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Review

Cupuassu Fruit, a Non-Timber Forest Product in Sustainable Bioeconomy of the Amazon—A Mini Review

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Abstract: This study examines the importance of cupuassu, a tropical fruit native to the Amazon, to Brazil's biodiversity, the Amazon biome, and its potential for economic development. Cupuassu is a Non-Timber Forest Product and a fruit of the Theobroma genus, which also includes cocoa. Just in the state of Pará alone, cupuassu production in 2019 was over 4100 t with a gross value of 2.6 million USD produced. However, cupuassu cultivation still needs investment through technological advances to overcome threats such as witches' broom disease and mycotoxin contamination. Cupuassu fruit is composed of pulp, seeds, and a shell; all these parts have a chemical composition with numerous bioactive compounds, especially the seeds, which also contain stimulant compounds, besides lipids and proteins. The processing of the whole cupuassu fruit has its economic value in the commercialization of the pulp, the extraction of cupuassu butter, and a product called Cupulate®. However, in this process, the cake resulting from the oil pressing, often considered a waste product, has potential as a source of proteins, peptides, lipids, and bioactive molecules with functional and nutritional properties. Recycling this fruit processing waste can create high-value-added products for various industries and promote a circular economy.

Keywords: Amazon biome; agroforestry systems; waste cake; Cupulate®; theacrine; theograndins; *Theobroma grandiflorum*

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1. Introduction

1.1. Brazil Biodiversity Products

Brazil is one of the main producers and exporters of agricultural products in the world, with soy, meat, forest products (cellulose, wood, and paper), cereals (mainly corn), sugar and alcohol, coffee, fibers, tobacco, juice, leather, cocoa, and dairy products present as the principal commodities, accounting for more than 65% of Brazil's exports [1]. Commodities are natural resource-intensive products in their raw (primary) state and involve a small degree of industrialization. Agricultural products (soft commodities) are characterized by standardized production and large quantities, whose prices are formed on commodity internal or external exchanges. However, the interaction of all demands for agricultural commodities should pass through the well-known 4F concept (Food, Fiber, Fuel, and Forests), whose products can meet basic human and environmental needs. To supply the needs of the population with the regenerative capacity of the planet's natural resources, a global change in production and consumption paradigms will be necessary. The productive sector will have to improve the use of these resources, reconciling sustainable production. In this scenario, forests will undoubtedly play the main role [2].

The "natural resource curse" is an economic concept based on the assumption that resource-rich economies tend to have lower economic growth rates. In this context, export specialization in natural resource products makes economies mainly concentrated in primary sectors. However, this concept fails in the Amazon biome since preservation must coexist with extractivism while production and suitable practices increase [3].

Brazil is the home of 20% of the world's biodiversity, but using this resource within the principles of bioeconomy, the development of new products and ingredients can lead the country to the international market with unique flavors and nutritional sources, in addition to contributing to the preservation of the environment and income generation for the local economy [4].

1.2. The Amazon Biome

The Amazon is the largest tropical forest on the planet, with over 6.5 million square kilometers, shared by eight South American countries: Brazil, Bolivia, Peru, Colombia, Ecuador, Venezuela, Guyana, Suriname, and French Guyana. In Brazil, the Amazon Biome covers approximately 4.2 million km^2, representing 49% of the Brazilian territory, and occupies the entire States of Acre, Amapá, Amazonas, Pará and Roraima, Rondônia and part of Mato Grosso, Maranhão, and Tocantins [5,6].

The delicate balance and complexity of Amazon life forms are very sensitive to human interference, as it has specific biomes, such as dense and open soil forests, varzea and igapos (flooded areas), and even savannas [7]. As a rainforest, the Amazon has enormous biodiversity and is home to the largest number of species of flora and fauna. It contains 20% of the world's water availability and large mineral reserves. Amazon water is not only in the soil or rivers, as there is a significant amount of water present as vapor in the air, the so-called "flying rivers", which are propelled by the winds. This phenomenon demonstrates that the Amazon's importance transcends its physical space since it is responsible for the water supply of several South American regions through the water vapor that is transported from the forest to distant regions [8].

1.3. The Amazon Forest—Products of the Amazon Forest and Their Importance for the Riverside and Peasant Population

The Amazonian economy today is still based on the production of commodities and monoculture. Cattle ranching, agribusiness, mainly soy, energy, minerals (aluminum, iron, copper, gold, and manganese), and forest products (wood, rubber, açaí, Brazil nuts, andiroba, and copaiba) are the strategic vectors in the Brazilian Amazon. As seen before, with a small degree of industrialization, these products are obtained in the region but processed abroad, generating scarce resources locally. A major challenge in the Amazon is currently the adequate use of forest resources with the addition of value and fair commercialization to bring a greater economic return than the formation of pastures or the sale of wood [9].

Agroecosystems or Agroforestry Systems (AFS) are an alternative to produce agricultural, forestry, and biodiversity products, also called products of sociobiodiversity for the riverside community and peasantry. AFS agricultural production systems are founded on principles of the triad of sustainability because they involve economic, social, and environmental aspects [10,11].

The production and growth model based on commodities is also not functional for the Amazon biome in terms of labor relations, because this model is marked by the overexploitation and precariousness of workers. In the bioeconomy of Amazonia 4.0, for example, development must value the traditional knowledge of peasants, riverside, indigenous, and Quilombola people. It will be necessary to train these individuals for the proposed model of technological increase, but more qualified workers contribute to the reduction of practices such as labor analogous to slavery and to the economic, social, and environmental development of the region [12].

The richness of Amazon biodiversity is also evident, with more than 2000 known medicinal species used by the local population that maintains a culture of medicine based on local knowledge. In addition, there are at least 1250 species from which essential oils with high economic value can be extracted for use in food, cosmetics, and medicine [11].

Non-Timber Forest Product (NTFP) identification is another way to invest in the bioeconomy and add value to Amazon products. They include fruits and nuts, vegetables, medicinal plants, gum and resins, essences, bamboo, rattans, palms, fibers and yarns, grasses, leaves, seeds, mushrooms, honey, and lacquer, among others. NTFPs can also be defined as all the resources or products that can be extracted from the forest ecosystem and that are used in home production or have social and cultural aspects [13,14].

The main NTFP (after rubber) produced in the Amazon today is açaí. Açaí is a tropical fruit that grows on an Amazonian endemic palm (*Euterpe precatoria* and *Euterpe oleracea*). It grows in clumps of up to 20 stems that can together produce 120 kg of fruit/year or even more under management systems. The processed Açai is a thick and homogeneous purple tincture that is consumed as a sauce over fish or as a heavy cream in the Brazilian state of Pará, where more than 90% of açaí is produced [15,16].

The second most popular Amazon NTFT is the Brazil nut (*Bertholletia* excelsa) tree. Next in the sequence comes the cupuassu tree, which is currently emerging as one of the most promising NTFPs, with the Amazon Creative Laboratory for Cupuassu and Cocoa (LCA CC) beginning its testing phase to implement the first geodesic biofactories in Pará State [11,17].

2. The Cupuassu

2.1. *Theobroma grandiflorum*

Theobroma (Figure 1) is a neotropical genus native to the Amazon, with 22 described species, of which 13 occur in Brazil. All have commercially valuable fruits, but only four species are cultivated: *Theobroma angustifolium*, *Theobroma bicolor*, *Theobroma cacao* (cocoa), and *Theobroma grandiflorum* (cupuassu) [18].

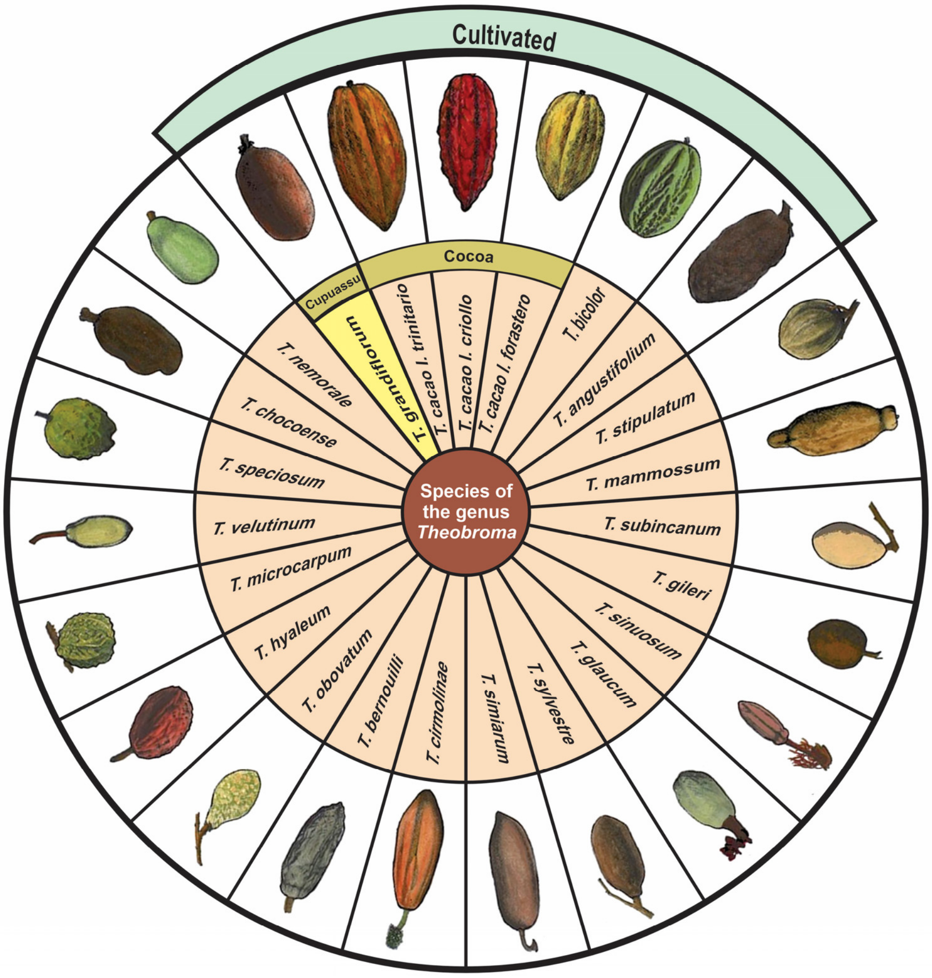

Figure 1. The genus *Theobroma* and its diversity of fruit types. Based on the museum of cocoa in Mexico. Source: Embrapa.

Theobroma seeds are rich in starch, protein, and oil, for which reason they are considered a very nutritive food. Seeds also have a volatile oil (cacao-essence) that gives them an aromatic flavor. The seeds also contain a red pigment, tannin, and small quantities of malic and tartaric acids, asparagine, and choline. The natives, who appreciate the pulp in natura or prepare refreshing drinks with it, often use most of the wild species. The seeds of most species may serve for the preparation of chocolate, but the most known and commercially important species are *T. cacao* and *T. grandiflorum* (cupuassu fruit), which are widely cultivated [19,20].

The results of recent complex genomic studies indicate that the cupuassu is a domesticated variant of its wild relative, the cupuí (*T. subincanum*—Figure 1). The first phase of domestication was 5000–8000 years ago. Intense human selection led to the cupuassu having distinct characteristics from the cupui species, such as larger fruits and lower trees. Human influence also played a significant role in the geographical distribution of cupuassu throughout the Amazon region. The study also suggests that cupuassu was domesticated before cacao [21].

2.2. Cupuassu Culture

In the Amazon, there are cupuassu trees known to be over 80 years old that still produce fruit. Three natural varieties of this exotic fruit are found in Amazon region: the round cupuassu, the most common in the region, has rounded ends, a 6 to 7 mm thick skin, and an average weight of 1.5 kg; the cupuassu-mamona, with elongated ends and thicker skin, which can produce a 2.5 kg fruit that reach up to 4 kg; and the seedless cupuaçu, whose fruit has a rounded shape. In Brazil, cupuassu is cultivated in the states of Pará, Rondônia, Amazonas, Acre, Maranhão, Tocantins, and Bahia (Figure 2) [22].

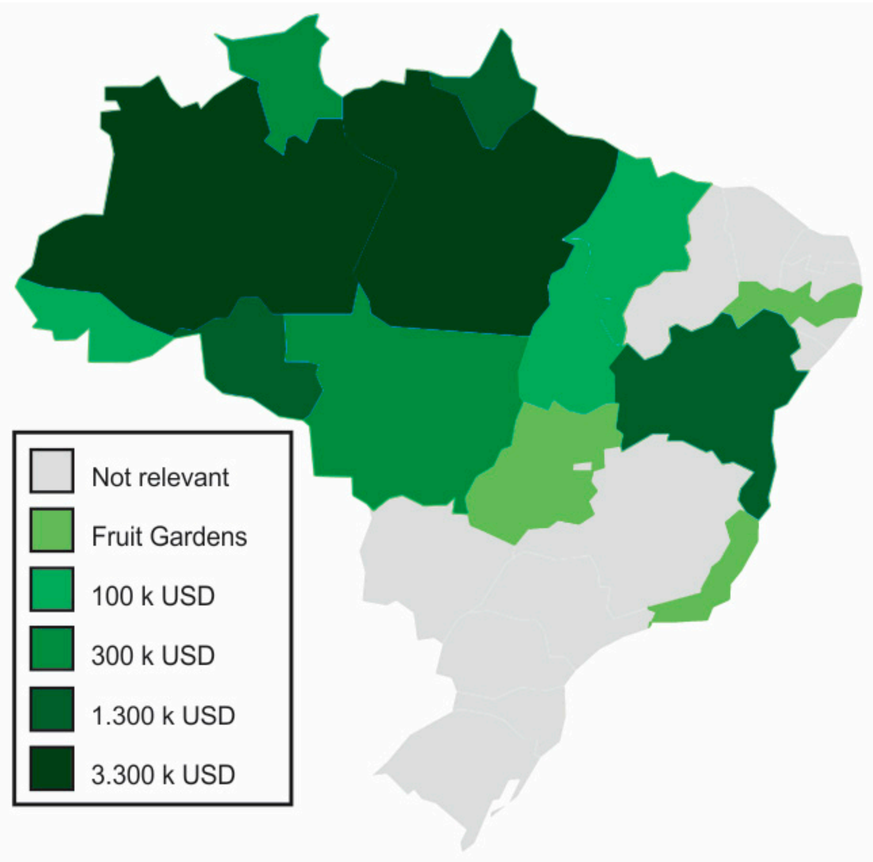

Figure 2. The Cupuassu plantation in Brazil. Darker colors are states with major production (data in USD). Modified from IBGE, 2017. Source: Embrapa.

The growing increase in cupuassu production according to Conceição et al. [23] is due to AFS. In an agricultural cooperative in Pará alone, production from 970 t in 2015 increased to 1125 t (2016), and in 2017, it reached 1757 t. Considering productivity, there was a significant increase from 1.10 t/ha to 1.72 t/ha, an increase of 46% from 2015 to 2017. The state of Pará also had a significant volume of production in 2018, with more than 2700 t. The area dedicated to growing cupuassu in Pará was 8500 hectares, with an average production of 3 t/ha.

The Brazilian state of Pará is considered the largest national producer of cupuassu, in 2017 (the last data from the Brazilian government) [24]. Data from 2019, of The Nature Conservancy Brazil [25], demonstrate that total value of cupuassu production reached 2.6 million USD. The quantity produced that year was 4100 t in the region of Pará state alone.

The increase in cupuassu production is also due to new technologies implemented throughout the production process coupled with more appropriate management of the culture, but most of them still are in a family farm unit. Cupuassu marketing includes sales to agricultural cooperatives and/or associations, seed processing companies, and pulp processing companies, as well as cosmetics industries intermediates. In fact, the growing demand for natural and exotic products has improve the export of cupuaçu, mainly to countries in Europe, the United States, and Japan, where they sell products like balms and lipsticks, moisturizing lotions, antiaging creams, soaps, hair masks, shampoos, and many others [26].

Cupuassu has been commercialized both wholesale and retail, with deliveries being made in rural properties or commercial establishments. The pulp is usually sold in polythene bags or 200 L drums, depending on the size of the cooperative. The average selling price of cupuassu by-products is also an important aspect of the marketing of this fruit, as the fruit quality must be taken into account (larger, riper fruits with fewer defects), the as well as the considerable transport costs in the marketing process, given the distance between most producing communities and consumer centers, and the cupuassu production period from October to April, peaking in January, February, and March [27].

Another important data concerning cupuassu fruit are the internationals patents registers. The name "cupuaçu" was first registered by Japan in 1998, but the patent was not discovered in Brazil until four years later when a cooperative of jelly producers in the Amazon was prevented from exporting derivatives of the fruit to Germany under the name 'cupuaçu'. Further investigation revealed that in 2002, the method of extracting oil from the seeds and the process of making "cupuaçu" chocolate (Cupulate®) were also patented in Japan and the European Union. However, Embrapa (Brazil government agricultural research center), in 1990, registered the process of extracting Cupulate® [28].

In 2008, "cupuaçu", as an exclusive trademark of Japan, had the registration canceled by the Japanese Patent and Trademark Office [29]. In 2015, Embrapa obtained a definitive patent for the name Cupulate® [30]. Nevertheless, from 1994 to 2021, Brazil filed 45 patents applications with cupuassu as a component, and in 2016, there were 63 international patents applications with cupuassu listed [31].

Regardless of all the international interest in cupuassu, the Brazilian government does not have specific agricultural incentives for this exotic fruit production chain yet. However, some programs and policies to help socio-biodiversity apply to the Amazon region and also contribute to improving cupuassu production. Tax incentives and rural credit, besides technical assistance programs (like Embrapa's), reach the cupuaçu farmers in the region, as well. The Food Acquisition Program (PAA) is a program from the government that buys agricultural products directly from family farmers, for distribution to social programs and public institutions [32]. The Amazon Fund is another program whose portfolio includes the cupuassu production chain. It aims to raise donations and government investments in efforts to prevent, monitor, and combat deforestation, and also to promote the conservation and sustainable use of the Legal Amazon [33].

Despite the lack of direct public incentive on its productive chain, cupuassu fruit (Figure 3) stands out as one of the Amazonian regional and exotic product with intense dissemination in the Brazilian territory, where people enjoy the pulp and a multitude of preparations with it like creams, ice cream, jelly, cookies, yogurt, liquor, and even wine, among others [34]. Cupuassu also has great potential for industrialization, and in the increasing demand for plant-based products, the global cupuassu market is estimated to be worth over 62 million USD by 2030 [31].

Figure 3. The cupuassu fruit. Source: Author's personal collection.

2.3. *Difficulties in Cupuassu Culture*

The challenges of the cupuassu culture today would be to develop genotypes with higher levels of fruit production and resistance to most common diseases. *Moniliophthora perniciosa* fungus (Figure 4A) is the pathogen responsible for witches' broom disease and the main pest affecting the cupuassu tree (Figure 4B,C) and fruits (Figure 4D); the same occurs to the cocoa tree. This pathogen is endemic to the Amazon forest [35].

Witches' broom disease mainly affects flowers, fruits, and the meristems of branches. When it affects growth points, it causes the overgrowth of leaflets, with an increase in lateral buds and thickening of the growing tissues and tissues in development. These changes originate the symptom, which gives the disease the name witches' broom. Unfortunately, producers poorly adopt phytosanitary pruning, the primary management measure for coexistence with this disease, which increases the proliferation of the fungus and production losses [36].

Another threat to cupuassu crops is moniliasis. The fungus *Moniliophthora roreri* attacks only the fruits of cocoa, cupuassu, and other plants of the genus *Theobroma*, such as cacauí (*T. speciosum*) and cupuí (*T. subincanum*) (Figure 1). The initial symptoms of the disease are a darkening of the fruit followed by the formation of a large amount of white powder, which are the spores of the fungus. These spores can spread through the air and by human handling without good practices, through bags or contact of healthy fruits with contaminated fruits. In July 2021, this disease occurred in the state of Acre but was totally eradicated due to the emergency actions of the Ministry of Agriculture of Brazil [37,38].

Diseases related to fungi in the genus Theobroma are already well known, including anthracnose, phomosis, cyllindrocladium, root rot, and progressive dieback, as well as insect pests such as fruit borers and other borers that mainly attack plant development. In the case of a fungal attack, chemical control is based on copper fungicides [39,40].

In general, the same diseases that affect cocoa also affect cupuassu. The use of biological agents, such as fungi of the genus Clonostachys and Trichoderma, has been successful against witches' broom and moniliasis, especially the species Trichoderma stromaticum in cocoa, and it is hoped that with new studies, promising products developed can be effective and economically viable for disease control in the cupuassu tree [41,42].

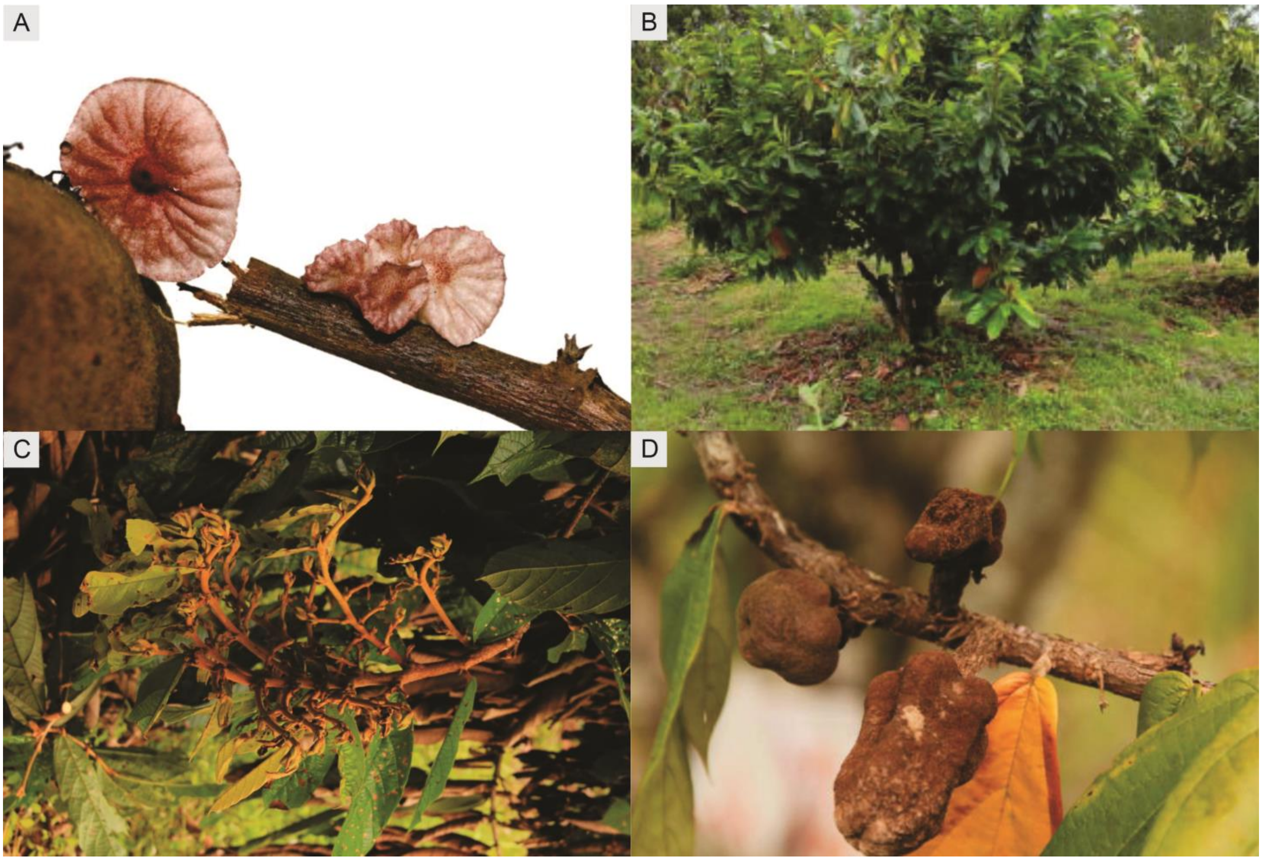

Figure 4. (**A**) *Moniliophthora perniciosa* fungus, the cause of witches' broom disease in cupuassu trees; (**B**) a healthy cupuassu tree; (**C**) witches' broom disease in a cupuassu tree; (**D**) atrophied cupuassu fruit by witches' broom disease. Source: Embrapa.

In practice, the management of witches' broom in the cupuassu tree is mainly carried out through the integration of cultural control measures, such as phytosanitary pruning, reduced shade, and genetic improvement trials. For example, Embrapa has selected and released several clones with higher productivity and resistance to witches' broom, such as the Manacapuru, Codajás and Coari clones, and the BRS Carimbó cultivar [43].

Alves et al. [38] cited a fungus isolated from *T. grandflorum* fruits: *Acremonium* spp., *Colletotrichum* spp., *Fusarium* spp., *Lasiodiplodia* spp., and *Phytophthora* spp. Therefore, another possible threat to cupuassu is the presence of thermoresistant fungi in the pulp. In addition to *Aspergillus niger* and *Aspergillus flavus*, the potential for mycotoxin production has been reported. For example, *A. niger* and *Fusarium* are very resistant, suggesting that the treatment given by the industry is probably not enough to ensure the destruction of the fungus. Therefore, there is a need to improve good agricultural and manufacturing practices and the implementation of quality control systems to minimize the risks associated with contamination by microorganisms when using cupuassu kernels for further processing [44].

2.4. Cupuassu Fruit—Chemical–Nutritional Composition, Bioactive and Stimulant Compounds

Cupuassu is a fruit composed of pulp (35% of the fruit), seeds (20%), and a shell (45%). The pulp of cupuassu fruit is a source of antioxidants such as monomeric flavan-3-ols (flavanols) and their oligomeric derivatives, called proanthocyanidins. Nonetheless, this polyphenol profile is in much lower levels than in the seeds [45]. The pulp also has a relatively high content of vitamin C (~100 mg/100 g), and soluble fiber (~2%), besides starch and polysaccharides from pectin in considerable amounts. As expected, the proteins and lipids levels, respectively, are very low in the pulp (~0.5% and 2%) [46].

The cupuassu seeds contain important flavonoids such as catechin and epicatechin (flavanols), quercetin, and Kaempferol (flavonols) [47,48]. The seeds also have flavones named theograndins that have been related to the reduction of oxidative stress in chronic diseases and were first reported in 2003 [49–51]. The cupuassu seed composition includes proteins (~8%), fibers (~5%), and carbohydrates (~20%). The cupuassu seed is very rich in fats (~60% dry weight) and the fatty acid profile includes palmitic, stearic, oleic, araquidic, and linoleic acids [46].

An important class of substances, due to its stimulant effects, also present in cupuassu are the methyl xanthines, purine alkaloids (or pseudoalkaloids), which have been found in the seeds and leaves of *T. bicolor*, *T. cacao*, *T. grandiflorum*, *T. microcarpum*, *T. obovatum*, *T. speciosum*, *T. sylvestre*, and *T. subincanum*. In cupuassu seeds, the levels of theobromine and caffeine are approximately 10 times lower than those in cocoa, and theophylline was not found. However, another purine alkaloid, called tetramethyl urate or theacrine, can be found in cupuassu seeds (Figure 5). Theacrine has anti-inflammatory and analgesic effects and acts as an adenosine antagonist receptor similar to caffeine, reducing fatigue, improving mood, focus, and motivation [52–55].

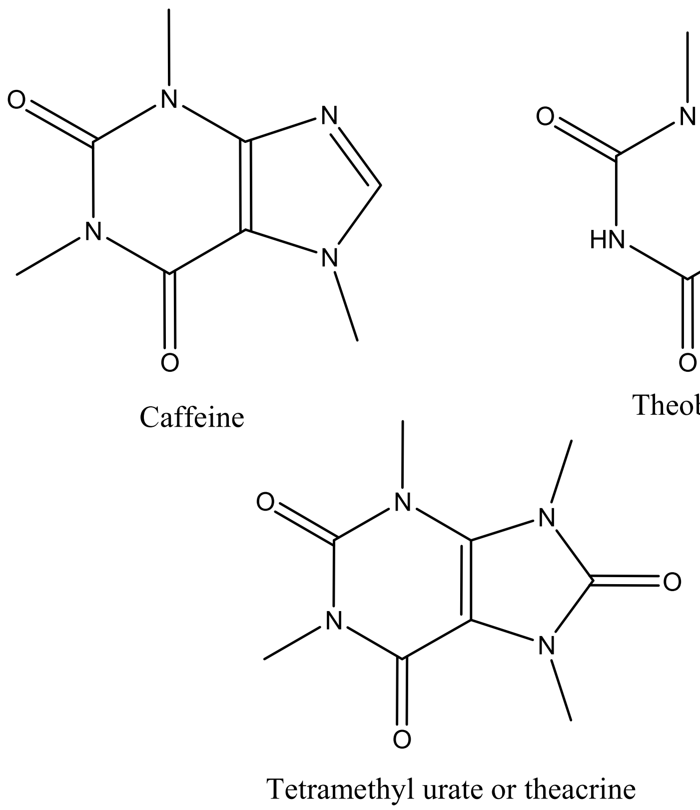

Figure 5. Similarity between the chemical structures of caffeine, theobromine, and theacrine, purine alkaloids found in cupuassu seeds.

2.5. Cupuassu Processing

Cupuassu economic value is based mainly on the industrialization and marketing of the pulp. As seen in Figure 6, after harvest, the cupuassu fruits are washed, selected, and then pulped. The pulp and the seeds are separated, and the shell remains as waste and is normally used as fertilizer, material for handicrafts, or even as biomass for energy generation [56].

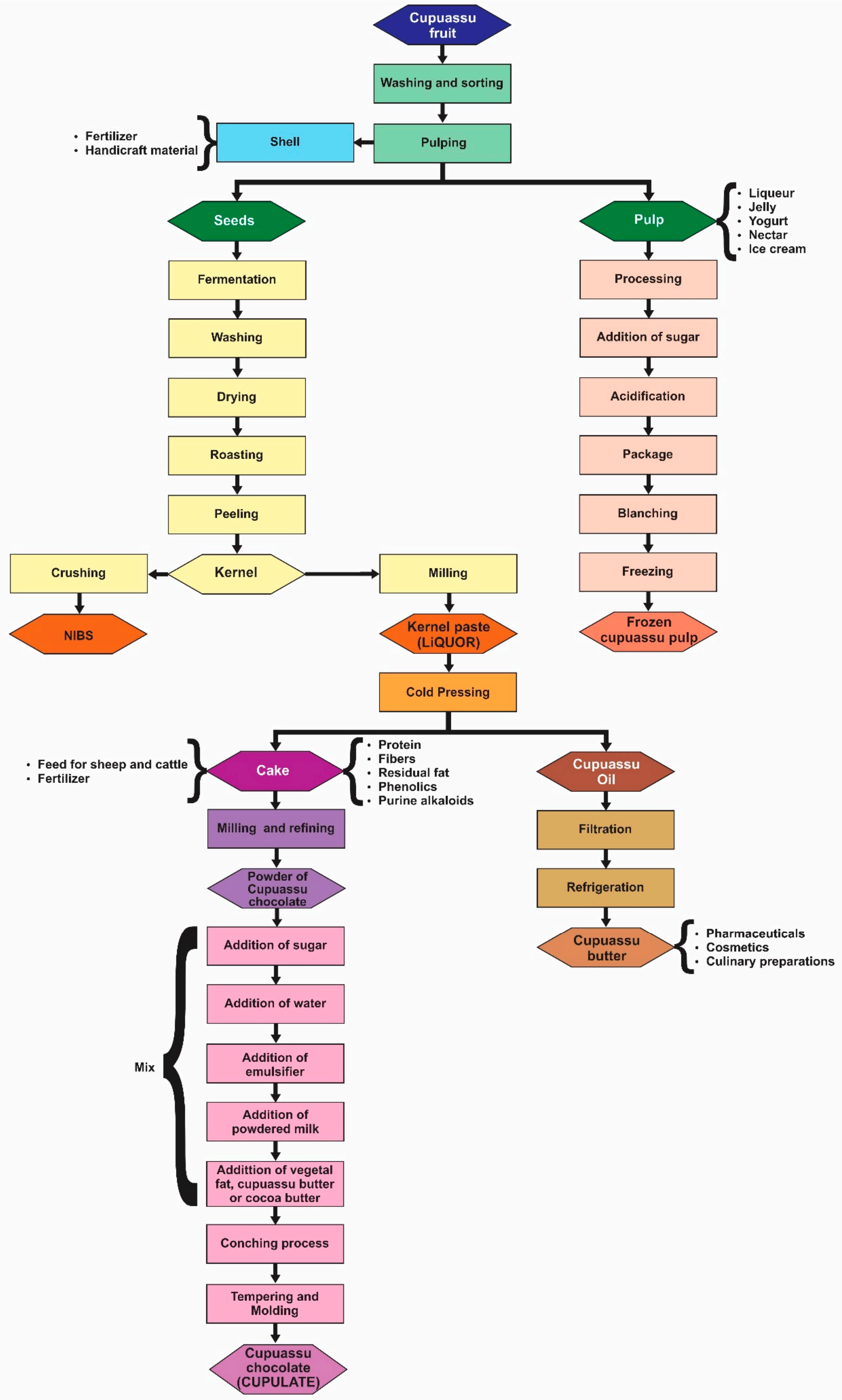

Figure 6. Flowchart of complete cupuassu processing. Based on Cohen and Jackix, 2009; de Araújo, 2011; and Santos, 2018. Source: Embrapa.

However, for antioxidant activity and total phenolic content the cupuassu shell had a higher amount of phenolics than pulp (though obviously lower than seeds). Condensed and hydrolyzed tannins were found, as well as flavan-3-ols, catechin, epicatechin, kaempferol (in seeds' phenolic profile), chlorogenic acid, acacetin, epicatechin, and naringenin [57]. Thus, this residue generated in the processing of cupuassu has a potential for the food and pharmaceutical industries. As an example, Jobby et al. [58] successfully used a cupuassu shell as a fortifying agent for bread.

As said before, with the processing of the pulp, several culinary artisanal products can be made. To prepare the frozen pulp, sugar, acidulant, and in some cases, preservatives are added. The pulp is then packed in plastic bags that are blanched and cooled until frozen [55,59]. It is important to note that significant levels of vitamin C are lost in the processed pulp [45].

The industrialization process of cupuassu seeds occurs similarly to that of cocoa seeds. The seeds of cupuassu fruit are fermented in a wooden box. The box has three compartments with shapes and volumes adequate for the process and capacity of the seeds. The box is placed under shelter from rain and sun to protect the seeds. Initially, the seeds are placed in the first compartment of the box, together with chopped banana leaves, to provide the inoculation of microorganisms on the surface of these leaves; they are then covered with burlap sacks to help retain the heat generated during fermentation. The total time of the process was 7 days, with the seeds being turned over after 48 h for the second compartment and after 72 h for the third compartment of the box. After fermentation, the beans are dried in the sun on a wooden barge until they reach a final humidity between 7 and 8% [60,61].

The seed fermentation process destroys their germination capacity, and from this point on, they are considered kernels. After washing, these kernels undergo a roasting process. The roasting of the fermented beans was performed in an oven at an average temperature of 180 degrees. With the peeling and breaking process, the kernel becomes some sort of cupuassu NIBS. With the milling process, this NIBS becomes a paste of kernels similar to the liquor in the cocoa processing chain. The cold pressing of this liquor then generates the cupuassu oil and a cake, which contains fiber, protein, and a fat residue [60,61].

The extracted oil then undergoes filtration and refrigeration to produce cupuassu butter, which is widely used in the cosmetic industry. However, not all agribusinesses (mostly family agriculture) incorporate the agroindustrial process, and thus, the cake resulting from oil pressing can be discarded in the environment, generating an environmental liability [62,63].

The cake is also considered a waste product in the process of obtaining cupuassu oil and can also be used in the production of cattle feed, but due to its abundance in phenolic compounds and the presence of purine alkaloids, it can also give rise to cupuassu chocolate, Cupulate® [64].

The milling and refining of this cake generates what can be considered cupuassu chocolate powder. To make chocolate bars, sugar, water, milk powder, cupuassu fat, vegetable fat, or even cocoa butter and an emulsifier (soy lecithin) are added to the powder. The emulsifier can be either added slowly to reduce the viscosity of the mass or only added at the end of the conching process [65,66].

Conching involves intense and long mixing, stirring, and aeration of the chocolate paste, which is heated to eliminate undesirable acidity and bitterness. Conching also dissolves any lumps to create a smooth, velvety texture. During this process of shearing, water loss, evaporation of undesirable volatiles, and chemical reactions such as Maillard and caramelization occur, resulting in the final production of characteristic chocolate flavors [67,68].

After this, the tempering process is followed, which allows the fat present to be stabilized, avoiding the production of whitish stains (fat bloom). Finally, molding and cooling result in cupuassu chocolate (Cupulate®), with a solid and shinning format [69].

2.6. Cupuassu Potentials

The largest residue from the processing of fruit pulp is the cupuassu shell, mainly due to its size, and since the kernels already have a partial reuse according to production levels, been used to make the cupuassu butter and the Cupulate®. The shell could be used to use to make functional flour, as said before, but also can be used to make pressed ecological packaging [70].

The lyophilizate pulp, as cupuassu flour, is another technological product obtained from cupuassu. A alternative process, using reverse osmose and drying, is less economically viable [26].

A product made from the seeds and the roasted kernel (with lower temperatures) is the cupuassu milk. To produce this drink, it is first necessary to obtain a concentrate and protein isolate from the seeds to replace the nutritional profile of the milk traditionally used [71].

The more important residue of cupuassu processing, however, is the cake (the pressed kernels). The presence of many bioactive compounds, after oil pressing, also suggests that it can have a more important destination than animal feed or even the still modest production of Cupulate®. The production of flour from these pressed kernels is an excellent alternative for the waste that is produced in order to meet the low Cupulate® demand [72].

As already seen in the seeds, Costa et al. [62] demonstrated that the residual cake of cupuassu kernels had, besides antioxidant activity, nutritional potential with significant concentrations of macronutrients such as fibers (~20%), lipids (~25%), carbohydrates (~25%), and protein (~10%) that may be used in industry.

Da Cruz et al. [73] reported on three dipeptides and five novel peptides with in vitro inhibitory activity and demonstrated that cupuassu seed proteins are precursors of Angiotensin-Converting Enzyme (ACE) inhibitors in vitro. Although in vivo studies are necessary, cupuassu seeds may be a source of bioactive peptides with prospective antihypertensive properties and contribute to the utilization of a raw NTFP material as a functional material.

Lopes et al. [74] found that cupuassu seed proteins also had considerable nutritional potential, as they have higher biological value and amino acid composition than cocoa. According to Carvalho et al. [75], cupuassu seeds showed good amino acid composition, having fewer limiting amino acids in the seeds in natura than in fermented, dried, and roasted kernels. The study concluded that fermentation and roasting caused a slight reduction in the total protein and total amino acid contents when compared to the contents of the seeds that did not undergo these processing steps. The amino acid profile of the proteins, however, contains most of the essential amino acids and is, therefore, a food of good nutritional quality for human consumption.

The use of plant-based protein isolates in food formulations has recently become of interest due to greater sustainability and lower production costs. Technological processes can also be promoted for better absorption of these proteins, with their isolation and concentration [76]. Therefore, the utilization of the residue of cupuassu liquor after cold pressing (kernel cake) for human nutrition is promising. In fact, the project that gave financial support to this work had developed a plant-based kebab with a protein concentrate from the cupuassu cake. This cupuassu kebab had a good sensorial evaluation and is in its final process as a technological product (Technology Readiness Level—TRL).

Recycling fruit processing waste reduces the amount of organic waste, which in turn reduces environmental pollution and gas emissions. It also promotes resource conservation by utilizing parts of the fruit that would otherwise be discarded, increasing efficiency and reducing the environmental footprint. The extraction of bioactive compounds creates high-value-added products for various industries. This practice promotes the circular economy and reduces dependence on raw materials. Finally, cost savings are achieved by reducing disposal costs and providing affordable nutrients, benefiting both the environment and the economy [62].

3. Conclusions

Although waste from cupuassu processing is used in less technological activities such as animal feed, fertilizers, craft materials, and even biomass for energy production, it is clear that such use wastes a nutrient-rich and/or bioactive material. Moreover, with the increasing production of cupuassu AFS, these uses cannot compete with the increasing production in the northern region of Brazil, generating real waste.

In this way, the industrialization of cupuassu, with its multiple applications in the culinary, cosmetic, and nutritional sectors, demonstrates the potential for adding value to Non-Timber Forest Products. In addition, the exploration of cupuassu shells and especially cupuassu cake as a source of bioactive compounds, proteins, and peptides opens doors to new opportunities in the functional food and nutraceutical industries.

Finally, to realize the full potential of cupuassu, it is crucial to strike a balance between economic growth and environmental conservation. By embracing sustainable production and consumption paradigms, investing in advanced technologies, and valuing traditional knowledge and local communities. In this way, this model can serve as a basis for other NTFPs from the Amazon biome, and the cupuassu chain can create a model of a prosperous bioeconomy in the Brazilian Amazon that benefits riversides, forest people, and the planet.

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Abbreviations

AFS	Agroecosystems or Agroforestry Systems
NTFP	Non-Timber Forest Product
ACE	Angiotensin-Converting Enzyme

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