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Macauba (*Acrocomia aculeata*): promising source of nutrients and association with health benefits, a review

Macaúba (*Acrocomia aculeata*): promissora fonte de nutrientes e associação com benefícios a saúde, uma revisão

Macauba (*Acrocomia aculeata*): fuente prometedora de nutrientes y asociación con benefícios para la salud, una revisión

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Abstract
Macauba is widely distributed in Brazilian territory. In addition to being used in the biodiesel production and animal food, it is also rich in bioactive compounds. Therefore, the objective of this review is to present the nutritional composition, the main bioactive compounds, and the potential health benefits of macauba. Macauba has high content of carotenoids, tocopherols, proteins, phenolic compounds, oleic acid, and fiber. Due the presence of bioactive compounds, macauba have the potential to promote health and can be used to prevent or treatment chronic non-communicable disease. Furthermore, this fruit and their by-products can be used in the development of new food and pharmaceutical products, promoting benefit family farming and contribute to the health benefits.
Keywords: Macauba; Bioactive compounds; Health benefits.

Resumo
A macaúba é amplamente distribuída no território brasileiro. Além de ser utilizado na produção de biodiesel e ração animal, também é rica em compostos bioativos. Portanto, o objetivo desta revisão é apresentar a composição nutricional, os principais compostos bioativos e os potenciais benefícios à saúde da macaúba. A macaúba possui alto teor de carotenoides, tocoferóis, proteínas, compostos fenólicos, ácido oleico e fibras. Devido à presença de compostos bioativos, a macaúba tem potencial para promover a saúde e pode ser utilizada na prevenção ou tratamento de doenças crônicas não transmissíveis. Além disso, este fruto e seus subprodutos podem ser utilizados no desenvolvimento de novos produtos alimentícios e farmacêuticos, promovendo benefícios à agricultura familiar e contribuindo para benefícios à saúde.
Palavras-chave: Macaúba; Compostos bioativos; Benefícios a saúde.

Resumen
Macauba está ampliamente distribuida en el territorio brasileño. Además de ser utilizado en la producción de biodiesel y alimentación animal, también es rico en compuestos bioactivos. Por lo tanto, el objetivo de esta revisión es presentar la composición nutricional, los principales compuestos bioactivos y los beneficios potenciales para la salud de la macauba. Macauba tiene un alto contenido de carotenoides, tocoferoles, proteínas, compuestos fenólicos, ácido oleico y fibra. Debido a la presencia de compuestos bioactivos, la macauba tiene el potencial de promover la salud y puede utilizarse en la prevención o el tratamiento de enfermedades crónicas no transmisibles. Además, este fruto y sus derivados pueden ser utilizados en el desarrollo de nuevos productos alimenticios y farmacéuticos, promoviendo beneficios para la agricultura familiar y contribuyendo a beneficios para la salud.
Palabras clave: Macauba; Compuestos bioactivos; Beneficios de la salud.

1. Introduction

Changes related to food consumption patterns, the food production chain and environmental factors make it necessary to look for food sources that contribute to meet the industry's demand, associated with health benefits and environmental preservation (Le et al. 2020). In this sense, the appreciation of native cultures is of great importance to contribute to these issues and provide economic and public health benefits.

Macauba (*Acrocomia aculeata*) is a palm tree present in great extension in the Brazilian territory, present in the states of Minas Gerais, São Paulo, Rio de Janeiro, extending through the center-west, north and northeast of Brazil. Its fruit is composed of distinct parts: shell, pulp, endocarp and kernel. The shell can be used in handicrafts, the pulp in obtaining oil for the manufacture of biodiesel and the pulp press-cake, its co-product, in animal feed, the endocarp used in the production of charcoal and the kernel in obtaining oil used in the cosmetic industry (Vianna et al. 2017). However, macauba is also used in human food and its co-products have great potential for application in the food industry (Lima et al., 2018).

Macauba pulp and kernel are consumed in natura or in regional culinary preparations, and present compounds of interest to health, such as carotenoids, dietary fiber and proteins (Coimbra; Jorge 2011). Among the products obtained from macauba, oil stands out, with two types, pulp and kernel, with different compositions. Kernel oil stands out for its high fatty acid profile in lauric and oleic acids, while pulp oil stands out for its expressive content of oleic and carotenoids and tocopherol (Coimbra & Jorge 2011; Lieb et al. 2019).

Due to its chemical composition, with a high content of bioactive compounds, such as carotenoids, tocopherol, dietary fiber, proteins, oleic acid, macauba has great potential to act in the prevention or reduction of several pathologies that have a great impact on health. Thus, as macauba is a fruit present in the Brazilian flora and still little explored and with possible health potential, the objective of this review is to present the physical-chemical and nutritional aspects, the main bioactive compounds, and the association of health benefits attributed to consumption of macauba.

2. Methodology

This work was carried out through a narrative literature review, according to Brizola; Fantin (2016). For the construction of this work, scientific articles were searched in the following databases: Scientific Electronic Library Online (SciELO), National Library Medicine (NIH), PubMed, ScienceDirect, Elsevier.

The bibliographic research was carried out based on the search for the following keywords: macauba, *acrocomia aculeata*, bocaiuva, carotenoids, oleic acid, phenolic compounds, fiber, bioactive compounds, proteins, tocopherol. Articles published from 2000 to 2022, in English and Portuguese, were delimited with inclusion criteria. The articles resulting from the research were evaluated and those of greater importance for the proposed questioning were included.

3. Results and Discussion

3.1 Botanical description and chemical composition of macauba

Macauba is a palm tree with a wide geographic distribution in the Americas, and in Brazil it is considered as the one with the greatest dispersion with natural occurrence in almost the entire territory. However, the highest concentrations are located in Minas Gerais, Goiás, Mato Grosso and Mato Grosso do Sul, being widely spread across cerrado areas (Lima et al. 2018). Macauba reaches a stem of 10 to 15 m in height and 20 to 30 cm in diameter. The node region is covered with dark, pointed spines about 10 cm long, and the green leaves are 4 to 5 meters long and thorns in the central region. The fruits are arranged in bunches and have a spherical or slightly flattened shape, with a diameter ranging from 2.5 to 5.0 cm (Sanjinez-Argandona & Chuba 2011).

Fruiting occurs throughout the year and the fruits ripen mainly between September and January and their exploitation is still rudimentary, traditionally linked to community extractivism (Pires et al. 2013). The fruit is composed of four parts: shell (epicarp), pulp (mesocarp), endocarp and kernel. The epicarp breaks easily when mature. The mesocarp is fibrous, mucilaginous, yellow in color. The endocarp has a hard consistency, and the oilseeds are white in color and covered with a thin layer of integument. Each fruit usually contains a seed surrounded by a hard and dark endocarp (Vianna et al. 2017).

Macauba kernel stands out for its high protein and dietary fiber content, and macauba pulp also has a significant content of protein and dietary fiber (Table 1), and a high content of carotenoids, with a content of 300 – 348 μg g^{-1} of total carotenoids and 49 – 59 μg g^{-1} of β-carotene (Hiana et al. 2006; Coimbra; Jorge 2012). However, the great highlight related to macauba is based on the expressive content of lipids, both related to the pulp and the kernel (Lieb et al. 2019). Pulp and kernel oils have different lipid profile and composition (Table 2). The pulp oil has an orange color due to the presence of carotenoids, being an oil of the oleic/palmitic type composed mainly of oleic acid (C18:1). Kernel oil is light in color, with a high content of saturated fatty acids, predominantly lauric acid (Coimbra; Jorge 2012; Lieb et al. 2019). Kernel oil is similar to coconut oil, but it has the important characteristic of not only having a high content of lauric acid, but also having an outstanding percentage of oleic acid, which are important characteristics related to health (Lescano et al. 2015; Río et al. 2016). Pulp oil has been popularly known as “cerrado olive oil”, because its characteristics are similar to olive oil (Coimbra; Jorge 2011).

Other bioactive compounds are present in macauba, such as tocopherols and phenolic compounds. Macauba pulp has a higher value of tocopherol when compared to kernel, 212 mg kg^{-1} and 23 mg kg^{-1}, respectivelly (Coimbra & Jorge 2012; Schex et al. 2018). Study carried out by Oliveira et al. (2017) evaluating the content of total phenolics present in macauba oils showed 3.9 mg EAG/100g in pulp oil and 0.70 mg EAG/100g in kernel oil.

Table 1 - Macauba chemical composition (%) (wet base).

	Pulp	Kernel
Moisture	4.20 – 5.98	2.52 – 4.97
Ash	1.50 – 2.17	1.86 – 2.08
Protein	5.31 – 6.72	16.44 – 28.61
Lipid	23.00 – 42.00	46.00 – 65.00
Total dietary fiber	13.89 – 20.26	12.49 – 15.81
Carbohydrate	6.22 – 6.92	5.81 – 6.06

Source: Adapted from Lescano et al. (2015); Evaristo et al. (2016); Coimbra; Jorge (2011).

Table 2 - Fatty acid profile of macauba pulp and kernel oils.

Fatty acid	Pulp oil	Kernel oil
Caprylic (C8:0)	-	3.67 – 4.90
Capric (C10:0)	-	2.79 – 3.27
Lauric (C12:0)	0.39 – 0.74	39.02 – 43.75
Mystic (C14:0)	0.38 – 0.41	9.21 – 13.40
Palmitic (C16:0)	19.10 – 24.70	8.25 – 9.20
Palmitoleic (C16:1)	3.75 – 4.28	-
Stearic (C18:0)	1.62 – 1.70	2.24 – 2.93
Oleic (C18:1)	52.57 – 64.90	26.27 – 32.70
Linoleic (C18:2)	5.54 – 13.80	3.08 – 3.82
Linolenic (C18:3)	1.40 – 2.26	-
Saturated	21.40 – 27.10	59.91 -62.84
Unsaturated	72.90 – 78.60	36.14 – 40.09

Source: Adapted from Coimbra; Jorge (2011), Lieb et al. (2019), Munhoz et al. (2018).

3.2 Macauba and its potential use in human food

Despite its abundant fruiting and other characteristics, macauba is a wild palm tree and in almost the entire national territory it has been exploited domestically, well below its economic potential, and its exploitation is still carried out in a rudimentary way, traditionally associated with to community extractivism (Evaristo et al. 2016). The use of macauba resources is very diverse, and all its parts can be used in different sectors. The shell can be used as wood, the leaves serve as raw material for crafts and animal fodder. The press-cake, a co-product of the extraction of oil, has a high production and can be used as a component of animal feed. The endocarp can be used as charcoal and in the replacement of concrete gravel, or even as craft material. The kernel can be used to obtain oil and be used as an ingredient in the manufacture of soap and cosmetics (César et al. 2015; Evaristo et al. 2016; Ramos et al. 2008).

Macauba emerged as a promising raw material for the production of biodiesel due to its expressive oil content, high productivity, and good adaptation to different climatic conditions (Evaristo et al. 2016). Another relevant aspect for the use of macauba in the production of biofuels is due to the fact that its fruit generates a high number of co-products that can be used (César et al. 2015). Macauba pulp press-cake can be used in animal feed, especially for ruminants, as a substitute for traditionally used foods. This substitution triggers positive points related to cost reduction, given the high yield of this co-product and its low cost, associated with nutritional benefits for animals due to its fiber content (Riqueira et al. 2017).

Despite its prominent use in the production of biodiesel and animal feed, the uses of macauba and its co-products in human food are present great potential, due to the nutritional value. A study with the development of alfajor using macauba pulp flour proved to be well accepted by children and even added a higher fiber and lipid content to the product, improving the nutritional profile of the product when compared to the control product (Rodrigues et al. 2017). The press-cake, a co-product of the extraction of oil, can be transformed into ingredients for human consumption, due to its high composition in dietary fiber, carotenoids and oil with a high oleic content, and be used in the formulation of cakes, breads and cookies (Dessimoni-Pinto et al. 2010).

The great potential of macauba use is based on the production of oil, presenting great productivity and oils with characteristics desired by the industrial sectors. Brazil is a major importer of olive oil, as the country has low cultivation of olive trees (International Olive Oil Council 2018). In contrast, macauba is a native plant and is found practically throughout the entire national territory (Lima et al. 2018). Equating the issue of processing and demonstrating similar health benefits between both oils, one can motivate the planting and industrialization of macauba oil, as well as its co-products. Potentially, the final cost of pulp oil should be lower than that practiced for olive oil, making it more accessible to the Brazilian population. Unlike the olive tree, macauba can be cultivated in practically the entire Brazilian territory, due to its adaptability to various environmental conditions (Pires et al. 2013). Considering the high cost of olive oil practiced in the Brazilian market and the possible availability of an alternative from the Brazilian flora itself, an important strategy is the inclusion of macauba pulp oil as a component of the daily diet.

Thus, macauba presents itself as a palm tree with extensive use, and all its parts can be used, whether for use for food purposes or subsidies for agriculture and other sectors, demonstrating the importance of studies and research on the fruit of this palm. In addition, the insertion of macauba in the food sector favors the generation of jobs and appreciation of family farming.

3.3 Correlation between main properties and potential health benefits

Non-communicable chronic diseases such as obesity, diabetes, metabolic syndrome, among others, are currently a major public health problem and have a great impact at an economic and social level (Apovian et al. 2015). With this, it becomes important, strategies that aim to contribute to the prevention and treatment of these pathologies. Among them, food and compounds present in foods that can trigger benefits in these pathological conditions stand out (WHO 2018). In this sense, macauba has beneficial potential in the treatment and prevention of diseases, due to the content of protein, fiber, oleic acid, carotenoids, phenolic compounds, and tocopherol.

The high protein content present in macauba, especially in kernel, may favor health promotion and adequate consumption of this extremely important macronutrient. Proteins are characterized by being of vital importance to living beings. Its functions range from catalysis of chemical reactions, transport of other molecules, transmission of nerve impulses, immune protection, hormonal function, among others (Shevkani et al. 2021). It has been suggested that the possible association between cardiovascular disease and protein intake is caused by the effect of protein intake on plasma LDL and weight maintenance (Wu 2016). A recent study using macauba kernel as a protein source improved the lipid profile and short-chain fatty acid content in rats (Duarte et al. 2022). In addition to proteins, as a significant source of dietary fiber, the consumption of macauba can be considered an important functional food in clinical conditions such as preventing obesity, reducing blood glucose, and also playing an important role in modifying the intestinal microbiota. There is a high association between the consumption of dietary fibers and the modification of the intestinal microbiota, resulting from the production of short chain fatty acids (SCFAs) by the fermentation of dietary fibers, culminating in positive effects on lipid and glucose metabolism (Barber et al. 2020). In addition, the consumption of dietary fiber helps reduce weight gain and control obesity through the greater satiety mechanism promoted by fiber (Waddell et al. 2022).

The high proportion of oleic acid present in the macauba pulp oil, close to that found in olive oil, raises the hypothesis of a similar biological action on the lipid metabolism alleged to this traditional oilseed (Guasch-Ferre et al. 2020). Oleic acid play a protective role in cardiovascular diseases, it is the preferred substrate of ACAT (acyl-CoA:cholesterol acyltransferase) and thus helps the formation of cholesteryl esters, reducing the amount of free cholesterol in the cell, which induces the activity of LDL receptors in the liver, triggering, therefore, neutral action on cholesterolemia when compared to the consumption of saturated fats (Damgaard et al. 2013; Edwards et al. 2000; Rumsey et al. 1995). Macauba, because it has a lipid composition similar to olive oil, with a high oleic content, may favor the control of obesity and oxidative stress, through the inhibition of lipogenic pathways, with the ability to inhibit the nuclear translocation of sterol-regulatory element-binding protein 2 (SREBP-2) which is related to the transcription of enzymes involved in the endogenous synthesis of cholesterol (Hernandez-Rodas et al. 2017). Furthermore, oleic acid induces beta-oxidation of fatty acids through peroxisome proliferator-activated receptor gamma (PPARγ), contributing to lower synthesis of triacylglycerols and lower hepatic secretion of VLDL (very low-density lipoprotein) (Ou et al. 2001). Oleic acid is related to reduced inflammation due to the ability to block the NF-κβ complex through the activation of genes responsible for the IL-10 protein, which is a potent anti-inflammatory molecule and lower expression of inflammatory genes (Ni et al. al. 2015).

An important bioactive compound present in macauba pulp are carotenoids, which have important antioxidant activity. They function as regulators of the immune system response and reduce the risk of chronic non-communicable diseases such as cancer, cardiovascular diseases, cataracts, macular degeneration and oxidative stress (Johnson et al. 2018; Wang et al. 2013). The high concentration of carotenoids present in macauba pulp oil can function as a natural antioxidant, capable of reducing the rate of lipid oxidation reactions (Coimbra; Jorge 2011). Carotenoids, in addition to being essential compounds for health maintenance and acting to reduce inflammation by modulating the nuclear factor kappa B (NF-κβ) pathway, are associated with effects on adipose tissue, interfering with adipocyte hypertrophy and differentiation, fatty acid oxidation and thermogenesis, leading to the darkening of white adipose tissue (Bonet et al. 2015). Carotenoids have been shown to affect adipocyte function through interaction with the transcription factor PPARγ, interfering with adipocyte differentiation, as demonstrated in a study using experimental animals and finding an association between carotenoids and lower adipose tissue gain, related to lower PPARγ expression (Bonet et al. 2015; Ribot et al. 2012).

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The antioxidant activity of phenolic compounds is mainly due to their reducing property and chemical structure. These characteristics play an important role in the neutralization or scavenging of free radicals and chelation of transition metals, acting both in the initiation stage and in the propagation of the oxidative process (Babbar et al. 2011). This mechanism of action of antioxidants plays an important role in reducing lipid oxidation in tissues, because when incorporated into human food, they reduce the risk of developing pathologies, such as atherosclerosis and dyslipidemia (Toma et al. 2020). Phenolic compounds from food have been the focus of many studies about their anti-inflammatory, antimicrobial and antilipidemic properties. These compounds prevent peroxidation and oxidative modifications of LDL-c through their antioxidant activities (Gavahian et al. 2019). Additionally, tocopherols also have antioxidant activity and are related to attenuation of oxidative stress and inflammatory response, associated with the effect on thermogenesis with increased expression of the UCP1 gene (gene expressed in brown adipose tissue) in white adipose tissue (Tanaka-Yachi et al. 2018).

4. Conclusion

Macauba presents itself as a promising source of nutrients and bioactive compounds, with great potential for application in the food industry, and also shows a great association with health benefits, and may be a promising functional food, contributing to the prevention of chronic non-communicable diseases. Thus, research that helps to clarify the impact of inserting macauba in human food is of great importance.

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