Macaúba: An Alternative for Sustainable Fuel Production

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This study evaluates the potential of macaúba (*Acrocomia aculeata*) as a raw material for the sustainable production of biofuels. Accordingly, the following research questions were posed: What techniques are used to convert macaúba into sustainable fuel? How does macaúba-based biofuel compare to fossil fuel? What is the long-term feasibility of using macaúba biofuel as a sustainable fuel source?

The overall objective of this research is to present the importance of utilizing macaúba biomass as an alternative for sustainable fuel production. Specifically, the objectives are to:

Demonstrate how macaúba can be transformed into sustainable fuel; compare macaúba-based biofuel with fossil fuels; evaluate the long-term feasibility of using macaúba biofuel as a sustainable energy source.

The study was conducted through a literature review, analyzing articles published between 2015 and 2025 in databases such as Science Direct, Google Scholar, repositories from various universities, and the *Electronic Proceedings of Petrochemical Engineering*, in addition to relevant books. The results showed that the physicochemical parameters of macaúba oil can significantly influence process yield, further demonstrating that biodiesel production is feasible.

Keywords: Macaúba, Biofuel, Sustainability

1. INTRODUCTION

Biodiesel production has received increased attention due to global environmental concerns and the fact that alternative renewable energy sources are now a topic of significant interest. Biodiesel is defined as mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats—a clean-burning biofuel compared to fossil fuels—that can be produced entirely from renewable sources. Vegetable oils have so far been considered the most attractive renewable source for biodiesel production due to their environmental benefits, such as those derived from macaúba.

Macaúba is an oil-bearing palm tree primarily distributed throughout Central and South America, and across most of Brazil. It is one of the species with the highest potential for economic exploitation due to its high oil yield and the use of by-products from oil extraction and processing (Borges et al., 2021).

Currently, large-scale biodiesel production is carried out through alkali-catalyzed transesterification of vegetable oils in the presence of a short-chain alcohol to form fatty acid esters and glycerol. This conventional production method presents negative effects, including sensitivity to water and free fatty acids

(FFA), which react with the alkaline catalyst to form soaps (saponification reaction). This side reaction complicates the separation of biodiesel and glycerol and reduces overall reaction yield.

The characterization of the physicochemical properties and thermal behavior of oil-bearing fruits for biofuel production has attracted interest within the scientific community and the general public—particularly regarding their potential use as partial substitutes for fossil fuels and their possible role in reducing air pollutants that harm human, animal, and plant health.

Therefore, the research seeks to answer the following questions: What techniques are used to convert macaúba into sustainable fuel? How does macaúba-based biofuel differ from fossil fuel? What is the long-term viability of using macaúba biofuel as a sustainable source of energy?

Consequently, biodiesel emerges as a promising alternative for Brazil and the world, especially in the context of the growing need for renewable energy sources and the reduction of greenhouse gas emissions.

In light of this, the general objective of this article is to present the importance of using macaúba biomass as an alternative for sustainable fuel production. Specifically, it aims to demonstrate the transformation process of macaúba into sustainable fuel, compare macaúba-based biofuel with fossil fuels, and evaluate the long-term viability of using macaúba biofuel as a sustainable source of energy.

THEORETICAL FRAMEWORK

This research is supported by theoretical references that strengthen the understanding of the topic addressed in this study. The main sources are Salomon and Lora (2005), Carneiro and Silva (2024), and Guerra et al. (2023).

Salomon and Lora (2005) state that the biomass used in biofuel production is derived from any organic material, whether of animal or plant origin, but always constituted of a renewable resource. Typically, the organic matter used in its production is found in nature or generated by animals or humans through agricultural, industrial, and domestic activities.

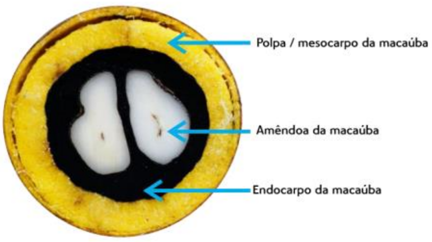
Based on the above, this assessment is accurate, as biomass is indeed a renewable energy source derived from any organic material—either plant-based or animal-based—and is used to produce biofuels. This organic matter is renewable in a relatively short period, unlike fossil fuels.

Carneiro and Silva (2024) present two main routes for utilizing macaúba: thermochemical conversion and biochemical conversion. In the biochemical route, the oil extracted from macaúba undergoes transesterification, producing biodiesel and glycerol. In the thermochemical route, pyrolysis is employed, resulting in bio-oil, biochar, and syngas.

As observed above, these routes demonstrate the high potential of macaúba as a renewable energy source, enabling full utilization of the plant. This contributes to energy diversification, reducing dependence on fossil fuels and promoting a sustainable, low-carbon economy.

Guerra et al. (2023) highlight that the generation of this energy source depends on several requirements, namely: the quality of the raw material; agronomic factors, where climate and soil must be suitable; availability of cultivation areas; and technological requirements, such as extraction technology, oil refining, and transesterification, among others. This author emphasizes the importance of evaluating quality when producing biofuel, as it is essential in determining the final production processes.

Figure 1 – Parts of the Macaúba



Source: Pachêco et al. (2016)

The macaúba (*Acrocomia aculeata*) is a Brazilian plant with high oil yield (Figure 1), notable water and nutrient efficiency, enabling the development and strengthening of its respective production chains to meet the growing domestic demand for renewable biofuel. In this context, Guerra et al. (2023) presented macaúba biodiesel production in four stages:

1. **Depulping** – removal of the external peel, pulp, and nut, revealing the almond.
2. **Mixing** – the peel/pulp is mixed using a heated analog magnetic stirrer to prevent the loss of vitamins present in the oil.
3. **Extraction** – crude oil and cake are obtained using a press.
4. **Filtration and Processing** – the final stage uses a filter to refine the oil, which is then directed to biodiesel production via transesterification.

Currently, large-scale biodiesel production is carried out through alkali-catalyzed transesterification of vegetable oils in the presence of a short-chain alcohol to form fatty acid esters and glycerol. This conventional method has drawbacks in the transesterification reaction due to the presence of FFAs or water in the raw material.

However, Guerra et al. already addresses the extraction, treatment, and processing of macaúba biomass, explaining the techniques and reactions involved in biodiesel production, thereby validating the importance of its utilization.

The process of obtaining biodiesel by esterification consists of the reaction of a carboxylic acid with a monoalcohol to form esters, using acidic or enzymatic catalysts, with water as a by-product.

In this context, when monoesters are obtained from hydroesterification, the reaction begins with the hydrolysis of a tri-, di-, or monoacylglycerol molecule, producing glycerol and a mixture of fatty acids. Biodiesel is produced by esterifying these fatty acids.

Through this sequence of reactions, a final product with higher purity is obtained compared to traditional transesterification, free from impurities such as soaps and acylglycerols.

METHODOLOGY

This study qualifies as a bibliographic research project, using technical procedures based on a rigorous process for selecting studies to conduct data collection and literature review, grounded in published materials.

The search was conducted in the following databases: **Science Direct**, **Google Scholar**, repositories from various universities, and the *Electronic Proceedings of Petrochemical Engineering*, as well as books related to the topic.

Following the stages of the review, the inclusion criteria were defined as:

- Full-text articles available for free;
- Studies published within the last ten years;
- Publications in Portuguese or English.

The exclusion criteria included:

- Studies that did not address the objectives of the research;
- Articles and books outside the established time frame.

The data collection and systematization period took place between March and June 2025.

The descriptors used for the search were: **Green Diesel**, **Macaúba**, and **Biofuels**. A total of nine articles and one master's thesis were selected, with questions posed regarding the importance of using macaúba biomass as an alternative for sustainable fuel production.

Additionally, a chart was created showing the number of articles related to the key topics identified as relevant for developing the paper.

The research considered environmental aspects and the advantages and disadvantages compared to fossil fuels. This approach made it possible to observe both technological advances in the biofuels sector and the persistent challenges in ensuring that second-generation ethanol can become a viable and sustainable large-scale alternative.

This allowed for a critical evaluation of the hypothesis proposed in the introduction, taking into account the various databases used—such as SciELO, CAPES, EPE, and Google Scholar—and the publications consulted up until 2025.

RESULTS AND DISCUSSION

To understand the technological intensity and innovation level of Second-Generation Ethanol (E2G) compared to First-Generation Ethanol (E1G), it is important to understand the production cycle of E1G, which represents one of the processes used to obtain ethanol (both anhydrous and hydrated). The cycle begins with the **Agricultural Phase**, which includes planting, cultivation, and harvesting of sugarcane, the feedstock for subsequent production stages.

Currently, there are two harvesting methods for sugarcane: **mechanical** and **manual**. Combined with whether or not the cane is burned in the field prior to harvesting, these factors are key in determining the amount of impurities in the cane's vegetal composition. Upon arrival at the mill, sugarcane is classified based on the percentage of impurities present. "Clean cane" (with an impurity content of less than 0.6%) is considered the most suitable for ethanol production due to the low level of contaminants (ALBARELLI, 2013; REIN, 2007).

Regarding the specific research objectives of this study:

- Three articles (27%) addressed how macaúba is transformed into sustainable fuel;
- Two articles (18%) discussed the differences between macaúba-based biofuel and fossil fuel;
- Five articles (55%) focused on assessing the long-term viability of using macaúba biofuel as a sustainable energy source (Figure 1).

For data analysis, **Bardin's method** was applied—a systematic technique for content analysis. This method adopts objective and rigorous procedures to describe message content, enabling detailed and grounded interpretation. The selected studies were organized into thematic axes, aiming to answer the objectives established in this research.

The analysis process follows three main stages:

1. **Pre-analysis** – organization and familiarization with the material. This included collecting studies based on the inclusion and exclusion criteria, preparing and conducting an initial overview reading to select only relevant studies.
2. [Following stages would be described based on the complete Bardin methodology.]

CONCLUSIONS

By analyzing the importance of using macaúba biomass as an alternative for sustainable fuel production, the results obtained in this study suggest that the physicochemical parameters of macaúba oil can significantly influence process yield. Furthermore, findings show that biodiesel production from macaúba is feasible.

Due to its low cost as a raw material, it is concluded that the characteristics of crude macaúba pulp oil allow its use as feedstock for biodiesel production, making it a versatile and renewable energy source.

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