

Review Article

Ethnomedicinal applications, food value, pharmaceutical and economic potentials of Macauba palm (*Acrocomia aculeata*) - A systematic review

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Abstract

Purpose: To review the ethnomedicinal applications, food value, pharmaceutical and economic potentials of Macauba palm (*Acrocomia aculeata*).

Methods: The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was used in the review. PubMed, Google Scholar, ScienceDirect, Web of Science, and SciELO were used to identify studies published from 2010 to 2025. One hundred and twenty-seven records were located, fifty-nine complete texts were evaluated, and forty-three studies were included in the synthesis.

Results: Macauba palm has antioxidant, antidiabetic, and antimicrobial properties, with oleic acid, carotenoids, and tocopherols among the bioactive compounds that support its use in food and pharmaceutical products. It offers animal feed coproducts, industrial products, such as biocomposites and activated carbon, and high-quality oils. As a source of biofuel, its oil has the potential for biodiesel and aviation fuels.

Conclusion: Macauba palm has significant potential to promote sustainable growth, food security, human nutrition, health, and renewable energy. Macauba palm would transform 21st-century tropical and subtropical agriculture and bioeconomy through strategic investment, research, and the facilitation of policy frameworks.

Keywords: *Acrocomia aculeata*, Ethnomedicinal role, Macauba palm, Food value, Pharmaceutical benefits

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INTRODUCTION

Macauba palm (*Acrocomia aculeata*), sometimes called *acrocomia* or *aculeata*, and also known as macaw palm, grugru palm, was once considered only a rough, wild plant growing in Brazil, Colombia, Mexico, and the Caribbean. This spiny and solitary- stemmed palm is now coming out

today as one of the most promising multifunctional crops of the 21st century [1]. Hiding in the back of all the thorns of this plant is an asset: a fruit of high-quality oil content, a seed of protein content, leaves, fibres and shells that sustain the cosmetic industry to the bioenergy industry [2,3]. Macauba palm is a wonderful tree

crop that grows in the expansive savannas and open forests of tropical America.

It comprises several species in the genus *Acrocomia* (A), including *A. aculeata*, *A. totai*, *A. intumescens*, and *A. crispa* [1]. Among these, *A. aculeata* is the most studied and commercially valuable species due to its wide distribution across Brazilian territory and its higher oil output. Cultural and local economic values are still held by other species, particularly in the Caribbean and Central America, and mutual and individual potential in research and use should be understood [2].

The striking feature of macauba palm is not only the variety of its uses, but also its longevity. This plant is heliophytic and does not interfere with crops. It colonises degraded pastures, can withstand high and hot temperatures, drought, and even wildfires [2]. It is adapted effectively to fertile clay soils as well as marginal agricultural lands [4,5]. It is also considered a non-competitive crop within food production systems due to its suitability for degraded and underutilized lands [4]. The ecological stability of macauba palm and its adaptability to diverse environments highlight its relevance for climate-sensitive agriculture [6]. In addition, its high productivity and valuable co-products further support its potential role in sustainable land recovery and bioeconomic systems [7]. Macauba palm is an ancient component of traditional life, being used in folk medicine across the wetlands of the flood Pantanal in its native habitat, up to the dry Caatinga shrubland, to treat cardiovascular diseases, respiratory diseases, and nutritional deficiencies [8]. Such applications are increasingly supported by emerging scientific evidence, particularly from preclinical studies demonstrating antioxidant, anti-inflammatory, antidiabetic, and antimicrobial activities of its bioactive compounds [7]. Macauba palm, with its high monounsaturated fatty acids (palm pulp oil) and its high medium-chain fatty acids (palm kernel oil), is used in high-value biofuels such as sustainable aviation fuel.

Although Latin America is the centre of macauba palm research and cultivation, its relevance is increasing worldwide. Suitability models suggest a high potential for expansion into tropical Africa and parts of Asia, where macauba palm can serve as a sustainable alternative crop because similar savanna and pastureland habitats exist [6]. Countries in Central Africa, Southern Asia, and Northern Australia have started pilot tests on its application in energy and food systems, indicating that the Macauba palm can become a strategic resource for the world in the next

decades [6]. With the convergence of issues such as climate change, food security, energy transition, and the need for circular economies, the macauba palm is a valuable resource in tropical and subtropical regions [7].

Socio-economic factors of macauba palm farming are also important. Rural employment opportunities are generated through harvesting, processing, and fruit collection activities, which are often labour-intensive [8]. The fact that it will be included in the agro-industrial system will facilitate the association of environmental recovery with rural development, the development of alternative sources of income, and the reduction of reliance on synthetic drugs and fossil fuels.

In recent reviews, macauba palm has been discussed in several ways, from its nutritional and phytochemical characteristics [7] to its role in the bioeconomy [8], agronomy, and oil extraction [2-4]. The gap yet to be addressed is the strategic placement of macauba palm as part of the greater bioeconomy story: how the collective action of its ethnomedicinal practices, food value, pharmacogenic properties, and industrial practices can shape policies, investments, and sustainable development. This review seeks to present a critical, integrative synthesis of studies on the macauba palm (*Acrocomia aculeata*) regarding its ethnomedicinal uses, pharmaceutical characteristics, nutritional and food possibilities, biofuel feasibility, and economic future. This review aims to determine the purpose of the macauba palm as a multipurpose crop within the broader framework of climate-smart agriculture, sustainable development, and the circular bioeconomy.

METHODS

This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, which ensure transparency and consistency in reporting [9]. The literature search was conducted in PubMed, Google Scholar, ScienceDirect, Web of Science, and SciELO for papers published between 2010 and 2025. Each database was modified to the following Boolean search term: "Macauba palm" OR "*Acrocomia aculeata*" OR "*Acrocomia spp.*" AND (ethnomedicine OR biofuel OR pharmaceutical OR nutritional value OR economic potential). Non-indexed studies were also captured in Google Scholar and SciELO by screening grey literature (e.g., theses, dissertations, and institutional reports).

Studies that met the inclusion criteria were peer-reviewed articles that investigated the ethnomedicinal, nutritional, pharmaceutical, and industrial potential of the macauba palm. To ensure accuracy and avoid misinterpretation, studies published in languages other than English were excluded. Also, only publications published since 2010 were included to capture the interest of science and industry in *Acrocomia*, which have grown tremendously in this period, ensuring that the evidence base is up-to-date and applicable. Articles that were not peer-reviewed, such as blogs, websites, or opinion articles, were excluded because they sometimes lack methodological rigidity and can be prone to bias.

Two independent reviewers filtered the titles, abstracts and full texts. The dispute was resolved through discussion and arbitration by an external reviewer. Of 127 records identified, 59 were evaluated at the full-text level and 43 were included in the study. The flow diagram for PRISMA 2020 (Figure 1) illustrates the selection process.

The quality of included studies was assessed using the AMSTAR 2 systematic review tool, the ROBIS risk-of-bias review, and crude design criteria (objective clarity, study design, outcome validity) for experimental and observational studies [10]. Although the qualification was not taken as a criterion to eliminate any study, the risk-of-bias evaluation was used in interpreting results.

Since the study designs were heterogeneous, the outcomes were synthesized using thematic synthesis. Data extracted were coded into a category of predefined data (i) ethnomedicinal and pharmacological potential, (ii) products and coproducts, (iii) biofuel potential, and (iv) economic potential. Under each theme, the research's convergence, divergence, and gaps were compared. This coding scheme enabled a systematic synthesis of the narratives rather than just listing the studies.

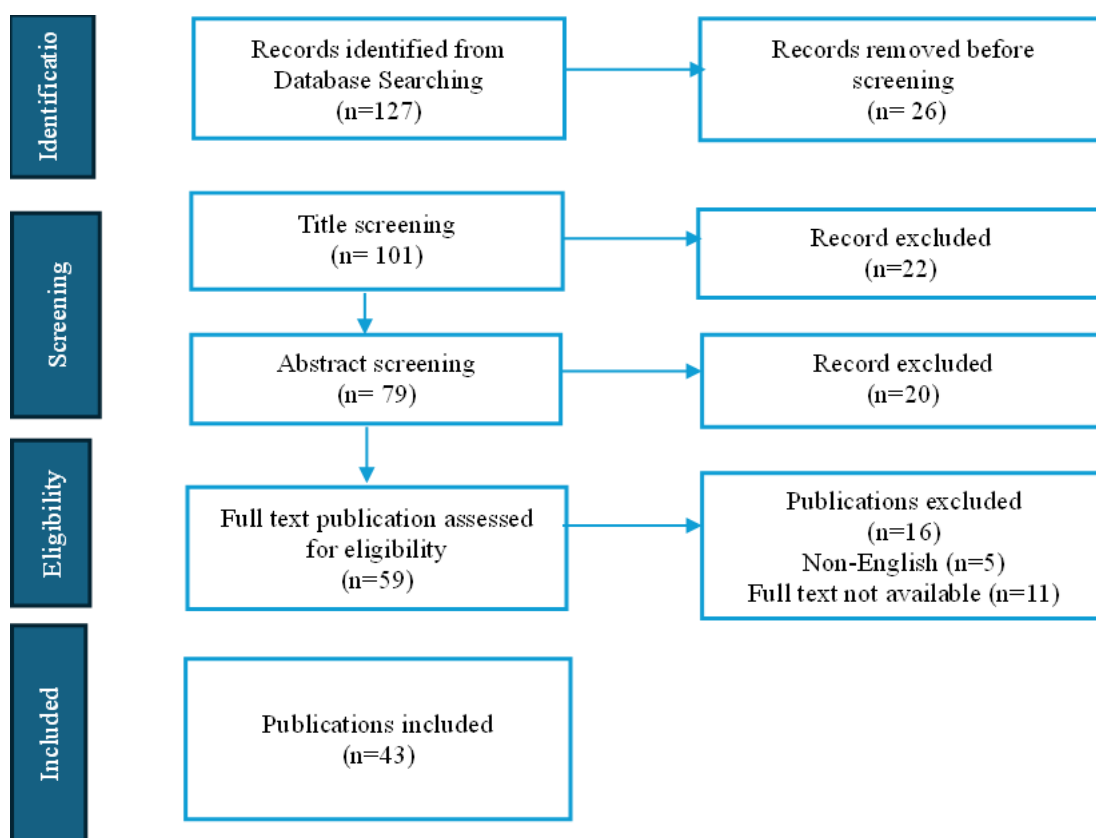


Figure 1: PRISMA flow diagram for search of relevant literature

RESULTS

The synthesized results of the study, by thematic area, are as follows.

Macauba palm ethnomedicinal application and pharmaceutical potential

Across the reviewed literature, the Macauba palm (*A. aculeata*) is considered a reliable

ethnomedicinal source, particularly for cardiovascular, metabolic, and inflammatory disorders. Traditional knowledge explains that its fruit and pulp are used to treat heart complications, respiratory conditions, vitamin A deficiency, and diabetes [11,13,14]. These applications are supported by modern pharmacological research, which demonstrates that their oils are rich in oleic acid, carotenoids, tocopherols, and phenolic antioxidants, bioactive compounds repeatedly associated with cardiovascular protection and reduction of oxidative stress [8,11,12,17]. This similarity in folk use as both biochemical evidence and a medicinal plant reinforces its applicability as a source of functional foods and medicine.

The most recurring theme of the studies reviewed is the antidiabetic effect of macauba palm. A series of animal trials using macauba palm pulp, kernel, and leaf extracts have shown reductions in blood glucose, cholesterol, and oxidative stress [13,15,18]. The effects are attributed to the antioxidant compounds β -carotene and vitamin E [13,15], which are present in macauba oil [17]. Nonetheless, there are variations in the methods of delivery. Although conventional methods rely on crude extracts and oils [13], recent research suggests that nanoemulsion preparations are more effective at increasing bioavailability and therapeutic effects [16]. Not only do these

nanoemulsions inhibit α -glucosidase and lipase, which are among the enzymes that play a major role in glucose and fat metabolism, but they also exhibit selective cytotoxicity towards cancer cells and none towards normal blood cells [16]. However, these anticancer results are only from in vitro studies, and they require additional in vivo and clinical trials before any therapeutic interest can be established. Figure 2 describes the pharmacological processes of action of antioxidant and antidiabetic effects of macauba palm bioactive compounds.

In addition to metabolic disorders, the antimicrobial potential of the macauba palm is also demonstrated. Oil extracts are reported to have a synergistic effect with traditional antibiotics, increasing their action against resistant *E. coli*, *Staphylococcus aureus* and *Candida spp* [19]. This suggests a dual purpose for macauba palm oil as an antimicrobial agent and as a supplement to existing therapies. However, the effects are still mostly preclinical, and no human trials have proven them.

Collectively, it is evident that the macauba palm holds great potential for ethnomedicine and pharmaceutical development. Its bioactive substances are consistent with traditional cardiovascular, antidiabetic, and anti-inflammatory applications [8,11-13,15,18].

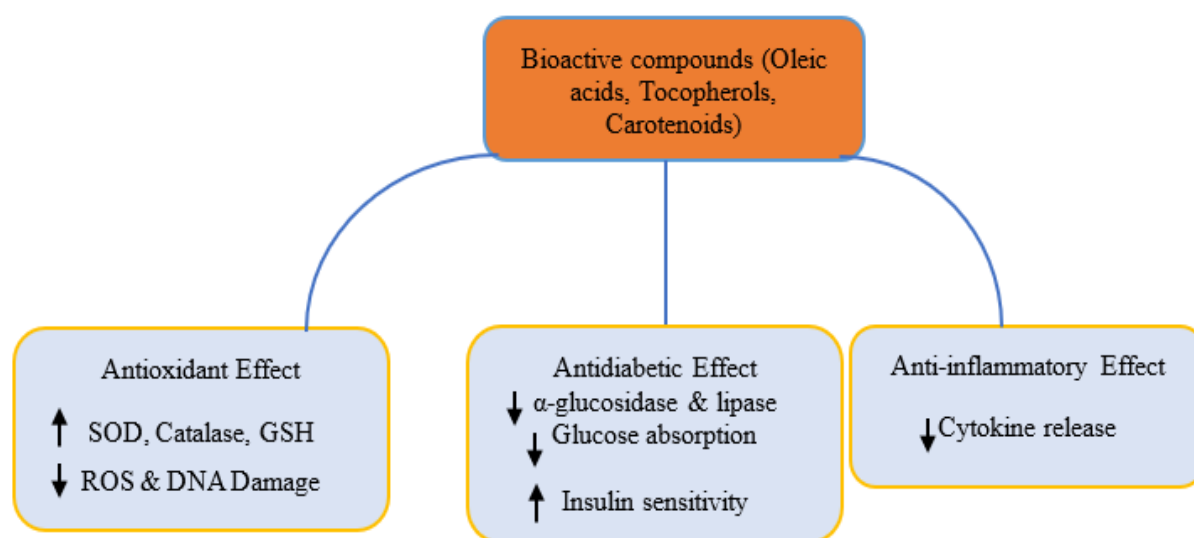


Figure 2: Pharmacological processes of action of macauba palm bioactive compounds. **Key:** SOD = Superoxide dismutase, ROS = Reactive oxygen species, GSH = Glutathione

Simultaneously, new studies on nanoformulations and antimicrobial combinations can enhance their therapeutic potential [16,19]. Nonetheless, the lack of universal dosage regimes, clinical testing, and safety investigations

over time is also a major limitation. It will be necessary to bridge these discontinuities to move the macauba palm from a promising traditional remedy to a legitimate pharmaceutical asset.

Comprehensive products from macauba palm

Studies have shown macauba palm to be a versatile crop with potential in the food, cosmetic, feed, and industrial sectors. It produces both pulp and kernel oil, with different fatty acid compositions: oleic and linoleic acids in the pulp and medium-chain fatty acids in the kernel, making it an option for replacing traditional vegetable oils in cooking and processed foods [9,11,20].

Notably, its pulp oil has high antioxidant levels (carotenoids, tocopherols) which increase its nutrients and prolong its shelf-life [9,12,17]. In addition to oils, coproducts like press cakes, husks, and shells are sources of fibre, proteins and minerals that can be converted to animal feed, flours and biomaterials [21-23].

The nutritional benefit is backed by the experiments done to prove that the addition of macauba pulp meal in the pigs' meal without a reduction in the growth performance justifies its use as a substitute for cereals and soy-based feeds [23]. In addition to this, the kernel residues are being extracted for plant-based diets and aquaculture feed concentrates in the form of proteins [22]. This is in accordance with the augmented inclination for sustainable and less

costly feeds. However, other authors claimed higher levels of backfat deposition at high inclusion levels, and thus, there is a need to optimize the formulations [23].

Pulp and kernel oils are also effective in cosmetic applications and are emollient, anti-ageing and have photoprotective properties. The studies show that prepared macauba palm oil extracts prepared by use of the supercritical fluid (SCF) extraction technique, i.e., supercritical carbon dioxide- extracts and supercritical compressed propane- extracts oil fractions can be prepared and utilized in sunscreens and prevent the destruction of skin lipids by UV [17]. Its bioactive profile provides the possibility of functional skincare, yet it is yet to be commercialized [2,8]. The industrial opportunities go even further, shells and husks are turned into activated carbon in water purification, fibres in biocomposites and biodegradable packaging materials [24-27].

Macauba palm is not a single-purpose crop since it produces a variety of products that have a range of value chains. Its potential circular bioeconomy application, both in food, cosmetics and industrial applications [9,17,21-23], is shown by its consistency, although scaling and product optimization require further development.

Table 1: Ethnomedicinal, pharmaceutical and health benefits of macauba palm

Aspect	Details	Sources
Ethnomedicinal uses	Treats cardiovascular diseases, vitamin A deficiency, respiratory diseases, cold, and diabetes. Used against rheumatic aches, skin sores and digestive discomfort. Acts as a laxative and an analgesic	[11,13,14]
Pharmaceutical potential	Macauba palm oil nanoemulsion is used as an anti-diabetic and anti-cancer agent.	[16]
Bioactive compounds	High in monounsaturated fatty acid, oleic acid and monounsaturated fatty acid; High in beta-carotene (precursor of vitamin A), tocopherols (vitamin E), flavonoids, phenolic acids	[11,17]
Nutritional composition	Pulp oil contains antioxidants (β -carotene and vitamin E)	[17]
Antioxidant & anti-inflammatory effects	Three plant extracts: aqueous (EA-Aa), ethanol (EE-Aa), and methanol (EM-Aa) extracts of <i>Acrocomia aculeata</i> have been tested; of them, the use of EA-Aa was the most effective in triggering antioxidant pathways, reducing the reactive species (ROS) and DNA oxidation, and maintaining catalase and glutathione activity.	[13]
Antimicrobial action	Improves the effect of antibiotics on resistant bacteria	[19]
Functional food potential	Source of functional foods and phytomedicines as a result of its high content of nutrients and bioactive compounds	[16,17]

Biofuel potential of macauba palm

One of the most thoroughly documented themes of the macauba palm is its biofuel potential because of its oil potential and favourable fatty

acid composition. Several studies note that the macauba palm oil is an excellent feedstock to produce biodiesel and sustainable aviation fuel because it contains a combination of monounsaturated and medium-chain fatty acids

[28-31]. Macauba palm performs competitively or even better when compared to other oil crops. Macauba palm (*Acrocomia aculeata*) has been reported to produce up to 6.2 t/ha; oil yields, which are comparable to African oil palm (*Elaeis guineensis* Jacq.; 6 - 7 t/ha) and much higher than soybean (*Glycine max*; 0.4 - 0.6 t/ha) and sunflower (*Helianthus annuus*; 0.8 - 1.2 t/ha) [31,34]. This comparative advantage also goes further to support the fact that macauba palm holds a high potential as a biodiesel and aviation biofuel feedstock.

On the contrary, the bioethanol potential of lignocellulosic residues (press-cakes, fibres, shells) is more fluctuating. Ethanol production was reported as 80 - 140 L/ton of dry biomass, which is much less than sugarcane bagasse (220 - 280 L/ton) or maize stover (250 - 300 L/ton) under favorable fermentation conditions [9,33]. The poor fermentation results that have been realized on the macauba palm residues can be mostly attributed to the high lignin content and failure of existing pretreatment and fermentation processes. Increment in enzymatic hydrolysis and optimization of yeasts have been promising in enhancing the conversion rates, although the same economic feasibility is not feasible at a large scale [30,33]. This speculation indicates that although it is expected that liquid fuels obtained using macauba palm oil are on the verge of achieving commercial maturity, second-generation ethanol routes are still technologically limited and will need specific innovation.

In addition to technical viability, the development of biofuels is strongly related to policy and socioeconomic situations. Brazil has been leading in that, the country has made use of macauba palm as part of biodiesel requirements in the National Program for Production and Use of Biodiesel (PNPB) and this has not only spurred rural development but has also curtailed the dependence on fossil fuel [9]. Nonetheless, smallholder farmers are still not involved in large numbers, and this has brought about concerns regarding the fairness of the distribution of benefits across the biofuel value chain.

Environmentally, fuels derived from the macauba palm have been reported to emit lower greenhouse gas emissions than petroleum-derived fuels, aligning with climate change mitigation objectives [32-34]. However, there are still doubts about cultivating in the future due to global warming and decreased precipitation [34]. The comparative evidence, when combined, points to a high potential of macauba palm biofuels in the energy transition, although the potential of this energy source will only be

achieved through conversion technology, favorable policies and comprehensive production models.

Economic potential of macauba palm

The literature describes macauba palm as a very competitive non-food oil crop, with yields of oil reaching 6.2 t/ha, which is comparable with the yield of oil palm and much higher than the yields of the soybean, sunflower, and canola [31,34]. This productivity renders macauba palm a good feedstock for bioenergy and industries. Pilot projects in Brazil exhibit that they are integrated in silvopastoral system, where the macauba palm plantations cover degraded pastures and generate two sources of income through cattle and oil crops [9]. Suitability models have also applied this promise to other tropical and subtropical areas outside of Brazil [34] and support its value as a strategic crop globally.

The key factor in commercialization of macauba palm has been the National Program of Production and Use of Biodiesel (PNPB) in Brazil, which required the biodiesel to be blended with other fuels and also encouraged the diversification of feedstock. As a success, PNPB formed an assured market of biodiesel which minimized reliance on fossil fuels and encouraged investment in oilseed crops like macauba palm [9,30]. Another feature of the program was the so-called Social Fuel Seal, which provided tax concession to biodiesel companies that purchased the feedstock of smallholder farmers. This policy led to the creation of jobs in rural areas, diversification of income, and better utilization of land by incorporating the macauba palm in the once degraded pastures [9].

Nevertheless, PNPB has been limited in significant ways as well. Smallholder farmers have not been equally involved in supplying macauba palm due to long juvenile stages of the palm (4 to 6 years before it first fruits), expensive establishment, and mechanical harvesting have not been introduced [9,48]. As a result, the vast majority of the benefits of the program went to larger agribusinesses, with smallholders being left with a very small share despite the Social Fuel Seal framework. Moreover, the infrastructural differences and access to credit in those regions made macauba palm an excellent biodiesel feedstock, which was scaled down, restricting the success of production to areas of Brazil with greater connectivity.

This highlights the fact that though PNPB gave a very important platform upon which the

integration of macauba palm into the bioeconomy could take place, the existence of structural barriers is still evident. The new policy frameworks will require going beyond the market requirements and tax incentives to include special credit lines, cooperative production systems, and the extension services that minimize the entry barriers of the small holder. These inclusive measures are necessary to make sure that the economic potential of macauba palm will play its part in rural development equally and without further cementing the status quo of inequality in the accessibility to agricultural innovation and market.

Future perspectives

In the future, macauba palm is a promising crop that will be able not only to promote food security and health but also renewable energy and a sustainable industry. Its oils and coproducts are over and over again found as promising sources of nutrient-rich flours, plant-based proteins, antioxidants, anti-ageing and photospecific bioactive products [16,50]. One of the most promising directions of innovation is the integration of these bioactive compounds into the functional foods, nutraceuticals and cosmetics. But these potentials will need harder evidence from clinical studies and regulatory approval to convert them into commercial products.

Simultaneously, the byproducts and the leftovers of macauba palm can be utilized to develop the circular bioeconomy. The shells and fibres may be turned into biocomposites, ropes, activated carbon or biodegradable packaging and eliminate the reliance on synthetic materials [22,26,27]. Such a multipurpose use of the entire plant is in line with the sustainability objectives, although the expansion of such value chains would entail investment in processing facilities and market building.

The environmental resilience also has a connection with future cultivation opportunities. Macauba palm has the potential to be used in climate-smart farming due to its capacity to grow on marginal soils and during fluctuating climatic conditions [8,9]. However, future estimates of increasing temperature and decreased rainfall are also problematic and can be a threat to long-term productivity [34]. Climate adaptation, breeding, harvesting mechanization, and propagation guidelines will thus prove very crucial in supporting yields in the future scenario.

The macauba palm has a future in its use in diversified and sustainable value chains. It can

be a foundation of bio-based economies when coordinated innovation is made in food, pharmaceutical, cosmetic, feed, and industrial sectors. However, the achievement of this vision will be determined by closing the knowledge gap, enhancing technological development, and the inclusive involvement of large-scale ventures as well as smallholder farmers [8,9,34,50].

Health and nutrition

Literature review synthesis has indicated the macauba palm (*Acrocomia aculeata*) as a truly versatile species in terms of its health and nutritional roles. The scientific explanation of its ethnomedicinal applications in the treatment of wounds, cardiovascular, metabolic, and inflammatory diseases has a solid scientific case in biochemical richness, comprised of a vast abundance of oleic acid, carotenoids, tocopherols, and phenolic compounds. The traditional knowledge of macauba palm is now accompanied by current evidence of pharmacological effects; antidiabetic, antioxidant, antimicrobial, and potential anticancer agent effects have all validated macauba palm as food source that can be developed into a functional food, nutraceutical, or other plant-based therapeutic products.

The pharmaceutical potential is also achieved through the development of nanoformulation technologies like oil-based nanoemulsions that enhance the bioavailability and delivery of bioactive compounds. Nevertheless, there are barriers on the way to mainstream healthcare translation. The present research has not yet addressed regulatory obstacles, such as safety testing, toxicology research, and clinical trials. Commercialization of macauba-derived nutraceuticals is likely to have serious delays in the case of lack of standardized protocols and safety testing.

The macauba palm in the bigger bioeconomy, therefore, requires shifting the laboratory findings into policy and investment aspects. The overall ethnomedicinal and pharmacological evidence suggests that macauba palm may form the basis of novel functional foods, nutritional supplements and phytopharmaceuticals that may help end increasing cardiovascular and metabolic disease burdens in tropical areas and globally. To realize this potential, the following strategies should be coordinated, including policies to facilitate clinical research and standardization of products, investments to facilitate cultivation, processing and development of value chains. These would enhance healthcare innovation and put macauba palm as a resource in the field of health.

Industrial and Bioenergy Applications

Bioethanol yield obtained from *Acrocomia aculeata* is still inconsistent. Fermentation of press-cake hydrolysates has been reported to possess low fermentation efficiencies, although studies suggest it could be forward-moving when enzyme pretreatment and yeast optimization are implemented. These discrepancies demonstrate why experimental designs and comparative field data must be standardised; otherwise, it is difficult to know what variation arises due to biomass composition, pretreatment processes, or climatic growing conditions.

Concurrently, macauba palm exhibits good potential for bioenergy due to its high oil production and good fatty acid content, which renders it applicable in biodiesel and airplane biofuels. Lignocellulosic residues also have the potential to produce bioethanol and other bioproducts; cost-effective conversion of the biomass will be achieved through improved pretreatment and fermentation technologies.

More than technical innovation is needed in order to realize this potential. Positive policies, focused investments and sustainable development policies will be necessary. Inclusion of macauba palm as a biofuel in the national and regional biofuel initiatives would diversify the national and regional energy portfolios and would also spur the economy of the rural areas through value chains that encompass the extraction of oil and the use of residues. Public-private partnerships, participation schemes by farmers, and investment in pretreatment technology would make sure that the macauba palm biofuels not only lead to the energy security and climate objectives but also to inclusive economic development, making the palm a foundation of the new bioeconomy.

Food source and circular bioeconomy

Macauba palm, as a food source, has enormous potential regarding not only a high-quality edible oil source but also a producer of nutrient-rich food coproducts, notably high-fibre pulp meals, kernel flours, and prebiotic dietary fibre. It is also within a circular bioeconomy, and its published applications are animal feed, cosmetics, biocomposites, activated carbon, and biodegradable packaging. This power to idealize the entire plant does not just diversify the potential markets but also raises the sustainability and profitability of production. However, there is little information on the postharvest loss and storage stability of the macauba fruits and coproducts. There is a lack of

research on issues like spoilage rates, rancidity of oil and shelf-life, which may compromise the feasibility of food and industrial products made out of macauba palm in large markets.

To maximize the value of the wide range of products that macauba palm offers, it is important to coordinate frameworks that will enhance innovation, investment, and principles of a circular economy. The introduction of biorefinery strategies and value-chain value-addition policies has the potential to speed up the process of converting pilot projects into large-scale industries, and specific funding of research can help overcome the problem of formulation when it comes to feed, food, and cosmetic applications. Simultaneously, by investing in small- and medium-scale processing infrastructure, the rural producers would be able to gain more value in their localities.

Socioeconomic inclusion

Macauba palm offers economic opportunities of multifunctional value chain to stimulate growth in rural areas, as shown in the case of the biodiesel program in Brazil. Nonetheless, smallholder farmers are still not well involved. High costs of establishment, low yields in the 4 – 6 years juvenile phase and manual harvesting pose a lot of entry barriers. The fact that policy structures, models of cooperation, and credit systems are not specifically designed to support the interests of smallholders implies that the economic gains of macauba palm cultivation may remain concentrated in large agribusinesses working to derail its effective contribution to the fair development of the rural community.

The smallholders may find a way of getting involved in the macauba palm value chain through inclusive agribusiness models, including farmer cooperatives, contract farming schemes, and community-based processing units. The experience of oil palm and coffee cooperatives implies that collective ownership and collective bargaining may help to alleviate marginalization and make the distribution of benefits more balanced [51,52]. It is thus going to be necessary to unlock the full economic potential of macauba palm through strategies that will be deliberate in terms of profitability and inclusiveness. Credit access policies, incentivizing the use of farmer cooperatives and encouraging mechanization can reduce the barrier to entry, and any investments in infrastructure and value chain development will enable the production to grow much larger than the localized stories of success.

Environmental considerations

Macauba palm is viable in terms of its capacity to be cultivated with a marginal soil type, drought-infected areas, which might result in carbon absorption. Nevertheless, future climatic change (e.g., higher temperature, reduced precipitation) is likely to alter its most suitable areas of growth and breeding and crop management technologies, in terms of climate adaptation, must be developed. Simultaneously, the increase in the cultivation of macauba palm casts doubts on the unwanted ecological trade-offs. Monoculture on a large scale might endanger biodiversity, or cause the displacement of native species, and even the development of the risks of invasive behaviour outside the land of their origin. This will require a balance between expansion and biodiversity conservation and agroecological production, which will help to prevent the mistakes that were witnessed in the case of other commercial oil crops.

Even with the tremendous potential of the macauba palm, much still needs to be researched. Additional studies are required to learn more about the performance of the crop in the long run, particularly in conditions of climatic stress like drought and heat; the effect of breeding programs on oil yield and fruit production and the effect of machine operations and better techniques of picking the fruits and the handling of fruits after picking to minimize losses. There will also be a need for more safety testing and regulatory protocols for it to be used as health products and medicines. The development of inclusive business models and their performance require studies to determine how consumers will respond to macauba-based products.

The majority of the research and agricultural experience of macauba palm is presently in Latin America. Nevertheless, climatic and land condition studies indicate that the crop would also be good in areas like sub-Saharan Africa, Southeast Asia, and the Caribbean, where they also have dry and marginal land. This implies that macauba palm can rise above being a local crop and become a valuable source of sustainable development in the world.

CONCLUSION

Macauba palm (*Acrocomia aculeata*) is a multipurpose and sustainable agricultural and climate-smart crop that has great potential in health, food, energy, and environmental industries. The high bioactive compounds of this crop can be used in pharmaceutical and health

industries, and its high oil content and biomass underline it as a useful feedstock for biodiesel, aviation fuel, and other bio-based products. It has the capacity to grow on poor soils and in arid areas, making it a climate-resistant crop, which will aid in the restoration of land and sustainable production. Moreover, when the smallholder farmers are better integrated, the cultivation of macauba can create rural jobs and empower local livelihoods and an inclusive bioeconomy. Macauba palm can be strategically used to enhance renewable energy, climate adaptation and sustainable production systems in tropical and subtropical developing economies with proper investment, research and supportive policies of the government.

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None provided.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

No conflict of interest is associated with this work.

Contribution of authors

We declare that this work was done by the author(s) named in this article, and all liabilities pertaining to claims relating to the content of this article will be borne by the authors.

REFERENCES

- de Lima NE, Carvalho AA, Meerow AW, Manfrin MH. A review of the palm genus *Acrocomia*. *Neotropical green gold. Organisms' Diversity Evolution* 2018; 18(2): 151-161.
- Cabrera OG, Grimaldi LM, Grimaldi R, Ribeiro AP. Macauba (*Acrocomia aculeata*): biology, oil processing, and technological potential. In *Oilseed Crops-Uses, Biology and Production* 2022. doi: 10.5772/intechopen.105540
- Rodrigues AS, Aguiar RM, Maro TA, Roa JP, Nelson DL, Benassi VM. Technological prospecting of macaúba (*Acrocomia aculeata*) in Brazil in the 21st century. *Observatory of the Latin American Economy* 2023; 21(7): 6897-6914.
- Giunco AJ, Simões Ribeiro Leite R, da Paz MF, Fonseca GG. *Acrocomia* spp.: A promising multifunctional crop for sustainable development and bioeconomy. *J Sustainable Forestry* 2025; 44(8): 795-823.
- Morales-Marroquín JA, Alves-Pereira A, Díaz-Hernández BG, Alves Vianna S, de Araújo Batista CE, Colombo CA, Baldin Pinheiro J, Zucchi MI. Genetic variations associated with adaptation in *Acrocomia* palms: A comparative study across the Neotropics for crop improvement. *PLoS One* 2025; 20(6): e0324340.
- Borges CE, dos Santos JC, Evaristo AB, da Cunha TG, von dos Santos Veloso R, Barroso GM, Souza PG, da Silva RS. Distribution and future projection of potential cultivation areas for *Acrocomia aculeata* (Arecaceae) worldwide: the emerging energy culture of the tropics. *Theoretical Applied Climatol* 2021; 146(3): 1069-1078.
- Sorita GD, Favaro SP, Gambetta R, Ambrosi A, Di Luccio M. Macauba (*Acrocomia* spp.) fruits: A comprehensive review of nutritional and phytochemical profiles, health benefits, and sustainable oil production. *Comprehensive Rev Food Sci Food Safety* 2025; 24(1): e70097.
- Vargas-Carpintero R, Hilger T, Mössinger J, Souza RF, Barroso Armas JC, Tiede K, Lewandowski I. *Acrocomia* spp.: neglected crop, ballyhooed multipurpose palm or fit for the bioeconomy? A review. *Agronomy Sustainable Dev* 2021; 41(6): 75.
- Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021; 372: n71. doi:10.1136/bmj.n71
- Storman M, Storman D, Jasinska KW, Swierz MJ, Bala MM. The quality of systematic reviews/meta-analyses published in the field of bariatrics: A cross-sectional systematic survey using AMSTAR 2 and ROBIS. *Obesity Rev* 2020; 21(5): e12994.
- Lescano CH, Oliveira IP, Silva LR, Baldivia DS, Sanjinez-Arg EJ, Arruda EJ, Moraes IC, Lima FF. Nutrient content, characterization and oil extraction from *Acrocomia aculeata* (Jacq.) Lodd. fruits. *Afr J Food Sci* 2015; 9(3): 113-119.
- Lescano CH, Iwamoto RD, Sanjinez-Argandona EJ, Kassuya CA. Diuretic and anti-inflammatory activities of the microencapsulated *Acrocomia aculeata* (Arecaceae) oil on Wistar rats. *J Medicinal Food* 2015; 18(6): 656-662.
- Monteiro-Alfredo T, Matafome P, Iacia BP, Antunes KÁ, dos Santos JM, da Silva Melo da Cunha J, Oliveira S, Oliveira AS, Campos JF, Magalhães M, Cabral C. *Acrocomia aculeata* (Jacq.) Lodd. ex Mart. leaves increase SIRT1 levels and improve stress resistance. *Oxidative Med Cellular Long* 2020; 2020(1): 5238650.
- da Silveira Agostini-Costa T. Bioactive compounds and health benefits of some palm species traditionally used in Africa and the Americas—a review. *J Ethnopharmacol* 2018; 224: 202-229.
- Monteiro-Alfredo T, Oliveira S, Amaro A, Rosendo-Silva D, Antunes K, Pires AS, Teixo R, Abrantes AM, Botelho MF, Castelo-Branco M, Seça R. Hypoglycaemic and antioxidant properties of *Acrocomia aculeata* (Jacq.) Lodd ex Mart. extract are associated with better vascular function of Type 2 diabetic rats. *Nutrients* 2021; 13(8): 2856.
- Lafourcade Prada A, Rodríguez Amado JR, Trentin Perdomo R, Gomes GB, Tavares de Almeida DA, Cavalheiro LF, Gasparotto Júnior A, Florentino Neto S, Utrera Martines MA. *Acrocomia aculeata* oil-loaded nanoemulsion: A promising candidate for cancer and diabetes management. *Pharmaceuticals* 2025; 18(8): 1094.
- Aires GC, de Carvalho Junior RN. Potential of supercritical *Acrocomia aculeata* oil and its technology trends. *Applied Sci* 2023; 13(15): 8594.
- da Silva PV, Ramiro MM, Iriguchi EK, Corrêa WA, Lowe J, Cardoso CA, Arena AC, Kassuya CA, Muzzi RM. Antidiabetic, cytotoxic and antioxidant activities of oil extracted from *Acrocomia aculeata* pulp. *Natural Product Res* 2019; 33(16): 2413-2416.
- Sampaio RS, Pereira RL, Coutinho HD, Almeida-Bezerra JW, Moraes-Braga MF, dos Santos Santana M, da Silva ME, dos Santos AT, Fonseca VJ, Costa AR, da Silva VB. Chemical composition and antimicrobial potential of *Acrocomia aculeata* (Jacq.) Lodd. ex Mart. and *Syagrus cearensis* Noblick (Arecaceae). *Microbial Pathogenesis* 2023; 180: 106147.
- dos Santos Fonseca JV, Batista JD, de Oliveira MC, Diniz NC, dos Santos Lima M, Madruga MS, Magnani M, Borges GD. Low-fat and rich-fiber macauba (*Acrocomia* spp.) sauces: Physical and oxidative stability, nutritional quality and sensory characteristics. *Food Biosci* 2021; 43: 101272.
- Nogueira NH, Nogueira DC, da Fonseca Machado AP, Reguengo LM, do Nascimento RD. Emerging berries from the Brazilian Amazon and Atlantic Forest biomes: new sources of bioactive compounds with potential health benefits. *Food Function* 2024; 15(11): 5752-5784.
- Toledo de Silva SH, Silva LB, Eisner P, Bader-Mittermaier S. Production of protein concentrates from macauba (*Acrocomia aculeata* and *Acrocomia totai*)

- kernels by sieve fractionation. *Foods* 2022; 11(22): 3608.
23. Dias EF, Hauschild L, Moreira VE, Caetano RP, Veira AM, Lopes MS, Guimarães SE, Bastiaansen J, Campos PH. Macauba (*Acrocomia aculeata*) pulp meal as alternative raw material for growing pigs. *Livestock Sci* 2021; 252: 104675.
 24. Vieira SS, Magriotis ZM, Santos NA, das Graças Cardoso M, Saczk AA. Macauba palm (*Acrocomia aculeata*) cake from biodiesel processing: an efficient and low-cost substrate for the adsorption of dyes. *Chem Engine J* 2012; 183: 152-161.
 25. Santos FL, Pereira RV, Scinocca F, Grupioni CM, Castro RP. Macauba palm endocarps under compression forces considering the different treatments: A study about physical and mechanical properties for seed extraction. *Industrial Crops Products* 2024; 20: 119-121.
 26. Stefani R, Bento LM, da Silva Mello G. Bio-based Materials Inspired from Brazilian Cerrado Wastes. In *Food Packaging* 2019: 108-124. CRC Press.
 27. da Silva Fernandes FA, Serra JC, de Oliveira Costa DD, Martin CA. Production of biodegradable polymeric composites with the addition of waste. *Materials* 2023; 16(18): 6305.
 28. da Silva JQ, Santos DQ, Fabris JD, Harter LV, Chagas SP. Light biodiesel from macaúba and palm kernel: Properties of their blends with fossil kerosene from the perspective of an alternative aviation fuel. *Renewable Energy* 2020; 151: 426-433.
 29. Fischer G, Reeler J, Tramberend S, van Velthuisen H. Sustainable Aviation Biofuels for South America: A systems analysis investigation into opportunities for current and future sustainable biofuel feedstock product. *International Institute for Applied System Analysis*. 2024: 82p
 30. Sales de Aguiar Machado PA, de Souza Silva PV, Antunes Fonseca M, Maurício de Jesus JV, Castro Leal N, Veiga Menezes E, de Andrade Royo V, Alves de Oliveira D, Malveira Brandão M, de Melo Júnior AF. Use of Macauba (*Acrocomia Aculeata*) for Biofuels: Perspectives and challenges in the energy sector. *J Social Environmental Management* 2025; 19(6).
 31. Fernández-Coppel IA, Barbosa-Evaristo A, Corrêa-Guimarães A, Martín-Gil J, Navas-Gracia LM, Martín-Ramos P. Life cycle analysis of macauba palm cultivation: A promising crop for biofuel production. *Industrial Crops Products* 2018; 125: 556-566.
 32. Nazari MT, Mazutti J, Basso LG, Colla LM, Brandli L. Biofuels and their connections with the sustainable development goals: a bibliometric and systematic review. *Environ Dev Sustainability* 2021; 23(8): 11139-11156.
 33. Machineni L. Lignocellulosic biofuel production: review of alternatives. *Biomass Conversion Biorefinery* 2020;10(3): 779-791.
 34. Duque TS, Barroso GM, Borges CE, Mendes DS, da Silva RS, Evaristo AB, Dos Santos JB. Current and future development of *Acrocomia aculeata* is focused on biofuel potential and climate change challenges. *Scientific Reports* 2025; 15(1): 8120.
 35. Machado W, Figueiredo A, Guimarães MF. Initial development of seedlings of macauba palm (*Acrocomia aculeata*). *Ind Crops Products* 2016; 87: 14-19.
 36. Ciconini G, Favaro SP, Roscoe R, Miranda CH, Tapeti CF, Miyahira MA, Bearari L, Galvani F, Borsato AV, Colnago LA, Naka MH. Biometry and oil contents of *Acrocomia aculeata* fruits from the Cerrados and Pantanal biomes in Mato Grosso do Sul, Brazil. *Ind Crops Products* 2013; 45: 208-214.
 37. Barbosa-Evaristo A, Fernández-Coppel IA, Corrêa-Guimarães A, Martín-Gil J, Duarte-Pimentel L, Saraiva-Grossi JA, Navas-Gracia LM, Martín-Ramos P. Simulation of macauba palm cultivation: an energy-balance and greenhouse gas emissions analysis. *Carbon Management* 2018; 9(3): 243-254.
 38. Corrêa JB, Dias HC, Tonello KC, Cicco VD, Silva E, Silveira LJ, Sato AY. Surface runoff of rainfall in an experimental plantation of macaúba palm (*Acrocomia aculeata*) under different forms of management. *Tree Magazine* 2018; 42(1): e420104.
 39. Silveira VAD, Paula HBD, Francelino MR, Filpi HEFCM, Kuki KN, Zanuncio JC, Imbuzeiro HMA. Agroclimatic referential for *Acrocomia aculeata* (Jacq.) Lodd. ex Mart. based on its diversity center in Minas Gerais, Brazil. *Ciência Florestal* 2023; 33(4), e64546.
 40. da Silva César A, de Azedias Almeida F, de Souza RP, Silva GC, Atabani AE. The prospects of using *Acrocomia aculeata* (macaúba) a non-edible biodiesel feedstock in Brazil. *Renewable Sustainable Energy Rev* 2015; 49: 1213-1220.
 41. Castro CA, Resende RT, Kuki KN, Carneiro VQ, Marcatti GE, Cruz CD, Motoike SY. High-performance prediction of macauba fruit biomass for agricultural and industrial purposes using Artificial Neural Networks. *Industrial Crops Products* 2017; 108: 806-813.
 42. Resende RT, Kuki KN, Correa TR, Zaidan UR, Mota PH, Telles LA, Gonzales DG, Motoike SY, Resende MD, Leite HG, Lorenzon AS. Data-based agroecological zoning of *Acrocomia aculeata*: GIS modeling and ecophysiological aspects into a Brazilian representative occurrence area. *Industrial Crops Products* 2020; 154: 112749.
 43. Machado W, Guimarães MF, Lira FF, Santos JV, Takahashi LS, Leal AC, Coelho GT. Evaluation of two fruit ecotypes (total and sclerocarpa) of macaúba (*Acrocomia aculeata*). *Industrial Crops Products* 2015; 63: 287-293.
 44. Vargas-Carpintero R, Hilger T, Tiede K, Callenius C, Mössinger J, Souza RF, Barroso Armas JC, Rasche F, Lewandowski I. A collaborative, systems approach for the development of biomass-based value webs: the case of the *Acrocomia* palm. *Land* 2022; 11(10): 1748.
 45. Guatimosim E, Pinto HJ, Barreto RW. *Passalora acrocomiae* sp. nov. and *Exosporium acrocomiae* from the palm *Acrocomia aculeata* in Puerto Rico. *Mycotaxon* 2013; 122(1): 61-67.

46. Maia AC, Santos GK, Gonçalves EG, Navarro DM, Núñez-Avellaneda LA. 2-Alkyl-3-methoxypyrazines are potent attractants of florivorous scarabs (Melolonthidae, Cyclocephalini) associated with economically exploitable Neotropical palms (Arecaceae). *Pest Management Sci* 2018; 74(9): 2053-2058.
47. Souza ID, Lyra-Lemos RP, Guzzo EC. Potential of native palm species in Northeast Brazil as hosts for the invasive mite *Raoiella indica* (Acari: Tenuipalpidae). *Experimental and Applied Acarol* 2020; 80(4): 509-520.
48. Duque TS, Barroso GM, Borges CE, Mendes DS, da Silva RS, Evaristo AB, Dos Santos JB. Current and future development of *Acrocomia aculeata* is focused on biofuel potential and climate change challenges. *Scientific Reports* 2025; 15(1): 8120.
49. Araújo MR, de Melo Júnior AF, Menezes EV, Brandão MM, Cota LG, de Oliveira DA, de Andrade Royo V, Vieira FA. Fine-scale spatial genetic structure and gene flow in *Acrocomia aculeata* (Arecaceae): Analysis in an overlapping generation. *Biochemical Systematics Ecol* 2017; 71: 147-154.
50. Aleixo DT, Gualberto AC, Valle AB, da Silva LC, Ferreira KC, Lemos AS, Fabri RL, Tavares GD, Cazarim MD, Gameiro J, Pittella F. Macauba oil carried by polymeric micelles reduces migration and proliferation of triple-negative breast cancer cells. *RSC Pharmaceutics* 2024; 1(3): 524-535.
51. Rahayu NS, Nugroho AA, Yusuf RR. Exclusion of smallholders in the Indonesian palm oil industry. *KnE Social Sci* 2022: 1158-1182.
52. Bennett EA, Grabs J. How can sustainable business models distribute value more equitably in global value chains? Introducing "value chain profit sharing" as an emerging alternative to fair trade, direct trade, or solidarity trade. *Business Ethics Environment Responsibility* 2025; 34(2): 581-601.