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# USE OF MACAUBA (*Acrocomia aculeata*) FOR BIOFUELS: PERSPECTIVES AND CHALLENGES IN THE ENERGY SECTOR

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## ABSTRACT

**Objective:** This article presents an overview of the use of *Acrocomia aculeata* (macauba) in biofuel production, highlighting its industrial potential, environmental benefits, and the main challenges in its large-scale implementation within the energy sector.

**Theoretical Framework:** Given the intensifying global climate crisis caused by greenhouse gas emissions from fossil fuel combustion, the adoption of renewable sources such as biodiesel has become essential. Macauba stands out due to its high oil productivity and adaptability to poor soils and arid conditions, positioning itself as a strategic crop for sustainable energy generation.

**Method:** A narrative literature review was conducted through searches in scientific databases (Scopus, Web of Science, and Google Scholar), using keywords such as "biofuel," "macauba," "energy sector," and "biotechnology in biofuels." Articles published in English and Portuguese in recent years were selected, focusing on production techniques, benefits, and the limitations of macauba-based biodiesel.

**Results and Discussion:** Macauba shows high potential as a renewable energy source, providing oil yields up to 6 tons/hectare, surpassing conventional crops like soy. It also contributes to aviation biofuel alternatives due to its fatty acid profile. Despite these advantages, issues like high production costs, delayed fruiting, lack of structured

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supply chains, and high oil acidity pose significant barriers. Addressing these gaps requires further research, species domestication, and strategic economic planning.

**Keywords:** Biofuel, Biotechnology, Energy Sector, Macauba, Renewable Energy.

## UTILIZAÇÃO DA MACAÚBA (*Acrocomia aculeata*) PARA BIOCOMBUSTÍVEIS: PERSPECTIVAS E DESAFIOS NO SETOR ENERGÉTICO

### RESUMO

**Objetivo:** Este artigo apresenta uma análise sobre a utilização da *Acrocomia aculeata* (macaúba) na produção de biocombustíveis, evidenciando seu potencial industrial, os benefícios ambientais e os principais desafios para sua implementação em larga escala no setor energético.

**Referencial Teórico:** Diante do agravamento das mudanças climáticas decorrentes da queima de combustíveis fósseis, torna-se essencial a adoção de fontes renováveis como o biodiesel. A macaúba se destaca por sua alta produtividade de óleo e por sua adaptabilidade a solos pobres e regiões áridas, configurando-se como uma alternativa estratégica para geração de energia sustentável.

**Método:** Realizou-se uma revisão narrativa da literatura em bases científicas como Scopus, Web of Science e Google Acadêmico, utilizando palavras-chave como "biocombustível", "macaúba", "setor energético" e "biotecnologia em biocombustíveis". Foram selecionados artigos em inglês e português dos últimos anos que abordam as técnicas de produção, os benefícios e as limitações do uso da macaúba para biodiesel.

**Resultados e Discussão:** A macaúba apresenta alto potencial como fonte de energia renovável, com produção de até 6 toneladas de óleo por hectare, superando culturas convencionais como a soja. Além disso, destaca-se como alternativa de biocombustível para aviação, devido ao seu perfil de ácidos graxos. Apesar dessas vantagens, ainda existem entraves como custos elevados, tempo prolongado até a frutificação, ausência de cadeia produtiva estruturada e acidez elevada do óleo. Para superá-los, são necessários avanços na pesquisa, domesticação da espécie e planejamento econômico estratégico.

**Palavras-chave:** Biocombustível, Biotecnologia, Energia Renovável, Macaúba, Setor Energético.

## USO DE LA MACAÚBA (*Acrocomia aculeata*) PARA BIOCOMBUSTIBLES: PERSPECTIVAS Y DESAFÍOS EN EL SECTOR ENERGÉTICO

### RESUMEN

**Objetivo:** Este artículo analiza el uso de *Acrocomia aculeata* (macaúba) en la producción de biocombustibles, destacando su potencial industrial, los beneficios ambientales y los principales desafíos para su adopción a gran escala en el sector energético.

**Marco Teórico:** Frente a la crisis climática global intensificada por las emisiones de gases de efecto invernadero derivadas del uso de combustibles fósiles, la adopción de fuentes renovables como el biodiésel es fundamental. La macaúba destaca por su alta productividad de aceite y su adaptabilidad a suelos pobres y condiciones áridas, posicionándose como un cultivo estratégico para la generación de energía sostenible.

**Método:** Se realizó una revisión narrativa de la literatura mediante búsquedas en bases científicas como Scopus, Web of Science y Google Scholar, utilizando palabras clave como "biocombustible", "macaúba", "sector energético" y "biotecnología en biocombustibles". Se seleccionaron artículos en inglés y portugués publicados en los últimos años, centrados en técnicas de producción, beneficios y limitaciones del biodiésel a base de macaúba.

**Resultados y Discusión:** La macaúba demuestra un alto potencial como fuente de energía renovable, con una producción de hasta 6 toneladas de aceite por hectárea, superando cultivos convencionales como la soja. Además, se considera prometedora como biocombustible para aviación debido a su perfil lipídico. No obstante, persisten barreras como los altos costos de producción, el largo tiempo hasta la fructificación, la falta de cadenas productivas

estructuradas y la alta acidez del aceite. Superar estos desafíos requiere más investigación, domesticación de la especie y planificación económica estratégica.

**Palabras clave:** Biocombustible, Biotecnología, Energía Renovable, Macaúba, Sector Energético.

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## 1 INTRODUCTION

Currently, the planet is experiencing environmental disturbances of unprecedented magnitude, primarily driven by the intensification of global climate change (Soares, 2025). These changes are intrinsically linked to global warming and the worsening of the greenhouse effect, phenomena resulting from the increased atmospheric concentrations of gases such as carbon dioxide, methane, and nitrogen oxides (Souza, 2024). The burning of fossil fuels, especially petroleum-derived products, is the main source of these emissions, fueling industrial processes, transportation, and large-scale energy generation (Souza, 2024). In light of this, the environmental impacts resulting from energy dependence on fossil resources have become one of the most urgent issues on international political and environmental agendas, requiring structural and sustainable solutions for the global energy matrix (Al-Ghussain, 2019).

In response to this scenario, the development and adoption of renewable energy technologies have taken a central role in strategies aimed at mitigating greenhouse gas emissions and promoting environmental sustainability. In recent decades, the search for viable, clean, and economically sustainable alternatives to fossil fuels has intensified, driven both by international environmental commitments and by growing social pressure for sustainable development models (Souza, 2024; Junior *et al.*, 2025). Within this context, several countries have adopted public policies focused on energy transition, including incentives for research, technological innovation, and investment in infrastructure for the use of renewable sources (Pallotta, 2022; Vernersbach *et al.*, 2021). Among the studied and implemented options, biofuels have stood out for their capacity to directly replace fossil fuels, particularly in the transportation and electricity generation sectors. Furthermore, they present a lower environmental impact during combustion, releasing reduced amounts of atmospheric pollutants (Duarte *et al.*, 2022).

Among the plant species with potential for biofuel production, the native palm *Acrocomia aculeata*, commonly known as macauba, has emerged as a significant option (Santos

& Laurentino, 2021). This species has a high oil yield, extracted from both the pulp and the kernel, enabling the maximization of production per cultivated hectare. Moreover, macauba exhibits excellent adaptability to adverse edaphoclimatic conditions, being capable of growing in sandy, low-fertility soils and in environments with water scarcity, conditions under which many traditional oilseed crops would not thrive (Santos & Laurentino, 2021; Favaro & Rocha, 2022). These characteristics grant the species relevant agronomic advantages, positioning it as a strategic alternative for large-scale cultivation in tropical and subtropical regions. In addition to its productive potential, its integration into agroforestry systems and its contribution to carbon sequestration reinforce its role in addressing climate change (Lopes, 2020; Rodolfo, 2022).

However, despite its promising agronomic and environmental attributes, the macauba production chain still faces significant obstacles, especially in logistical, technological, and economic aspects (Jager, 2023). Among the main challenges are the lack of efficient mechanized harvesting processes, limited infrastructure for industrial oil processing, and a shortage of public policies and economic incentives that would support its commercial insertion (Favaro & Rocha, 2022; Jager, 2023). From a scientific standpoint, further advancements are needed in the genetic improvement of the species and in the optimization of biotechnological processes for converting its oil into biodiesel, aiming at cost reduction and increased competitiveness compared to other energy sources (Moreira; Junior, 2023; Moreira; Rezende; Pasa, 2019). In view of these gaps, research has been conducted to enhance the productivity, sustainability, and economic viability of macauba as a bioenergy feedstock.

In this context, the present article aims to conduct a narrative literature review on the use of *Acrocomia aculeata* in biofuel production. It seeks to analyze the scientific, agronomic, and economic foundations that justify the selection of this palm as a strategic raw material, as well as present the biotechnological innovations applied to its cultivation and conversion process into biodiesel. Additionally, the main bottlenecks faced in its large-scale adoption in the global energy sector are discussed. The relevance of this study lies in the urgency of promoting the gradual replacement of fossil fuels with renewable sources, in order to mitigate the effects of climate change and foster a model of socio-economic and industrial development that is sustainable, resilient, and environmentally responsible.

## 2 METHODOLOGY

This study presents a narrative perspective of the literature, focusing on the use of macauba in the production of biofuels and the challenges associated with the adoption of this plant in the energy sector. The purpose of this review is to present the biotechnological techniques applied to the production of biodiesel derived from macauba oil, consolidating existing knowledge on these innovative strategies and providing detailed and up-to-date information on such practices. Furthermore, it aims to highlight the current perspectives and obstacles related to the large-scale cultivation of this species for bioenergy purposes.

A literature search was conducted in major scientific databases, such as Scopus, Web of Science, and Google Scholar, using keywords including “biofuel,” “macauba,” “energy sector,” “biotechnology in biofuels,” and “implementation of *Acrocomia aculeata*.” The selection criteria for the articles included publications in English and Portuguese from recent years that addressed biodiesel production from macauba oil and its use in the energy sector, particularly in transportation, as well as the effectiveness of new production protocols for this compound, and studies that examined the challenges faced in the energy industry for incorporating the plant into large-scale systems.

This review aims to disseminate detailed information about the current advances in one of the key areas of ecotechnology, serving as a valuable reference for improving the biotechnological practices currently employed in the development of biofuels. The relevance of this topic lies in the urgent need for atmospheric decarbonization to promote environmental conservation, considering that biodiesel is a renewable, organic-based resource. Through the use of macauba, this process may become significantly more optimized and efficient, thus contributing meaningfully to global sustainable development.

## 3 RESULTS AND DISCUSSIONS

The need to develop and expand biofuel production has emerged over the past decades as a response to environmental commitments established following the 3rd United Nations Conference on Climate Change, particularly with the signing of the Kyoto Protocol. This international agreement aimed primarily to reduce greenhouse gas emissions, which play a central role in climate change associated with global warming. The main regulated gases include methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and especially carbon dioxide ($CO_2$), the most abundant greenhouse gas in the

atmosphere and the leading contributor to the intensification of the greenhouse effect (Moreira & Junior, 2023; Al-Ghussain, 2019; Vidal, 2019).

In this context, several authors highlight biodiesel as one of the most viable alternatives to the energy crisis caused by the depletion and environmental impact of fossil fuels. According to Nascimento *et al*. (2022), Guerra *et al*. (2023), and Vernersbach *et al*. (2021), biodiesel stands out due to its renewable origin, whether animal or plant-based, being produced from natural oils as a final product. The most commonly employed processes for obtaining biofuels include transesterification, hydroesterification, and thermal cracking. As Nascimento *et al*. (2022) report, transesterification is the most widely used method, based on the reaction between triglycerides and alcohols in the presence of a catalyst, resulting in biodiesel and glycerol, the latter of which is applicable in the pharmaceutical, cosmetic, and medical sectors. Hydroesterification occurs in two stages: first, triglycerides are hydrolyzed, forming fatty acids and glycerol; then, the fatty acids react with alcohols, producing biodiesel. Thermal cracking, in turn, consists of heating the triglyceride to produce compounds with similar properties to fossil fuels, although technically they are not classified as biodiesel. Additionally, other methods such as interesterification have been explored, allowing, through chemical or enzymatic catalysts, the modification of the fatty acid profile of oils, thus adjusting their physicochemical characteristics for specific purposes (Cabrera *et al.*, 2022).

The selection of raw material is a determining factor in the feasibility of biofuel production. Nobre *et al*. (2014) and Junqueira *et al*. (2019) emphasize the importance of identifying crops with high yield and elevated oil content. In this regard, the macauba palm (*Acrocomia aculeata*) has stood out for its productive and adaptive characteristics. According to Aguiar *et al*. (2022), macauba produces spherical and slightly flattened fruits, measuring 3.5 to 5 cm in diameter, with a rigid endocarp strongly adhered to the mesocarp, and a high-oil-content edible kernel. The extracted oil can be used not only for biofuel production, but also in the food, cosmetic, and pharmaceutical industries (Lopes & Silveira, 2019).

When compared to other widely cultivated oilseed crops, such as soybean, corn, sunflower, and oil palm (*Elaeis guineensis*), macauba demonstrates superior oil productivity. Its oil yield is estimated to reach up to 6.0 tons per hectare, whereas soybean, the most commonly used crop for biodiesel production, yields between 0.2 and 0.6 tons per hectare. Although oil palm exhibits a yield comparable to macauba, its requirement for fertile soils and abundant water availability limits its geographic distribution. In contrast, macauba can thrive in sandy soils, with low fertility and limited water resources, substantially expanding its potential cultivation areas (Rodolfo, 2022; Junqueira *et al.*, 2019; Aguiar *et al.*, 2022).

Several studies have advanced the chemical characterization of macauba oil. Junqueira *et al.* (2019), Cabrera *et al.* (2022), and Cardoso, Machado & Caramão (2016) report that the mesocarp oil is predominantly composed of oleic acid (approximately 50%), palmitic acid (20%), and linoleic acid (14%). The kernel oil, in turn, is rich in lauric acid (over 30%) and oleic acid (36%). This composition gives the oil considerable industrial versatility, including potential applications in aviation. Vilalva (2021) highlights the use of macauba oil in the production of bio-kerosene (QAV-1), a strategic fuel amid the growing demand in the aviation sector. QAV-1 is composed of short-chain hydrocarbons (C8–C14), and lauric acid, abundant in macauba kernels, has 12 carbon atoms, making it highly compatible with these requirements. Silva *et al.* (2020) demonstrate that methyl esters derived from lauric acid sources can be blended up to 5% by volume into JET A-1 fuel, promoting a significant reduction in greenhouse gas emissions and decreasing dependency on fossil-derived fuels. As Ribeiro & Ribeiro (2019) point out, the use of biofuels in aviation is becoming increasingly necessary, contributing to a cleaner energy matrix for the aviation industry.

Other studies show the potential of macauba oil in improving the energy efficiency of sustainable engines. Arumugam *et al.* (2024) reported that a mixture consisting of 80% soybean biodiesel and 20% macauba oil demonstrated positive results, including a 5–10% increase in engine efficiency, a 3–5% decrease in exhaust gas temperature, and, most importantly, a 10–15% reduction in greenhouse gas emissions. These findings underscore macauba's viability as a performance-enhancing component for existing biofuels.

In addition to its oil, other parts of the macauba plant may also be utilized. The endocarp, for instance, can be converted into charcoal, representing a valuable by-product of the biodiesel production chain with potential applications in metallurgy, steelmaking, and domestic fuel sectors, enabling full biomass utilization (Evaristo *et al.*, 2016).

Despite its evident advantages, the commercial-scale implementation of macauba still faces significant barriers. Lopes (2020) points out the high initial investment required to establish silvopastoral systems with this species, along with the long maturation period, around five years, before fruit production begins, which delays financial returns. Another critical challenge is the lack of a structured supply chain: current macauba exploitation is largely extractive, with logistical challenges such as long distances for fruit collection, improper harvesting techniques, and inadequate storage conditions, all of which affect fruit quality and, consequently, oil quality. Viana, Fávaro & Anjos (2024) emphasize that the species is still undergoing domestication, requiring further time and research to become viable for large-scale agricultural systems.

Finally, technical challenges also arise in oil extraction. The extractive nature of harvesting often results in degraded oil quality, with elevated acidity levels that favor the formation of mono- and diglycerides instead of triglycerides, which are essential for efficient biodiesel production (Rezende & Pasa, 2019).

**Table 1**

*Recent key findings from the scientific literature on macauba (Acrocomia aculeata) and its application in biofuel production*.

| Author(s) | Title | Year | Key Findings |
|---|---|---|---|
| Viana, Fávaro & Anjos | Análise prospectiva da cadeia da macaúba. | 2024 | Macauba is a high oil-yielding palm with potential for sustainable industries. Patent analysis shows increasing global interest in its use for biodiesel, food, and personal care sectors. |
| Arumugam *et al*. | Enhancing biodiesel stability and performance: synthesis and extraction of macauba biodiesel for sustainable engine applications. | 2024 | A fuel blend with 20% macauba biodiesel (BSM20) showed superior engine performance, improved fuel and thermal efficiency, and reduced emissions (CO, NOx, PM) compared to other blends. |
| Moreira & Junior | Estudo sobre e viabilidade e impacto da utilização de biocombustíveis na redução de emissões de gases de efeito estufa em motores de combustão interna de veículos leves. | 2023 | Ethanol use in Brazil's light vehicle fleet, analyzed via bottom-up emissions modeling, significantly reduces $CO_2$, supporting programs like RenovaBio, PROCONVE, and PROMOT. |
| Guerra *et al*. | Criatividade e Inovação na Indústria: uso da Macaúba na Produção do Biodiesel. | 2023 | Macauba is a native, sustainable alternative to soybean in biodiesel production. Its adoption strengthens energy diversification but requires genetic improvement and supply chain expansion. |
| Nascimento *et al*. | O biodiesel na matriz energética brasileira: da sua inserção aos dias atuais. | 2022 | Biodiesel supports sustainable development, reduces pollutant emissions, and promotes regional economic growth. Its integration reflects |

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|---|---|---|---|
| | | | Brazil's eco-compatible energy transition. |
| Cabrera *et al*. | Macauba (*Acrocomia aculeata*): Biology, Oil Processing, and Technological Potential. | 2022 | Macauba stands out for its oil productivity and sustainability. The chapter details the full processing chain and highlights applications in food, cosmetics, and biofuels. |
| Aguiar *et al*. | Prospecção tecnológica sobre a macaúba (*Acrocomia aculeata*) no brasil do século XXI. | 2022 | Despite the increase in patent filings related to macauba, technological development for energy purposes, such as biodiesel, remains incipient, with few patents granted up to 2021. |
| Rodolfo | Valorização da cadeia produtiva da Macaúba (*Acrocomia aculeata*): desenvolvimento de modelos de negócio sustentáveis. | 2022 | Macauba agroforestry in Legal Reserve Areas could generate R$ 2.2 billion/year in the Jequitinhonha Valley, with capital return in 6 years and benefits for land recovery and energy supply. |
| Vilalva | Produção de ésteres leves derivados de óleo de amêndoa de macaúba para potencial aplicação como biocombustível de aviação. | 2021 | Distilled esters from macauba almond oil are rich in short-chain fatty acids, offering physicochemical properties comparable to aviation fuel (QAV-1) for sustainable jet fuel alternatives. |
| Vernersbach *et al*. | A visão dos especialistas sobre a importância do Biodiesel no Cenário Energético Global. | 2021 | Brazil's energy policy integrates biodiesel blends to reduce $CO_2$ emissions in transportation, enhancing its role in global climate strategies and clean energy leadership. |

Authors, 2025.

## 5 CONCLUSIONS

Macauba (*Acrocomia aculeata*) emerges as a highly qualified and strategic alternative for biofuel production, combining agronomic and chemical characteristics that make it particularly promising in the global energy landscape. Its high oil yield per hectare, along with its remarkable adaptability to low-fertility soils and water-scarce environments, offers

significant advantages over other oilseed crops widely used in the biodiesel industry. These attributes reinforce macauba's role as a renewable, clean, and environmentally sustainable source, with great potential to contribute to the gradual replacement of fossil fuels and the decarbonization of the energy matrix.

This study has highlighted the importance of adopting biofuels on a global scale as a response to the environmental threats posed by global warming and the intensification of the greenhouse effect. In this context, macauba oil stands out as a strategic renewable resource that can be incorporated into energy solutions sustainably and with minimal environmental impact. Furthermore, its by-products and industrial versatility expand its applicability, particularly in sectors such as aviation, metallurgy, and cosmetics.

However, despite its many advantages, the large-scale expansion of macauba as an energy crop still faces significant challenges. Key obstacles include the high initial investment required for cultivation systems, the long period before the onset of fruiting, the lack of a structured production chain, and the current predominance of extractive practices. In this regard, the domestication of the species becomes a critical step toward its consolidation in the renewable energy market. Advancing genetic improvement programs, developing management technologies suited to mechanization, and implementing public policies aimed at structuring the production chain are essential measures to ensure the technical and economic viability of macauba as a pillar of the bioeconomy and the global energy transition.

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