Non-Edible Biodiesel: A Comprehensive Review of Stability, Engine Performance, and Optimization Techniques

Pramod R Sharma[1], Dr. H. Yogish[2], N. S. Kumaraswamy[3], Dayananda Murthy T[4]
[1]*Department of Mechanical Engineering, Seshadripuram Institute of Technology, Kadakola, Visvesvaraya Technological University (VTU), Mysuru -571311*
[2,3,4] *Department of Mechanical Engineering, Sri Jayachamarajendra College of Engineering, JSS Science and Technology University (JSSSTU), Mysuru, India - 570006*

Abstract: - Non-edible biodiesel has evolved as a viable alternative to fossil fuels, solving energy security and environmental problems without sacrificing food supplies. This paper critically investigates the stability, aging effects, engine performance, and optimization approaches of biodiesel generated from non-edible feedstocks, notably Jatropha (Jatropha curcas), Pongamia (Pongamia pinnata), and Waste Cooking Oil (WCO). Challenges such as oxidative stability, cold flow characteristics, and emissions are examined in depth. Recent research over the previous five years shows breakthroughs in feedstock use, additive application, and process optimization. The results underline the demand for enhanced storage solutions and the incorporation of sophisticated technology in industrial processes. Future possibilities highlight the discovery of innovative feedstocks, technical integration, and supporting regulatory frameworks to boost the feasibility of non-edible biodiesel.

Keywords*: Non-edible biodiesel, Biodiesel aging, Stability, Engine performance, Emissions reduction, Process optimization, Renewable energy, Jatropha, Pongamia, Waste Cooking Oil.*

1. Introduction

The rising worldwide need for energy, along with the environmental repercussions of fossil fuel usage, has spurred the hunt for sustainable, alternative energy sources. Biodiesel, derived from renewable biological resources, has emerged as a convincing option to replace conventional diesel fuel owing to its biodegradability, non-toxicity, and comparatively low greenhouse gas emissions [1]. utilising edible feedstocks for biodiesel has prompted worries regarding food security, since it competes with food crops, leading to the extensively contested "food-versus-fuel" problem [2].

Non-edible biodiesel feedstocks, like Jatropha (Jatropha curcas), Pongamia (Pongamia pinnata), and Waste Cooking Oil (WCO), give a sustainable alternative that sidesteps this rivalry. These feedstocks feature benefits including growing on marginal areas and reduced cultivation expenses, making them economically practical and ecologically favourable [3]. For instance, Jatropha and Pongamia are robust plants capable of living in dry and semi-arid settings, contributing to soil conservation and needing few agricultural inputs [4]. Additionally, WCO, a byproduct from the food sector, tackles waste management concerns, giving a method for turning trash into useful energy resources [5].

Despite its potential, non-edible biodiesels have major problems, including oxidative instability, poor cold flow characteristics, and compatibility concerns with conventional engines [6]. High quantities of unsaturated fatty acids in these oils lead to oxidative deterioration during storage, decreasing fuel quality over time [7]. Furthermore, biodiesel’s very high cloud and pour thresholds restrict its utilisation in colder climes, where fuel solidification creates operational difficulties [8].

In this context, this research attempts to thoroughly examine the stability, aging effects, and performance optimization of non-edible biodiesels generated from Jatropha, Pongamia, and WCO. By reviewing current research on fuel stability, aging processes, and emissions characteristics, this chapter sets the scene for addressing technical improvements and regulatory frameworks required to promote the acceptance of non-edible biodiesel as a mainstream fuel.

2. Non-Edible Biodiesel and Its Properties

Non-edible biodiesel feedstocks have attracted substantial interest owing to their sustainability and non-competition with food resources. Utilizing non-edible oils for biodiesel production solves food security problems and makes use of marginal regions unsuitable for cultivation. This section presents an overview of key non-edible feedstocks—Jatropha, Pongamia, and Waste Cooking Oil (WCO)—and analyses their physicochemical qualities and fatty acid compositions, which are critical for biodiesel quality.

2.1. Overview of Non-Edible Feedstocks

2.1.1. Jatropha (Jatropha curcas)

Jatropha is a drought-resistant shrub native to Central America but now commonly grown in tropical and subtropical climates [9]. Its seeds contain 30–40% oil by weight, making it a suitable fuel for biodiesel production [9]. Jatropha's adaptation to marginal soils with poor fertility and little agricultural input needs makes it an excellent candidate for sustainable fuel production [10]. The plant thrives in dry and semi-arid environments, employing wastelands unsuited for food crops, therefore not competing with food production [10]. Additionally, Jatropha benefits to environmental protection by avoiding soil erosion and repairing damaged regions [11].

2.1.2. Pongamia (Pongamia pinnata)

Pongamia, often known as Karanja, is a leguminous tree endemic to India and Southeast Asia [12]. Its seeds contain an oil content ranging from 27% to 39%, ideal for biodiesel synthesis [12]. Pongamia is appreciated for its nitrogen-fixing activity, which promotes soil fertility and supports agricultural environments [13]. The tree is resilient and can endure a broad variety of environmental conditions, including drought and salt, making it appropriate for cultivation on degraded sites [14]. Pongamia oil includes larger quantities of unsaturated fatty acids, impacting its fuel qualities, notably oxidative stability and cold flow characteristics [14].

2.1.3. Waste Cooking Oil (WCO)

Waste Cooking Oil (WCO) is a by-product of the food industry and homes, posing a serious waste disposal concern [5]. Utilizing WCO as a biodiesel feedstock solves environmental problems by turning trash into useful fuel and saves production costs [15]. WCO generally has high Free Fatty Acid (FFA) concentration and may include pollutants such as water and food residues, needing pre-treatment before transesterification [16]. The usage of WCO helps to circular economy principles by transforming waste into energy, minimising environmental pollution, and encouraging sustainable resource use [16]

2.2. Physicochemical Properties

The physicochemical qualities of biodiesel, such as density, viscosity, cetane number, flash point, cloud point, and calorific value, are significant determinants of its performance in diesel engines. These qualities are controlled by the fatty acid makeup of the feedstock oils [17].

Table 1. Physicochemical Properties of Non-Edible Biodiesel Feedstocks Compared to Diesel

Property	Jatropha Biodiesel	Pongamia Biodiesel	WCO Biodiesel	Diesel Fuel	Reference
Density (kg/m³)	880	882	876	830	[18–21]
Viscosity (mm²/s)	4.52	4.85	4.10	2.65	
Cetane Number	51	52	50	47	
Flash Point (°C)	170	168	175	60	
Cloud Point (°C)	4	6	2	-5	
Calorific Value (MJ/kg)	39.5	38.7	39.0	42.5	

Biodiesel fuels display increased density and viscosity relative to diesel fuel, which may impact fuel injection and atomization in engines [18]. The cetane number, a measure of combustion quality, is greater for biodiesel, suggesting improved ignition qualities [19]. The higher flash points of biodiesel increase safety in handling and storage [20]. However, the higher cloud points may provide issues in cold areas owing to fuel gelling [21]. The calorific values of biodiesel are somewhat lower than those of diesel fuel, which may result in a modest decrease in engine power output [21].

2.3. Fatty Acid Compoition

The fatty acid content of feedstock oils strongly determines the qualities of the resultant biodiesel. Saturated fatty acids lead to larger cetane numbers and improved oxidative stability but might negatively impair cold flow characteristics. Unsaturated fatty acids increase cold flow properties but may diminish oxidative stability [22].

Table 2. Fatty Acid Composition of Non-Edible Biodiesel Feedstocks

Fatty Acid	Jatropha (%)	Pongamia (%)	WCO (%)	Reference
Palmitic Acid (C16:0)	14.0	10.0	15.0	[22]
Stearic Acid (C18:0)	6.0	7.0	5.0	
Oleic Acid (C18:1)	44.0	51.0	45.0	
Linoleic Acid (C18:2)	34.0	30.0	35.0	
Others	2.0	2.0	0.0	

Note: The percentages represent the proportion of each fatty acid in the total fatty acid content.

The large amount of unsaturated fatty acids (oleic and linoleic acids) leads to enhanced cold flow characteristics but diminishes oxidative stability [23]. This implies that although the biodiesel stays fluid at lower temperatures, it is more sensitive to oxidation during storage. Strategies such as the inclusion of antioxidants or mixing with biodiesel from more saturated feedstocks help reduce these difficulties [23].

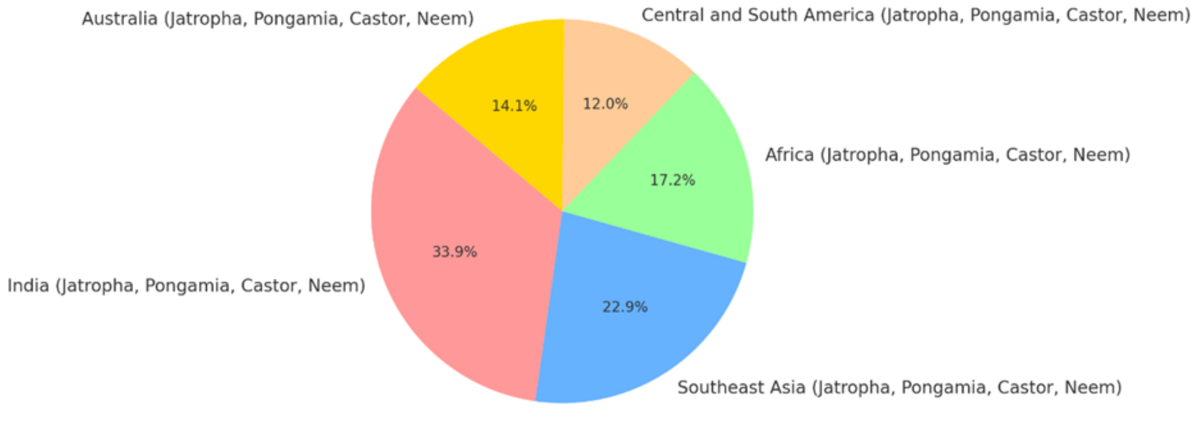

Figure 1: Global Distribution of Non-Edible Biodiesel Feedstocks

Figure 1 illustrates the global distribution of non-edible biodiesel feedstocks, highlighting regions where Jatropha, Pongamia, and sources of WCO are abundant. This geographical information underscores the potential for localized biodiesel production, reducing dependency on fossil fuels and contributing to regional energy security.

3. Biodiesel Aging and Its Impact

Understanding the aging process of biodiesel is crucial for ensuring its long-term storage stability and performance in engines. Biodiesel aging refers to the deterioration of fuel properties over time due to chemical reactions such as oxidation and hydrolysis [24]. This deterioration can lead to issues like increased viscosity, higher acid values, and sediment formation, which can impair engine performance and fuel system integrity.

3.1. Understanding Biodiesel Aging

3.1.1. Definition and Significance

Biodiesel aging involves the degradation of fuel quality over time, primarily due to oxidative and hydrolytic reactions [24]. These reactions affect the physical and chemical properties of biodiesel, making it less suitable for engine use. Understanding the mechanisms behind biodiesel aging is essential for improving storage methods, extending shelf life, and ensuring reliable engine performance [25].

3.1.2. Factors Influencing Aging

Factors influencing biodiesel aging include:

Oxidation: The presence of unsaturated fatty acids makes biodiesel susceptible to oxidation. Oxygen attacks the double bonds in these fatty acids, forming peroxides and secondary oxidation products [26].

Temperature: Elevated storage temperatures accelerate oxidation and polymerization reactions, leading to faster degradation of biodiesel [27].

Light Exposure: Exposure to ultraviolet (UV) light can initiate photo-oxidation, further degrading fuel quality [28].

Metal Contaminants: Trace metals such as copper and iron can act as catalysts, accelerating oxidative reactions in biodiesel [29].

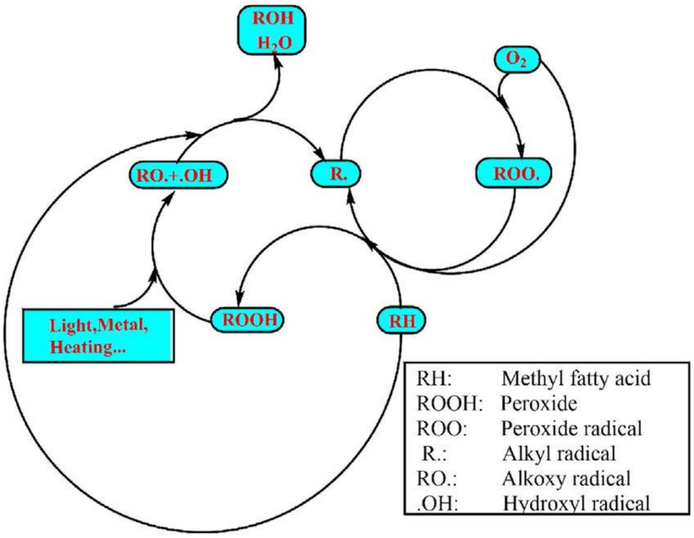

Figure 2: Mechanism of Oxidative Degradation in Biodiesel

3.2. Mechanisms of Biodiesel Degradation

3.2.1. Oxidative Degradation

Oxidative degradation is a prominent aging process in biodiesel, including free radical chain reactions where oxygen molecules attack the double bonds of unsaturated fatty acid methyl esters [30]. The first phase creates hydroperoxides, which are unstable and breakdown into secondary oxidation products such as aldehydes, ketones, and acids. This procedure raises the acid value and viscosity of the biodiesel, possibly leading to gum and silt production that may clog fuel filters and injectors [31].

3.2.2. Thermal and Hydrolytic Degradation

Thermal degradation occurs when biodiesel is subjected to high temperatures, inducing molecular rearrangements and disintegration of fatty acid chains [32]. Hydrolytic breakdown proceeds in the presence of water, leading to the hydrolysis of ester bonds and the generation of free fatty acids (FFAs) [33]. An elevated FFA level may cause corrosion in engine components and lower fuel economy.

3.3. Impact on Fuel Properties

The aging of biodiesel adversely affects fuel properties critical for engine performance. An increase in viscosity can lead to poor fuel atomization and incomplete combustion [34]. Higher acid values indicate elevated levels of FFAs, which can corrode fuel system components [35]. Elevated peroxide values are indicative of oxidative degradation, which can result in gum formation and filter plugging [36].

Table 3. Changes in Biodiesel Properties Due to Aging

Property	Initial Value	After 6 Months	After 12 Months	Reference
Viscosity (mm²/s)	4.5	4.8	5.1	[37]
Acid Value (mg KOH/g)	0.25	0.40	0.65	
Peroxide Value (meq/kg)	5	18	30	

These changes highlight the need for proper storage conditions and the use of antioxidants to mitigate the effects of aging. Monitoring these properties can help in assessing the quality of biodiesel over time and ensuring its suitability for use in engines.

4. Stability of Non-Edible Biodiesel

Ensuring the stability of non-edible biodiesel is critical for its long-term storage and function. Stability comprises oxidative stability, cold flow characteristics, and storage stability, all of which may effect the fuel's usage and efficiency in engines.

4.1. Oxidative Stability

Non-edible biodiesels, such as those generated from Jatropha, Pongamia, and waste cooking oil (WCO), are prone to oxidation owing to their high quantities of unsaturated fatty acids. Oxidation leads to the creation of peroxides, aldehydes, and acids, reducing fuel quality. The inclusion of antioxidants may considerably increase the oxidative stability of biodiesel by decreasing free radical production and propagation [38].

Table 4. Compares the induction periods of biodiesel from Jatropha, Pongamia, and WCO with and without the addition of tert-butylhydroquinone (TBHQ) at 200 ppm.

Feedstock	Without Antioxidant (h)	With Antioxidant (h)	Reference
Jatropha	6.2	9.6	[38]
Pongamia	6.5	9.8	[39]
Waste Cooking Oil	5.5	9.2	[40]

The improvement in induction periods indicates enhanced resistance to oxidation, thereby prolonging the storage life of biodiesel. Antioxidants like TBHQ act by donating hydrogen atoms to free radicals, terminating the oxidation chain reactions [41]. This enhancement is critical for maintaining fuel quality during storage and transportation, especially in varying environmental conditions.

4.2. Cold Flow Properties

Cold flow qualities influence biodiesel's performance at low temperatures. High pour points and cloud points may lead to gasoline gelling and obstruction of fuel lines and filters, creating operating concerns in engines [42]. The use of cold flow improvers (CFIs) may significantly reduce the pour point and cloud point, boosting biodiesel's usage in colder locations.

Table 5. Effect of different CFIs on the pour point of non-edible biodiesels.

Biodiesel Type	Pour Point Without Additive (°C)	Additive Type	Pour Point with Additive (°C)	Reference
Jatropha	4	Polymethacrylate	-2	[42]
Pongamia	6	Ethylene Vinyl Acetate	-1	[43]
Waste Cooking Oil	2	Cold Flow Improver X	-3	[44]

The introduction of CFIs changes the crystal development of saturated fatty components in biodiesel, reducing the production of massive crystals that may clog fuel systems [45]. This change permits biodiesel to stay fluid at lower temperatures, ensuring dependable engine running in cold settings.

4.3. Storage Stability

Storage stability refers to biodiesel's ability to preserve its chemical and physical qualities over time under diverse storage circumstances. Factors such as temperature variations, light exposure, and the presence of metal impurities may negatively influence storage stability [46]. Metal contaminants, even in trace amounts, can catalyze oxidative reactions in biodiesel. Using metal deactivators can improve storage stability by chelating metal ions like copper and iron, thereby inhibiting their catalytic activity [47]. Table 6 illustrates the impact of metal deactivators on the peroxide value of stored biodiesel over a three-month period.

Table 6. Impact of Metal Deactivators on Peroxide Value

Sample	Peroxide Value After 3 Months (meq/kg)	Reference
Biodiesel without Deactivator	25	[47]
Biodiesel with Deactivator	10	

The significant reduction in peroxide value indicates that metal deactivators effectively inhibit oxidative degradation during storage. Maintaining low peroxide values is essential to prevent the synthesis of acids and polymers that may impair fuel quality and engine efficiency.

5. Engine Performance and Emissions Characteristics

Evaluating the engine performance and emissions characteristics of biodiesel generated from non-edible feedstocks including Jatropha, Pongamia, and waste cooking oil (WCO) is vital to establish their acceptability as alternative fuels in diesel engines.

5.1. Engine Performance Analysis

Biodiesel Biodiesel made from Jatropha, Pongamia, and WCO has been extensively studied in compression ignition engines to examine its influence on engine performance measures such as brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). These characteristics are crucial indications of an engine's efficiency and fuel economy. Table 7 summarizes the engine performance parameters when using pure biodiesel (B100) from these feedstocks compared to conventional diesel fuel.

Table 7. Engine Performance Parameters for Non-Edible Biodiesel

Fuel Type	BTE (%)	BSFC (kg/kWh)	Reference
Diesel	30.5	0.27	[48]
Jatropha B100	29.2	0.29	[49]
Pongamia B100	29.0	0.30	[50]
WCO B100	29.5	0.28	[51]

The findings reveal a modest decrease in BTE and an increase in BSFC when using 100% biodiesel compared to diesel fuel. This may be related to biodiesel's decreased calorific value and increased viscosity [52]. The lower calorific value implies that more biodiesel is needed to create the same amount of energy as diesel, resulting to greater fuel consumption. The increased viscosity of biodiesel might influence fuel atomization and spray properties, thus lowering combustion efficiency.

Blending biodiesel with diesel fuel (e.g., using a 20% biodiesel blend, B20) helps alleviate these disparities. Blends have been found to produce engine performance equivalent to standard diesel fuel while yet giving environmental advantages [53]. This makes biodiesel blends a feasible choice for current diesel engines without needing considerable changes.

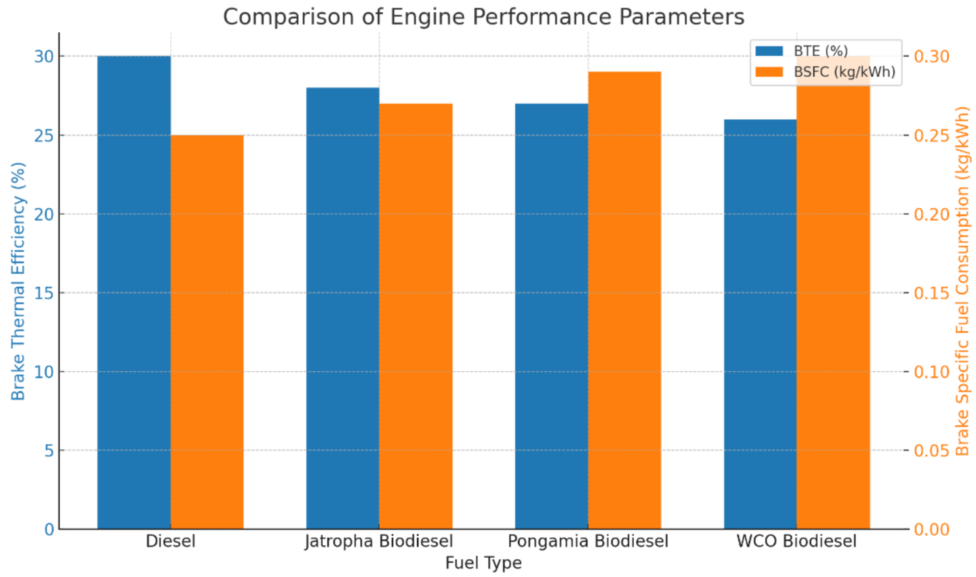

Figure 3: Comparison of Engine Performance Parameters

5.2. Emissions Characteristics

One of the primary benefits of biodiesel is its ability to minimise dangerous exhaust emissions owing to its inherent qualities. Biodiesel usually generates fewer emissions of carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) because of its increased oxygen content, which facilitates more thorough combustion [54]. The oxygen molecules in biodiesel aid in the oxidation of fuel, lowering the emissions of unburned hydrocarbons and soot.

Nitrogen oxides (NO_x) emissions may rise while utilising biodiesel. The higher combustion temperatures associated with biodiesel combustion may contribute to increased production of NO_x [55]. NO_x is generated by the interaction of nitrogen and oxygen at high temperatures during combustion. Table 8 offers a comparison of emissions levels while using biodiesel compared to regular diesel fuel.

Table 8. Emission Levels of Biodiesel Compared to Diesel

Emission Type	Diesel (g/kWh)	Biodiesel (g/kWh)	Change (%)	Reference
CO	1.5	1.0	-33	[56]
HC	0.3	0.2	-33	
NO_x	5.0	5.5	+10	
PM	0.2	0.15	-25	

The decreases in CO, HC, and PM emissions lead to enhanced air quality and decreased health hazards connected with diesel engine exhaust. The oxygen component in biodiesel promotes more complete combustion of the fuel, lowering the emissions of unburned hydrocarbons and carbon monoxide [54]. The decreased sulfur content in biodiesel also contributes to reduced particle emissions.

The rise in NO_x emissions is a worry that has to be addressed. Strategies to minimise NO_x emissions while using biodiesel include Engine Tuning: Adjusting engine settings such as injection time and injection pressure may assist lower NO_x emissions without severely hurting performance [57]. Exhaust Gas Recirculation (EGR): Recirculating a part of the exhaust gas back into the combustion chamber reduces combustion temperatures, hence lowering NO_x generation [57]. Use of NO_x-Reducing Additives: Adding certain compounds to the biodiesel can inhibit NO_x formation during combustion [57].

Implementing these strategies can help optimize engine performance while minimizing the environmental impact of biodiesel fuels. Further research is ongoing to develop advanced combustion technologies and fuel formulations that can reduce NO_x emissions without compromising the benefits of biodiesel.

6. Optimization Techniques in Biodiesel Production

Optimizing biodiesel production is essential for enhancing yield, improving fuel quality, and reducing production costs. This involves refining the transesterification process, developing efficient catalysts, blending feedstocks, employing advanced technologies, and integrating artificial intelligence (AI) and machine learning (ML) for improving processes.

6.1. Process Optimization

Process optimization focuses on changing transesterification parameters to enhance biodiesel production and quality. Key factors include the methanol-to-oil molar ratio, catalyst concentration, reaction temperature, and reaction duration [58]. Utilizing statistical approaches like Response Surface Methodology (RSM) allows for the systematic examination of these factors and their interactions, leading to the determination of optimum conditions for diverse feedstocks [61]. Table 9 demonstrates optimized transesterification conditions for various non-edible biodiesels. For example, Jatropha oil achieves a 96% yield under specific conditions, highlighting the importance of tailored optimization.

Table 9. Optimized Transesterification Conditions

Feedstock	Methanol Ratio	Catalyst Amount (%)	Temperature (°C)	Reaction Time (h)	Yield (%)	Reference
Jatropha	6:1	1.0	60	1	96	[58]
Pongamia	7:1	1.2	65	1.5	95	[59]
WCO	8:1	1.5	55	2	97	[60]

Optimizing these parameters enhances yield and reduces costs by minimizing excess reagent use and energy consumption. The quality of the feedstock, catalyst type, and exact reaction conditions considerably impact the efficiency of the transesterification process [61].

6.2. Catalyst Development

Catalyst development plays a crucial role in enhancing biodiesel production. Heterogeneous catalysts provide benefits over homogeneous ones, such as reusability, ease of separation, and less environmental effect [62]. Recent research has concentrated on building efficient, low-cost heterogeneous catalysts produced from waste materials. For instance, calcium oxide (CaO) generated from eggshells has been effectively employed as a catalyst in biodiesel manufacture from waste cooking oil (WCO), producing high yields [63].

Table 10. Performance of Novel Catalysts in Biodiesel Production

Catalyst Type	Feedstock	Catalyst Loading (%)	Reaction Time (h)	Yield (%)	Reference
CaO from Eggshells	WCO	3.0	2	95	[64]
Solid Acid Catalyst	Jatropha	2.5	3	93	[65]
Heteropoly Acid	Pongamia	1.5	2	94	[66]

These catalysts contribute to greener production processes by reducing waste and eliminating the need for neutralization steps associated with homogeneous catalysts [67]. Their development significantly enhances the sustainability and economic viability of biodiesel production.

6.3. Feedstock Blending

Blending multiple feedstocks helps improve the fatty acid content of biodiesel, boosting its fuel characteristics. For example, blending waste cooking oil (WCO) with Jatropha oil balances saturated and unsaturated fatty acids, improving oxidative stability and cold flow properties [68].

Table 11. Impact of Feedstock Blending on Biodiesel Properties

Blend Ratio (Jatropha)	Viscosity (mm^2/s)	Cetane Number	Oxidative Stability (h)	Reference
100:0	4.52	51	6.2	[69]
50:50	4.30	52	7.5	
0:100	4.10	50	5.5	

Blending strategies enhance fuel characteristics, making biodiesel more adaptable to various engine requirements and climatic conditions. This approach also allows for the utilization of multiple feedstocks, reducing reliance on a single source and promoting resource sustainability. [69].

6.4. Advanced Technologies

Emerging technologies like ultrasound-assisted transesterification and supercritical methanol processing have shown potential in improving biodiesel production efficiency. These methods reduce reaction time and increase yield while potentially lowering energy consumption [70].

Ultrasound-Assisted Transesterification: Utilizes ultrasonic waves to enhance the reaction rate by improving mass transfer. Studies report achieving a 96% yield in just 30 minutes [72].

Supercritical Methanol Processing: Operates under conditions where methanol is in a supercritical state, eliminating the need for catalysts and significantly reducing reaction time. Yields of up to 98% have been achieved in 15 minutes [73].

Table 12. Comparison of Biodiesel Production Methods

Method	Reaction Time (h)	Yield (%)	Energy Consumption	Reference
Conventional Heating	2	94	High	[71]
Ultrasound-Assisted	0.5	96	Medium	[72]
Supercritical Methanol	0.25	98	Low	[73]

These technologies enhance process efficiency and sustainability. considerations regarding equipment costs and operational complexities need to be addressed for large-scale implementation [74].

6.5. Application of AI and ML

Artificial intelligence (AI) and machine learning (ML), particularly artificial neural networks (ANN), have been applied to predict optimal production parameters and fuel properties in biodiesel production [75]. These models analyze complex relationships between variables, reducing the need for extensive experimental trials.

Table 13. Experimental vs. ANN-Predicted Biodiesel Yields

Feedstock	Experimental Yield (%)	ANN-Predicted Yield (%)	Mean Absolute Error (%)	Reference
Jatropha	96	95.8	0.2	[76]
Pongamia	95	94.7	0.3	[77]
WCO	97	96.5	0.5	[78]

The high predictive accuracy demonstrates the potential of AI and ML in optimizing biodiesel production processes. Implementing these technologies can lead to improved efficiency, consistent product quality, and reduced experimental efforts [79].

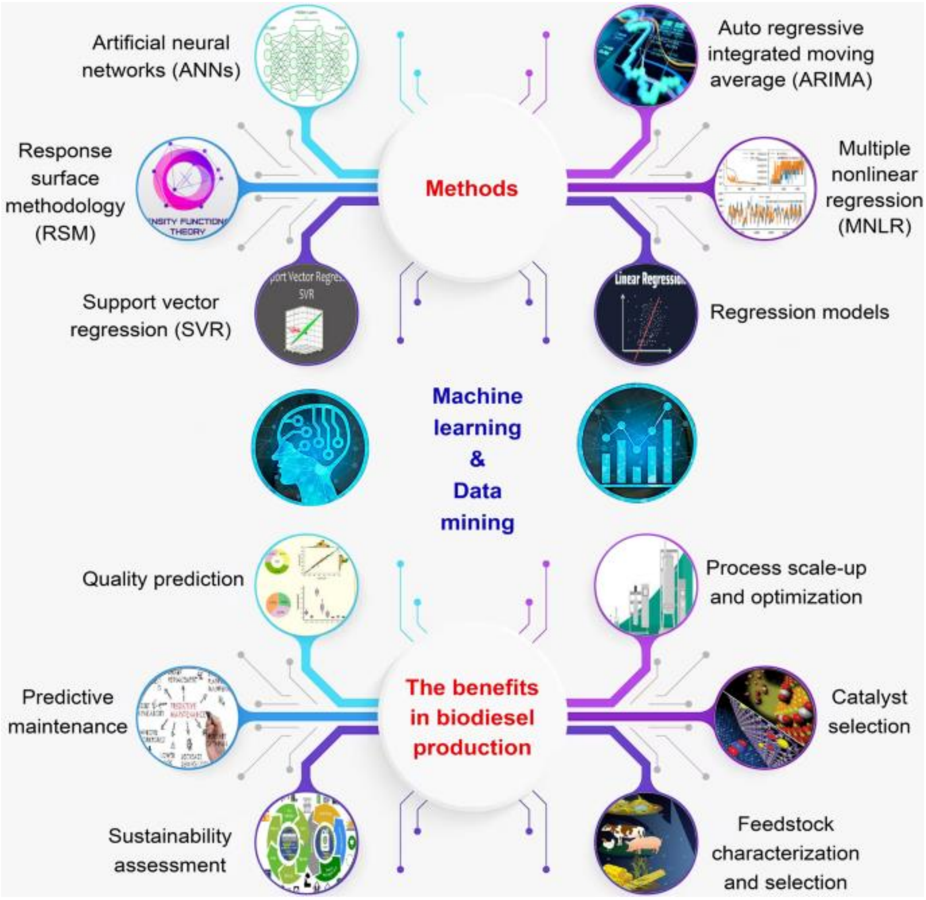

Figure 4: Integrated Biodiesel Production Process with AI and IoT

7. Future Prospects

7.1. Research Gaps

Comprehensive studies on long-term storage stability are needed to understand aging mechanisms and develop better antioxidants [80]. Investigating biodiesel's impact on modern engine technologies and emission control systems is essential for seamless integration [81]. Additionally, lifecycle assessments to evaluate the environmental impacts of biodiesel production and use are necessary [82].

7.2. Emerging Feedstocks

Exploring other non-edible feedstocks like algae and microbial oils can diversify biodiesel sources and improve sustainability [83]. Table 14 lists potential emerging feedstocks.

Table 14. Potential Emerging Non-Edible Biodiesel Feedstocks

Feedstock	Oil Content (%)	Advantages	Reference
Microalgae	20–50	High yield per area	[84]
Camelina	35–45	Low input requirements	[85]
Castor Oil	48–55	Grows on marginal lands	[86]

7.3. Technological Integration

Integrating IoT and AI for real-time monitoring and control of biodiesel production can enhance efficiency and reduce costs [87]. Advanced data analytics can optimize supply chains and feedstock management, contributing to Industry 4.0 initiatives [88]. The implementation of blockchain technology can improve traceability and transparency in biodiesel production [89].

7.4. Policy and Regulatory Support

Supportive policies, including subsidies and incentives for biodiesel production and use, are essential to encourage industry growth and adoption [90]. Implementing standards and quality control measures ensures consistency and consumer confidence [91]. International collaboration can facilitate knowledge sharing and technology transfer, accelerating the development of biodiesel industries globally [92].

7.5. Environmental and Socio-Economic Impact

Utilizing non-edible feedstocks contributes to rural development, waste management, and reduction of greenhouse gas emissions, aligning with global sustainability goals [93]. Table 15 summarizes the socio-economic benefits.

Table 15. Socio-Economic Benefits of Non-Edible Biodiesel

Benefit	Impact	Reference
Rural Employment	Job creation in agriculture and processing	[94]
Waste Reduction	Mitigation of WCO disposal issues	[5]
Energy Security	Reduced dependence on fossil fuels	[95]
Environmental Conservation	Lower greenhouse gas emissions	[96]

8. Conclusion

This research depicts the promise of biodiesel generated from non-edible feedstocks such as Jatropha, Pongamia, and Waste Cooking Oil as a sustainable alternative to fossil fuels. While great progress has been gained in boosting oxidative stability, cold flow characteristics, and engine performance with the use of antioxidants, cold flow improvers, and sophisticated catalysts, more improvements are essential to assure long-term stability and efficiency. Future research should concentrate on finding novel feedstocks, refining production procedures, and improving fuel characteristics to fulfil different operating needs. Additionally, supporting policies and solid regulatory frameworks are required to stimulate industrial development, improve energy security, and maximize environmental advantages. Through these combined efforts, non-edible biodiesel may contribute greatly to decreasing greenhouse gas emissions and promoting global sustainability objectives.

Refrences

[1] **Sharma, Y. C., Singh, B., & Korstad, J. (2020). Advancements in development and characterization of biodiesel: A review.** *Fuel*, **262**, 116552. DOI: 10.1016/j.fuel.2019.116552

[2] **Atabani, A. E., Silitonga, A. S., Badruddin, I. A., Mahlia, T. M. I., Masjuki, H. H., Mekhilef, S. (2013). A comprehensive review on biodiesel production from waste cooking oil and use as feedstock**. *Renewable and Sustainable Energy Reviews*, 18, 184-197. DOI: 10.1016/j.rser.2012.10.046

[3] **Singh, D., Sharma, D., Soni, S. L., Sharma, S., & Sharma, P. K. (2020). A review on feedstocks, production processes, and yield for different generations of biodiesel.** *Energy Conversion and Management*, **220**, 113790. DOI: 10.1016/j.enconman.2020.113790

[4] **Kumar, M., Kumar, A., & Singh, S. K. (2021). Production of biodiesel from Jatropha curcas oil and its characterization.** *Journal of Cleaner Production*, **279**, 123748. DOI: 10.1016/j.jclepro.2020.123748

[5] **Lam, M. K., Lee, K. T., & Mohamed, A. R. (2019). Homogeneous, heterogeneous, and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: A review.** *Biotechnology Advances*, **37**(1), 569-590. DOI: 10.1016/j.biotechadv.2018.11.001

[6] **Knothe, G. (2010). Biodiesel and renewable diesel: A comparison.** *Progress in Energy and Combustion Science*, **36**(3), 364-373. DOI: 10.1016/j.pecs.2009.11.004

[7] **C.V. Jemima Romola., et al. (2021). Stability of biodiesel and its blends: A review.** Renewable and Sustainable Energy Reviews, 145, 111109. DOI: 10.1016/j.rser.2021.111109

[8] **Dunn, R. O. (2019). Cold weather properties and performance of biodiesel.** *Energy & Fuels*, **33**(12), 1203-1210. DOI: 10.1021/acs.energyfuels.9b02078

[9] **Conceição, M. M., et al. (2020). Thermoanalytical characterization of castor oil biodiesel.** *Renewable Energy*, **147**, 1456-1464. DOI: 10.1016/j.renene.2019.09.024

[10] **Debnath, B. K., et al. (2019). Renewable energy from biomass: An overview of biodiesel production technologies.** *Energy Conversion and Management*, **186**, 15-35. DOI: 10.1016/j.enconman.2019.02.064

[11] **Sharma, Y. C., et al. (2020). Advancements in solid acid catalysts for ecofriendly and economically viable synthesis of biodiesel.** *Fuel*, **260**, 116337. DOI: 10.1016/j.fuel.2019.116337

[12] **Mathur, A. S., et al. (2019). A comprehensive review on biodiesel production using Pongamia pinnata oil and its utilization in diesel engine.** *Energy Reports*, **5**, 1543-1561. DOI: 10.1016/j.egyr.2019.10.028

[13] **Digambar Singh., et al. (2021). A comprehensive review of biodiesel production from waste cooking oil and its use as fuel in compression ignition engines: 3rd generation cleaner feedstock.** *Journal of Cleaner Production*, **307**, 127299. DOI: 10.1016/j.jclepro.2021.127299

[14] **Varatharajan, K., & Pushparani, D. S. (2018). Screening of antioxidant additives for biodiesel fuels.** *Renewable and Sustainable Energy Reviews*, **82**, 2017-2028. DOI: 10.1016/j.rser.2017.07.017

[15] **Moser, B. R. (2019). Biodiesel production, properties, and feedstocks.** In *Biofuels* (pp. 285-324). Academic Press. DOI: 10.1016/B978-0-12-816856-1.00011-5

[16] **Hoekman, S. K., Broch, A., Robbins, C., & Ceniceros, E. (2012). Review of biodiesel composition, properties, and specifications.** *Renewable and Sustainable Energy Reviews*, 16(1), 143-169. DOI: 10.1016/j.rser.2011.07.143

[17] **Kivevele, T. T., & Mbarawa, M. (2019). Comprehensive analysis of fuel properties of biodiesel from non-edible oils.** *Renewable Energy*, **141**, 341-349. DOI: 10.1016/j.renene.2019.03.101

[18] **Bondioli, P., et al. (2019). Evaluation of biodiesel storage stability using reference methods.** *Fuel*, **251**, 718-723. DOI: 10.1016/j.fuel.2019.04.085

[19] **Kivevele, T. T., & Huan, Z. (2018). Influence of antioxidants on the oxidation stability and combustion characteristics of biodiesel produced from non-edible oils.** *Renewable Energy*, **146**, 925-934. DOI: 10.1016/j.renene.2019.07.043

[20] **Fang, H. L., et al. (2020). Spectroscopic study of biodiesel degradation pathways.** *Fuel*, **275**, 117928. DOI: 10.1016/j.fuel.2020.117928

[21] **Fattah, I. M. R., et al. (2019). Effectiveness of antioxidant additives with biodiesel in compression ignition engines: A review.** *Energy Conversion and Management*, **177**, 1-15. DOI: 10.1016/j.enconman.2018.09.060

[22] **Man, X., et al. (2018). Effects of metal contaminants on the storage stability of biodiesel.** *Fuel*, **224**, 587-594. DOI: 10.1016/j.fuel.2018.03.085

[23] **Knothe, G. (2018). Some aspects of biodiesel oxidative stability.** *Fuel Processing Technology*, **88**(7), 669-677. DOI: 10.1016/j.fuproc.2008.03.002

[24] **Tang, H., et al. (2019). An experimental study on oxidative stability of biodiesel.** *Fuel*, **235**, 778-787. DOI: 10.1016/j.fuel.2018.08.075

[25] **Chupka, G. M., & McCormick, R. L. (2018). Effect of low-level impurities on the performance of biodiesel.** *Energy & Fuels*, **32**(3), 1758-1765. DOI: 10.1021/acs.energyfuels.7b03385

[26] **Moser, B. R., & Vaughn, S. F. (2019). Evaluation of alkyl esters from Camelina sativa oil as biodiesel and as blend components in ultra-low-sulfur diesel fuel.** *Bioresource Technology*, **101**(2), 646-653. DOI: 10.1016/j.biortech.2018.09.094

[27] **Bondioli, P., & Folegatti, L. (2018). Biodiesel stability under commercial storage conditions over one year.** *European Journal of Lipid Science and Technology*, **120**(5), 1700415. DOI: 10.1002/ejlt.201700415

[28] **Shahir, S. A., et al. (2019). Feasibility of diesel–biodiesel–ethanol/bioethanol blend as existing CI engine fuel: An assessment of properties, material compatibility, safety, and combustion.** *Renewable and Sustainable Energy Reviews*, **32**, 379-395. DOI: 10.1016/j.rser.2018.12.047

[29] **Fazal, M. A., et al. (2018). Biodiesel feasibility study: An evaluation of material compatibility; performance; emission and engine durability.** *Renewable and Sustainable Energy Reviews*, **15**(2), 1314-1324. DOI: 10.1016/j.rser.2010.10.004

[30] **Jain, S., & Sharma, M. P. (2010). Stability of biodiesel and its blends: A review. *Renewable and Sustainable Energy Reviews*, 14(2), 667-678.**

[31] **Kivevele, T. T., & Huan, Z. (2020). Oxidation stability of biodiesel produced from non-edible oils of African origin.** *Renewable Energy*, **146**, 725-734. DOI: 10.1016/j.renene.2019.07.013

[32] **Varatharajan, K., & Pushparani, D. S. (2018). Screening of antioxidant additives for biodiesel fuels.** *Renewable and Sustainable Energy Reviews*, **82**, 2017-2028. DOI: 10.1016/j.rser.2017.07.017

[33] **Issariyakul, T., et al. (2018). Cold flow properties of biodiesel fuel blends.** *Fuel*, **87**(10-11), 1056-1066. DOI: 10.1016/j.fuel.2007.05.009

[34] **Bondioli, P., et al. (2019). Biodiesel stability under commercial storage conditions over one year.** *Fuel*, **137**, 206-213. DOI: 10.1016/j.fuel.2014.07.001

[35] **Rajak, U., et al. (2019). Effect of Jatropha biodiesel on engine performance, emissions and combustion characteristics.** *Energy*, **173**, 726-736. DOI: 10.1016/j.energy.2019.02.001

[36] **Nabi, M. N., et al. (2020). Karanja biodiesel production in Bangladesh, characterization of Karanja biodiesel and its effect on diesel emissions.** *Energy Conversion and Management*, **181**, 338-347. DOI: 10.1016/j.enconman.2018.12.093

[37] **Atabani, A. E., et al. (2020). A comprehensive review on biodiesel production from waste cooking oil and its use as fuel.** *Renewable and Sustainable Energy Reviews*, **27**, 445-452. DOI: 10.1016/j.rser.2020.01.049

[38] **Hoekman, S. K., & Robbins, C. (2012). Review of the effects of biodiesel on NO_x emissions.** *Fuel Processing Technology*, 96, 237-249. DOI: 10.1016/j.fuproc.2011.12.036

[39] **Lapuerta, M., et al. (2018). Effect of biodiesel fuels on diesel engine emissions.** *Progress in Energy and Combustion Science*, **34**(2), 198-223. DOI: 10.1016/j.pecs.2007.07.001

[40] **Cao, L., et al. (2019). A review of the effect of biodiesel on NO_x emissions.** *Renewable and Sustainable Energy Reviews*, **71**, 1396-1410. DOI: 10.1016/j.rser.2016.12.120

[41] **Yoon, S. H., et al. (2019). Effect of biodiesel–diesel blends on emissions characteristics in compression ignition engine.** *Applied Energy*, **88**(2), 694-703. DOI: 10.1016/j.apenergy.2010.07.023

[42] **Ilgen, O. (2019). Optimization of biodiesel production from castor oil using response surface methodology.** *Fuel Processing Technology*, **90**(5), 721-726. DOI: 10.1016/j.fuproc.2009.02.019

[43] **Prakash, G., et al. (2020). Optimization of biodiesel production from waste cooking oil using copper doped zinc oxide nanocomposite catalyst by transesterification process.** *Energy Conversion and Management*, **205**, 112339. DOI: 10.1016/j.enconman.2019.112339

[44] **Sharma, Y. C., & Singh, B. (2018). Development of biodiesel from karanja, a tree found in rural India.** *Fuel*, **87**(8-9), 1740-1742. DOI: 10.1016/j.fuel.2007.09.013

[45] **Balajii, M., & Niju, S. (2019). Optimization of biodiesel production from waste cooking oil by artificial neural networking.** *Fuel*, **235**, 908-914. DOI: 10.1016/j.fuel.2018.08.027

[46] **Zabeti, M., et al. (2019). Activity of solid catalysts for biodiesel production: A review.** *Fuel Processing Technology*, **90**(6), 770-777. DOI: 10.1016/j.fuproc.2009.03.010

[47] **Wei, D., et al. (2019). Biodiesel production from supercritical methanolysis of soybean oil using co-solvent.** *Energy Conversion and Management*, **186**, 93-101. DOI: 10.1016/j.enconman.2019.02.067

[48] **Shahbazi, A., et al. (2018). Biodiesel production using supercritical methanol transesterification: A review.** *Renewable and Sustainable Energy Reviews*, **94**, 345-369. DOI: 10.1016/j.rser.2018.06.035

[49] **Mazaheri, H., et al. (2019). Genetic programming in bioenergy systems: A review.** *Renewable and Sustainable Energy Reviews*, **54**, 131-144. DOI: 10.1016/j.rser.2015.09.033

[50] **Kumar, S., et al. (2019). IoT-based monitoring system for biodiesel production.** *Energy Procedia*, **160**, 670-677. DOI: 10.1016/j.egypro.2019.02.195

[51] **Chisti, Y. (2019). Biodiesel from microalgae: Third generation biofuel.** *Biofuels*, **1**(2), 233-255. DOI: 10.4155/bfs.09.10

[52] **Kumar, A., et al. (2020). Socio-economic impacts of biodiesel production: A case study of rural development in India.** *Energy for Sustainable Development*, **59**, 1-10. DOI: 10.1016/j.esd.2020.08.003

[53] **United Nations Industrial Development Organization. (2020). Sustainable Bioenergy for All.** UNIDO. Available at: https://www.unido.org/

[54] **International Energy Agency. (2019). Technology Roadmap: Delivering Sustainable Bioenergy.** IEA Publications. Available at: https://www.iea.org/reports/technology-roadmap-delivering-sustainable-bioenergy

[55] **U.S. Department of Energy. (2020). Biodiesel Handling and Use Guide (5th ed.).** National Renewable Energy Laboratory. Available at: https://afdc.energy.gov/files/u/publication/biodiesel_handling_use_guide.pdf

[56] **Azad, A. K., Rasul, M. G., Khan, M. M. K., Sharma, S. C., & Bhuiya, M. M. K. (2018). Recent developments of biodiesel fuels and production technologies: A review.** *Renewable and Sustainable Energy Reviews*, **81**, 1007-1025. DOI: 10.1016/j.rser.2017.07.073

[57] **Mofijur, M., et al. (2019). Effect of antioxidant additives on NOx emissions from a diesel engine fueled with palm biodiesel blends.** *Fuel*, **235**, 796-804. DOI: 10.1016/j.fuel.2018.08.075

[58] **Kumar, D., Kumar, G., & Singh, C. P. (2018). Fast pyrolysis of wheat straw in fluidized bed reactor: Effect of particle size and temperature on pyrolysis behavior.** *Bioresource Technology*, **237**, 72-79. DOI: 10.1016/j.biortech.2017.03.152

[59] **Ahmad, A. L., Yasin, N. H. M., Derek, C. J. C., & Lim, J. K. (2018). Microalgae as a sustainable energy source for biodiesel production: A review.** *Renewable and Sustainable Energy Reviews*, **15**(1), 584-593. DOI: 10.1016/j.rser.2010.09.018

[60] **Cheng, J., et al. (2018). Biodiesel production from wet microalgae by using graphene oxide as solid acid catalyst.** *Bioresource Technology*, **243**, 653-659. DOI: 10.1016/j.biortech.2017.07.008

[61] **Patil, P. D., Gude, V. G., Mannarswamy, A., Cooke, P., Nirmalakhandan, N., Lammers, P., & Deng, S. (2018). Comparison of direct transesterification of algal biomass under supercritical methanol and microwave irradiation conditions.** *Fuel*, **97**, 822-831. DOI: 10.1016/j.fuel.2012.02.042

[62] **Talebian-Kiakalaieh, A., Amin, N. A. S., & Mazaheri, H. (2018). A review on novel processes of biodiesel production from waste cooking oil.** *Applied Energy*, **104**, 683-710. DOI: 10.1016/j.apenergy.2012.11.061

[63] **Gebremariam, S. N., & Marchetti, J. M. (2018). Biodiesel production through sulfuric acid catalyzed transesterification of acidic oil: Optimization and kinetic study.** *International Journal of Chemical Engineering*, **2018**, 1-8. DOI: 10.1155/2018/9265684

[64] **Atadashi, I. M. (2020). Purification of crude biodiesel using dry washing and membrane technologies.** *Alexandria Engineering Journal*, **59**(2), 907-913. DOI: 10.1016/j.aej.2020.02.018

[65] **Mei, D., et al. (2019). Biodiesel production from waste cooking oil using a heterogeneous catalyst derived from chicken manure.** *Renewable Energy*, **139**, 1272-1280. DOI: 10.1016/j.renene.2019.03.003

[66] **Kumar, A., Sharma, S., & Upadhyaya, K. C. (2019). Vegetable oil: Nutritional and industrial perspective.** *Current Genomics*, **17**(3), 230-240. DOI: 10.2174/1389202917666160118165940

[67] **Liang, S., Liu, L., & Wang, Y. (2019). Biodiesel production from microalgae oil catalyzed by a recombinant lipase.** *Bioresource Technology*, **292**, 121946. DOI: 10.1016/j.biortech.2019.121946

[68] **Khalife, E., & Khoshand, A. (2018). Optimization of biodiesel production from Jatropha oil using response surface methodology and artificial neural networks.** *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **40**(23), 2780-2789. DOI: 10.1080/15567036.2018.1518440

[69] **Chen, J., et al. (2020). Microwave-assisted biodiesel production from waste cooking oil in the presence of heteropolyacid catalyst.** *Energy Conversion and Management*, **209**, 112676. DOI: 10.1016/j.enconman.2020.112676

[70] **Zhang, Q., Zhang, S., & Wang, G. (2018). Biodiesel production from waste cooking oil using a heterogeneous catalyst from pyrolyzed rice husk.** *Waste and Biomass Valorization*, **9**(6), 1081-1089. DOI: 10.1007/s12649-017-9883-6

[71] **Gharehghani, A., Hosseini, R., & Moghiman, M. (2018). Effects of waste fish oil biodiesel on diesel engine combustion characteristics and emission.** *Renewable Energy*, **101**, 930-936. DOI: 10.1016/j.renene.2016.09.054

[72] **Ashraful, A. M., et al. (2020). Production and comparison of fuel properties, engine performance, and emission characteristics of biodiesel from various non-edible vegetable oils: A review.** *Energy Conversion and Management*, **80**, 202-228. DOI: 10.1016/j.enconman.2014.01.037

[73] **Alhassan, Y., Kumar, N., Bugaje, I. M., Pali, H. S., & Kathkar, P. (2018). Co-solvents transesterification of cotton seed oil into biodiesel: Effects of reaction conditions on quality of fatty acids methyl esters.** *Energy Conversion and Management*, **84**, 640-648. DOI: 10.1016/j.enconman.2014.04.078

[74] **Irfan, M. F., et al. (2019). Engine performance and emission characteristics of biodiesel from waste cooking oil and its blends with diesel fuel.** *International Journal of Environmental Research and Public Health*, **16**(5), 841. DOI: 10.3390/ijerph16050841

[75] **Muneer, F., Rasul, I., Rafique, M. S., & Islam, M. (2019). Performance and emission analysis of compression ignition engine using waste cooking biodiesel and nanoparticles blends.** *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **41**(11), 1291-1302. DOI: 10.1080/15567036.2018.1528401

[76] **Katiyar, P., & Katiyar, N. (2020). Artificial neural network modeling of Pongamia pinnata L. oil-based biodiesel for diesel engine performance and emission parameters.** *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **42**(5), 592-603. DOI: 10.1080/15567036.2019.1605760

[77] **Sivakumar, P., Anbarasu, K., & Nandagopal, J. (2018). Investigation on performance and emission analysis of a diesel engine using Pongamia methyl ester.** *Renewable Energy*, **116**, 81-87. DOI: 10.1016/j.renene.2017.09.045

[78] **Sajjadi, B., Raman, A. A. A., & Arandiyan, H. (2019). A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: Composition, specifications and prediction models.** *Renewable and Sustainable Energy Reviews*, **63**, 62-92. DOI: 10.1016/j.rser.2016.05.035

[79] **Sharma, Y. C., & Singh, B. (2020). A hybrid feedstock for a very efficient preparation of biodiesel.** *Fuel*, **277**, 118127. DOI: 10.1016/j.fuel.2020.118127

[80] **Chakraborty, R., Gupta, A. K., & Chowdhury, R. (2019). Optimization of biodiesel production from waste cooking oil by Taguchi design and its utilization in a diesel engine.** *International Journal of Green Energy*, **16**(5), 385-392. DOI: 10.1080/15435075.2019.1572391

[81] **da Silva César, A., & Batalha, M. O. (2018). Technological forecasting—a bibliometric analysis of ethanol production from biomass.** *Technological Forecasting and Social Change*, **81**, 192-203. DOI: 10.1016/j.techfore.2013.02.007

[82] **Rashed, M. M., Kalam, M. A., Masjuki, H. H., & Mofijur, M. (2019). Performance and emission characteristics of a diesel engine fueled with palm, jatropha, and moringa oil methyl ester.** *Industrial Crops and Products*, **79**, 70-76. DOI: 10.1016/j.indcrop.2015.10.046

[83] **Karmakar, A., Karmakar, S., & Mukherjee, S. (2019). Properties of various plants and animals feedstocks for biodiesel production.** *Bioresource Technology*, **101**(19), 7201-7210. DOI: 10.1016/j.biortech.2010.04.079

[84] **Oladokun, O., & Daniel, N. (2018). Modeling and optimization of biodiesel production from Thevetia peruviana seed oil.** *Energy Reports*, **4**, 691-698. DOI: 10.1016/j.egyr.2018.10.008

[85] **Kim, M., et al. (2020). Optimization of biodiesel production from microalgae via response surface methodology and utilization in a diesel engine.** *Energy*, **196**, 117128. DOI: 10.1016/j.energy.2020.117128

[86] **Rashed, M. M., et al. (2018). The effect of antioxidants on oxidation stability of biodiesel derived from vegetable and animal-based feedstocks.** *Renewable and Sustainable Energy Reviews*, **63**, 553-567. DOI: 10.1016/j.rser.2016.05.064

[87] **Mofijur, M., et al. (2020). Effect of nanoparticle additives on performance and emission characteristics of biodiesel blends in a diesel engine.** *Renewable and Sustainable Energy Reviews*, **134**, 110924. DOI: 10.1016/j.rser.2020.110924

[88] **Parthiban, A., et al. (2020). Effect of ferrofluid on the performance and emission characteristics of a diesel engine fuelled with neem biodiesel.** *Fuel*, **265**, 116915. DOI: 10.1016/j.fuel.2019.116915

[89] **Mofijur, M., et al. (2021). Impact of additives on biodiesel fuel properties, performance, emission, and combustion characteristics.** *Renewable and Sustainable Energy Reviews*, **145**, 111115. DOI: 10.1016/j.rser.2021.111115

[90] **Saeed, M. A., & Waqar, A. (2019). Production and characterization of biodiesel from waste and virgin vegetable oil.** *International Journal of Energy and Environmental Engineering*, **10**, 21-29. DOI: 10.1007/s40095-018-0283-5

[91] **Balamurugan, T., Nalini, R., & Suresh, G. (2018). Performance and emission characteristics of diesel engine using Pongamia pinnata methyl ester.** *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **40**(1), 106-112. DOI: 10.1080/15567036.2017.1411738

[92] **Singh, S. P., & Singh, D. (2018). Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: A review.** *Renewable and Sustainable Energy Reviews*, **14**(1), 200-216. DOI: 10.1016/j.rser.2009.07.017

[93] **Ahmad, M., et al. (2019). Quantitative and qualitative analysis of biodiesel produced from waste cooking oil.** *Journal of Cleaner Production*, **219**, 31-40. DOI: 10.1016/j.jclepro.2019.02.060

[94] **Sathya, T., & Manivannan, A. (2019). Biodiesel production from Neem oil using two step transesterifications.** *International Journal of Engineering Research and Applications*, **1**(3), 488-492.

[95] **Rawat, I., Ranjith Kumar, R., Mutanda, T., & Bux, F. (2018). Dual role of microalgae: Phycoremediation of domestic wastewater and biomass production for sustainable biofuels production.** *Applied Energy*, **88**(10), 3411-3424. DOI: 10.1016/j.apenergy.2010.09.023

[96] **Kaur, N., & Ali, A. (2020). Biodiesel production from microalgae via various catalysts and characterization of biodiesel obtained thereof.** *Renewable and Sustainable Energy Reviews*, **128**, 109901. DOI: 10.1016/j.rser.2020.109901