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DELONIX REGIA BIODIESEL: A REVIEW OF ITS POTENTIAL UTILIZATION FOR SUSTAINABLE ENERGY AND NATIONAL DEVELOPMENT

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ABSTRACT

This review explores the potential of flamboyant (*Delonix regia*) seed oil biodiesel as a sustainable alternative fuel for compression ignition engines, with a particular focus on its implications for national development. *Delonix regia* is abundant in Nigeria and offers various uses, including ornamental, ecological, medicinal, and economic applications, particularly from its seeds. The biodiesel derived from its seeds, *Delonix regia* methyl ester or biodiesel, possesses physicochemical properties suitable for compression ignition engines applications. The paper highlights the critical role of energy and exergy analyses in comprehensively understanding and optimizing engine performance and combustion characteristics when using biodiesel blends. These analyses are crucial for identifying energy losses and enhancing overall efficiency. The review also discusses the application of optimization techniques, such as Design of Experiment and Artificial Neural Networks, to further improve engine performance. Ultimately, this paper concludes that *Delonix regia* biodiesel, supported by rigorous thermodynamic analysis, presents a significant opportunity for national development. It can drive energy independence, foster economic diversification, ensure environmental sustainability, and promote evidence-based policymaking. To fully realize this potential for a cleaner, more sustainable energy landscape, key policy actions are recommended: full-scale deployment, standardization, local value chain promotion, policy integration, and capacity building.

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INTRODUCTION

The global reliance on fossil fuels has severely impacted the environment and depleted non-renewable resources (Filipenco 2025; IEA, 2023). In response, biodiesel, derived from renewable sources, has gained considerable attention due to its environmental benefits and sustainable nature (Manzanera et al., 2008; Randive et al., 2024). Among various non-edible feedstocks, *Delonix regia*, commonly known as the flamboyant tree, stands out as a promising candidate for biodiesel production because of its high oil yield and non-edibility (Thiruselvam, et al., 2024; Ogbuanu et al., 2017). Understanding the significant energy transformations that occur during combustion in combustion ignition engines (CIEs) is best achieved through a combination of energy and exergy analyses (SayinandKahraman, 2016; Khan et al., 2023). The *Delonix regia* plant is widespread throughout Nigeria's tropical and subtropical regions. It's highly valued for its striking ornamental appearance and its ability to thrive in various soil types, particularly sandy or loamy soils (Modiet et al., 2016; Saroj et al., 2022).

Its ubiquitous presence is largely due to extensive cultivation in urban areas, along roadsides, and in parks, where its vibrant red-orange flowers are highly prized (Saroj et al., 2022). Nigeria's tropical climate provides ideal growing conditions, as the tree tolerates drought and some salinity. Its rapid growth and ease of propagation from seeds further contribute to its widespread availability (Jibo et al., 2022; National Research Council, 1980). In Nigeria, *Delonix regia* offers more than just aesthetic appeal; it serves a diverse array of practical purposes. Beyond enhancing landscapes with its vibrant flowers, it provides excellent shade due to its expansive canopy and dense foliage, making it a valuable asset in Nigeria's tropical climate for homes, parks, and livestock (Kamel et al., 2012). Ecologically, *Delonix regia* is a nitrogen-fixing legume, that improves soil fertility and effectively controls erosion, aiding in the rehabilitation of degraded land (Rajput et al., 2024; Kamel et al., 2012; Fahad et al., 2022; Heuzé et al. 2020). Traditionally, various parts of *Delonix regia*—including its leaves, bark, flowers, and seeds—are used in medicine to treat a range of ailments (Tiwari and Talreja, 2023). The tree is reported to possess anti-inflammatory, antibacterial, antifungal, anti-diarrheal, and antioxidant properties (Sharma and Arora, 2015;

Yadav et al., 2024; Shewale et al., 2011; Saroj et al., 2022). It's also recognized for its hepatoprotective, antidiabetic, anti-ulcer, anticancer, and antimalarial effects (Solomon et al., 2025; Ndung'u et al., 2024; Nagarajan et al. 2015; Saroj et al., 2022), and is traditionally used for chronic fever, joint pain, bronchitis, asthma, and gynecological issues (Solomon et al., 2025; Mutie et al., 2023; Tiwari and Talreja, 2023).



Fig. 1. Flamboyant Tree (*Delonix regia*)

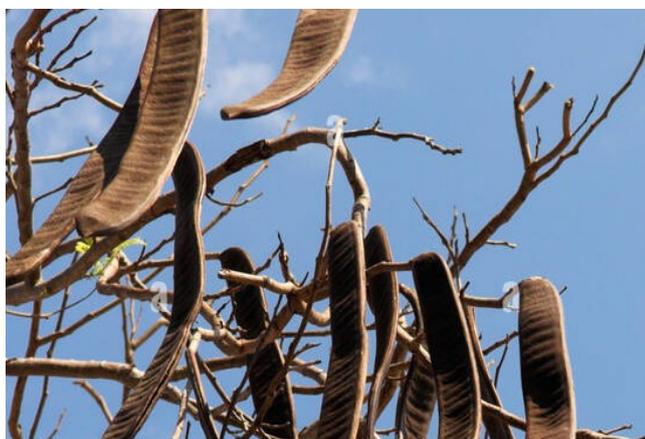


Fig. 2. *Delonix regia* Seed Pod



Fig. 3. *Delonix regia* Seeds

Economically, *Delonix regia* is a rich resource. Its leaves and processed seed meal are suitable as livestock feed, though they require proper treatment to deactivate anti-nutrients (Bake et al., 2014; Olufayo and Falola, 2018). The woody pods and timber serve as firewood and for light construction, fence posts, and tool handles (CIFOR-ICRAF, n.d.; Heuzé et al., 2020; Orwa 2009). The hard seeds are used in crafts, and a water-soluble gum extracted from them acts as a binder in the textile and tablet industries (Nwokocha et al., 2018; Igwe and Nwokocha, 2014; StuartXchange, 2024). The flowers also provide bee forage, supporting apiculture (Apiculture in India, n.d.; Ebada et al., 2023). The seeds of *Delonix regia* hold particular value. In traditional medicine, they're believed to offer anti-

inflammatory properties for joint pain, support digestive health, and provide immune benefits due to their antioxidant content (Yadav et al., 2024; Shewale et al., 2011; Saroj et al., 2022). Research also suggests a potential hepatoprotective role (Solomon et al., 2025; Nagarajan et al., 2015) and antimicrobial effects (Solomon, et al 2025; Sharma et al., 2012). Other traditional uses include treating constipation, chronic fever, malaria, and gynecological issues (Solomon, et al., 2025; Mutie, et al., 2023; Tiwari and Talreja, 2023). Industrially, processed seeds serve as a protein source for animal feed (Bake, et al., 2024). The seeds also yield a fatty oil with diverse industrial applications in tanning, soap-making, illumination, and pharmaceuticals, additionally demonstrating insecticidal and antibacterial properties (Krishnamoorthy et al., 2023; Ammar et al., 2025; Stuart X change, 2024; Ribeiro-Barros, et al, 2018). Finally, the oil cake remaining after oil extraction makes for a good fertilizer (Heuzé et al. 2020; Orwa, 2009).

Physicochemical and Fuel Properties of *Delonix regia* Oil Biodiesel: The *Delonix regia* seed oil exhibits favorable properties such as a high flash point (201.3°C), high viscosity (43.75 mm²/s), and a density of 0.942 kg/m³ (Thiruselvam, et. al. 2024). These properties necessitate transesterification - either by methanolysis or ethanolysis, to reduce viscosity and improve fuel usability (Ejilal et al, 2010, Ejilal et al., 2016; Ejilal et al, 2017; Gambo et al, 2017, Gambo et al, 2020). The resulting biodiesel, known as *Delonix regia* methyl ester (DRME), is comparable to conventional diesel in terms of cetane number and heating value similar to *Jatropha curcas* oil methyl ester (Saxena, 2013; Koh, et al., 2011; Ejilal et al, 2010). This similarity to other seed oil biodiesels makes it suitable for CIEs without requiring major modifications (Canakci and Sanli, 2008; Kosuru et al., 2024, Ejilal, et al., 2016; Soja, et.al., 2017).

Thermodynamic Analyses of *Delonix regia* Oil Biodiesel in CIEs: Energy is the essential driver of sustainable economic growth for any nation, boosting productivity, increasing income, and creating jobs. Its crucial role in economic development cannot be overstated, despite the common inevitability of energy degradation within a system (Abubakar, et. al., 2020). To better understand and optimize fuel utilization in CIEs, researchers employ two key thermodynamic principles: energy analysis and exergy analysis. Energy analysis, based on the first law of thermodynamics, focuses on evaluating how energy flows and transforms within a system. In CIEs, fuel energy converts partially into mechanical work, while the remaining energy is lost as heat and exhaust gases (Şanlı and Uludamar, 2019). Thermal efficiency is a key measure of this conversion, and optimizing combustion parameters can enhance it (Sivaramakrishnan and Ravikumar, 2004). Conversely, exergy analysis incorporates the second law of thermodynamics, focusing on the quality of energy and pinpointing inefficiencies within the system. This analysis helps identify energy losses stemming from heat transfer, friction, and incomplete combustion (Kotas, 1985). While studies indicate that biodiesel blends generally have lower exergy efficiency than diesel, this can be improved by optimizing engine parameters (Nazzal et al., 2019). Research comparing biodiesel blends with conventional diesel, such as that by Şanlı and Uludamar (2019), shows similar trends in energy and exergy efficiencies, though biodiesel's oxygenated nature can lead to slightly higher exergy destruction. Fuel properties like cetane number and oxygen content influence combustion characteristics, including ignition delay, heat release rate, and cylinder pressure. Specifically, *Delonix regia* biodiesel blends demonstrate a shorter ignition delay and lower peak pressures compared to diesel, which in turn reduces NO_x and soot emissions (Ashraful et al., 2014; Kegl, 2011). Furthermore, it could be observed from Ghazali et al., (2015) that using biodiesel leads to decreased carbon monoxide (CO) and hydrocarbon (HC) emissions. Significant performance improvements have been achieved by optimizing engine parameters using statistical and computational methods. The commonly employed techniques include Design of Experiment (DoE), Response Surface Methodology (RSM), and Artificial Neural Networks (ANN). It was reported that, Najafi et al. (2018) successfully used RSM to optimize energy and exergy efficiencies with waste cooking oil biodiesel.

Gaps in Research and Future Directions: Despite the increasing body of research on biodiesel as an alternative fuel for CIEs, significant gaps persist, particularly concerning specific non-edible feedstocks like *Delonix regia* biodiesel or methyl ester. While general studies on biodiesel performance are abundant, the unique characteristics of *Delonix regia* methyl esters (DRME) necessitate dedicated and in-depth investigations to fully unlock its potential. One primary research gap lies in the limited comprehensive studies specifically focused on *Delonix regia* biodiesel. While its availability and basic properties have been noted, there is a critical need for detailed analyses across a wider range of operating conditions. This includes systematically analyzing various blend ratios of DRME with conventional diesel to identify optimal mixtures that balance engine performance, emissions reduction, and fuel economy. Furthermore, thorough investigations into how varying engine loads impact the combustion efficiency and emission profiles of DRME blends are essential for real-world application.

Understanding the effects of different injection parameters, such as injection pressure and timing, on DRME combustion is crucial for fine-tuning engine control strategies to maximize benefits. These detailed parametric studies are vital for developing robust datasets that support the widespread adoption of *Delonix regia* biodiesel. Another area requiring more attention is the underutilization of exergy analysis for optimization, particularly in real-time engine control. While energy analysis (first law of thermodynamics) provides insights into energy conversion quantities, exergy analysis (second law of thermodynamics) offers a deeper understanding of energy quality and the sources of irreversibility and destruction within the combustion process (Kotas, 1985; Şanlıand Uludamar, 2019). This qualitative perspective is invaluable for identifying areas where energy is wasted due to inefficiencies, such as heat transfer losses or chemical reactions that do not proceed optimally. Applying exergy analysis in real-time settings could lead to dynamic adjustments in engine operation for instantaneous efficiency improvements and reduced exergy destruction, a frontier that remains largely unexplored for biodiesel applications (Wang *et al.*, 2024).

Looking ahead, integrating ANN and hybrid models with thermodynamic analysis presents a promising future direction for developing intelligent engine systems. When combined with the rigorous insights from energy and exergy analyses, these advanced computational models can facilitate more accurate predictions, optimize control strategies, and even enable self-adaptive engine management systems (Najafi *et al.*, 2018). Such intelligent systems could dynamically adjust engine parameters to maximize efficiency and minimize emissions for *Delonix regia* biodiesel, paving the way for more sustainable and responsive power generation. This holistic approach is critical for bridging the gap between theoretical understanding and practical, real-world application of *Delonix regia* oil biodiesel in CIEs.

Role of Biodiesel and Thermodynamic Analysis in National Development: The pressing need for sustainable and resilient energy systems has brought renewable energy research to the forefront of national development strategies. Examining the energy and exergy analyses of combustion processes in CIEs powered by *Delonix regia* biodiesel blends offers a crucial path to achieving diverse developmental goals. This approach is vital because it can strengthen energy security, environmental sustainability, economic diversification, and technological innovation—all essential for a nation's growth and resilience (Akande *et al.*, 2024; Shahare *et al.*, 2017).

Key Contributions to National Development: Firstly, a nation's energy security is deeply connected to its ability to generate reliable and affordable energy from domestic resources. Countries like Nigeria, heavily reliant on imported petroleum, struggle with volatile prices, supply chain disruptions, and foreign exchange pressures (Dike, 2017). This review highlights *Delonix regia* biodiesel as an indigenous, non-edible option that paves the way for localized energy production, lessening dependence on imported fuels and boosting

national energy independence. Developing local biofuel industries encourages domestic production and reduces the financial strain of fuel imports (Adewuyi, 2020; Aliyu *et al.*, 2017; Yami, 2020; Abdulkareem, 2012).

Secondly, a historical overreliance on crude oil exports has limited the economic flexibility of oil-producing nations. Producing biodiesel from underutilized biomass like *Delonix regia* seeds introduces a viable route for economic diversification. Establishing a biodiesel value chain—from seed collection and oil extraction to processing and distribution—can create new industries in rural and urban fringe areas. This fosters agribusiness and generates employment opportunities at various stages, uplifting local economies, reducing poverty, and promoting inclusive economic growth, especially where *Delonix regia* trees are abundant (Adefarati and Adekanye, 2019).

Thirdly, climate change and environmental degradation are urgent global challenges largely driven by fossil fuel use. *Delonix regia* biodiesel, derived from non-toxic and biodegradable sources, offers a cleaner alternative to petroleum diesel. Its sulfur-free composition and oxygenated structure lead to lower emissions of harmful pollutants like carbon monoxide (CO), hydrocarbons (HC), and particulate matter (Hurdogan, 2016). Exergy analysis allows researchers to quantify energy losses and irreversibility, supporting the development of optimized combustion technologies that minimize environmental impact (Dincerand Rosen, 2012). This aligns with national and international sustainability goals and commitments under the Paris Agreement (UN, 2015).

Finally, effective national energy planning relies on evidence-based policymaking. This review provides a comprehensive scientific foundation for promoting biofuels. Integrating energy and exergy analysis offers a dual perspective on both the quantity and quality of energy transformations within biodiesel-fueled engines (Bejan *et al.*, 1996). Such insights are invaluable for creating regulations, subsidy programs, and research agendas that support renewable fuel development. They also inform investment decisions, directing funding toward technologies with the highest potential for efficiency and environmental benefits. This approach directly supports several Sustainable Development Goals (SDGs), including Affordable and Clean Energy (Goal 7), Decent Work and Economic Growth (Goal 8), Industry, Innovation, and Infrastructure (Goal 9), and Climate Action (Goal 13) (UNDP, n.d.).

Analytical Insights for National Progress: These analytical methods provide distinct yet complementary insights that significantly impact a nation's progress. The ability of energy and exergy analyses to support national development is summarized in Table 1. In terms of efficiency evaluation, energy analysis measures the ratio of energy input to output, while exergy analysis precisely identifies the potential for useful work and quantifies energy losses. Together, these methods guide improvements in engine and system design, directly leading to reduced fuel consumption nationwide (Cengeland Boles, 2019). For waste reduction, energy analysis quantifies thermal losses, whereas exergy analysis accurately locates where energy becomes irreversibly degraded during combustion. This combined understanding supports the creation of more sustainable and cost-effective energy systems by minimizing waste (Moran *et al.*, 2008). In resource optimization, energy analysis helps assess fuel economy, while exergy analysis reveals the true quality of energy usage. By improving how efficiently fuel is utilized, these analyses help conserve national energy resources (Shahare *et al.*, 2017). Concerning technology innovation, energy analysis provides performance benchmarks, and exergy analysis directs the development of cleaner combustion technologies. This dual approach informs green engineering solutions and stimulates local research and development initiatives, fostering innovation (Oloruntoba and Adekanye, 2019). Finally, regarding environmental impact, energy analysis measures emissions, and exergy analysis tracks energy degradation. These insights are vital for enabling smoother transitions to cleaner energy sources and fulfilling national climate commitments, ensuring a healthier environment for all (Kosuru *et al.*, 2024).

Table 1. Impact of Thermodynamic Analysis on National Development

Concept	Energy Analysis	Exergy Analysis	Impact
Efficiency Evaluation/ Performance Assessment	Appraises input/output ratios; assesses fuel economy; benchmarks performance	Pinpoints valuable work capacity and inefficiencies; uncovers energy quality utilization	Helps improve engine and system design, reducing fuel consumption leading to energy savings and reduced reliance on imported fuels
Waste Reduction/ Loss Mitigation	Quantifies heat losses; evaluates emissions	Finds irreversibility in combustion; monitors energy degradation	Supports design of more sustainable and cost-effective energy systems
Resource Optimization /System Enhancement	Aids in refining engine and system architecture, lowering fuel use; gauges emissions	Backs creation of more sustainable and economical energy setups	Improves fuel utilization efficiency, saving national energy resources
Technology Innovation /Strategic Benefits	Elevates fuel usage effectiveness, preserving national energy reserves	Directs cleaner combustion methods; informs eco-friendly engineering and local research	Informs green engineering solutions and local R&D initiatives
Environmental Impact	Measures environmental discharge; enables shifts to cleaner energy and climate pledges	Tracks energy degradation; supports eco-friendly engineering and local R&D initiatives	Enables cleaner energy transitions and climate commitments

Recommended Policy Actions for *Delonix regia* Biodiesel Development

To fully realize the potential of *Delonix regia* biodiesel for national development, the following policy actions are recommended:

- i. **Invest in Research and Development (R&D):** Prioritize funding for studies on varying blend ratios, engine loads, and injection parameters for *Delonix regia* biodiesel. Further explore integrating advanced optimization techniques like ANN and hybrid models with thermodynamic analysis to develop intelligent engine systems (Najafi et al., 2018; Mitchell, 2011). This aligns with calls for stronger R&D in African biofuel development (African Development Bank Group, 2019).
- ii. **Facilitate Full-Scale Implementation and Standardization:** Support pilot projects and initiatives aimed at the full-scale deployment of *Delonix regia* biodiesel. Develop and enforce national standards for biodiesel blend compositions to ensure quality and compatibility with existing engine technologies (Shaah et al., 2021; NAFDAC, 2019). This is crucial for successful integration into the national energy landscape (Ariyoosu et al., 2024).
- iii. **Promote Local Production and Value Chains:** Encourage investments in local facilities for *Delonix regia* seed collection, oil extraction, and biodiesel processing. Implement policies that support agribusiness and rural communities involved in the biodiesel value chain (Ariyoosu et al., 2024). This can diversify the economy and create employment opportunities (Rajput et al., 2024).
- iv. **Integrate into National Energy Policy:** Incorporate *Delonix regia* biodiesel into national energy portfolios and strategic energy planning documents in accordance with international mandates (Morgera et al., 2009). Provide incentives for its adoption, such as tax breaks or subsidies for producers and consumers, to accelerate its mainstream integration (Federal Republic of Nigeria, 2007; Ariyoosu et al., 2024). Such policies are critical for a long-term shift away from fossil fuels (Oloruntoba and Adekanye, 2019).
- v. **Raise Awareness and Build Capacity:** Educate the public, industry stakeholders, and policymakers about the benefits and technical viability of *Delonix regia* biodiesel. Develop training programs for engineers and technicians in energy and exergy analyses and biofuel production (Skills for Africa, n.d.; The Middle Belt Reporters (n.d.)). Increased awareness and skilled labor are vital for successful adoption (Mbamalu, 2019).

Summary: This paper reviews the use of *Delonix regia* (flamboyant) seed oil biodiesel as a sustainable alternative fuel for CIEs. *Delonix regia* is widely available in Nigeria, offers diverse uses including ornamental, shade, ecological, medicinal, and economic applications, particularly from its seeds. The biodiesel derived from its seeds (DRME) exhibits suitable physicochemical properties for CI engines. The review emphasizes the importance of energy and exergy analyses

diversification, and bolster environmental sustainability. This intelligent harnessing of local resources offers a transformative pathway towards a more resilient, inclusive, and sustainable future.

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