesterification [11][12] [13]. The integration of multiple shell-derived catalyst into a composite material can synergistically enhance catalytic activity, surface area, and stability. These shells has also been found to constitute environmental health hazards which harbors mosquito and other pathogenic parasites that cause diseases and their usage would rid the environment of stench and odors and provide a cleaner environment [14].

Gas chromatography–mass spectrometry (GC–MS) is an important analytical technique for the molecular characterization of biodiesel because it enables the separation and identification of individual fatty acid methyl esters (FAMEs) according to their chromatographic retention behaviour and mass spectral fingerprints. Recent studies have demonstrated the application of GC–MS for identifying the principal FAME constituents of biodiesel produced from non-edible seed oils and for establishing the chemical composition of the resulting fuel. GC–MS characterization is particularly useful for confirming the occurrence of methyl esters following transesterification and for determining the relative distribution of saturated and unsaturated fatty-acid methyl esters. This compositional information is important because fatty-acid chain length and degree of unsaturation influence major biodiesel properties, including viscosity, cetane number, oxidative stability, density and cold-flow behavior.

A major importance of GC–MS is its ability to identify individual FAME compounds, such as methyl palmitate (C16:0), methyl stearate (C18:0), methyl oleate (C18:1), methyl linoleate (C18:2), and methyl linolenate (C18:3). The relative distribution of these compounds is important because the degree of saturation and carbon-chain length strongly influence biodiesel properties such as cetane number, oxidative stability, viscosity, density, cold-flow behavior and heating value. Consequently, the GC–MS fatty-acid profile provides a chemical basis for interpreting the measured fuel properties of biodiesel [15]. GC–MS also provides evidence of the success and quality of the transesterification reaction. A biodiesel chromatogram dominated by FAMEs, together with the identification of the expected methyl esters, supports successful conversion of the feedstock oil into biodiesel. The technique can additionally reveal residual or unexpected organic compounds that may arise from incomplete reaction, feedstock constituents or contamination. ASTM E2997 specifically recognizes GC–MS for identification of FAMEs and petroleum-derived components in biodiesel products [16].

Furthermore, recent work involving an eggshell-derived heterogeneous catalyst demonstrates the relevance of combining waste-shell-derived catalysts, process optimization and detailed biodiesel characterization in developing sustainable biodiesel production routes. Thus, GC–MS provides molecular-level evidence that complements conventional physicochemical characterization and helps establish the relationship between the chemical composition and fuel properties of biodiesel

These are done using mass spectral information that assists compound identification through comparison with reference libraries. The source manuscript emphasizes that GC–MS is especially useful for qualitative identification, while quantitative total ester determination requires calibrated procedures and appropriate

standards. ASTM E2997-25 and related analytical procedures distinguish compound identification from quantitative biodiesel analysis.

The degree of unsaturation is an important structural variable in biodiesel. Unsaturated esters generally have lower crystallization tendencies than highly saturated esters, which can improve low-temperature flow. At the same time, additional double bonds provide sites that are susceptible to oxidative attack. Consequently, a biodiesel rich in polyunsaturated FAMEs may require attention to oxidation stability and storage conditions. Saturated C16–C18 esters can contribute differently to cetane behavior and cold-flow performance. These relationships provide the basis for interpreting the molecular profile obtained by GC–MS. Tentative library matches were not treated as definitive structural identifications, whereas non-FAME assignments were excluded from the FAME fraction. GC remains useful for FAME characterization and biodiesel-quality assessment [17], while ASTM E2997-25 distinguishes GC–MS identification from quantitative determination of total biodiesel content [16].

2. MATERIALS AND METHOD

2.1 Procurement and Pre-Treatment of Samples

The *Gliricidia sepium* seed (GSS) samples were procured from Ladoke Akintola University of Technology, Ogbomoso (8º 061 N40º 141E) and Pakiotan farm in Ogbomoso (8º 061 N40º 141E), Oyo State. These locations were chosen based on the abundance of GSS trees and the proximity to the research location. On the other hand, periwinkle shell was procured at the King Adesida market, Akure (6º 211 N4º 471E), in Ondo State, Nigeria, while the egg and snail shells were obtained from the WAZOBIA market at Ogbomoso (8º 061 N40º 141E).

Matured brown pods of *Gliricidia sepium* were harvested and shelled using a decorticating machine after which it was cleaned to obtain a clean seed. The seed were oven dried for 5 h at 100 ºC to reduce the residual moisture that had been trapped and later ground into fine powder. Each sample was weighed, bottled, labeled, and kept in an airtight plastic container to ensure there is no moisture exchange with the surrounding [18]. Each shell sample was collected and cleaned of contaminants using distilled water and oven dried for 5 h at 100 ºC to reduce the moisture that had been trapped and later ground into fine powder. Each sample was weighed, bottled, labeled, and kept in an airtight plastic container to ensure there is no moisture exchange with the surrounding [19].

2.2 Extraction of Oil from *Gliricidia Sepium* seed

The apparatus used were Soxhlet extractor, heating mantle, round-bottom flask, condenser and extraction solvent (petroleum ether with the following impurity level; Acidity and Alkalinity;0.01 ml N%, Non-volatile matter; 0.001 %, Water ;0.02 % and wt. per ml. at 20 ºC ;0.660-0.680g).

A 20 g of ground seed sample was placed in a thimble, then add 300 mL of petroleum ether into the round-bottom flask. The Soxhlet apparatus was then assembled and connected to a condenser. The system is then heated at 60–70°C (near solvent boiling point). The extraction process was allowed to run for continuous/ reflux extraction 6 h (approximately 8–12 cycles) [20]. At the end of the process, the solvent was recovered using a rotary evaporator or distillation setup and the extracted oil was dried in an oven at 50°C to remove residual solvent and cooled in a desiccator and the oil is weighted [21]. The percentage oil yield was calculated using Equation 1.

$$\text{Oil Yield (\%)} = \frac{\text{Mass of Extracted Oil}}{\text{Mass of Seed Sample}} \times 100 \quad (1)$$

Post extraction treatment such as filtration, degumming and neutralization was carried out on the extracted oil and stored in airtight amber bottles to prevent oxidation. The oil extraction was carried out at UNIOSUN research laboratories in Ejigbo, Osun state. Plate 3.1 shows the petroleum ether laboratory grade used for the solvent extraction process as well as the soxhlet extraction apparatus.

Using the Design Expert software (Version 13), an optimal mixture design was employed to combine the sample powders in varying proportions to achieve maximum catalytic activity. The experimental matrix incorporated three factors: snail shell sample (X_1), egg shell sample (X_2), and periwinkle shell sample (X_3).

After blending according to the optimized ratio given by the design expert, the mixtures were homogenized using a ball mill at 250 rpm for 2 h. The composite sample was then placed in the oven to remove residual moisture. The composite mixture consisting of 14 different samples were arranged in the muffle furnace and calcined at temperatures of 900 ºC. To extract the ash content (calcium oxide) of the synthesized sample, the calcination process was allowed to run through a temperature controller in a Muffle Furnace with the aim of removing all volatile compounds, according to [22]. The resulting white powder was cooled in a desiccator and stored in airtight cellophane bags. This is to prevent the absorption of moisture and CO_2 from the atmosphere. The final product was labeled R1 to R14. The thermal decomposition reaction is presented in Equation 2.



(a) (b)

Plate 1. (a) Solvent extraction using petroleum ether (b) Soxhlet extraction apparatus for Oil extraction

$$Ca\ CO_3\ (s) \rightarrow Ca\ O\ (s) + CO_2\ (g)\ Ca\ CO_3\ (s)\ \rightarrow Ca\ O\ (s) + CO_2\ (g) \quad (2)$$

To determine the crystalline phases and confirm CaO formation, X-ray diffraction analysis (XRD) was carried out on the calcined samples. The raw shell of the synthesized shell residue was also characterized using a Mini Flex IIX-ray diffractometer with Ca-ka radiation fixated between 20 and 80 ^{o}C with a step size of 0.04 at a scanning speed of 3rpm and compared with the calcined samples. An XRF spectrometer, a powerful instrument designed to unveil the elemental composition of various materials under investigation was also used to measure the energies and intensities of the emitted X-rays, identifies which elements and compounds are presents and their concentration/quantification levels as indicated across the periodic table. Both XRF and XRD analysis were carried out at the National Geoscience research laboratory in Kaduna, Nigeria.

2.3 Transesterification Process for Biodiesel Production

Transesterification of the GSSO was carried out by mixing 2 ml of methanol and 210 mg of catalyst in a 50 ml round bottom flask for 1h to produce calcium methoxide after which 7 g of the oil was then added. The mixing was done in a closed vessel to prevent the methanol from evaporating. A magnetic stirrer was used to produce a homogenous mixture. Methanol was adopted as the reaction alcohol because it is widely acceptable, available, and less costly and it also has a faster reaction rate [23][24].

To optimized the biodiesel yield, Box- Behnken Method of the Design Expert software was used to optimize the transesterification process parameters namely; methanol to oil molar ratio (6:1, 12:1 and 18:1), catalyst loading (1,3 and 5 % wt of oil), reaction temperature (50, 65 and 70 ^{o} C), reaction time (30, 35 and 40 min.) and mixing speed (rpm). Response Surface Methodology (4 factors) was used for selecting the best model. The reaction mixture was then transferred to the separating funnel and kept for 3 h for the lighter phase (biodiesel) and the denser phase (glycerol) was collected separately. The Centrifugation process was carried out at 4000 rpm for 7 min to separate the catalyst from the biodiesel while the catalyst was washed with water and dried in the oven. The biodiesel was then cooled to room temperature and sealed with a para-film before being kept in an enclosed closet [22].

2.4 Characterization of the Biodiesel

The biodiesel produced was characterized to determine its properties and ensure that the fuel produced was suitable for use in automobiles either as a partial or a complete fuel. The properties determined were

kinematic viscosity, specific gravity, flash point, pour point and cloud point, saponification value, cetane number, density and heating value.
Each of the fuel properties were done based on the following standards; density at 40 ◦C (ASTM D 6751), kinematic viscosity at 40 ◦C, flash point (ASTM D 93), sulfur content (wt. %) (ASTM D 4294), and acid value (mg KOH/g) (ASTM D 974) and then compared with the American Standard and Testing Materials (ASTM D 6751) and ASTM D-951.

2.5 GC-MS Analysis of the Produced Biodiesel

Prior to GC–MS analysis, the purified Gliricidia sepium biodiesel was separated from residual glycerol and other impurities, washed, dried and filtered. Approximately 0.10 mL of the purified biodiesel was transferred into a clean GC vial and diluted to 1.0 mL with GC-grade n-hexane, corresponding to an approximately 1:10 (v/v) dilution. The solution was thoroughly mixed to ensure homogeneity and filtered through a PTFE syringe filter before being transfered to the auto-sampler vial. An aliquot of 1.0 µL of the diluted biodiesel sample was injected into the GC–MS system for chromatographic separation and mass-spectral identification of the constituent fatty acid methyl esters (FAMEs). Chromatographic components within the produced biodiesel was then identified. The source manuscript states that compounds were assigned by comparison with the NIST23 spectral library and classified as confirmed FAMEs, tentative library matches or non-FAME components. Confirmed FAMEs were limited to methyl-esters whose proposed structures were consistent with the library assignments and high-quality spectral matches.
The GC–MS instrument information are; (Instrument model; 7890A GC system, 5675C Inert MSD with triple –Axis detector, column specification; Capillary column, carrier gas; Helium gas, Dimension: 30mx250umx 0.25 um, Column: Agilent 19091-433HP-5Ms 5%phenyl methyl silox). The analytical results are therefore interpreted from the reported library matches and chromatographic data.

3. RESULTS AND DISCUSSION

3.1 Extracted oil from *Gliricidia sepium* Seed

The average yield of oil from the three replicate extraction was 34.50 % by weight of dry feedstock, this was from replicates 36.30, 22.80 and 44.4 % seed dry weight respectively. The observed variability in oil extraction yield was attributed primarily to the heterogeneous nature of the seed material, particularly differences in seed maturity and moisture content, together with variations in particle size, solvent penetration, extraction efficiency and handling losses. Because the extraction yields varied considerably, the raw seed batches should ideally have been homogenized and the extraction conditions standardized before replicate determination. All these would have to be taken care of in the future study. Although, ASTME and EN does not recommend a particular threshold for yield, however, literatures indicates that oil yield above 30 % are considered suitable for biodiesel production while many researchers have also categorized into poor (less than 20 %), moderate (between 20 to 30 %), good (30 to 50 %) and excellent (above 50 %) oil yield from all biodiesel feedstock.
The yield obtained from this study falls within the medium biodiesel feedstock categories as observed from previous studies ranging from edible to non- edible as well as animal fats and microalgae, the oil contents always exhibit significant variability based on location and the physiology of the feedstock sample. Low oil yielding feedstock (soya beans) contains 15 – 25 % oil content, moderate oil yielding (sun flower, *Gliricidia sepium* , and rapeseed) gives 30 – 45 % while high oil yielding feedstock (palm oil, coconut and Jatropha) gives 40 -65 % oil content. These range are consistently reported by [26] [27].
In a 2025 characterization study, oil contents for Tiger nut (Cyperus esculentus), Sesame (Sesamum indicum), Chlorella vulgaris biomass were roughly 26.2 %, 51.3 %, and 53.6 % by dry weight, respectively, indicating variability of oil yielding crops. [28]-[29] that, the oil content percentages represent the proportion of oil relative to the dry seed/ biomass weight before extraction which remain a central parameter in feedstock selection for biodiesel production, although the actual oil yields can vary with cultivar, growing conditions, and processing methods. From the foregoing, the observed yield validates *Gliricidia sepium* seed oil as a moderate, promising non-edible feedstock for biodiesel production.

3.2 Physicochemical Properties of the Extracted Oil

The physicochemical properties of *Gliricidia sepium* seed oil were evaluated to determine its suitability as a biodiesel feedstock. The results obtained include specific gravity (0.87), refractive index (1.05), pH (4.37), free fatty acid (FFA) (1.125%), iodine value (118.7 g I_2/100 g), acid value (2.25 mg KOH/g), and saponification value (200 mg KOH/g). Table 1 shows the physicochemical properties of the oil extracted from *Gliricidia sepium* seed sample.

Table 1 Physicochemical properties of the oil extracted from *Gliricidia sepium* seed sample.

Property	Value Obtained
Specific gravity	0.87
Refractive index	1.05
pH	4.37
Free fatty acid (FFA, %)	1.125
Iodine value (g I_2/100 g)	118.7
Acid value (mg KOH/g)	2.25

Pre-treatment operation was carried out on the extracted oil before being subjected to transesterification process.

3.3 Transesterification Process Results

The esterified oil sample was subjected to base-catalyzed transesterification process using methanol as a reaction medium. This is based on the methods used [30] [31].

The results showed that run 11 gave the highest of 85 % biodiesel yield with the optimal operating conditions such as methanol to oil molar ratio (12:1), catalyst loading (3 % wt of oil), reaction temperature (50 ^{o} C), reaction time (30) respectively. This is presented in the experimental design Table 2. The mass of oil used was calculated from the known volume (10 mL) and density of the esterified oil. Biodiesel yields obtained from the 25 experimental runs optimized to evaluate the influence of reaction parameters on conversion efficiency

Table 2 Optimization of the Transesterification Process Experimental Lay Out

Run	A: Methanol: Oil Ratio mol/mol	B: Catalyst Loading wt/%	C: Temperature ^{o}C	D: Time min	Yield %
1	12	1	70	40	46.24
2	12	1	65	30	82.00
3	12	5	70	35	45.00
4	12	5	65	40	60.13
5	18	3	70	30	46.01
6	18	3	65	35	50.00
7	12	1	70	30	58.00
8	18	1	50	40	70.00
9	12	5	50	30	70.00
10	6	5	70	35	50.00
11	12	3	50	30	85.00
12	12	3	70	40	51.58
13	12	1	70	30	55.00
14	12	1	50	40	58.00
15	6	5	50	30	60.00
16	12	5	65	40	50.00
17	6	3	50	30	73.60
18	12	3	70	35	52.80
19	12	1	70	30	55.00
20	6	1	70	35	39.94
21	18	5	50	30	59.64
22	6	5	70	40	32.97
23	18	3	50	30	65.00
24	6	3	70	35	52.80
25	18	3	65	40	70.00

3.3.1 ANOVA for the transesterification process

The quadratic response surface model developed to describe the transesterification process exhibited strong statistical reliability and predictive capability. The coefficient of determination (R^2 = 0.9685) indicates that

96.85% of the variability in biodiesel yield is explained by the selected process variables, confirming an excellent model fit. Comparable R^2 values have been reported in optimized heterogeneous catalytic biodiesel systems, demonstrating the suitability of response surface methodology (RSM) for modeling complex transesterification reactions [32] [33].

The adjusted R^2 (0.9243) was in close agreement with the predicted R^2 (0.8520), with their difference remaining well below the acceptable limit of 0.20, indicating good predictive performance without overfitting. The adequate precision value of 19.17, which far exceeds the minimum recommended value of 4, confirms a strong signal-to-Noise ratio and validates the model's applicability for navigating the experimental design space [34]. In addition, the low coefficient of variation (5.97%) reflects high experimental precision and reproducibility, which is essential for laboratory-scale transesterification studies.

The model F-value of 21.95 with a p-value < 0.0001 confirms that the developed quadratic model is highly significant and that the selected reaction parameters collectively exert a strong influence on biodiesel yield. Table 3 shows the transesterification process experimental lay out identifying factors, variables and the corresponding yield for each experimental trial. Table 4 shows the Fit statistics of the experiment, displaying the interactions between the important components of the ANOVA characteristics.

Table 3 ANOVA for quadratic model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3626.47	14	259.03	21.95	< 0.0001	significant
A-Methanol:Oil Ratio	374.26	1	374.26	31.71	0.0002	
B-Catalyst Loading	175.94	1	175.94	14.91	0.0032	
C-Temperature	54.12	1	54.12	4.58	0.0579	
D-Time	327.70	1	327.70	27.76	0.0004	
AB	8.89	1	8.89	0.7530	0.4059	
AC	485.13	1	485.13	41.10	< 0.0001	
AD	481.13	1	481.13	40.76	< 0.0001	
BC	171.03	1	171.03	14.49	0.0034	
BD	187.44	1	187.44	15.88	0.0026	
CD	3.08	1	3.08	0.2606	0.6208	
A^2	392.51	1	392.51	33.25	0.0002	
B^2	204.95	1	204.95	17.36	0.0019	
C^2	476.00	1	476.00	40.33	< 0.0001	
D^2	339.80	1	339.80	28.79	0.0003	
Residual	118.03	10	11.80			
Lack of Fit	60.73	7	8.68	0.4541	0.8244	not significant
Pure Error	57.31	3	19.10			
Cor Total	3744.51	24				

Table 4. Fit statistics

Std. Dev.	3.44	R^2	0.9685
Mean	57.55	Adjusted R^2	0.9243
C.V. %	5.97	Predicted R^2	0.8520
		Adeq Precision	19.1696

3.4 Results of Characteristics of the Produced Biodiesel from GSS

The biodiesel (methyl ester) properties and its relativity with the relevant international standards were determined and presented in Table 5. The individual components are discussed as follows;

The density (Fuel Structure) measured was found to be 0.8878 g/cm ^{3} which falls within the EN 14214 acceptable range (0.86–0.90g/cm³). The density of a sample is directly influenced by fatty acid chain length and degree of unsaturation. The value confirms effective triglyceride-to-FAME conversion from the experimental procedures. The iodine value (111.918) complies with EN 14214 (≤120), the slight reduction compared with the oil feedstock could be due to overall molecular weight shift or dilution effect [35], while this enhances cold flow properties, it may also reduce oxidative stability, necessitating antioxidant treatment for long-term storage [27].

The flash point (72–77°C) is below ASTM minimum (93°C), strongly indicating residual methanol contamination. Methanol significantly lowers flash point and compromises storage safety,

Table 5. Results of biodiesel properties produced from *Gliricidia Sepium* oil and its compliance status

Fuel Property	Experimental Value	ASTM D6751 Limit	EN 14214 Limit	Compliance Status
Density (kg/m³ at 15°C)	0.8878 g/cm³	– (not specified)	0.86–0.90 g/cm³	Within EN limit
Cetane Number	46.01	≥47	≥51	Slightly below standard
Acid Value (mg KOH/g)	0.3566	≤0.50	≤0.50	Within standard
Iodine value (g I_2/100 g)	111.918	≤ 120	≤ 120	Slightly Below standard
Water Content (%)	0.08	≤0.05	≤0.05	Slightly above limit
Kinematic Viscosity (mm²/s at 40°C)	6.986–7.224	1.9–6.0	3.5–5.0	Above limit
Cloud Point (°C)	8.4–9.9	Report	−3 to 12	Acceptable
Flash point (°C)	72–77	93	101	Below limit
Fire Point (°C)	81–89	No official limit ≥93 (flash point)	-	Must be Close to Flash point
Pour Point (°C)	3.3–4.4	Report	−15 to 10	Acceptable
Smoke Point (mm)	50–55	–	–	Acceptable
Heating Value (MJ/kg)	34.3–35.1	37–40 typical	37–40 typical	Slightly lower

Additional vacuum evaporation may be necessary [27] while the Sulphur quantity (1.5 ppm) is well within ASTM and EN limits. This confirms the environmental advantage of the produced biodiesel, supporting reduced SOx emissions. The water content (0.08%) which is a little bit above the acceptable limits of EN and ASTM of 0.05 wt. %. Excess water in biodiesel results in microbial growth, fuel instability, reduced heating value and corrosion thus further drying (vacuum) is recommended for adequate dryness of the reaction products. The cetane number (46.01) is a bit below ASTM (≥47) and EN (≥51) limits. Cetane number decreases with increasing unsaturation [36]. The calorific value (34.3–35.1 MJ/kg) is slightly lower than standard biodiesel values (~37–40 MJ/kg). Literature has it that biodiesel inherently contains oxygen (~10–12%) thereby reducing its energy density relative to petrol-diesel. Elevated moisture likely contributed to this slight depression in cetane number.

The acid value (0.3566 mgKOH/g) falls within the standard because the maximum allowable limit (0.5 mgKOH/g). Acidic fuels accelerate corrosion and injector wear [27]. Viscosity is one of the most critical fuel parameters influencing fuel atomization, spray characteristics, and combustion efficiency in diesel engines. Biodiesel typically exhibits higher viscosity than petroleum diesel due to the presence of long-chain fatty acid methyl esters (FAMEs) and stronger intermolecular forces between ester molecules. These characteristics increase internal resistance to flow during fuel injection [27]. The measured viscosity range of 6.986–7.224 mm²/s for *Gliricidia sepium* biodiesel is slightly above the ASTM D6751 acceptable limit of 1.9–6.0 mm²/s. Higher viscosity values in biodiesel may arise from several factors such as high concentration of long-chain saturated fatty acids, incomplete transesterification leading to residual triglycerides or presence of trace impurities such as glycerides or unreacted oil.

High viscosity fuels may cause poor atomization, larger droplet formation, injector fouling, and incomplete combustion, which can negatively affect engine efficiency and emissions [37] [38]. However, moderate viscosity can improve fuel lubricity, thereby reducing wear in fuel injection systems. The slightly elevated viscosity observed in this study therefore suggests that while the biodiesel demonstrates acceptable flow behavior, blending with petro-diesel or further purification could improve compliance with fuel standards. Cloud point represents the temperature at which wax crystals first appear during cooling, marking the onset of poor cold-flow properties in biodiesel fuels. As the temperature decreases, crystallization of saturated fatty acid methyl esters begins, which can clog fuel filters and affect engine operability [27]. The measured cloud point of 8.4 to 9.9 °C falls within the general biodiesel range reported for many vegetable oil feedstock, which typically varies from −3 °C to 12 °C depending on fatty acid composition, positive values near 10 °C may be attributed to higher proportions of saturated esters such as palmitic or stearic methyl esters. Since ASTM D6751 requirement only reports the cloud point rather than a strict limit, the obtained values are acceptable and mainly indicate the fuel's suitability for particular climatic conditions [38]. For tropical regions such as Nigeria, where ambient temperatures rarely approach freezing conditions, these cloud point values are unlikely to pose operational problems in diesel engines.

The fire point is the minimum temperature at which fuel vapors sustain continuous combustion after ignition, reflecting the thermal safety of the fuel during storage and handling. The fire point values of 81–89 °C indicate moderate thermal stability and ignition resistance. In general, biodiesel fuels exhibit higher flash and fire points than petroleum diesel due to their lower volatility and oxygenated structure, making them safer during transportation and storage [38]. Typical biodiesel fuels may exhibit fire points between 86 and 202 °C depending on feedstock and blend ratio. Although the measured fire point is relatively lower than some biodiesel fuels reported in literature, it still demonstrates adequate ignition safety characteristics and suggests minimal presence of highly volatile contaminants such as methanol. Pour point is defined as the lowest temperature at which a fuel remains capable of flowing under gravity. It is an important parameter for evaluating fuel handling and pumping characteristics at low temperatures. The obtained pour point range of 3.3 to 4.4 °C aligns well with typical biodiesel fuels, which commonly show pour points between −15 °C and 10 °C depending on feedstock composition.

Higher pour points are generally associated with higher saturated fatty acid content, which leads to earlier crystallization during cooling. Conversely, biodiesels derived from oils with higher unsaturation levels tend to exhibit lower pour points. The relatively moderate pour point obtained in this study indicates that the Gliricidia biodiesel maintains acceptable flow properties under moderate temperature conditions, supporting its practical applicability in warm climates. Smoke point indicates the temperature at which fuel begins to produce visible smoke due to incomplete combustion. It is related to fuel composition, particularly aromatic compounds and carbon-to-hydrogen ratio. The smoke point values of 50–55 suggest relatively clean combustion characteristics for the produced biodiesel. Biodiesel generally produces lower soot and particulate emissions than conventional diesel because the oxygen content in fatty acid methyl esters promotes more complete combustion [39].

Improved smoke point characteristics are also attributed to lower aromatic hydrocarbon content, higher oxygenated molecular structure and better combustion oxidation processes. Consequently, biodiesel fuels such as *Gliricidia sepium* methyl ester often demonstrate reduced smoke opacity and particulate emissions in compression ignition engines. The Specific gravity reflects the relative density of fuel compared with water and influences fuel injection and spray penetration during combustion. Typical biodiesel fuels have densities around 0.86–0.90 g cm^{-3}, slightly higher than petroleum diesel due to the presence of oxygenated ester functional groups. The specific gravity of 1.1264 obtained in this study is significantly higher than conventional biodiesel values. Such elevated density may indicate the presence of residual glycerol or catalyst impurities, incomplete separation during purification, measurement temperature differences or presence of heavier molecular compounds

High density fuels can influence fuel injection quantity and spray penetration, potentially affecting engine combustion characteristics. However, density variations can often be corrected through blending with diesel fuel or improved purification techniques. Heating value (calorific value) represents the energy released during complete combustion of the fuel and is a critical indicator of engine power potential. The heating value obtained in this study (34.3–35.1 MJ/kg) is slightly lower than that of petroleum diesel (≈42–45 MJ/kg) but is consistent with typical biodiesel fuels which commonly range between 37–40 MJ/kg depending on feedstock composition. The lower energy content of biodiesel is primarily attributed to presence of oxygen atoms in fatty acid methyl esters, lower carbon-to-hydrogen ratio compared to hydrocarbons and reduced energy density

This characteristic often results in slightly higher brake specific fuel consumption (BSFC) in biodiesel-fueled engines. Nevertheless, biodiesel compensates for this limitation through cleaner combustion and reduced emissions, making it an attractive renewable alternative fuel [39].

The physicochemical properties obtained for *Gliricidia sepium* biodiesel demonstrate characteristics typical of plant-derived biodiesel fuels. The fuel exhibits acceptable cold-flow properties, moderate thermal stability, and reasonable energy content, indicating its suitability for use in compression ignition engines, particularly in tropical climates. Thus, maintaining optimized washing, vacuum methanol recovery, and molecular sieve drying can also elevate the condition to make it better. The composite shell CaO catalyst effectively facilitated ester formation (validated by density and iodine value compliance). For those values that fell short of the acceptable standards (flash point, viscosity, water content, calorific value), the reaction product may have to be subjected to post-reaction purification such as methanol recovery, washing, drying and degumming or blending with petroleum diesel (e.g., B10–B20) to fully comply with international biodiesel standards such as ASTM D6751 and EN 14214 [27]. The primary limitation is downstream processing, not catalyst inefficiency.

3.5 GC-MS Chromatograms and Fatty Acid Profile of the Biodiesel Produced

The analysis was interpreted primarily as a qualitative characterization, the chromatogram contained nine major peaks between 7.608 and 10.011 min as shown in Table 6. Methyl palmitate (5.83%), methyl linoleate (18.26%) and methyl stearate (4.59%) were classified as confirmed FAMEs based on their methyl-ester identities and high-quality library matches. Together, they represented 28.68% of the relative chromatographic area. This value is the summed relative area of the three confirmed FAME peaks only, it is

not a measurement of total FAME content, biodiesel conversion or methyl ester mass fraction. Methyl linoleate was the predominant confirmed FAME. This profile is consistent with reports identifying linoleic acid as an important component of *G. sepium* seed oil and provides qualitative molecular evidence of transesterification [26] [40].

Within the three confirmed FAME peaks, polyunsaturated FAMEs, principally methyl linoleate (C18:2), accounted for 63.67% of the relative confirmed-FAME area, whereas saturated FAMEs represented 36.33%, no MUFA was confidently identified among the major peaks. These percentages describe the distribution of the confirmed FAME signal and should not be interpreted as the fatty-acid composition of the entire biodiesel sample. The linoleate content may favour low-temperature flow but increase oxidation susceptibility, while palmitate and stearate may support higher cetane behavior but impair cold-flow properties. These interpretations are limited to the confidently identified major peaks and do not constitute a complete quantitative composition.

Table 6. GC–MS Identified Compounds in *Gliricidia sepium* Biodiesel

Peak	Retention time (min)	Identified compound	Formula	Molecular weight (g mol^{-1})	Area (%)	NIST quality	Classification
1	7.608	Hexadecanoic acid, methyl ester (methyl palmitate)	$C_{17}H_{34}O_2$	270.45	5.83	99	Confirmed FAME
2	7.825	Hexadecanoic acid, ethyl ester (ethyl palmitate)	$C_{18}H_{36}O_2$	284.48	3.78	98	Non-FAME: FAEE
3	8.214	9,12-Octadecadienoic acid, methyl ester (methyl linoleate)	$C_{19}H_{34}O_2$	294.47	18.26	99	Confirmed FAME
4	8.271	Octadecanoic acid, methyl ester (methyl stearate)	$C_{19}H_{38}O_2$	298.51	4.59	99	Confirmed FAME
5	8.414	9,12-Octadecadienoic acid/related ester	$C_{18}H_{32}O_2$*	280.45*	18.19	99	Tentative library match
6	8.477	Octadecanoic acid, ethyl ester (ethyl stearate)	$C_{20}H_{40}O_2$	312.53	3.06	99	Non-FAME: FAEE
7	9.290	Cyclododecyne/related compounds	—	—	2.51	94	Tentative non-FAME/ambiguous
8	9.439	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester	$C_{19}H_{38}O_4$	330.51	9.95	87	Non-FAME: hydroxy/glyceride-type compound
9	10.011	1-cis-Vaccenoylglycerol	$C_{21}H_{40}O_4$*	356.54*	33.83	93	Non-FAME: glyceride-type compound

*Formula/molecular mass should be treated as tentative where the library match was not unambiguous.

The identified methyl esters agree with previous chromatographic studies of *G. sepium* biodiesel [41] and the established use of transesterification for biodiesel production [7]. The absence of a confidently identified MUFA should be interpreted cautiously because it may reflect co-elution, detection limits, library limitations or the abundance of other components rather than the complete absence of oleate-derived esters. Table 4.7 showed the confirmed FAME distribution.

Table 7. Confirmed FAME Distribution

FAME class	Identified compounds	Relative area (%)	Distribution within confirmed FAMEs (%)
Saturated fatty acid methyl esters (SFA)	Methyl palmitate + methyl stearate	10.42	36.33
Monounsaturated FAMEs (MUFA)	None confidently identified	0.00	0.00
Polyunsaturated FAMEs (PUFA)	Methyl linoleate	18.26	63.67
Total confirmed FAMEs	—	**28.68**	**100.00**

3.7 Non-FAME components and tentative assignments

The reported no MUFA means that, the peak does not met the criteria for confident identification under the GC–MS conditions used, but not a proof that MUFA was absent from the biodiesel. *Gliricidia sepium* seed oil is known to contain oleic acid, so methyl oleate would be chemically expected after transesterification, if

that component was present in the feedstock. However, methyl oleate may not have been confidently resolved or identified because of chromatographic co-elution or limitations of library-based identification. It indicate that the applied GC–MS analysis was based on library matching rather than retention-time confirmation with authentic FAME standards and calibrated quantitative determination. The Ethyl palmitate (3.78%) and ethyl stearate (3.06%) were classified as FAEEs and therefore excluded from the confirmed FAME total. Their presence may reflect minor esterification involving ethanol or another ethyl source, although library matching cannot establish their formation pathway. Their reported areas are relative chromatographic responses, not validated concentrations. Including them in the FAME total would overestimate methyl ester content.

The 8.414-min peak represented 18.19% of the chromatographic area but was retained only as a tentative library match because possible assignments included 9,12-octadecadienoic acid, ethyl linoleate and linolelaidic acid. Its area therefore cannot be assigned quantitatively to any one compound or included in the confirmed FAME total. Peaks at 9.290, 9.439 and 10.011 min were similarly excluded from the confirmed FAME fraction. They were tentatively associated with cyclododecyne/related compounds, a hydroxy-ester or glyceride-type compound, and 1-cis-vaccenoylglycerol, respectively. These assignments indicate possible component identities but require authentic standards or complementary analytical evidence for confirmation. The GC-MS fragmentation and peak profile results are shown in Figure 2 to Figure 7.

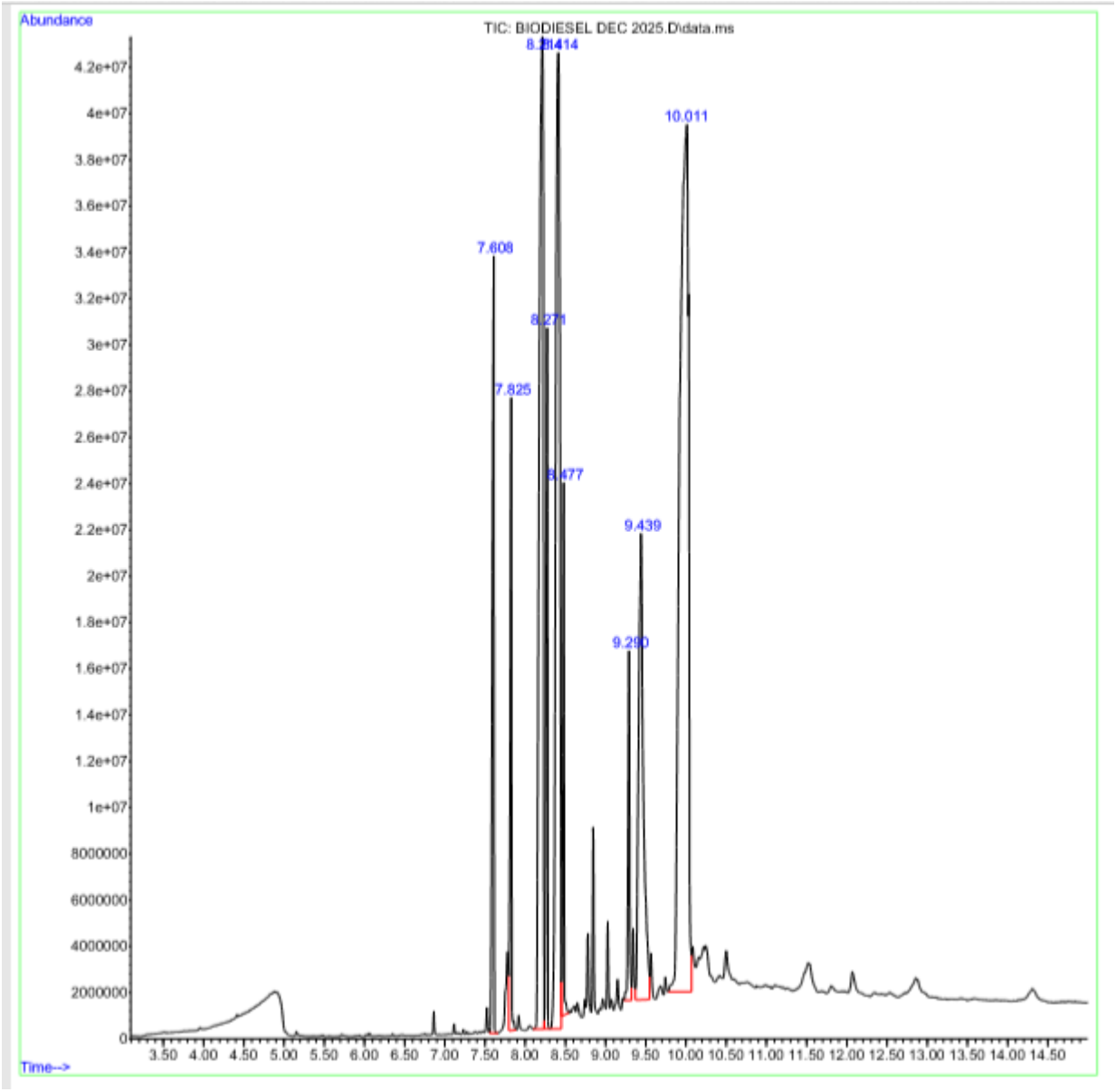


Figure 2. GC-MS fragmentation and peak profile from the biodiesel test

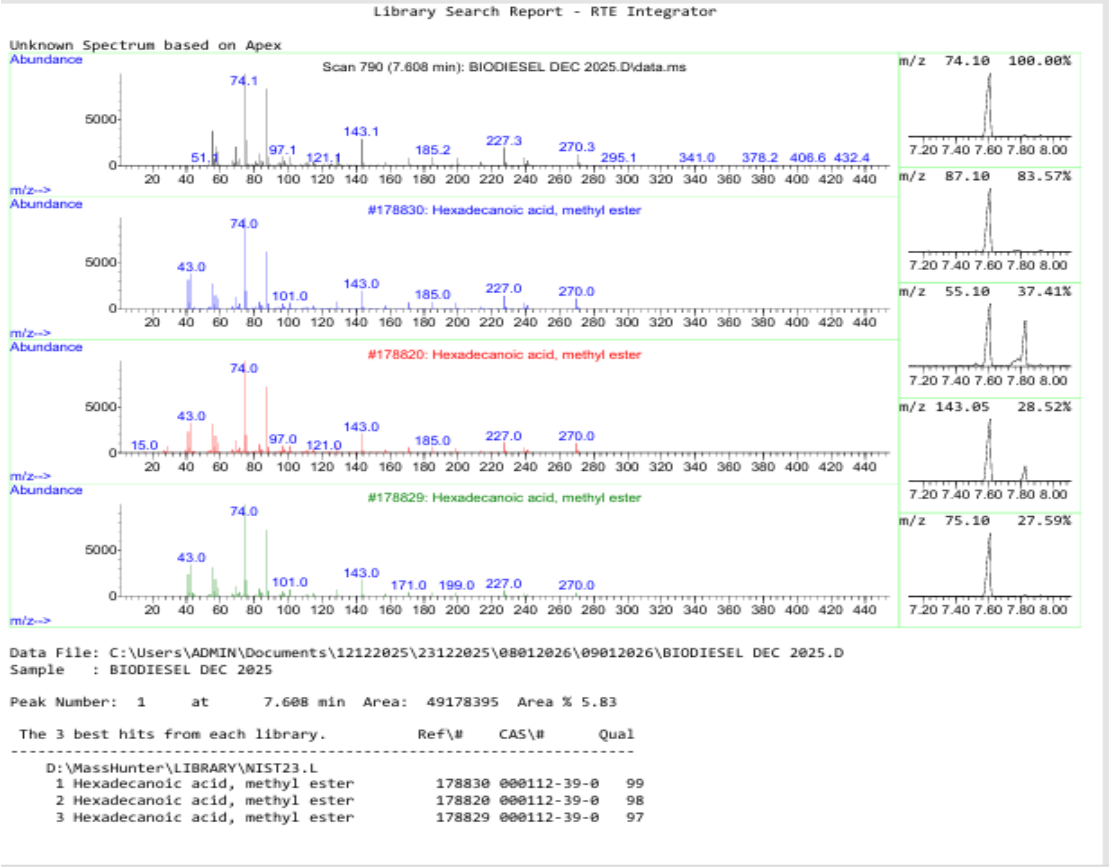


Figure 3. GC-MS library match spectrum and identified compounds from the biodiesel test- Hexadecanoic acid, methyl ester (methyl palmitate- $C_{17}H_{34}O_2$)

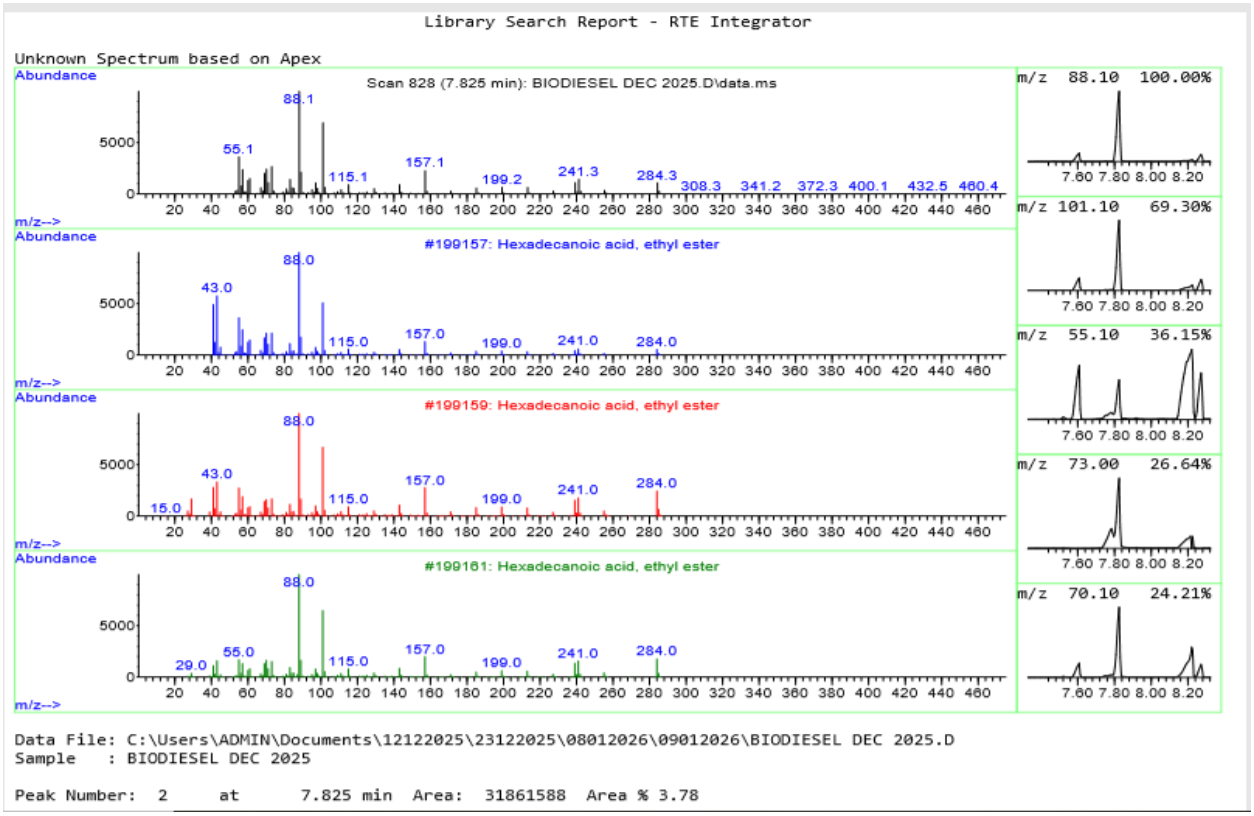


Figure 4. GC-MS fragmentation profile and identified compounds from the biodiesel test- Hexadecanoic acid, ethyl ester (ethyl palmitate- $C_{18}H_{36}O_2$)

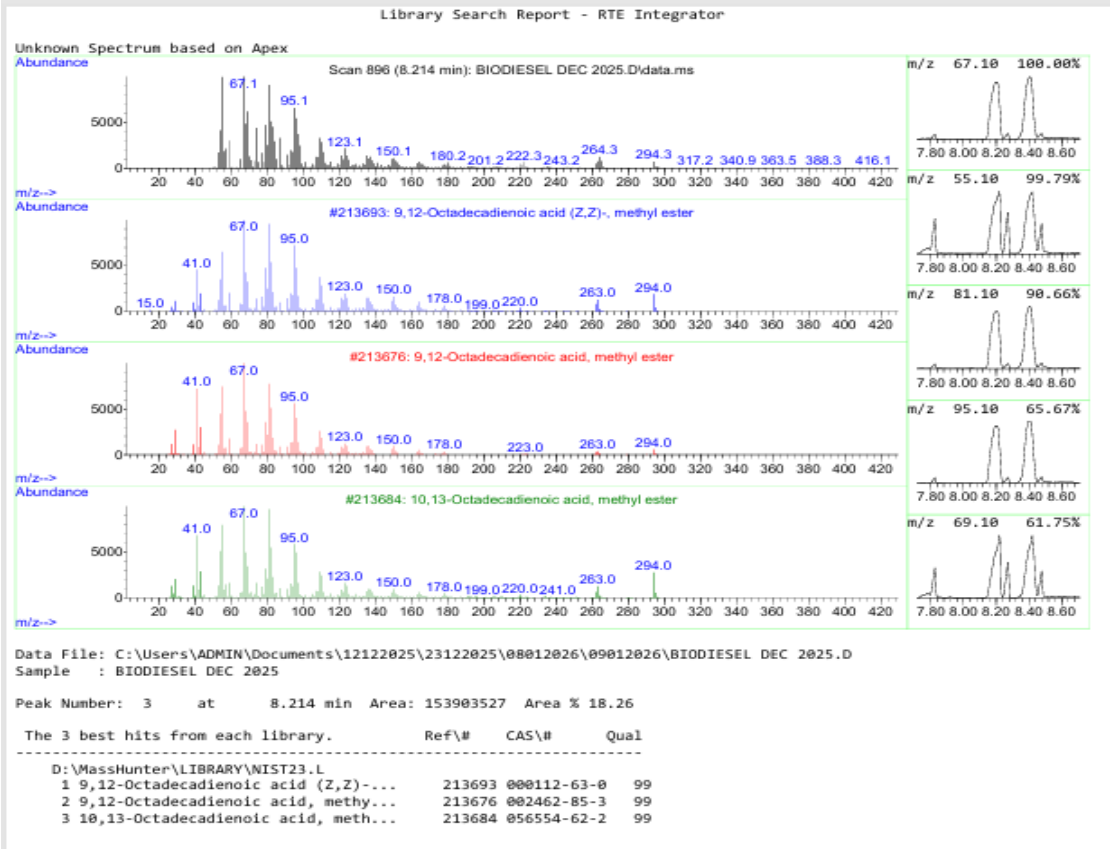


Figure 5. GC-MS fragmentation profile and identified compounds from the biodiesel test-9,12-Octadecadienoic acid, methyl ester (methyl linoleate- $C_{19}H_{34}O_2$)

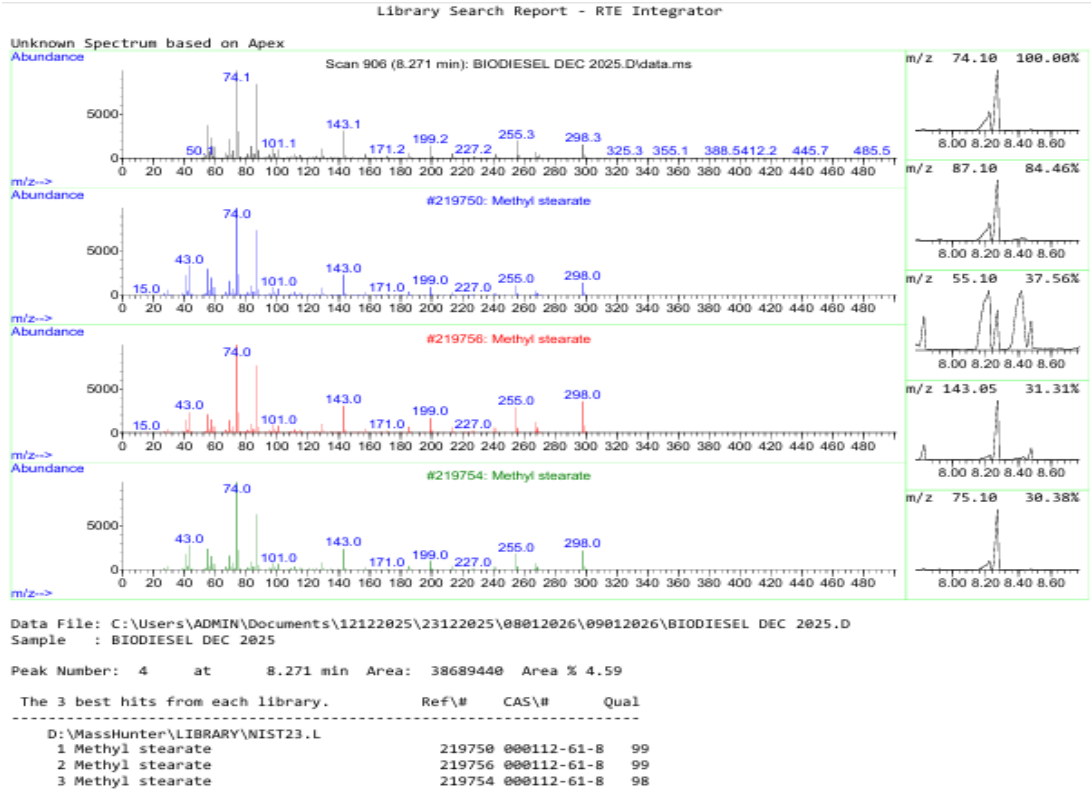


Figure 6. GC-MS fragmentation profile and identified compounds from the biodiesel test-Octadecanoic acid, methyl ester (methyl stearate- $C_{19}H_{38}O_2$)

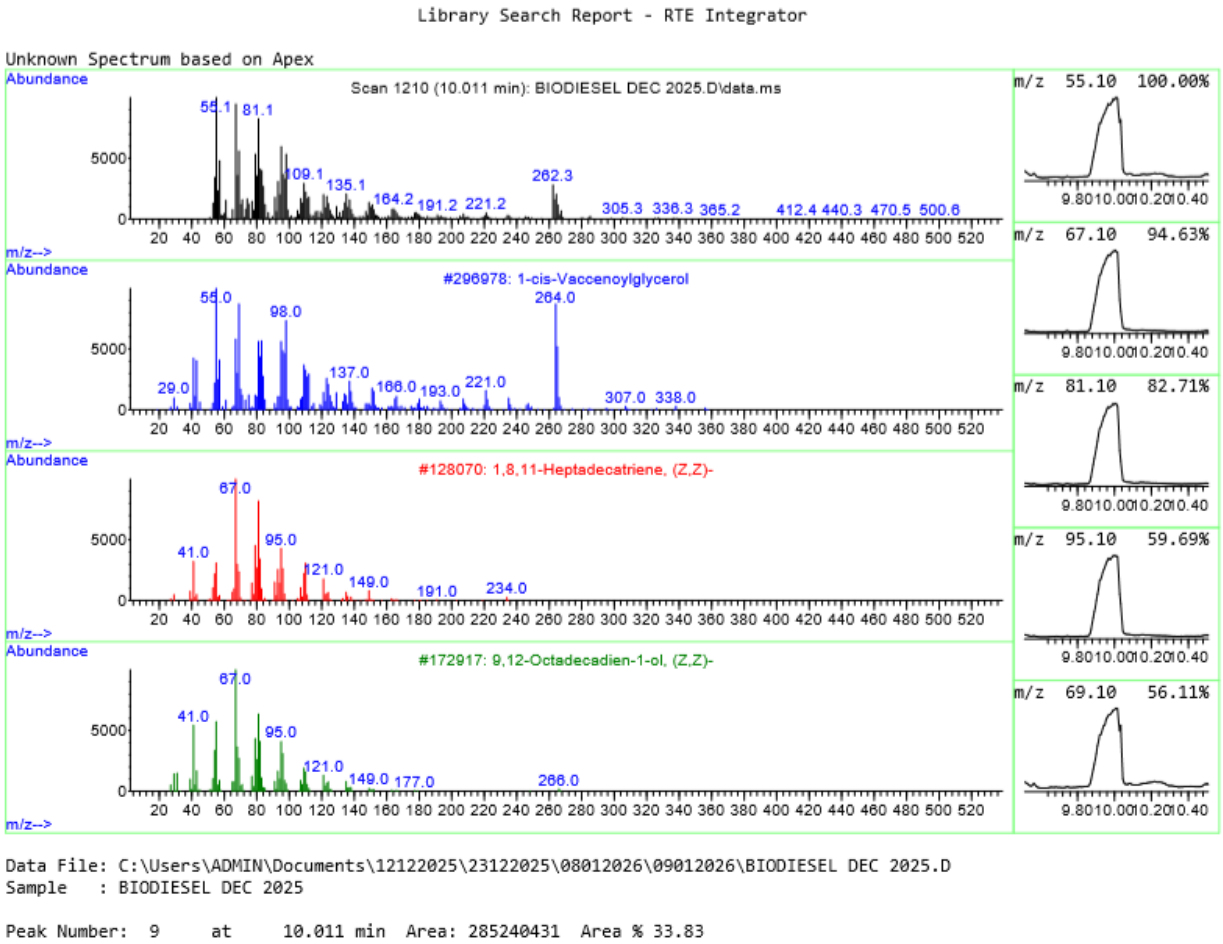


Figure 7. GC-MS fragmentation profile and identified compounds from the biodiesel test- 1-cis-Vaccenoylglycerol ($C_{21}H_{40}O_4$*)

The 10.011-min peak, assigned to 1-cis-vaccenoylglycerol, accounted for 33.83% of the area. This value is a relative peak response and does not represent biodiesel conversion, total ester content or glyceride concentration. The assignment may indicate residual glyceride material, incomplete conversion or an alternative library match. If confirmed, glyceride-type material could affect viscosity, deposits and specification compliance. Confirmation requires a method for mono-, di- and triacylglycerols, such as the GC procedure described in ISO/TS 17306 [42].

3.8 Analytical Limitations and Quantitative Significance

The 28.68% confirmed-FAME area represents only the relative signal assigned to three methyl esters under the applied GC–MS conditions, not total FAME content. The 63.67% PUFA and 36.33% SFA values describe the relative distribution within those three confirmed FAME peaks, not the composition of the complete sample. Similarly, the 33.83% glyceride-type area and the areas of FAEEs and tentative components cannot be interpreted directly as concentrations.

Because library matching is primarily qualitative, detector response, volatility, ionization efficiency, co-elution and the absence of calibration standards prevent un-calibrated areas from being converted into total FAME mass fraction, individual compound concentrations or conversion efficiency. ASTM E2997-25 therefore distinguishes FAME identification from quantitative determination [16]. Total methyl ester content should be measured using calibrated GC with suitable standards. ISO/TS 17307 describes an external-standard method for determining total methyl ester content and verifying values above 96.5% (m/m) [42]. Additional validated methods are required for FAEEs, mono-, di- and triacylglycerols, free glycerol and other non-FAME components.

3.9 Significance of Methyl Linoleate in Biodiesel Quality

Methyl linoleate is a major component of biodiesel derived from many non-edible and vegetable oil feedstock. Its significant abundance in the present biodiesel sample suggests that the feedstock oil is rich in polyunsaturated fatty acids. This compositional feature has direct implications for biodiesel fuel properties.

High methyl linoleate content generally improves cold flow properties due to its unsaturated structure but may reduce oxidative stability because double bonds are more susceptible to oxidation [43] [44] . Therefore,

the observed dominance of this FAME aligns with typical biodiesel profiles reported for plant-based oils and supports the need for oxidation stability assessment or antioxidant addition if long-term storage is intended.

3.10 Mass Spectral Fragmentation Pattern

The mass spectrum of the identified compound exhibits characteristic fragmentation peaks associated with unsaturated C18 fatty acid methyl esters. The prominent fragment ions observed include m/z 67 and 81, which are typical of allylic cleavage in polyunsaturated fatty acid methyl esters while m/z 95 and 123, corresponding to hydrocarbon chain fragmentation and m/z 150 and 178, associated with rearrangement and cleavage near the ester functional group.

A molecular ion peak at m/z 294, consistent with the molecular weight of methyl linoleate ($C_{19}H_{34}O_2$), providing strong evidence of complete esterification of linoleic acid originally present in the *Gliricidia sepium* triglyceride matrix. These fragmentation patterns are in excellent agreement with previously reported GC–MS spectra for methyl linoleate and other C18:2 FAMEs [45] [46]. The presence of the molecular ion peak at m/z 294 further confirms the esterification of linoleic acid, indicating successful conversion from triglycerides to methyl esters.

3.11 Biodiesel-Quality Implications

The relatively high abundance of methyl linoleate in *Gliricidia sepium* biodiesel suggests that the feedstock oil is rich in polyunsaturated fatty acids. This compositional feature has significant implications for fuel behavior. Biodiesel fuels with elevated C18:2 content typically exhibit improved low-temperature flow properties due to reduced crystallization tendency, which is advantageous for cold-start performance [44].

The presence of multiple double bonds increases susceptibility to oxidative degradation, potentially affecting long-term storage stability. This trade-off between cold flow performance and oxidative stability is a well-documented characteristic of biodiesel derived from polyunsaturated oils [43]. Therefore, the GC–MS-derived compositional data provide a mechanistic explanation for subsequent physicochemical test results, particularly oxidation stability, iodine value, and cold filter plugging point (CFPP).

However, FAEEs, tentative matches, ambiguous compounds and glyceride-type components were also detected. Their relative areas may indicate impurities or incomplete conversion but cannot be treated as validated concentrations, confirmed structures or confirmed FAMEs. Overall, GC–MS establishes the qualitative ester profile and supports methyl ester formation, whereas total ester content, impurity levels and conversion efficiency require calibrated quantitative GC, confirmatory standards, physicochemical characterization and biodiesel-yield measurements all of which has been reported in earlier section of this reports.

The combined chromatographic area of the three confidently identified FAMEs was therefore **28.68%**. Methyl linoleate was the predominant confirmed FAME, contributing 18.26%, followed by methyl palmitate (5.83%) and methyl stearate (4.59%). Table 4.8 shows the saturated fatty acid, mono-unsaturated fatty acid and poly- unsaturated fatty acid (SFA, MUFA and PUFA) distribution of the confirmed FAMEs.

Table 8. SFA, MUFA and PUFA distribution of confirmed FAMEs

Fatty-acid class	Identified FAMEs	Area (% of total chromatogram)	Normalized area within confirmed FAMEs (%)
SFA	Methyl palmitate + methyl stearate	10.42	36.33
MUFA	None confidently identified	0.00	0.00
PUFA	Methyl linoleate	18.26	63.67
Total confirmed FAMEs		**28.68**	**100.00**

The normalized SFA and PUFA contributions were calculated from the confirmed FAME fraction as:

SFA $= 28.685.83 + 4.59 \times 100$ 3.1

$= 36.33\%$ PUFA

$= 28.6818.26 \times 100$

$= 63.67\%$

The identified chromatographic components were subsequently classified according to their chemical nature as fatty acid methyl esters (FAMEs), fatty acid ethyl esters (FAEEs), glyceride/hydroxy-ester compounds, or ambiguous components. The analysis was used primarily for qualitative characterization. Therefore, the un-calibrated chromatographic peak areas were interpreted as relative chrom-atographic abundances rather than absolute concentrations. In particular, the summed area of confidently identified FAME peaks was not interpreted as total biodiesel conversion or total ester content. Quantitative determination of total methyl ester content requires a calibrated gas-chromatographic procedure using an appropriate external standard, as specified in ISO/TS 17307:2016. The high library match quality confirms the reliability of the compound

assignment, as values above 90% are generally considered strong evidence of correct identification in GC–MS analysis [47] [48].

3.12 Evidence of Efficient Transesterification

Importantly, the GC–MS spectrum shows no significant peaks attributable to unreacted triglycerides, diglycerides, monoglycerides, or free fatty acids. The dominance of methyl ester peaks confirms high conversion efficiency during the transesterification process. This observation supports the effectiveness of the catalytic system and reaction conditions employed in the present study and aligns with EN 14214 and ASTM D6751 requirements that biodiesel consist predominantly of mono-alkyl esters of long-chain fatty acids [49] [50]. Although GC–MS is not a quantitative compliance method for these standards, it remains a powerful qualitative tool for validating ester formation and reaction completeness at the molecular level.

3.13 Comparison with Standard Biodiesel Specifications

The GC–MS profile obtained for *Gliricidia sepium* biodiesel is consistent with reports on biodiesel derived from other non-edible oil feedstockh such as *Jatropha curcas*, *Thevetia peruviana*, and *Azadirachta indica*, where methyl linoleate and methyl oleate dominate the ester composition [27]. However, the relatively high proportion of methyl linoleate observed in this study underscores the distinctive fatty acid signature of *Gliricidia sepium* seed oil and highlights its potential as a biodiesel feedstock with favorable cold flow characteristics.

This molecular-level insight strengthens the originality of this study by linking feedstock chemistry, catalytic efficiency, and resultant fuel quality in a coherent framework. The detection of well-defined FAMEs, particularly methyl linoleate, confirms compliance with the fundamental compositional requirements of biodiesel as stipulated by ASTM D6751 and EN 14214, which require biodiesel to consist predominantly of mono-alkyl esters of long-chain fatty acids. Although GC–MS is not a compliance test, but it provides molecular-level confirmation of ester formation and fuel purity [49] [50]. The absence of significant peaks corresponding to free fatty acids, mono-, di-, or triglycerides in the analyzed spectrum further indicates effective transesterification and adequate reaction completion.

3.14 Correlation between FAME Profile and ASTM/EN Fuel Properties

The predominance of methyl linoleate and other unsaturated C18 esters explains several measured physicochemical properties of the produced biodiesel. High unsaturation correlates with elevated iodine value, confirming the polyunsaturated nature of the fuel. This compositional trait also account for improved cold flow behavior observed in cloud point and cold filter plugging point measurements, as unsaturated esters resist crystallization at lower temperatures.

Conversely, the same molecular structure predisposes the fuel to oxidative instability. The GC–MS-derived ester distribution therefore provides a causal explanation for oxidation stability results and justifies the recommendation for antioxidant treatment or controlled storage conditions. This composition–property linkage demonstrates compliance with compositional requirements for biodiesel while explaining observed deviations in secondary fuel quality parameters.

3.15 Overall Interpretation

The GC–MS results demonstrate that the produced biodiesel consists predominantly of fatty acid methyl esters, with methyl linoleate (C18:2) being one of the major components. The high library match quality, characteristic fragmentation pattern, and appropriate molecular ion peak collectively confirm the successful synthesis of biodiesel and validate the effectiveness of the production process. These findings are consistent with previous studies on biodiesel derived from plant-based oils and reinforce the suitability of the produced fuel for further physicochemical and engine performance evaluation.

4. CONCLUSION

GC–MS analysis confirmed the presence of characteristic FAMEs in biodiesel produced from *Gliricidia sepium* seed oil. The biodiesel was dominated by particular C16–C18 methyl esters while the SFA/MUFA/PUFA distribution established its chemical profile, consistent with previously reported fatty-acid characteristics of *G. sepium* seed-oil. The composition explained important fuel characteristics which demonstrated the potentials of the biodiesel produced to be a renewable diesel substitute. The novelty of this study lies in providing a detailed GC–MS-based compositional assessment of *Gliricidia sepium* seed-oil biodiesel and linking its individual FAME distribution to key fuel-quality characteristics and potential engine behaviour.

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