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Use of agro-industrial waste from the processing of oilseeds and Amazonian fruits

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Abstract

The processing of fruits and vegetables in general generates a significant amount of waste, which is often discarded in the environment, losing the potential for using it in obtaining and/or developing other value-added products. Within this theme, some waste arising from the processing of Amazonian fruits and oilseeds, such as açaí and andiroba, deserves attention due to the large volume of waste generated from these species. The development of new ways of using these as raw materials to obtain products with high added value becomes a challenge, which can directly impact the preservation of the environment by reducing the disposal of these wastes and socioeconomic conditions, since viable alternatives of use can generate demand for specialized work. This literature review presents a survey of recent data on two raw materials: açaí and andiroba, in addition to the current picture on production, market, composition, and applications.

Keywords: organic acids; Amazon fruits; aggregation value; new products; subproducts.

Practical Application: An approach to the production chain was also taken, along with the application of strategies to stimulate the sustainable development of by-products of raw materials produced in the Brazilian Amazon region. The use of these agro-industrial by-products from Amazonian fruits can be a viable alternative for producing cellulose and obtaining organic acids.

1 INTRODUCTION

Fruits and vegetables are sources of nutrients and vitamins essential for human metabolism (Wallace et al., 2020). These can be used in their natural or processed form, resulting in the generation of by-products or co-products (Nieto et al., 2021). The Amazon biome stands out for its rich biodiversity, especially its flora (De Las Casas, 2019). Among these, açaí deserves to be highlighted, which has been commonly used by the local population to obtain pulps that can be consumed in the form of the so-called “açaí wine” (Da Silva et al., 2021), frozen, and frozen pulps (Carvalho et al., 2017). In all these forms of use, there is a very significant generation of waste/rejects (Costa et al., 2020).

Among other prominent fruits in the Amazon region, although not a native species, pineapple also deserves attention due to its high percentage of production and sensory characteristics, in addition to the generation of significant amounts of waste (from De S. Barros et al., 2020). These can be used to obtain various co-products with different possibilities for applications in the food, chemical, and pharmaceutical areas (Araujo et al., 2020), highlighting the extraction of bromelain.

In addition to the great diversity of edible species, oilseeds also stand out, such as andiroba (*Carapa guianensis* Aubl.). with great potential for sustainable management and use, promotion of local development, and income for extractives due to the versatility attributed to the oil, which is mainly used in the cosmetics industry (Brito et al., 2020). However, cooperatives associated with the extraction of andiroba oil have come up against the destination of the by-product of the processing of these seeds, which can be valued as raw materials to obtain products of commercial interest (Souza et al., 2020).

The use of these residues from the agro-industrial sector is of great interest and relevance for biotechnology, mainly for the Brazilian Amazon and its ecosystem, since they do not depend on territorial expansion, giving adequate destinations and high added value to residual biomass arising from processing.

2 METHODS

We performed a narrative and critical review of biomedical literature. PubMed/MEDLINE, Scielo, Scopus, Web of Science, Google Academic, Capes periodic, and Cochrane Library databases were searched for articles published in English, Spanish, French, and Portuguese over the last 5 years preferably.

2.1 Agro-industrial waste

The processing of agro-industrial raw materials from production chains, whether in the Amazon or any other location, generates tons of organic waste (Correa et al., 2019). Such waste

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is made up of different compositions, mineral, chemical, and biochemical, which can be reused in other applications, guaranteeing an alternative source and bringing economic and social advantages to producers. According to Maia et al. (2022) and Oliveira et al. (2021), these Amazonian residual biomasses can be used as valuable raw materials to obtain value-added products, which is in line with the principles of the circular economy.

2.2 Main co-products and their applications

The Amazon region stands out for its biodiversity, mainly for its flora and numerous edible species, generating a significant amount of post-processing by-products. It is worth mentioning that cassava and cassava peels are used to feed animals (Matte et al., 2021). Oilseeds include tucumã seeds (*Astrocaryum aculeatum*), babaçu (*Attalea speciosa*), andiroba (*Carapa guianensis*), from which fixed oils are extracted (Pereira et al., 2019); chestnut hedgehog is (*Bertholletia excelsa*) used as charcoal (Madeira di Beneditto & Siciliano, 2021); bacaba seed (*Oenocarpus bacaba*); and açaí (*Euterpe oleracea*), in addition to the by-products generated from pineapple processing (Sousa et al., 2020). In this review, two by-products will be discussed: açaí and andiroba, in addition to the current picture on production, market, composition, and its applications.

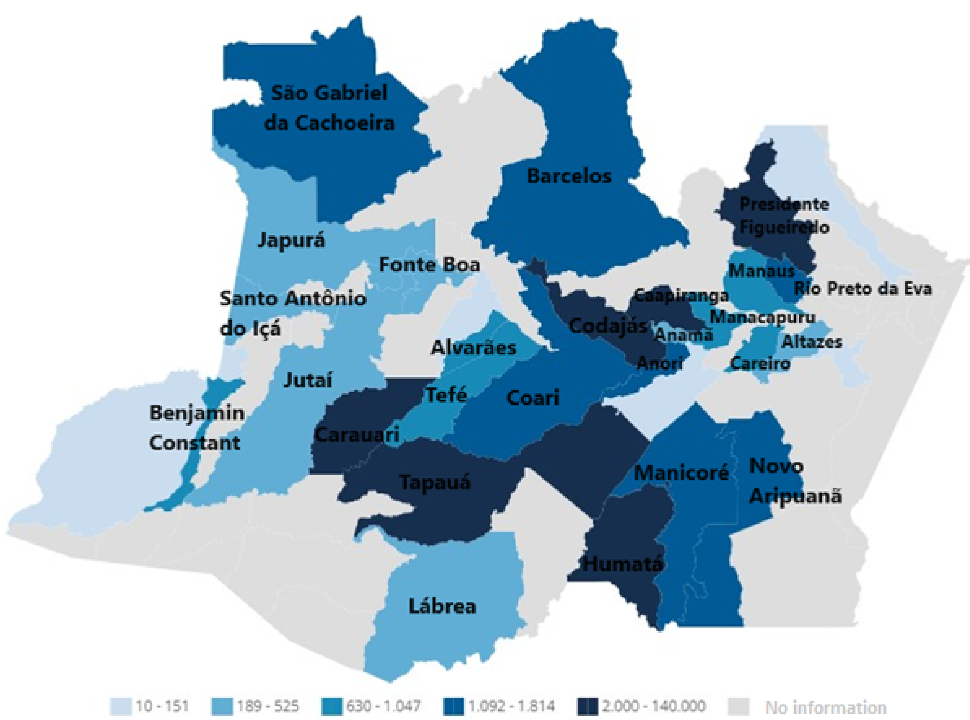
3 AÇAÍ

Açaí (*Euterpe* sp.) is a fruit from the açaí tree, a palm tree belonging to the Arecaceae family. It measures 3–20 m in height and presents peaks of production in the months of July to December (Lira et al., 2021). Its culture is extremely important for the food sector, presenting significant uses in the pharmaceutical and cosmetic industry, changing from a local and regional staple food of the Brazilian Amazon to an international fashion food, assuming different values (nutritional, symbolic, and economic) through its commodity chain (Barbosa & Carvalho Junior, 2022; Siqueira & Brondizio, 2011).

Of national production, the Northern region of Brazil corresponds to 87.5% of the total, where the State of Amazonas occupies the second position in the ranking of production in Brazil, with a share of 21.39% (CONAB, 2019), and the municipality of Codajás is the largest state producer. In the northern region of Brazil, Pará stands out, with 61.2% of the total national harvest (CONAB, 2019). Such an increase in production directly reflects the generation of by-products, which have been inappropriately discarded and/or underused.

In this activity, extractives predominate, although, in recent years, there has been a significant increase in cultivated areas due to easy access to different consumer markets, as well as its importance for food and nutritional security. In the state of Amazonas, its cultivation is practiced by more than 4,000 family farmers and rural producers, with some registering commercial cultivation (IDAM, 2020). The largest açaí productions, from 2019 to 2022, include the municipalities of Codajás, Borba, Anori, Manicoré, Coari, Rio Preto da Eva, Carauari, Humaitá, Lábrea, Tapauá, Nova Olinda do Norte, and Benjamin Constant (Figure 1), with the production of Native açaí at 38,000 tons (IDAM, 2020) and Cultivated açaí at 90,616 tons (IBGE, 2022).

The Amazonian açaí harvest has been growing over the last few years, with a significant increase in revenue. According to data from the agricultural production report (IBGE, 2022), from 2018 to 2022, it went from R$ 97,080 to R$ 178,723 thousand



Source: IBGE (2022).

Figure 1. Map of açaí cultivation producing regions (production value—thousand reais).

reais in revenue. The pit represents up to 85% of the weight of the fruit, that is, for every 100 tons of açaí, 80 tons are waste. It is estimated that more than 1,000,000 tons of seeds are produced annually and dumped in inappropriate places, waste that could very well be avoided by taking advantage of the physical, chemical, and nutritional characteristics found in these by-products (Sato et al., 2019).

3.1 Composition and nutritional value

One of the main aspects of emphasis when we talk about residues from vegetable processing is related to their nutritional composition, which can be equal to or even superior to the commonly used parts (Da Silva et al., 2016). Açaí seeds are rich in mannan, which after hydrolysis can be converted into mannose, glucose, and other monosaccharides (Ferreira Monteiro et al., 2019). The majority composition of the ground samples, in relation to the carbohydrate fraction, revealed the predominance of mannan, corresponding to 52.46% of their total dry weight, in addition to other structural glycides identified, such as glucose (8.40%), xylose (2.05%), galactose (1.51%), and arabinose (0.63%) (Ferreira Monteiro et al., 2019). Mannose is marketed as a dietary supplement, used to improve the texture of foods such as ice cream, candied fruits, and salad dressings (Hu et al., 2016).

Regarding the extractive content, the açaí almond contains around 4.48% extractives (Barros et al., 2021). These values may vary depending on the species, off-season, and location. Other studies have quantified values of approximately 9.89% of extractives (Barbosa & Carvalho Junior, 2022; Ferreira Monteiro et al., 2019). These components are removed through solvent extractions. The main extractives of açaí seeds are polyphenols, mainly condensed tannins (proanthocyanidins), which differ in their constitutive monomers (flavan-3-ols) such as catechin, epicatechin, gallocatechin, and epigallocatechin (Barbosa & Carvalho Junior, 2022). Such compounds can directly infer the antioxidant capacity of these raw materials since these bioactives have a high capacity to scavenge free radicals (Ketnawa et al., 2022). These characteristics reinforce the importance of using waste and by-products from the processing of Amazonian vegetables in applications that add value to their production chain.

3.2 Technological applications

Some alternatives for using the by-products generated from açaí processing have been studied. However, few solutions with operational capacity were presented (Barbosa & Carvalho Junior, 2022). The initiatives explored for more traditional use are the production of food inputs. Other opportunities can be implemented, such as the production of mannose and polyphenols.

Trends in environmental sustainability show that traditional processes are giving a new face to generating value in food products and, in other areas of activity, such as physical chemistry, biochemistry, and chemistry, bringing competitive advantage. Figure 2 shows the different possibilities for using açaí by-products in different technological niches and areas, proving itself as a multifunctional raw material due to its unique physical, chemical, and nutritional characteristics.

Table 1 provides a description of the different applications shown in Figure 2. Some of these trends are described as follows:

3.3 Socioeconomic importance

For Jorge (2020), a proposed model for the use of açaí residue could have a greater impact in the region through the implementation of the biorefinery concept that explores the characteristics of biomass in a more diverse way. They are very suitable and relevant for use in composting and organic fertilizers. Barbosa and Carvalho Junior (2022) suggest activity focusing on the production of mannose, polyphenol co-products, and sugar syrup. A net investment for the construction and operation of an açaí biorefinery to produce mannose and polyphenols would be estimated at US$ 64.2 million, with 74.7% annual revenue and a net profit of US$ 31.4 million per year (Jorge, 2020). Such a contribution would bring socioeconomic

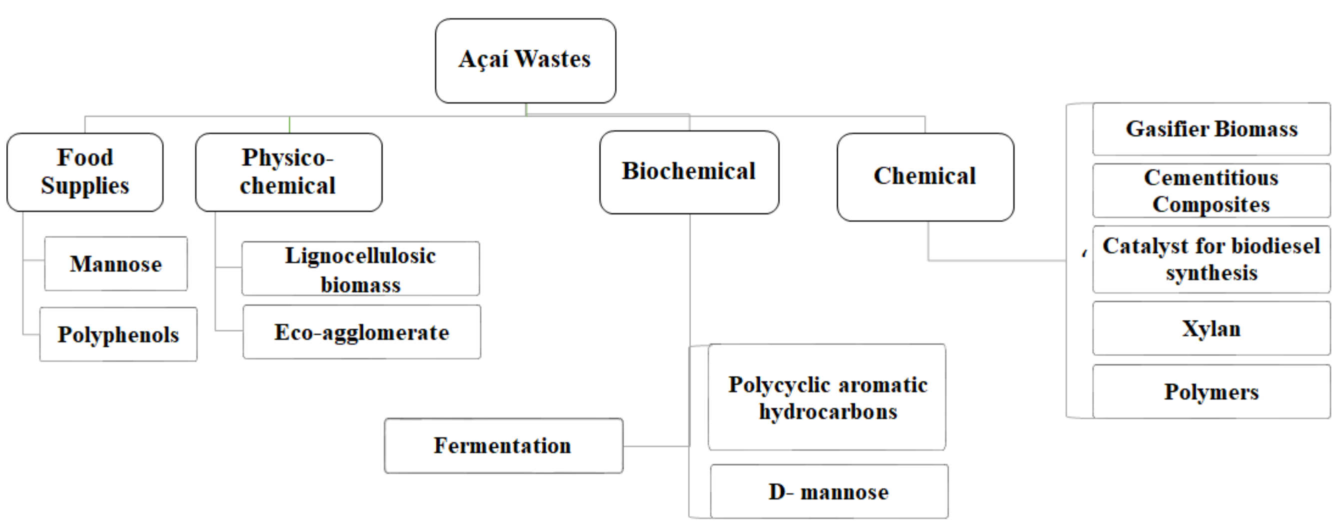


Figure 2. Applications for açaí residue.

benefits to the region, strengthening the açaí production chain, reusing this material, and giving added value to this by-product that is discarded.

4 ANDIROBA

Andiroba (*Carapa guianensis* Aublet.) comes from the andirobeira, a tree belonging to the Meliaceae family. Its name is of Tupi origin and means bitter oil (Nascimento et al., 2019). This is one of the most important trees of medicinal plants used as herbal medicines by indigenous peoples and traditional inhabitants of the region. It is widely distributed throughout the Brazilian Amazon forest, growing in floodplain and igapó regions, in addition to being also found in dry land areas (Lira et al., 2021).

Andiroba oil is one of the main non-timber forest products in the Amazon region (Figure 3). In this context, andiroba

Table 1. Production of compounds/bioproducts of the açaí waste.

Application	Description	References
Food inputs	The açaí production chain can be explored for the production of food inputs based on polyphenols and mannose.	(Barbosa & Carvalho Junior, 2022)
Biomass for gasifier	The açaí residue was used as biomass in a gasifier to generate energy. The resulting carbon was activated and employed as a profitable adsorbent for methylene blue and raw textile wastewater.	(Pessôa et al., 2019)
Cementitious composites	Use of natural açaí fiber in cementitious composites for applications in wall covering mortars and reinforcement of small structural points. However, the fiber must undergo treatment with a NaOH solution due to the loss of properties and durability found in its untreated use. The loss of these properties may harm their commercial use and application.	(De Azevedo et al., 2021)
Catalyst for biodiesel synthesis	The catalyst showed its catalytic activity due to the high content of metal oxides and carbonates with surface basic sites, making them highly efficient for biodiesel production, showing its activity at ester content above 92.5%.	(Mares et al., 2021)
Lignocellulosic biomass	Mass yields and physicochemical characteristics of lignocellulosic derivatives obtain a yield close to 64% of type I nanocrystalline cellulose (CNC) with a 45% degree of crystallinity. The extracted lignin was rich in methoxyl groups, p-coumaryl alcohol, and p-coumaric acid.	(Linan et al., 2021)
Eco-chipboard, lignocellulosic particle board	Chemical mercerization is responsible for the removal of SiO_2 and the formation of globular protrusions, leaving the fiber surface rougher, facilitating greater adhesion between the fibers and the castor-based polyurethane resin, providing better performance of physical properties (water absorption and swelling in thickness), as well as mechanical properties (modulus of rupture, gluing, and screw removal).	(De Lima Mesquita et al., 2018)
Xylan with industrial and biomedical applications	The degreased residue was subjected to successive extraction with hot water and 10% aq. KOH. The polysaccharides extracted with alkaline solution were recovered by dialysis, with a yield of 5.9%. It was then subjected to a freeze-thaw treatment, which after centrifugation gave rise to a fraction soluble in cold water and insoluble in cold water (yield of 4.2%). The monosaccharide composition of the fraction insoluble in cold water showed mainly xylose (97.2%) and small amounts of uronic acids (2.8%), indicating the presence of a xylan in this fraction.	(Cantu-Jungles et al., 2017)
Absorption of polycyclic aromatic hydrocarbons (PAHs) in lignocellulosic waste	PAHs represent an important class of carcinogens that are present as contaminants in several agri-food sources. Enzymatic pretreatment of lignin increases the availability of lignin functional groups by enzymatic depolymerization to increase the adsorption capacity of PAHs.	(Oliveira et al., 2019)
Extraction and green production of D-mannose	After acid hydrolysis and enzymatic catalysis of the chemical composition of the hydrolysate, it was found that mannan is the main component of mature seeds, and its content represents approximately 50% of the total dry weight and 80% of the total carbohydrates. Using 3% sulfuric acid to hydrolyze at 121°C for 60 min, 41 g/L mannose can be obtained, and the yield is about 30%. Enzymatic hydrolysis of the remaining 70% of mannan in seeds can increase the mannose concentration to 146.3 g/L, and the yield can reach 96.8%, which is the highest concentration of mannose extracted from plant residues.	(Wang et al., 2022; Zhang et al., 2009)
Recycled polymers	Hot compression molding is proven to be a good alternative for reprocessing of used PP and HIPS packages to obtain composites with an açaí fiber. The process tested disease was enough to sweet professional the compound without fiber degradation. It was concluded that the fiber increased the impact resistance of both polymers. Such a result represents a new alternative for the thermoplastic reinforcement material with açaí fiber for production composite. Tested on polymeric resins, polypropylene (PP) and polystyrene (PS), hot compression was a good alternative for obtaining composites.	(Da Costa Castro et al., 2010)

oil is sold mainly in open-air markets in the northern region of Brazil and markets in other regions of the country, as well as in the supply of export trade, being supplied as an input to pharmaceutical and cosmetic industries in Europe and the USA (Mendonça et al., 2020). Oil extraction on an industrial scale by cold pressing generates a solid by-product that reflects the characteristics of the main product (Mendonça et al., 2020).

Agricultural residues are low-cost materials that can be used to obtain products and materials with different texture characteristics and properties. Among the fruit species in the Brazilian Amazon, andiroba is sold for oil extraction, and from this extraction, tons of waste are generated, around 1,980 tons annually (Serafin et al., 2021). Processing waste from the extraction of andiroba oil is, therefore, a challenge, and in this case, cold pressing removes 34% of extra virgin oil, leaving a significant percentage of residual cake (approximately 66%) (Dos Santos et al., 2021).

In order to reduce the environmental impacts related to the final disposal of these by-products, the traditional disposal methods used are dumping the waste on portions of land adjacent to the production sites, using it as raw material in the production of feed for agriculture, or burning with insecticidal action (Carvalho et al., 2019). However, it is possible to reduce environmental impacts in other ways, such as the use of biotechnology, since this waste contains important bioactive compounds in its composition.

4.1 Composition and nutritional value

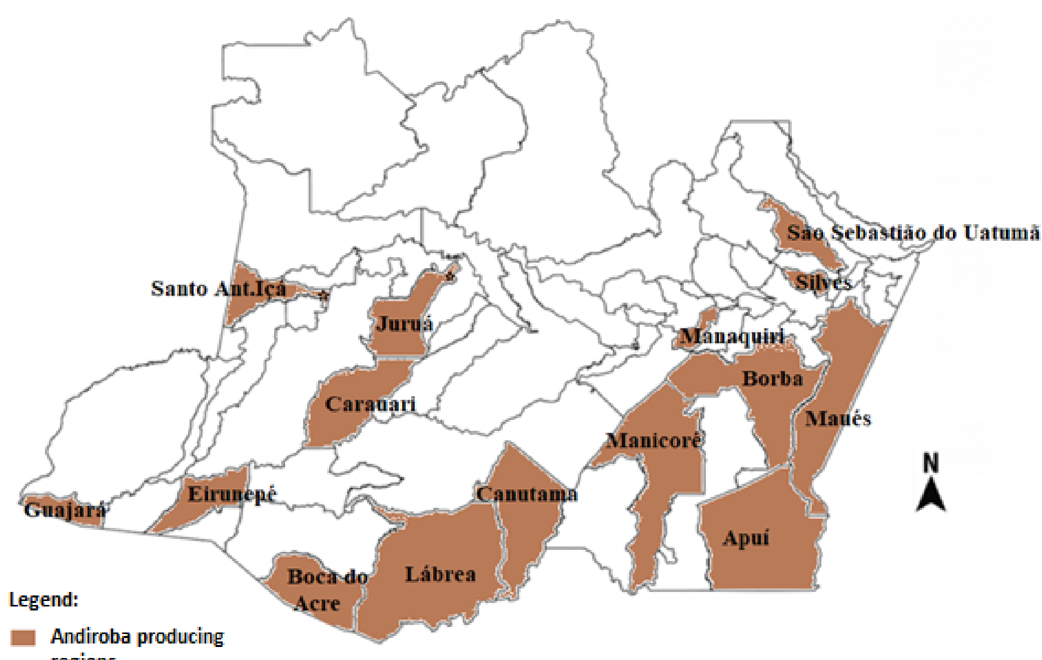
The chemical profile of andiroba seeds presents groups of lipid molecules, saponifiable compounds: oleic, palmitic, stearic, and linoleic acids; and non-saponifiable compounds, such as steroids, triterpenes and mainly tetranortriterpenes, or limonoids (Dos Santos et al., 2021).

The oil extracted from its seeds is widely used as it has anti-inflammatory, analgesic, antiarthritic, antitumor, larvicidal, and antimicrobial properties. From the cold pressing of seeds (almonds and shells), a solid by-product is produced (Mendonça et al., 2020), which has a range of applications yet to be explored.

4.2 Technological applications

The use of waste to obtain value-added materials such as activated carbon has been of fundamental importance as andiroba represents great potential to be explored technologically beyond its nutritional application (Serafin et al., 2021). For the use of the oil, it is possible to find several highly relevant works in the literature, such as the work of Melo et al. (2021), which verified the ability of andiroba oil to produce a nanoemulsion in reducing the side effects of doxorubicin—an anthracycline antibiotic used to combat various types of cancer. Although andiroba and its by-products present a relevant amount of bioactives with extremely important functions in metabolism, there is a lack of work on this topic, which could be explored and new uses increased in the region's development process, positively helping to improve socioeconomic conditions.

When searching for works on various scientific platforms, such as Science Direct, Web of Science, and Google Academic, among others, there is a low number of works on these platforms related to the development of by-products from this raw material. In total, 63 results were found, but not all of them are about the by-product; the majority are about the oil. Among these,



Source: IDAM (2020).

Figure 3. Map of andiroba-producing regions developed based on data from the Institute for Sustainable Agricultural and Forestry Development of the State of Amazonas (IDAM).

only four studies with by-products were referenced, with the objectives of developing activated carbon, larvicides, and lipase production (Figure 4 and Table 2). Thus, verifying that there is a need for a diversity of registered technological applications to address this need for communities in the interior of Amazonas.

Few ways of processing this by-product are presented to society. New forms of application are necessary, bringing important results that involve the state of Amazonas, and are extremely important to meet the difficulties of rural producers. In Table 2, it is possible to observe the descriptions of the few applications found.

4.3 Socioeconomic importance

Regarding the oleochemical industry, in the case of oilseeds, it is important to consider market aspects not only for the oil, as demonstrated in CGEE (2010), but also for defatted bran. Just like soy, protein has great nutritional value. Still, according to CGEE (2010), the topics of waste utilization and biotechnological processes in oleochemistry are at the bench research stage, but the results are promising and will take the experiments to the pilot phase, as in the case of the unconventional oleaginous raw material andiroba, which will add the generation of income and employment in local communities in the Amazon region. Biomasses have promising potential to meet global needs for renewable sources; these sustainable resources generate economic development together with an ecologically correct environment (Sarangi et al., 2020). Consequently, a good bioeconomic perspective can reduce environmental pollution and also facilitate the application of the circular bioeconomy, having immeasurable results for future generations (Mohanty et al., 2022). To this end, perspectives on the concept of biorefinery have been developed.

4.4 Integrated biorefinery approach

The biorefinery concept presupposes the separation of traditional areas and seeks to build integrated systems for the production of chemical compounds, food, and energy, obtaining maximum use of biomass (CGEE, 2010). The performances of the bioprocesses addressed in biorefineries are crucial strategies to make the work carried out with the by-products covered in this review economically viable, closing the cycle of the circular economy (Awasthi et al., 2022). Brazil is in a privileged position

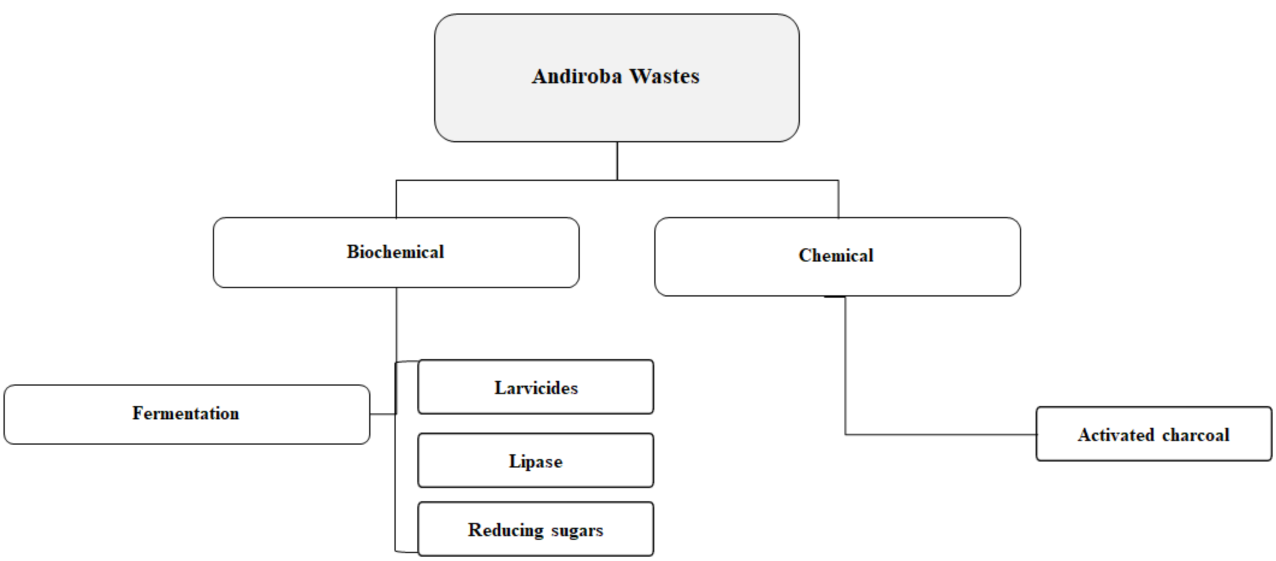


Figure 4. Use of andiroba by-products in different sectors.

Table 2. Production of compounds/bioproducts from andiroba waste.

Application	Description	References
Activated carbon	Andiroba bark was used as renewable biomass for the production of porous activated carbon as a CO adsorbent. The effect of activation times (1 h, 5 h, and 10 h) at 880°C on the physical characteristics of activated carbons was investigated. Another work was also on the removal of Fe and Mn ions from groundwater using activated carbon obtained from andiroba residue.	(Serafin et al., 2022; Thomaz et al., 2023).
Larvicides against *Aedes aegypti*	Andiroba seed hull extract in hexane, ethyl acetate, and dichloromethane had a significant residual larvicidal effect observed—100% on Day 6 at 250 µg/mL.	(Correa de Oliveira et al., 2022)
Lipase production	Production of lipases from oil extraction cake by solid-state fermentation using *Aspergillus ibericus*.	(Oliveira et al., 2017)
Fermentable sugars	The production of fermentable sugars from andiroba bark with alkaline pretreatment. The highest concentration of reducing sugars was obtained at a reaction time of 100 min, NaOH concentration of 4% (w/v), and temperature of 120°C.	(Souza et al., 2020)

enough to take the lead in the full use of biomass, as it is one of the planet's main potentials for renewable raw materials due to the great availability of large-scale crops, with emphasis on the sugarcane industry, by intense sun, radiation, abundance of water, and climate diversification (Pereira Jr. et al., 2008). Within a promising technology proposal for reusing waste from the production of açaí drinks and waste from the extraction of andiroba oil, as follows: The production of organic acids.

5 FINAL CONSIDERATIONS

This review addressed the use of açaí and andiroba by-products, where published data on these by-products are few. Most publications refer to açaí residue. In relation to the andiroba by-product, there are few applications studied, highlighting the importance of studying the destination to be given to waste, since they represent a material rich in value-added compounds and different applications for different sectors. Within the alternatives presented, the use of these residues builds an essential pillar, providing alternatives for industrial application for the residual biomass of these agro-industry products, contributing to the environmental conservation of the Amazon. This is a new challenge, to strengthen the bioeconomy that is based on the sustainable use of natural resources, reducing dependence on destructive economic activities, such as deforestation. By using these resources responsibly, we contribute to promoting sustainability, preserving the Amazon ecosystem, and reducing greenhouse gas emissions.

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