

Comparative Study of Soxhlet Extraction and Hydraulic Pressing for Biokerosene Production from Rubber Seeds (*Hevea brasiliensis*)

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ABSTRACT: Biokerosene is a renewable alternative to fossil-based kerosene, derived from biological resources such as rubber seeds. This study evaluates the effects of Soxhlet extraction and hydraulic pressing on biokerosene production, including the influence of stirring speed during degumming and the physicochemical characteristics of the product. Rubber seed masses of 50, 75, and 100 g were tested, with degumming conducted at 150 and 300 rpm. The highest oil yield (46%) was obtained using Soxhlet extraction at 50 g. However, superior product quality was achieved through hydraulic pressing at 75 g and 150 rpm, yielding the lowest free fatty acid (FFA) value (4.47 mg KOH/g) and the highest proportion of C10–C16 hydrocarbons (56.54%). The resulting biokerosene exhibited densities of 913.8–929.4 kg/m³ and viscosities of 2.6–3.6 cSt. These findings indicate that Soxhlet extraction is more effective for maximizing yield, while hydraulic pressing produces higher quality intermediates that are better suited for downstream upgrading into aviation fuel.

Keywords: rubber seeds; soxhlet extraction; hydraulic press; biokerosene

1. Introduction

The global energy landscape from 2024 to 2026 faces significant decarbonization challenges, with primary energy demand projected to grow by 2.2% per year and the transport sector accounting for a substantial share of carbon emissions (IEA, 2025). The development of Sustainable Aviation Fuel (SAF) or biokerosene has become a priority due to its potential to reduce greenhouse gas emissions by up to 80% while remaining compatible with existing engine infrastructure (The Business Research Company, 2026). Various biomass sources have been explored, including microalgae, coconut waste, and Palm Oil Mill Effluent (POME), each with distinct advantages and limitations. In this context, rubber seed oil (*Hevea brasiliensis*) represents a promising non-edible feedstock in Indonesia, with annual production reaching approximately 5 million tonnes, offering significant potential without competing with food resources.

Rubber seed oil exhibits favorable physicochemical properties for biofuel applications, including oil yields of 50.0–50.8%, high heating values (31.8–33.3 kJ/g), and flash points of 237–245 °C (Alam et al., 2024). Its composition is dominated by unsaturated fatty acids such as oleic and linoleic acids, which influence fuel characteristics (Alam et al., 2024; Tambunan et al., 2024). Additionally, its viscosity and density fall within ranges suitable for conversion into biohydrocarbon fuels (Tambunan et al., 2024). However, the

efficiency of biokerosene production is strongly influenced by the extraction and purification stages. Previous studies highlight the importance of extraction techniques in determining yield and composition (Mahreni et al., 2024), as well as the role of process parameters such as catalysts, temperature, and stirring speed in controlling conversion efficiency and product quality (Panjaitan, 2026; Maulana & Setyoningrum, 2019; Sisdikarini, 2026).

This study addresses the need for a more selective and efficient biokerosene production method by focusing on the targeted formation of C10–C16 hydrocarbons. The novelty lies in the direct comparison between Soxhlet extraction and hydraulic pressing, combined with the evaluation of stirring speeds (150 and 300 rpm) during degumming (Rahim & Nadir, 2024; Yang et al., 2021). Unlike solvent-based extraction, hydraulic pressing operates under mild mechanical conditions, preserving fatty acid composition and reducing free fatty acid formation, thereby improving hydrocarbon selectivity (Salimi et al., 2025; Zhang et al., 2024). Therefore, this study aims to determine the optimal processing conditions based on yield, physicochemical properties, and GC-MS analysis, while assessing the potential of rubber seed oil as a sustainable feedstock for aviation fuel production.

2. Materials and Methods

The rubber seeds used in this study were obtained from rubber plantations in the Pengaron area, South Kalimantan.

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The chemicals used included n-hexane, phosphoric acid, sodium hydroxide, pH indicators, and ethyl alcohol, all of which were analytical grade reagents. All of these chemicals were manufactured by Merck and obtained through local chemical suppliers. Furthermore, the Soxhlet extraction and hydraulic pressing methods were applied in the production process of biokerosene from rubber seed oil.

2.1. Experimental Procedure

A two-factor experimental design was used to evaluate the effects of rubber seed mass (50, 75, and 100 g) and stirring speed during the degumming (150 and 300 rpm) on oil yield, physicochemical properties, and hydrocarbon composition.

The dried rubber seeds were weighed at 50 g, 75 g, and 100 g using an Ohaus balance. Next, the rubber seeds were ground using a blender until smooth. The samples were then placed in a Soxhlet extraction apparatus lined with filter paper. Three hundred millilitres of n-hexane solvent was poured into a round-bottomed three-necked flask. The extraction results were then distilled using a simple distillation setup comprising a round-bottom flask, a condenser, and a heating mantle at 65–70 °C for approximately 60 minutes to completely remove the solvent.

In the hydraulic pressing method, the rubber seeds were first ground to facilitate oil extraction. Next, the rubber seeds were placed in a press cylinder lined with filter cloth, then pressed at 30 kN using a hydraulic press. The resulting rubber seed oil was filtered using filter paper and a vacuum pump.

The extracted rubber seed oil is then mixed with a 2% H₃PO₄ solution (w/w relative to the oil) for degumming. This process is carried out at 60 °C with stirring speeds of 150 and 300 rpm for 30 minutes. The resulting sample is then centrifuged at 4000 rpm for 10 minutes to separate the gum precipitate from the oil. This procedure is also applied to rubber seed oil obtained by hydraulic pressing.

The centrifuged oil is then added to a 1% NaOH solution (w/w relative to the oil). The mixture is stirred continuously for 10 minutes until soap forms at the bottom. Next, the mixture is filtered, and the oil layer is separated and collected for further analysis.

2.2. Analysis Method

2.2.1 Analysis of Physicochemical Properties (FFA, Density, and Viscosity)

Physicochemical analysis was conducted to evaluate the quality of rubber seed oil and biokerosene products produced before and after the conversion process. The parameters analysed included free fatty acid (FFA) content, density, and viscosity, which serve as the main indicators of stability, purity, and fuel flow characteristics.

FFA measurements were performed by alkalimetric titration with sodium hydroxide (NaOH) as the titrant and phenolphthalein as the indicator to determine the endpoint. FFA values were used to assess the extent of oil degradation and the need for additional purification steps.

The sample density was measured at room temperature using a pycnometer/densitometer, and viscosity was determined using a viscometer under controlled temperature

conditions. The density and viscosity parameters were used to evaluate the suitability of the fuel's physical properties relative to aviation fuel standards.

The results of this physicochemical analysis are then used to assess the suitability of rubber seed oil as a raw material for biokerosene and the effectiveness of the applied conversion process.

2.2.2 Mass Balance and Energy Conversion Analysis

Mass balance analysis was conducted to evaluate the efficiency of oil extraction and subsequent conversion processes from rubber seeds. The oil yields obtained from Soxhlet extraction and hydraulic pressing were calculated as the ratio of extracted oil to the initial mass of the raw material. Furthermore, conversion efficiency was determined to assess the effectiveness of transforming crude oil into refined biokerosene products.

$$\text{Oil Yield (\%)} = \frac{\text{Volume of extracted oil}}{\text{Mass of rubber seeds}} \times 100\% \quad (1)$$

$$\text{Conversion (\%)} = \frac{\text{Mass of refined product}}{\text{Mass of crude oil}} \times 100\% \quad (2)$$

$$\text{Overall Yield (\%)} = \frac{\text{Mass of refined product}}{\text{Mass of rubber seeds}} \times 100\% \quad (3)$$

2.2.3 Gas Chromatography–Mass Spectrometry Analysis (GC-MS)

Gas Chromatography–Mass Spectrometry (GC-MS) was used to identify and analyse biokerosene components. The analysis used an 8890 GC instrument with a 5977B mass spectrometer (MS), flame ionisation detector (FID), and autosampler/injector for accurate, repeatable measurements. Mass spectra, showing ion intensities as a function of mass-to-charge ratio, were compared with a standard library to determine the hydrocarbon distribution and the suitability of the sample for aviation fuel.

3. Results and Discussion

3.1. Free Fatty Acid Measurement

Free fatty acid (FFA) analysis was performed using the alkalimetric method. The results of FFA analysis using the solvent extraction and hydraulic press methods are shown in Table 1. These FFA values indicate oil damage, rancidity, or oil quality.

The analysis results in Table 1 show differences in FFA values across oil extraction methods. The FFA value in solvent extraction is higher than that in hydraulic pressing. This is due to oxidation during the solvent extraction process when heating (Asuquo et al., 2012). Therefore, the higher the FFA value, the greater the level of oil damage, as more triglyceride molecules are converted into glycerol and FFA (Wildan et al., 2013). Thus, the quality of the extracted biokerosene is lower than that obtained from hydraulic pressing. The lowest FFA value was 4.47 mg KOH/g in hydraulic pressing, while the highest was 59.04 mg KOH/g in Soxhlet extraction.

Table 1. FFA Data on Soxhlet Extraction and Hydraulic Press

Rubber Seed Mass (g)	Degumming Stirring Speed (rpm)	Free Fatty Acids (mg KOH/g)	
		Soxhlet Extraction	Hydraulic Press
50	150	27.74	4.86
	300	37.89	6.54
75	150	46.87	4.47
	300	59.04	6.59
100	150	35.97	5.47
	300	29.06	5.97

It is important to note that the FFA values in Table 1 were measured after degumming and neutralization. Crude rubber seed oil is known to have naturally high acidity. Aigbodion and Bakare (2005) reported that the natural form of rubber seed oil is highly acidic with an acid value of approximately 43.6 mg KOH/g, while Asuquo et al. (2012) reported FFA values of crude rubber seed oil reaching 43.62 mg KOH/g. The reduction in FFA from approximately 59 mg KOH/g in crude oil to 27.74 mg KOH/g in certain samples after degumming and neutralization demonstrates the purification process's effectiveness. However, these values remain substantially higher than the maximum limit for biodiesel feedstocks. According to ASTM D6751 (ASTM International, 2023), the standard specification for biodiesel (B100), the free fatty acid content must be below 0.5% (approximately 1 mg KOH/g) to prevent saponification during alkaline-catalyzed transesterification.

Table 2. Average Oil Yield from Soxhlet Extraction and Hydraulic Pressing

Sample Mass (g)	Soxhlet Yield (%)	Hydraulic Press Yield (%)
50	46.00	12.70
75	28.70	14.10
100	17.46	17.20

To produce pure hydrocarbons that meet biofuel standards, advanced processing stages are required. For high-FFA oils (>0.5%), a two-step process of acid-catalyzed esterification followed by alkaline transesterification is necessary to convert both free fatty acids and triglycerides into biodiesel (Morshed et al., 2011). For renewable jet fuel production, catalytic deoxygenation is essential to remove oxygen from fatty acid chains through hydrodeoxygenation (HDO), decarboxylation (DCO₂), and decarbonylation (DCO) pathways, producing hydrocarbons identical to fossil kerosene (Alkhoori et al., 2024; Chen & Wang, 2023). Given its fatty acid composition, dominated by palmitic, oleic, and linoleic acids, rubber seed oil has the potential to be converted to bio-jet fuel as effectively as other vegetable oils through these processes (Babatunde & Ogunkunle, 2022).

3.2. Mass Balance and Conversion Efficiency

Based on the data in Table 2, mass balance analysis shows that Soxhlet extraction produced a higher crude oil yield (46.0% at 50 g) compared to hydraulic pressing (12.7% at 50 g and 17.2% at 100 g). However, Soxhlet performance decreased with increasing sample mass due to mass transfer limitations, reduced solvent to solid ratio, and early solvent saturation, which hinder oil diffusion (De Castro & García Ayuso, 1998; IUPAC, 2025). In contrast, hydraulic pressing showed improved efficiency at higher sample mass as increased material loading enhanced mechanical compression and oil expulsion (Santoso, H. et al., 2014).

Table 3. Mass Balance and Conversion Efficiency

Parameters	Soxhlet Extraction	Hydraulic Press
Sample mass (g)	50.0	100.0
Crude oil (g)	23.0	17.46
Refined product (g)	9.4	9.25
Conversion efficiency (%)	40.9	53.0
Overall yield (%)	18.8	9.25

As shown in Table 3, despite the lower crude yield, hydraulic pressing achieved a higher conversion efficiency (53.0%) than Soxhlet extraction (40.9%), mainly because it had a lower free fatty acid (FFA) content, which reduced losses during purification. Soxhlet extraction, involving prolonged heating, promotes triglyceride hydrolysis and increases FFA formation, leading to greater product loss during degumming and neutralization (Onoji, S. E. et al., 2016; Alam, M. A. et al., 2024). Consequently, Soxhlet extraction resulted in a higher overall yield (18.8%), while hydraulic pressing produced a lower overall yield (9.25%) but with better product quality and higher suitability for downstream processing.

3.3. Density Measurement

Density measurement, as one of the physicochemical parameters of biokerosene, was carried out using a pycnometer. The density measurement results are shown in Figures 1 and 2, which were conducted to determine the density values in the solvent extraction and hydraulic compression methods that meet the standard density specifications for petroleum-based biokerosene.

The density measurement results in Figures 1 and 2 show differences in density values between the two methods, namely, Soxhlet extraction and hydraulic pressing. Biokerosene obtained from various treatments showed varying densities, but the differences remained within a similar range. The difference in biokerosene density values between the two methods is due to differences in constituent components, such as varying levels of free fatty acids, which result in different densities for each sample (Nicholas & Sanderson, 2003). The density of biokerosene in the Soxhlet extraction method, based on measurement results, ranged from 936 to 940 kg/m³, while the density in hydraulic pressing ranged from 913 to 929 kg/m³. The density of biokerosene from this experiment is relatively similar to that reported by Santoso et al. (2014) at 920 kg/m³ and higher

than that reported by Llamas et al. (2012) at 870 kg/m³. According to the standards set by the Directorate General of Oil and Gas Decree No. 21K/72/DDJM/1990, the maximum density of kerosene is 991 kg/m³. Therefore, the density of biokerosene in this study remains within the standard limits set.

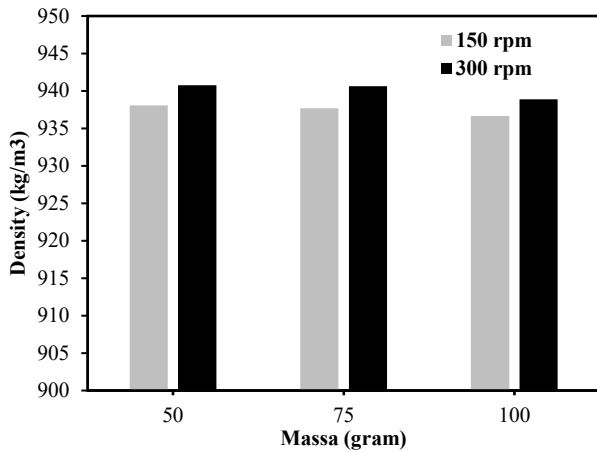


Figure 1. Density Results in Soxhlet Extraction Method

It is important to note that the density values obtained in this study, while meeting the national standard for kerosene (Directorate General of Oil and Gas Decree No. 21K/72/DDJM/1990), are considerably higher than the specifications for aviation turbine fuel (avtur) according to ASTM D1655. The ASTM D1655-25a standard requires a density at 15°C of 775–840 kg/m³ for Jet A and Jet A-1 aviation turbine fuels (ASTM International, 2025). This comparison indicates that our product is more suitable for household or industrial applications as fuel oil, or as a blending component with fossil kerosene, rather than as a direct substitute for aviation fuel. Llamas et al. (2012) demonstrated that blending vegetable oils with fossil kerosene can effectively reduce density to meet avtur specifications, showing that babassu and camelina biokerosenes could be blended with commercial Jet-A1 up to 10 vol% while meeting selected ASTM D1655 standards, including density, smoke point, flash point, and kinematic viscosity.

To produce pure hydrocarbons that fully meet aviation fuel standards (ASTM D7566), advanced processing stages are required. The conversion of vegetable oils into jet fuel-range hydrocarbons involves catalytic upgrading processes, including hydrotreating (hydrodeoxygenation and hydrodecarboxylation) followed by hydroisomerization. Galadima and Muraza (2015) reported that catalysts based on Ni and Mo supported on oxides are highly active for hydrotreating, while Pd and Pt supported on zeolites serve as effective hydroisomerization catalysts to improve cold-flow properties. For rubber seed oil specifically, Baidoo et al. (2022) demonstrated through simulation using the UOP HEFA (Hydroprocessed Esters and Fatty Acids) process that 81% of rubber seed oil feedstock could be converted to hydrocarbons with an aviation biofuel yield of 46%, establishing that rubber seed oil shows suitability and potential for sustainable aviation

biofuel production. Therefore, while our current product is refined rubber seed oil that meets kerosene density standards, further processing through catalytic deoxygenation and hydroprocessing is necessary to produce drop-in biofuels chemically identical to fossil fuels.

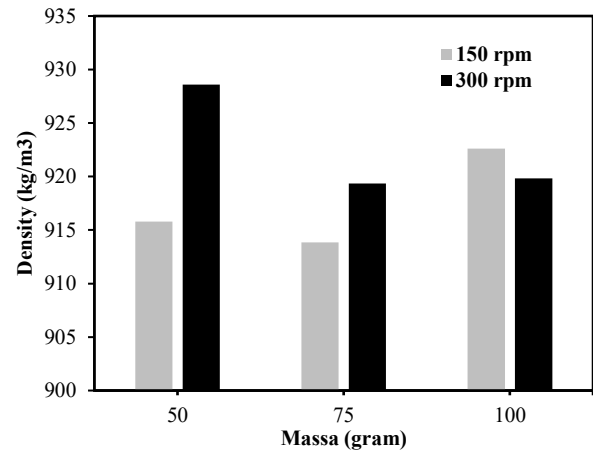


Figure 2. Density Results in Hydraulic Pressing Method

3.4. Viscosity Measurement

Viscosity measurements were conducted using an Ostwald viscometer, with water viscosity and density data used as references. The biokerosene viscosity values obtained from the Soxhlet extraction and hydraulic press methods showed significant differences, as shown in Figures 3 and 4. The viscosity values of the hydraulic press samples were higher than those of the Soxhlet extraction samples, although the differences were still within the same range. This difference occurs because viscosity is influenced by double bonds, molecular weight, and carbon chain length, and viscosity increases with longer fatty acid chains and decreases with increasing oil unsaturation (Adekunle, 2016).

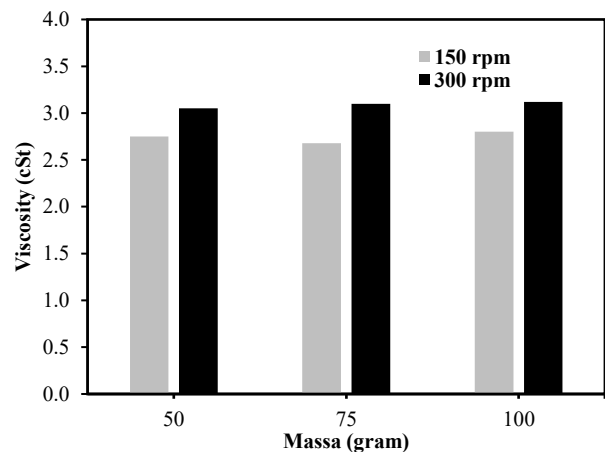


Figure 3. Viscosity Results in Soxhlet Extraction Method

GC-MS analysis showed that the Soxhlet-extracted sample had a longer carbon chain than the hydraulic-press sample. Therefore, this aspect affected the viscosity values of both methods. The biokerosene viscosity values in this study ranged from 3.1 to 3.4 mm²/s for Soxhlet extraction

and 2.6 to 3 mm²/s for hydraulic pressing. These values are lower than those reported by Llamas et al. (2020), which ranged from 3.26 to 8.26 mm²/s. Therefore, the biokerosene viscosity values in this study still meet the standards set forth in the Director General of Oil and Gas Regulation No. 21K/72/DDJM/1990 and ASTM-D1655, with a maximum viscosity of 8 mm²/s.

3.5. Biokerosene Analysis

A biorefinery is a concept for converting biomass or waste obtained directly or indirectly from microorganisms, algae, plant materials, etc., into various valuable by-products (biofuels, bioenergy, biochemicals, etc.) that are environmentally friendly and economically important (Agrawal & Verma 2024). In this study, biokerosene was produced from rubber seed oil using Soxhlet extraction and hydraulic pressing, followed by purification through degumming and neutralization.

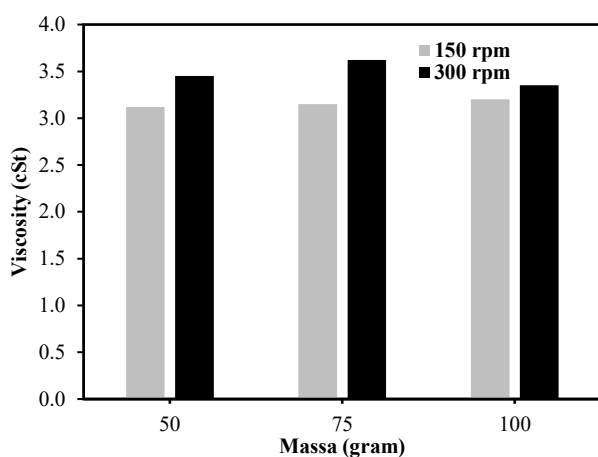


Figure 4. Viscosity Results in Hydraulic Pressing Method

GC-MS analysis was performed on all samples obtained by Soxhlet extraction and hydraulic pressing to evaluate the distribution of the resulting compound. The results indicate that only the 50 g samples, for both Soxhlet extraction and hydraulic pressing, exhibited a more pronounced and clearly defined carbon chain distribution, particularly within the C10–C16 range. This behavior can be attributed to a more favorable solvent-to-solid ratio in Soxhlet extraction and lower matrix complexity in hydraulic pressing, which enhances the selective release of hydrocarbon compounds while minimizing the co-extraction of heavier oxygenated species (Luque de Castro & García-Ayuso, 1998; Alam et al., 2024).

As shown in Figures 5 and 6, although all samples were dominated by fatty acid, only the 50 g samples showed a higher abundance and more distinct distribution of hydrocarbon compounds. In contrast, higher sample masses tended to produce chromatograms dominated by oxygenated compounds with less-defined hydrocarbon distributions, likely due to solvent saturation in Soxhlet extraction and increased co-extraction of complex lipid fractions during hydraulic pressing (Santoso et al., 2014; Onoji et al., 2016).

These findings suggest that lower mass conditions (50 g) provide better extraction selectivity toward hydrocarbon compounds, making them more representative for evaluating the potential of rubber seed oil as a precursor for bio-jet fuel range hydrocarbons (C10–C16) (Alkhoori et al., 2023; Chen & Wang, 2023).

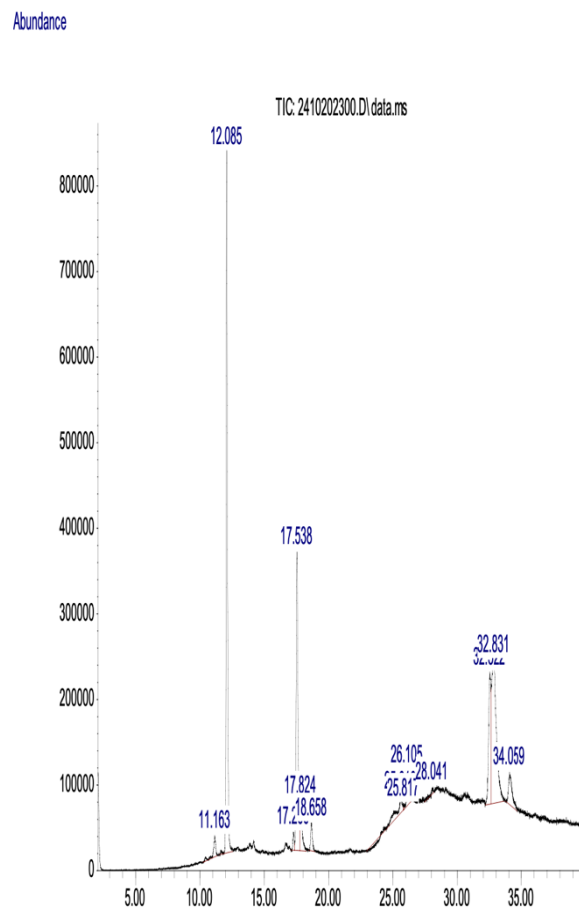


Figure 5. GC-MS Chromatogram of Biokerosene Product (Solvent Extraction)

As summarized in Figure 7, hydraulic pressing exhibited a higher proportion of C10–C16 hydrocarbons (56.94%) compared to Soxhlet extraction (32.54%), indicating improved selectivity toward jet fuel range hydrocarbons. The C10–C16 carbon range is particularly important as it corresponds to the typical composition of aviation turbine fuels (ASTM International, 2024; ASTM International, 2025). Soxhlet extraction yielded products dominated by fatty acids, such as pentadecanoic acid and oleic acid, whereas hydraulic pressing produced a more diverse composition, including hydrocarbons, aldehydes, and fatty acids. This trend is consistent with previous findings that mechanical extraction preserves hydrocarbon structures more effectively than thermal solvent-based methods (Santoso et al., 2014; Alam et al., 2024).

This difference is attributed to the extraction mechanism. Soxhlet extraction involves prolonged heating, which enhances lipid release but also promotes triglyceride

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hydrolysis and the formation of oxygenated compounds (Luque de Castro & García Ayuso, 1998; IUPAC, 2025). In contrast, hydraulic pressing operates under mild mechanical conditions, preserving the native oil composition and reducing the formation of free fatty acids and oxidized derivatives, thereby improving hydrocarbon selectivity (Alam et al., 2024).

removes oxygen from fatty acids through hydrodeoxygenation, decarboxylation, and decarbonylation pathways, producing n-paraffin hydrocarbons (Khan et al., 2019; Alkhoori et al., 2023). With appropriate catalysts such as Ni, Mo, Pd, and Pt supported on materials like γ -Al₂O₃ or zeolites, and suitable operating conditions of 300–400 °C and 1–5 MPa, this process can convert rubber seed oil into drop in bio jet fuel with properties comparable to fossil derived fuels (Eller et al., 2016; Muhammad et al., 2019; Chen et al., 2023).

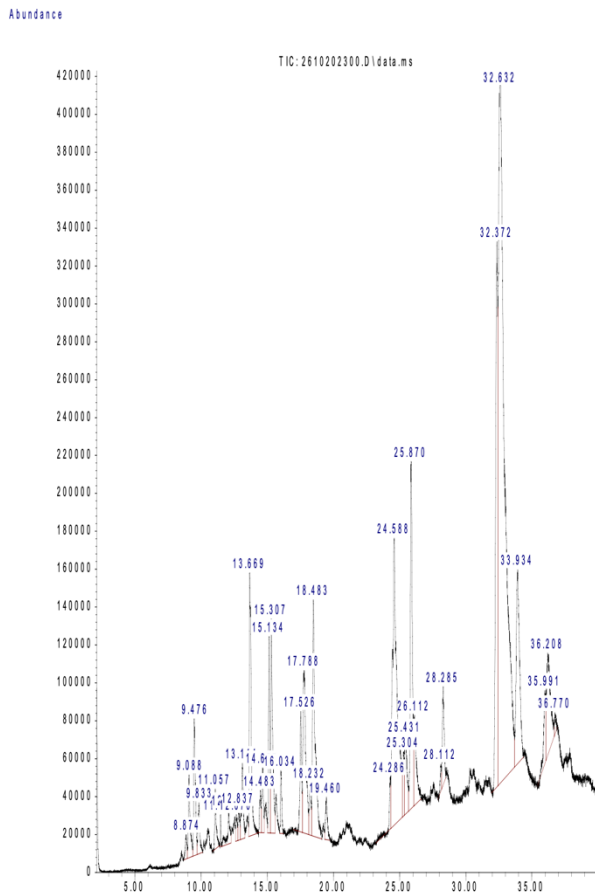


Figure 6. GC-MS Chromatogram of Biokerosene (Hydraulic Press)

In terms of energy content, although the Higher Heating Value was not experimentally measured, literature data suggest that rubber seed oil has an HHV of approximately 37–40 MJ/kg (Onoji et al., 2016; Hernando, 2013), which is below the ASTM requirement of 42.8 MJ/kg for aviation fuels (ASTM International, 2024). This indicates that additional upgrading processes are required to improve fuel quality. Furthermore, simulation studies have shown that rubber seed oil can be effectively converted hydrocarbons via hydroprocessing routes, such as the HEFA process, yielding significant biojet fuel yields (Baidoo et al., 2022).

It is important to note that the product obtained in this study is refined rubber seed oil, not pure hydrocarbons; although its physical properties, such as density and viscosity, approach those of kerosene, the presence of oxygenated compounds prevents it from being classified as aviation fuel. To achieve fuel quality that meets ASTM standards, catalytic deoxygenation is required, a process that

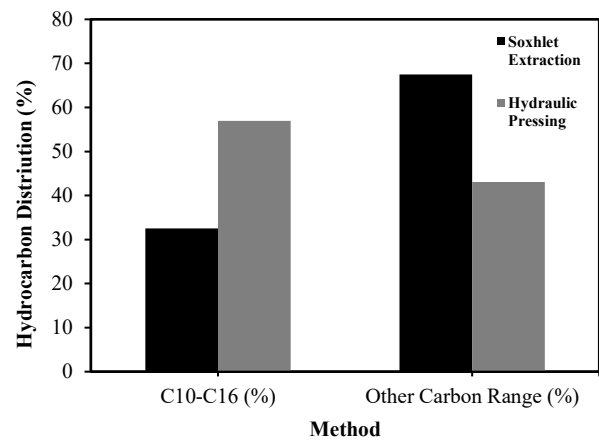


Figure 7. Comparison of carbon chain distribution in biokerosene products obtained from Soxhlet extraction and hydraulic pressing.

Overall, these findings demonstrate that while Soxhlet extraction is more effective in maximizing oil yield, hydraulic pressing provides better hydrocarbon selectivity and product quality, making it more suitable as a feedstock preparation step for advanced biojet fuel production.

4. Conclusions

Biokerosene production from rubber seeds was successfully achieved using Soxhlet extraction and hydraulic pressing, showing distinct performance in terms of yield and product quality. The highest crude oil yield (46%) was obtained using Soxhlet extraction at a sample mass of 50 g. However, superior product quality was achieved by hydraulic pressing at 75 g and 150 rpm, yielding the lowest free fatty acid (FFA) value (4.47 mg KOH/g) and the highest selectivity toward C10–C16 hydrocarbons (56.54%). In terms of physicochemical properties, Soxhlet extraction produced biokerosene with higher density and viscosity, whereas hydraulic pressing produced biokerosene with lower density and viscosity, indicating more favorable fuel characteristics. Overall, Soxhlet extraction is more effective at maximizing yield, while hydraulic pressing enhances hydrocarbon selectivity within the jet fuel range, making it more suitable for further upgrading into aviation biofuel. However, the current product remains a refined rubber seed oil intermediate requiring further catalytic processing.

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Statement

During the preparation of this work, the authors used ChatGPT 4 to improve English language and to proofread the text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

CRedit authorship contribution statement

Indah Retno Wulandary: Conceptualization, Investigation, Formal analysis, Writing – original draft, Writing – review and editing, Visualization, Validation.

Abubakar Tuhouloula: Conceptualization, Methodology, Supervision, Resources, Validation, Writing – review and editing.

Meilana Dharma Putra: Investigation, Formal analysis, Visualization, Validation, Writing – review and editing.

Dewi Dheana Hermana: Investigation, Resources, Data curation, Formal analysis.

Annisa Maghfira: Investigation, Visualization, Data curation.

Marliana Hartati: Resources, Validation, Writing – review and editing.

Nur Ainah: Investigation, Data curation, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data availability

The data supporting this study are included in the article and its appendices, and additional raw data are available from the corresponding author upon reasonable request.

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