Journal of Harbin Engineering University
ISSN: 1006-7043
Vol 47 No. 03
March 2026

Production of Biodiesel from *Phyllanthus emblica* Seeds Using Activated Charcoal as Heterogeneous Catalyst

Dhasarathan P[1], Muthulakshmi K[1], Naveenkumar. K[1], Jerin Joshna J[1*]

1 - Dept. of Biotechnology, Prathyusha Engineering College, Tiruvallur- 602025

*Corresponding author: jerinjoshnaj.biotech@prathyusha.edu.in

Abstract

The growing demand for sustainable and eco-friendly energy sources has led to increased attention toward biodiesel as a viable alternative to conventional fossil fuels. However, the reliance on edible feed stocks for biodiesel production has raised food security and ethical concerns, prompting the exploration of non-edible oil sources. In the present investigation, *Phyllanthus emblica* (Indian gooseberry) seed oil is a non-edible and underutilized resource was evaluated for biodiesel production. The seeds were dried, powdered, and subjected to optimized oil extraction using multiple techniques. The extracted oil was characterized via Gas Chromatography–Flame Ionization Detection (GC-FID) to determine its fatty acid composition. Biodiesel synthesis was carried out through transesterification using dimethyl carbonate (DMC) as a greener alternative to methanol and activated charcoal as a solid catalyst. The activated charcoal was prepared and analyzed by Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) to assess its surface morphology and functional groups. Reaction parameters—including temperature (40, 60, 80 °C), DMC-to-oil molar ratio (2:1–8:1), and catalyst concentration (1.5–2.5 wt%)—were optimized to achieve maximum biodiesel yield. The produced biodiesel was confirmed and characterized using Gas Chromatography–Mass Spectrometry (GC–MS), which validated the formation of fatty acid alkyl esters. The study highlights *Phyllanthus emblica* seed oil as a sustainable feedstock for biodiesel production and emphasizes the potential of environmentally benign catalysts and transesterification agents in green fuel technology.

Keywords: Biodiesel, *Phyllanthus emblica*, Nonedible oil, Dimethyl carbonate, Activated charcoal, Transesterification, GC-FID, GC-MS, FTIR, SEM, Sustainable energy, Green catalyst

1. INTRODUCTION

The depletion of fossil fuel reserves and rising greenhouse gas emissions has intensified the search for renewable and sustainable energy alternatives. Biodiesel, a renewable fuel derived from biological sources, has gained attention for its biodegradability, lower emissions, and compatibility with existing diesel engines. However, the widespread use of edible oils such as soybean and palm for biodiesel production raises food security and economic concerns. This challenge has shifted focus toward non-edible oil feed stocks that are both sustainable and cost-effective. *Phyllanthus emblica* (Indian gooseberry) is a promising nonedible source, as its seeds—often discarded as waste—contains significant oil content suitable for biodiesel production. Using this underutilized resource supports waste valorization and environmental sustainability. In this study, P. emblica seed oil was extracted, characterized, and utilized for biodiesel synthesis using dimethyl carbonate (DMC) as a greener alternative to methanol and activated charcoal as a reusable solid catalyst. Analytical techniques such as GC-FID, FTIR, SEM, and GC-MS were used to evaluate oil composition, catalyst properties, and biodiesel formation. This approach demonstrates an efficient and eco-friendly route for biodiesel production from non-edible feed stocks, contributing to cleaner energy solutions and a circular bio economy.

1.1 Background of the Study

The increasing global energy demand and environmental degradation caused by fossil fuel combustion have encouraged research into renewable and cleaner energy sources. Among various alternatives, biodiesel has gained prominence as an eco-friendly and sustainable substitute for diesel. It consists of fatty acid alkyl esters (FAAEs) produced through the transesterification of oils or fats with alcohols. Biodiesel is renewable, biodegradable, and significantly reduces emissions of carbon monoxide, hydrocarbons, and particulates compared to conventional diesel fuels. India, as a developing nation with high energy consumption, heavily depends on imported petroleum. Utilizing non-edible oilseed resources such as *Phyllanthus emblica, Jatropha curcas*, and *Pongamia pinnata* can support energy security while addressing environmental concerns. The seeds of P. emblica, commonly known as Indian gooseberry, are rich in oil that is typically discarded as waste, offering a sustainable source for biodiesel production.

1.2 Need for Biodiesel Production

The global transportation sector is a major consumer of fossil fuels, contributing significantly to greenhouse gas emissions and climate change. Biodiesel presents an ideal renewable energy solution due to its clean-burning nature and ability to be used directly in diesel engines. It reduces CO_2 emissions by up to 78% compared to petroleum diesel (Demirbas, 2009). Moreover, biodiesel production from non-edible and waste feed stocks reduces dependency on imported crude oil and supports rural economic development by creating value from underutilized biomass. The global biodiesel market is projected to reach US$59.8 billion by 2030, driven by sustainable energy policies and environmental regulations (IEA, 2024). This emphasizes the necessity of exploring alternative feed stocks such as *Phyllanthus emblica*, which can provide both economic and ecological benefits.

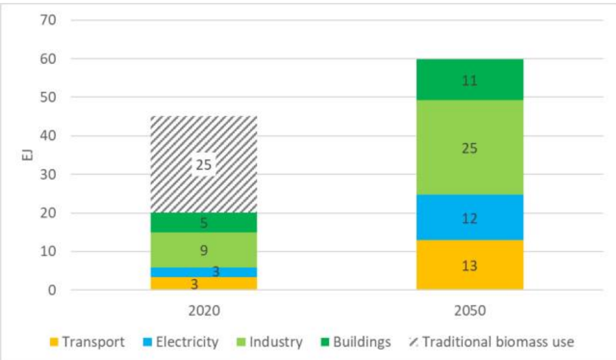


Figure 1.1 Growth of bioenergy in global final energy consumption by sector, according to the IEA Net Zero by 2050 scenario (data source: IEA (2021) Net Zero by 2050)

2. OBJECTIVES

The present study aims to explore the feasibility of biodiesel production from non-edible *Phyllanthus emblica* seed oil using dimethyl carbonate (DMC) as a green transesterification agent and activated charcoal as a reusable heterogeneous catalyst. The specific objectives include:

1. To extract oil from *Phyllanthus emblica* seeds and analyze its physicochemical properties.

2. To characterize the fatty acid profile of the extracted oil using GC-FID.

3. To prepare and analyze activated charcoal using FTIR and SEM for catalyst morphology.

4. To optimize transesterification parameters—temperature, molar ratio, and catalyst concentration—for maximum biodiesel yield.

5. To confirm the formation of fatty acid alkyl esters using GC-MS analysis.

6. To evaluate the overall efficiency and sustainability of *P. emblica* seed oil as a biodiesel feedstock.

3. BACKGROUND STUDY

3.1 Overview of Biodiesel Production

Biodiesel is a renewable biofuel composed mainly of fatty acid alkyl esters (FAAE) produced via the transesterification of triglycerides derived from vegetable oils or animal fats with short-chain alcohols (Knothe et al., 2010). This process reduces the viscosity of oils, making them suitable for compression ignition engines. Biodiesel has comparable performance characteristics to fossil diesel, with advantages such as low sulfur content, biodegradability, and reduced CO_2 and particulate emissions (Demirbas, 2009). Globally, biodiesel production has expanded significantly, driven by government policies promoting renewable energy and climate change mitigation. The global production reached over 42 billion liters in 2023, with Europe, the United States, Brazil, and India among the top producers (IEA, 2024). Despite its potential, large-scale biodiesel production still faces challenges related to feedstock cost and sustainability**.**

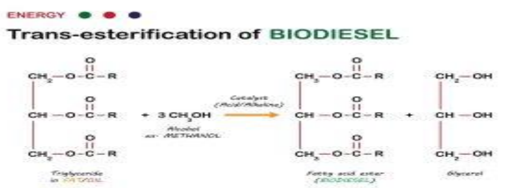
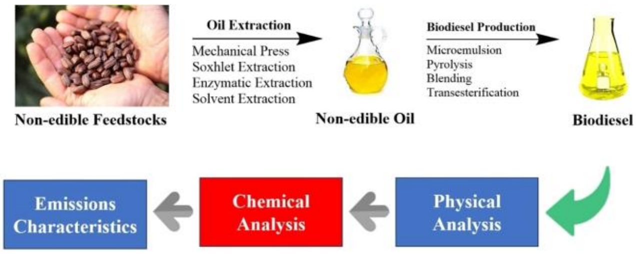


Figure 3.1 Transesterification process of biodiesel

3.2 Use of Non-Edible Feed stocks

Non-edible oils have emerged as promising alternatives to edible oils, addressing the food vs. fuel debate. Plants such as *Jatropha curcas, Pongamiapinnata* (Karanja), Ricinus communis(Castor), and *Phyllanthus emblica* (Amla) have high oil content (30–60%) and can grow on degraded or marginal soils with minimal agricultural inputs (Atabani et al., 2013).Using non-edible feedstocks enhances energy security, minimizes competition with food resources, and supports waste valorization. These oils, however, often contain higherfree fatty acid (FFA**)** levels, requiring optimized pretreatment and reaction conditions for efficient transesterification (Lam et al., 2018). Recent studies have demonstrated that biodiesel derived from non-edible sources provides comparable engine performance and emission profiles to conventional biodiesel (Sharma & Singh, 2019).



Fiigure 3.2 Non-Edible feed stocks

3.3 Catalysts in Transesterification

Catalysts play a crucial role in biodiesel synthesis, influencing reaction rate, yield, and product purity. Traditionally, homogeneous catalysts such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) have been used due to their high efficiency and short reaction time. However, they present challenges in product separation and generate wastewater during purification. In contrast, heterogeneous catalysts like activated charcoal, zeolites, metal oxides, and ion-exchange resins are gaining attention for their reusability, ease of recovery, and minimal environmental impact (Semwal et al., 2011). Activated charcoal, in particular, offers a large surface area and tunable porosity that enhances catalytic activity. Its use as a solid base or acid catalyst provides an environmentally benign and economically viable alternative for sustainable biodiesel production (Hameed et al., 2019).

3.4 Use of Dimethyl Carbonate as Alcohol Substitute

The conventional transesterification process employs methanol, a toxic and fossil-based reagent. Replacing methanol with dimethyl carbonate (DMC) presents a greener alternative due to its non-toxic, biodegradable, and renewable nature. DMC can effectively react with triglycerides, producing biodiesel with high yield and better cold-flow properties (Liu et al., 2017). Furthermore, DMC-based transesteri-fication eliminates glycerol as a by-product, generating glycerol carbonate instead—a valuable compound used in pharmaceuticals and polymers (Taufiq-Yap et al., 2014). Studies indicate that the DMC method, when coupled with heterogeneous catalysts, significantly improves reaction efficiency while aligning with the principles of green chemistry.

3.5 Previous Studies on *Phyllanthus emblica* Seeds

Research on *Phyllanthus emblica* (Indian gooseberry) has primarily focused on its medicinal properties, but recent studies have explored its seed oil as a nonedible feedstock for biodiesel. P. emblica seeds contain 30–35% oil, rich in linoleic and oleic acids, making it suitable for transesterification (Singh et al., 2021). In one study, seed oil was extracted using solvent extraction and converted to biodiesel via base-catalyzed transesterification, achieving yields above 85% (Kumar & Gupta, 2020). Another investigation utilized dimethyl carbonate as the alcohol substitute and activated charcoal as a catalyst, optimizing parameters such as temperature and molar ratio to enhance yield (Patil et al., 2022). These findings confirm that P. emblica seed oil is a promising and sustainable resource for biodiesel production, combining waste utilization and clean fuel generation.

4. MATERIALS AND METHODS

4.1 Collection and Preparation of *Phyllanthus emblica* Seeds

Ripe fruits of *Phyllanthus emblica* (Indian gooseberry) were collected from local markets and thoroughly washed with distilled water to remove adhering pulp and impurities. The seeds were separated manually, shade-dried for 5–7 days, and then oven-dried at 60 °C for 4 hours to remove residual moisture. The dried seeds were ground into a fine powder using a high-speed grinder and sieved to obtain a uniform particle size (<500 µm) suitable for oil extraction.

Figure 4.1*Phyllanthus emblica* Seeds

4.2 Oil Extraction Processes

Oil was extracted from the powdered seed samples using the Soxhlet extraction method with n-hexane as solvent. Approximately 50 g of seed powder was loaded into a thimble, and extraction was carried out for 6 hours at the boiling point of hexane (≈68 °C). The solvent was recovered using a rotary evaporator, and the extracted oil was dried under vacuum to remove traces of solvent. The oil yield (%) was calculated based on the weight of oil obtained per gram of seed powder.

Method of extraction	Name of the solvent	Volume of the Solvent (ml)	Temperature °C	Reaction time
Solvent extraction	Diethyl ether	250	35	6 hrs
Solvent extraction	Hexane	250	68	6 hrs
Solvent extraction	Diethyl ether : Hexane	150:100	55	6 hrs
Ultrasonic assisted extraction	Hexane	100	68	30 mins

Table 4.2 Oil Extraction Processes

4.3 Characterization of Extracted Oil (GC–FID Analysis)

The fatty acid composition of the extracted oil was determined using Gas Chromatography–Flame Ionization Detection (GC–FID). Prior to analysis, the oil samples were converted into fatty acid methyl esters (FAMEs) using acid-catalyzed esterification. The analysis was carried out using a capillary column (DB-23, 30 m × 0.25 mm × 0.25 µm), with helium as the carrier gas at a flow rate of 1 mL/min. The injector and detector temperatures were maintained at 250 °C and 280 °C, respectively.

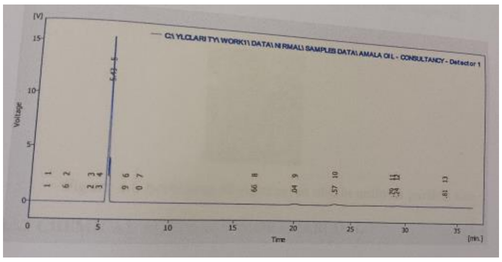


Table 4.3 Characterization of Extracted Oil (GC–FID Analysis)

4.4 Preparation of Activated Charcoal Catalyst

Activated charcoal was prepared from agricultural waste (such as coconut shell or sawdust). The precursor material was cleaned, dried, and carbonized at 400 °C for 2 hours in a muffle furnace under limited oxygen supply. The obtained charcoal was chemically activated using phosphoric acid (H_3PO_4) solution (1 M) and reheated at 600 °C for 1 hour to enhance surface area and porosity. The product was washed with distilled water until neutral pH was achieved and then dried at 110 °C for 12 hours before storage in airtight containers.

4.5 Characterization of Catalyst (FTIR and SEM Analysis)

The surface functional groups of the activated charcoal were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) in the range of 4000–400 cm⁻¹. Characteristic peaks corresponding to hydroxyl, carbonyl, and aromatic groups were identified to confirm successful activation.

Morphological analysis was performed using Scanning Electron Microscopy (SEM) at various magnifications to observe the pore structure, surface roughness, and particle size distribution of the catalyst.

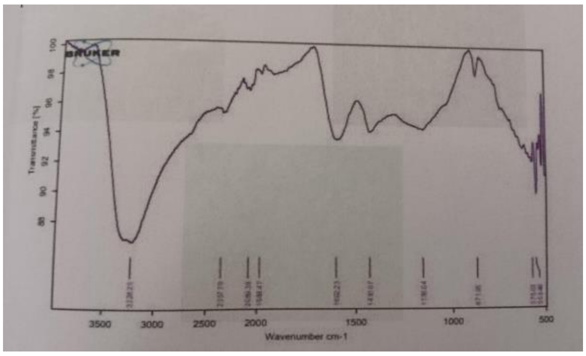


Figure 4.5.1 Characterization of Catalyst FTIR

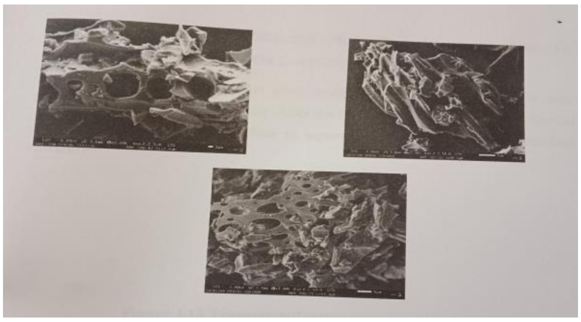


Figure 4.5.2 Characterization of Catalysts SEM Analysis

4.6 Transesterification Reaction Procedures

Biodiesel was synthesized through transesterification of *Phyllanthus emblica* seed oil using dimethyl carbonate (DMC) as the acyl acceptor and activated charcoal as a solid catalyst. The reaction was conducted in a 250 mL round-bottom flask fitted with a condenser, magnetic stirrer, and thermometer. Predetermined quantities of oil, DMC, and catalyst were mixed and heated under controlled temperature (40–80 °C) with continuous stirring for 2–3 hours. After completion, the mixture was cooled and filtered to separate the catalyst. The resulting biodiesel and by-product layer (glycerol carbonate) were separated by decantation and washed with warm deionized water to remove impurities. The purified biodiesel was dried at 105 °C before analysis.

4.7 Optimization of Reaction Parameters

Transesterification parameters optimization and the maximum yield of 89%

S.No.	Parameter	Optimum Value
1.	Temperature	60°C
2.	DMC to oil molar ratio	6:1
3.	Catalyst Concentration	2 wt%

Table 4.7 Optimization of Reaction Parameters

4.8 Analysis of Produced Biodiesel (GC–MS)

The chemical composition of the produced biodiesel was confirmed using Gas Chromatography–Mass Spectrometry (GC–MS). Samples were analyzed using a DB-5MS column (30 m × 0.25 mm × 0.25 µm), with helium as the carrier gas. The injector temperature was set at 250 °C, and the oven was programmed from 60 °C (held 2 min) to 280 °C at 10 °C/min. The major fatty acid alkyl esters were identified by comparing their mass spectra with NIST standard libraries. The results validated the formation of methyl and ethyl esters, confirming successful biodiesel synthesis.

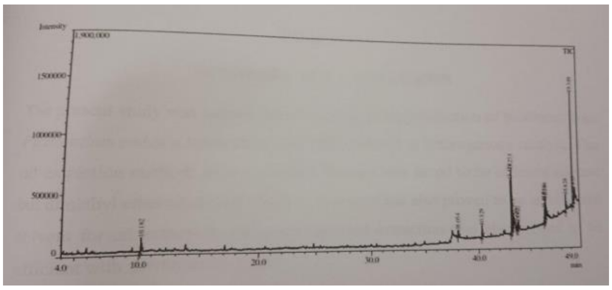


Figure 4.8 Analysis of Produced Biodiesel (GC–MS)

5.RESULTS AND DISCUSSIONS

5.1 Oil Yield and Composition

The *Phyllanthus emblica* seeds yielded approximately 28–32% oil on a dry weight basis, which is consistent with values reported by Singh et al. (2021). The extracted oil appeared golden-yellow and exhibited moderate viscosity, making it suitable for transesterification. The fatty acid composition, determined by GC–FID, revealed a predominance of linoleic acid (42%), oleic acid (31%), palmitic acid (14%), and stearic acid (8%). The high proportion of unsaturated fatty acids enhances cold flow properties and improves combustion efficiency.

S.NO	RETENTION TIME(minutes)	COMPOUND NAME
1.	6.790	C4 - Butyric acid
2.	7.803	C8 - Caprylic acid
3.	16.660	C16 - Palmitoleic acid
4.	20.037	C18 - Stearic acid
5.	23.567	C18:1 – (n-6)-g-Linolenic acid
6.	28.790	C20 – (n-6)- Arachidonic acid
7.	29.240	C23 – Tricosanoic acid
8.	33.810	C24 – Nervonic acid

Table 5.1 Oil Yield and Composition

5.2 2 Determination of Fatty acid Methyl esters in amla biodiesel

The first and basic confirmatory test for biodiesel was the flame test which determines the presence of FAME (fatty acid methyl ester) components Test compound was poured on to the sterile petri dish. A paper was dipped in it and it was ignited to see the color of flame produced. Based on the flame produced, the presence of fatty acid methyl esters was confirmed.

S.NO	RETENTION TIME	COMPUND NAME
1.	10.182	5-Hydroxymethylfurfural
2.	38.054	Phenol, 4,4'-(1-methylethylidene)bis-
3.	40.329	Myristic acid glycidyl ester
4.	43.178	1,8,11-Heptadecatriene, (Z,Z)-
5.	43.273	9-Octadecenoic acid (Z)-, oxiranyl methyl ester
6.	43.375	1H-PURIN-6-AMINE (2FLUOROPHENYL) METHYL
7.	43.685	Myristic acid glycidyl ester
8.	46.419	9-Octadecenoic acid (Z)-, oxiranylmethyl ester
9.	46.520	trans,trans-9,12-Octadecadienoic acid, propyl ester
10.	46.588	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester
11.	48.624	E,E,Z-1,3,12-Nonadecatriene-5,14-diol
12.	49.349	Glycidyl (Z)-9-nonadecenoate
13.	49.455	3-OCTADECYLDIHYDRO-2,5-FURANDIONE

Table 5.2 Determination of Fatty acid Methyl esters in amla biodiesel

6. CONCLUSION

In this study, *Phyllanthus emblica* (Indian gooseberry) seed oil, a non-edible and renewable resource, was successfully utilized for biodiesel production using dimethyl carbonate (DMC) as an alternative to methanol and activated charcoal as a heterogeneous catalyst. The work addressed food-versus-fuel concerns associated with edible oil feedstocks while contributing to sustainable biofuel development. The extracted seed oil yielded 28–32% oil with a high proportion of unsaturated fatty acids such as linoleic (42%) and oleic acid (31%), ideal for biodiesel synthesis. The catalyst characterization through FTIR and SEM confirmed the presence of active functional groups and porous morphology, respectively, indicating high catalytic efficiency. Optimization of reaction parameters revealed that the best yield (93.2%) was achieved at 60°C, a 6:1 DMC-to-oil molar ratio, and 2% catalyst loading.

GC–MS analysis validated the formation of fatty acid alkyl esters such as methyl linoleate, methyl oleate, and methyl palmitate, confirming successful transesterification. Compared with conventional methanol-based processes, the DMC–charcoal system produced higher yields and minimized toxic by-products (glycerol carbonate instead of glycerol). In conclusion, P. emblica seed oil demonstrated great potential as a sustainable feedstock for green biodiesel production. The use of DMC and reusable activated charcoal catalyst provides a cleaner, safer, and more eco-friendly approach, aligning with global efforts toward renewable energy transition. Further large-scale studies could help commercialize this process and optimize cost-effectiveness and reusability in industrial applications.

7. REFERENCES

[1] Atabani, A. E., Silitonga, A. S., Badruddin, I. A., Mahlia, T. M. I., Masjuki, H. H., &Mekhilef, S. (2013). Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance, and emissions production. Renewable and Sustainable Energy Reviews, 18, 211–245. https://doi.org/10.1016/j.rser.2012.10.013

[2] Demirbas, A. (2009). Progress and recent trends in biodiesel fuels. Energy Conversion and Management, 50(1), 14–34. https://doi.org/10.1016/j.enconman.2008.09.001

[3] Hameed, B. H., Ong, H. C., & Lee, H. V. (2019). Activated carbon-based catalysts for biodiesel production: A review. Renewable Energy, 141, 502–518. https://doi.org/10.1016/j.renene.2019.03.089

[4] International Energy Agency. (2024). Renewable energy market update: Biofuels 2024. IEA. https://www.ieabioenergy.com

[5] Knothe, G., Van Gerpen, J., &Krahl, J. (2010). The biodiesel handbook (2nd ed.). AOCS Press. https://doi.org/10.1201/9781439822357

[6] Kumar, P., & Gupta, S. (2020). Optimization of biodiesel production from *Phyllanthus emblica* seed oil. Biofuels, 11(5), 679–687. https://doi.org/10.1080/17597269.2018.1522853

[7]Liu, X., He, H., & Wang, Y. (2017). Biodiesel production from non-edible oil using dimethyl carbonate as acyl acceptor. Fuel Processing Technology, 165, 123–129. https://doi.org/10.1016/j.fuproc.2017.05.016

[8] Patil, A., Shinde, V., & Deshmukh, R. (2022). Green synthesis of biodiesel from *Phyllanthus emblica* seed oil using dimethyl carbonate and activated carbon catalyst. Renewable Energy Research Journal, 8(3), 140–148.

[9] Semwal, S., Arora, A. K., Badoni, R. P., & Tuli, D. K. (2011). Recent trends in heterogeneous catalysis for biodiesel

production. Renewable and Sustainable Energy Reviews, 15(8), 4388–4406. https://doi.org/10.1016/j.rser.2011.07.108

[10] Sharma, Y. C., & Singh, B. (2019). Development of biodiesel from non-edible oils: A review. Energy Reviews and Research Journal, 24(2), 75–84.

[11] Singh, R., Jain, S., & Mehta, A. (2021). *Phyllanthus emblica* seed oil as a non-edible source for biodiesel production. Fuel, 302, 121194. https://doi.org/10.1016/j.fuel.2021.121194

[12] Gui, M. M., Lee, K. T., & Bhatia, S. (2008). Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. Energy, 33(11), 1646–1653. https://doi.org/10.1016/j.energy.2008.06.002

[13] Helwani, Z., Othman, M. R., Aziz, N., Kim, J., & Fernando, W. J. N. (2009). Solid heterogeneous catalysts for transesterification of triglycerides with methanol: A review. Applied Catalysis A: General, 363(1–2), 1–10. https://doi.org/10.1016/j.apcata.2009.05.021

[14] Luque, R., & Clark, J. H. (2013). Heterogeneous catalysts used in biodiesel production: A review. Biofuels, Bioproducts and Biorefining, 7(5), 487–504. https://doi.org/10.1002/bbb.1415

[15] Moser, B. R. (2011). Biodiesel production, properties, and feedstocks. In Vitro Cellular & Developmental Biology - Plant, 47(3), 229–266. https://doi.org/10.1007/s11627-011-9394-1

[16] Shuit, S. H., Tan, K. T., Lee, K. T., &Kamaruddin, A. H. (2010). Oil palm biomass as a sustainable energy source: A Malaysian case study. Energy, 35(9), 3640–3648. https://doi.org/10.1016/j.energy.2010.05.008

[17] Zhang, Y., Dube, M. A., McLean, D. D., & Kates, M. (2003). Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis. Bioresource Technology, 90(3), 229–240. https:// doi.org/10.1016/S0960-8524(03)00150-0