

Valorization of Amazonian buriti (*Mauritia flexuosa*) semi-defatted residual cake as a circular economy strategy: A techno-economical analysis

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ABSTRACT

Buriti (*Mauritia flexuosa*) is an oleaginous specie in Brazilian Amazonia and Cerrado regions. Its oil, still mainly extracted by small communities, is largely employed in local culinary but also in cosmetic/pharmaceutical large industries. The main residue obtained by its processing is a semi-defatted cake, whose residual oil can be extracted by solvents. This strategy, within circular economy (CE) framework, can expand its production while minimizing resulting environmental impacts. However, not only residues management but improvement of the entire production process is essential for sustainability and economic gains. Therefore, this work was aimed at evaluating valorization of the Buriti semi-defatted as a CE strategy performing a techno-economical assessment, based on a case study of local production facility in Amazon region. Cake's oil extraction was experimentally evaluated by using ethanol as green alternative to organic solvents. Facility's manufacturing process was evaluated from a CE perspective and an economic feasibility analysis of the new scenario was provided. Results showed that the remaining oil can be experimentally extracted from the Buriti cake, using anhydrous or 95 % hydrous ethanol, increasing oil production and producing a defatted cake rich in proteins and carbohydrates that can be used in high-value products. The evaluation of the processing plant showed that a complete CE perspective must also consider improvement of the oil quality, achieved by Good Harvesting and Preprocessing Practices, avoiding losses while improving sustainability. Introduction of the CE scenario is economically feasible over the ongoing practices in some processing and market conditions. Defatted cake sale, low Buriti prices, and recovery of ethanol were key to decreasing the minimum processing rate to venture's feasibility. This work also highlights that public policies and technical support are essential to stimulate Brazilian bio-economies, generating local economic gains as well as environmental protection through sustainable exploitation of the biomes.

1. Introduction

Buriti (*Mauritia flexuosa*) is a fruit spreading over the Cerrado and the Amazon Forest in Brazil in mangroves of palm trees entitled “veredas” (Hernández-Valencia et al., 2018). It is a *keystone plant* (Van der Hoek et al., 2019), providing important ecosystem services, working as an important biome element for preservation and interaction between species and the environment (Bhomia et al., 2019), but also for local economic development (Van der Hoek et al., 2019; Virapongse, 2017). It is mainly exploited through extractive practices by family farming: the main and valued product obtained from Buriti processing is its oil,

whose industrial applications are nowadays mainly focused as ingredient in cosmetic products, such as body lotions, sunscreens, lotions for cracked skin, and lip balms, due to its moisturizing and healing properties (Mansur et al., 2020). In addition to oil, the buriti trees also provide fibers used in artisanal, textile, and other materials (Da Cruz Demosthenes et al., 2020). Moreover, literature reports the anti-inflammatory, probiotic and other nutritional effects of the buriti pulp and its oil (Curimbaba et al., 2020; Comunian et al., 2020; Freitas et al., 2017), along with antimicrobial and other technological functionalities (Reis et al., 2020; Speranza et al., 2016).

Buriti oil processing provides a significant amount of a residual cake,

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evaluated as a source of antioxidants, carotenoids, NEPA (non-extractable proanthocyanidins) (Resende et al., 2019; Mansur et al., 2020) but also a residual oil, that could be further extracted, improving sustainability and profitability of this chain. However, the current practice is the allocation of the cake as fertilizer, animal feed or burning. Sampaio Neto et al. (2018, 2020) and Aracava et al. (2022) showed that solid-liquid extraction using ethanol is a relevant alternative for oil extraction of cakes obtained from Brazilian Amazonia and Cerrado fruits and seeds processing such as Babassu, Baru and Brazil nut. For the Babassu cake in a single-phase extraction, the yield was approximately 65 %; for Baru press cake, results were close to 80 %, and for Brazil nut they can reach up to 100 %. Ethanol was also successfully applied for oil extraction of other lipid-rich materials, such as soybean (Sawada et al., 2014; Ferreira et al., 2022) and sunflower collets (Baümler et al., 2016), but also cakes and other residues obtained during processing, such as peanut (Magalhães et al., 2023) and sesame press cakes (Capellini et al., 2019), spent coffee grounds (Toda et al., 2023) and rice brain (Bessa et al., 2017). These results expressed the feasibility of using ethanol as an extraction solvent for these matrices, meeting the premises of “green” materials, reuse of materials (solvent recycle), increased yield of the process with higher-quality oil.

These works are within what literature calls Circular Economy perspective (Stahel, 2016). In contrast to classical “linear models”, in which, products are manufactured in a premise of “endless resources available on the planet”, unsustainable in a long term, the Circular Economy is presented as an alternative model. Indeed, any attempt to increase Buriti’s productive exploitation for economic development for local population, should be associated to sustainable extractive practices, that according to ecologists and environmentalists, could also enable forest preservation, in contrast to land zoning for large scale agriculture or cattle raising (Futemma et al., 2020; Boukerroui et al., 2018; Neri-Numa et al., 2018). In the Circular Economy model, the productive chain is considered a “puzzle”, in which the pieces can/should be connected to different ways of reaching the expected result, that is, the decrease of environmental impact (Blomsma and Brennan, 2017; Sarkis and Zhu, 2018; Weetman, 2019). In this way, the chain is analyzed in all instances where it is involved, considering *players* and *suppliers* that directly and indirectly influence the production process. The resource input and output are assessed according to their impact in other peripheral productive chains in reference to the main one. Thus, this model’s final goal is the reconfiguration of production processes, in a way that the “new model” has the lowest number of potential inputs and outputs, that is, is a “circular” process.

Considering the importance of the Buriti value chain in the Amazonian region, the perspective of increasing its exploitation in a sustainable perspective, particularly for the production of its most valued product, Buriti oil, this work was aimed at performing: i) the solid-liquid extraction of the oil from Buriti semi-defatted cake by using ethanol as green solvent; ii) an evaluation of the Buriti oil processing performed by an Amazonian local production facility in a circular economy perspective, considering the oil extraction from the residual cake as an alternative to improve Buriti chain circularity; iii) an economic feasibility study of this new scenario.

2. Materials and methods

2.1. Experimental oil extraction from buriti pulp semi-defatted cake

Semi-defatted buriti cake, obtained by cold pressing of the Buriti pulp, using a tubular radial *Expeller* equipment (extraction is further detailed in the Results and Discussion section), was kindly donated by the processing plant (Fig. 1A). For the extraction process, anhydrous ethanol (99 % m/m, Dinamica, Indaiatuba, Brazil), as well as its mixtures with water at 95 % and 50 % (mass fraction of ethanol) were used. Fig. 2 presents a flowchart showing the experimental solvent extraction procedure. The buriti pulp cake was dried for 24 hours at 80°C in a

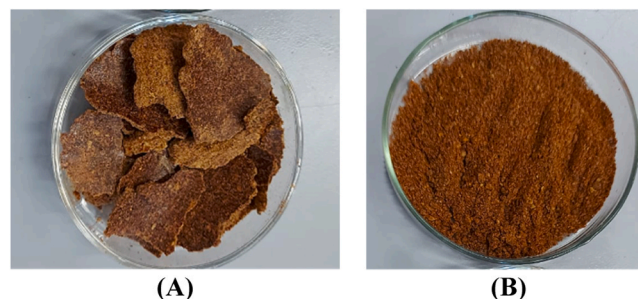


Fig. 1. (A) wet buriti semi-defatted cake; (B) milled dried particles.

temperature controlled forced air oven and subsequently milled in a knife mill (Marconi, model MA-340, Brazil) for particle reduction, to improve the interaction between solute and solvent during the extraction. The milled sample was separated in a vibratory sieve system (Model 1868, Bertel, Caieiras, Brazil) through a series of Tyler sieves (Tyler series, Tyler, Mentor, OH, USA). Sieves with the higher mass distribution were selected for the extraction experiments. Milled (Fig. 1B) and non-milled samples were kept refrigerated to avoid lipid degradation by temperature and light.

The lipid and water composition of dried and milled cake was determined. The water content (that could influence in the extraction) was evaluated according to AOCS official method Ca 2e-84 (AOCS, 2009), using an automatic Karl Fischer 870 KF Titrimplus, Metrohm (Herisau, Switzerland) titrator in triplicate; total lipids were evaluated using an Ankom Extractor XT15 equipment (Ankom Technology, Macedon, NY, USA), according to AOCS official method Bc3-49 (AOCS, 2009), in quadruplicate.

The extraction was performed using a temperature controlled orbital shaker system (NT712, Novatecnica, São Paulo, Brazil), composed of a single platform with individual metal clamps for extraction of 20 Erlenmeyers of different sizes (150–220 ml). Process parameters were based on the studies of Sampaio et al. (2020) and Aracava et al. (2022) for oil extraction from semi-defatted Babassu and Baru press cakes and set as 60°C, 200 rpm, solute:solvent ratio of 1:4 (in mass). Similar parameters were also employed by other authors for oil extraction using ethanol using different type of vegetable matrices and considering the production of oils with different fatty acid profiles (Baümler et al., 2016; Sawada et al., 2014; Magalhães et al., 2023; Ferreira et al., 2022; Capellini et al., 2019; Toda et al., 2023; Bessa et al., 2017). Anhydrous ethanol, 95 % hydrous ethanol (m/m), and 50 % hydrous ethanol (m/m) were used as extraction solvents. Samples were prepared in 200 ml Erlenmeyer flasks with 2.5 g of cake and 10 g of solvent, weighed in an analytical balance (Marte, AD5002, São Paulo, Brazil). Extract and raffinate (solid matrix after extraction) streams were separated through filtration using paper filter in a Kitasato apparatus.

A kinetic study for each solvent was performed up to 24 hours. At each time the lipid content of the extracts was evaluated following the described method. Extraction and chemical analyses were performed in duplicate, such that at each time four replicate values were obtained for calculation of the standard deviations.

Extracts obtained was submitted to evaporation under vacuum at 60°C in a rotary evaporator (Marconi, Brazil) for solvent removal and their fatty acids, probable triacylglycerol composition, melting and crystallization temperatures measured. Results were compared to those obtained for commercial buriti oil (Amazon Oil, Ananindeua, Brazil). The fatty acids (FA) composition was obtained by gas chromatography (GC) (official method Ce 1-62 AOCS, 2009), using an Agilent Gas Chromatograph (model 7890B, Santa Clara, CA, USA). The probable TAG composition was calculated based on FA profile data and oil’s trissaturated TAG content (0 % according to Saraiva et al., 2009). The method is based on combinatorial analysis, as described by Antoniosi Filho et al. (1995) used an algorithm implemented in MATLAB software

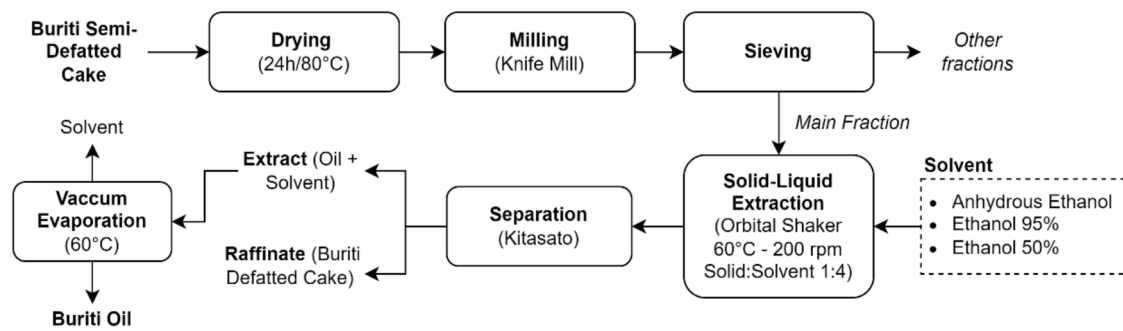


Fig. 2. Experimental procedure for oil extraction from buriti pulp semi-defatted cake.

by Ceriani (2005). Oils' melting and crystallization profiles were analyzed through differential scanning calorimetry (DSC) as reported by Pereira et al. (2019), using a 2920 DSC equipment (TA Instruments, USA) calibrated with standards of indium, naphthalene, cyclohexane, and decane (all with purity greater than 99.9 % m/m, Sigma-Aldrich, USA). Samples, of approximately 5 mg, in triplicate, were weighed in a calibrated microanalytical scale (Precisa XT220A, Switzerland) and hermetically sealed in aluminum pans. Samples were heated until 60°C, melted, cooled at 5 °C/min until −60°C, followed by heating at the same rate (Pereira et al., 2019). Endothermic and exothermic peaks were examined by the TA Universal Analysis 2000 software (TA Instruments, USA), according to transitions' peak top temperatures (peak top) and enthalpies of melting, crystallization, and other solid phase transitions.

2.2. Evaluation of Buriti oil production in the CE perspective

Our theoretical framework for analyzing the buriti oil production process were the studies of Borrello et al. (2017), Del Mar Contreras et al. (2019), Edwards et al. (2017), Maina et al. (2017), Teigiserova, Hamelin and Thomsen (2020), Rajakal et al. (2020), Weetman (2019) and Ellen MacArthur Foundation (2015). Information was obtained from a Buriti oil processing plant located in the Amazon region. This plant is inserted in the context of extractive production chains in the Amazon region, built under financing for promoting non-timber forest products production chains by communities and families of municipalities in the Amazon Forest region.

The production of the processing plant is organized by local residents that integrate a commercial and production association. The fruit is harvested on local vegetation near the production site and transported to the plant. Fruits are sorted, pre-processed and the oil extracted from its pulp, with packaging and storage. The plant's organizational chart is composed of supervisors, responsible for the production and for workers directly related to its process. The product commerce is done through a

non-governmental organization cooperation, destined to local markets, online sales, and chemical and pharmaceutical companies to manufacture non-culinary products.

Data was obtained by a semi-structured questionnaire, according to method described by Taherdoost (2022), and based on the production's flow diagram previously provided by the local association, briefly describing the overall steps: fruit reception, sanitization, pulping, drying, pressing, filtering, packing, and storage. The questionnaire consisted of a set of questions that served as a foundation for conduction of the interview. The questions performed and the answers provided allowed development of new inquiries, that improved the goals set by the authors. Table 1 presents the questionnaire applied to the processing plant supervisor (technical manager) and a person from the non-governmental organization responsible for commerce and technical support.

Based on the interview's results and the plant's diagram analysis, the buriti oil processing flow chart, with all input and output of materials/products and energy, was outlined. With the characterization of the flow chart and other information collected in the questionnaire, an alternative flow chart was elaborated, considering the circular economy principles. The modifications proposed to the production process, to increase its circularity, considered the introduction of the green technology concept, with reintegration of residues to the main process, defined as a loop. With the introduction of new technologies, both current and modified production processes were compared by economic feasibility evaluation.

As will be detailed, the main modification proposed for buriti oil's production process is the reuse of cake for oil extraction. The proposal consists of the introduction of a solid-liquid extraction stage employing a solvent with low environmental impact. The solvent most widely used in oil extraction by solid-liquid extraction in the food industry is hexane. However, this solvent presents high toxicity, volatility, and fossil fuel origin (Cheng et al., 2019; Magalhães et al., 2023; Bäuml et al., 2016).

Table 1
Questionnaire applied.

1. What is the amount of harvested fruit per year (kg per year)? How is the fruit harvested?
2. What is the amount of processed fruit by the Plant per year (kg per year)?
3. What is the market price of postharvest fruit (R\$ per kg)*? What is the fruit's price for the Processing Plant?
4. How is the fruit stored after harvesting by local farmers?
5. What is the distance between harvesting site and processing plant?
6. Upon arriving at the plant, how is the fruit stored prior to processing? In what type of packaging is it kept? Where are the fruits stored? Is there light, temperature, or humidity control?
7. What is the Buriti oil production yield (liter of oil per kg of fruit, or any other measurement unit to assess this income)? Do the association apply any systematic method to calculate the plant's yield? Is the fruit's amount of lipids/oil known?
8. What is the Buriti oil market price (R\$ per package)?
9. What is the type of packaging in which oil is commercialized? How is the bottled oil stored? Is there light or temperature control?
10. How is the logistics for final product delivery?
11. For what purpose is buriti oil marketed: food, cosmetics, or others.
12. Who are the main consumers of the marketed oil: private, institutional, public, local, regional, national, international?
13. What is the amount of cake generated by liter of oil produced or by kg of processed fruit?
14. What are the number of containers sold per year (containers/packages per year). Is 100 % of production sold?
15. What is the current destination for Buriti cake? Do local residents use the cake for some specific purpose?

* R\$ = Brazilian Real

Among more sustainable extraction technologies used in the food industry, supercritical carbon dioxide, water or ethanol have been the main choices. Carbon dioxide presents excellent extraction properties from food matrices compounds due to its physical properties, low process temperature, low toxicity and ease removal from the matrices (Cavalcanti et al., 2016; Da Porto et al., 2022). On the other hand, water or ethanol are interesting low-cost options and widely applied in food industry. In case of oil extraction, ethanol has shown to be efficient in extraction processes of a multitude of food compounds, particularly vegetable oils (Sampaio Neto et al., 2018; 2020; Aracava et al., 2022). From a CE perspective, it has low toxicity and a volatility that allows its recovery and reintegration in the industrial process. Thus, it was the solvent chosen in this study.

2.3. Economic feasibility analysis

The economic feasibility analysis was performed for two scenarios: (i) Scenario 1, called as BAU (Business As Usual), that is, the current production model (buriti oil extraction process with disposal of semi-defatted cake); (ii) Scenario 2, called as VAS (Value Added Scenario), that includes the oil extraction from semi-defatted cake using ethanol. The economic assessment of both scenarios applied the Net Present Value (NPV) method. The NPV establishes the present value of the cash flows of the business at the required rate of return of the project (Potrich et al., 2020; Žižlavský, 2014), calculated by Eq. (1).

$$NPV = \sum_{t=0}^n \frac{(NCF)_t}{(1+r)^{t-1}} \quad (1)$$

where NPV is the Net Present Value, NCF is the Net Cash Flow, r is the minimum rate of attractiveness, t is the investment period (year), and n is the total years of the investment. In this work, the NPV was determined by considering an *a priori* minimum rate of attractiveness (r) estimated by the national interest rate (SELIC “Special Settlement and Custody System”) (Banco Central do Brasil, n.d.). Considering the annual SELIC rate in Brazil when analysis was performed r was estimated as 11 %.

The NCF was determined by considering fixed costs (FC), variable costs (VC), product sales (PS), and working capital (WC). In this work, NCF was calculated by Eqs. (2) to (9) (according to the period), following the works of Turton et al. (2009) and Potrich et al. (2020), that performed an Economic Feasibility Analysis for soybean oil extraction using ethanol. In equations, R is Return and D , Depreciation.

$$R = PS - VC \quad (2)$$

$$D = 0.1 \cdot FC \quad (3)$$

$$WC = 0.15 \cdot FC \quad (4)$$

$$NFC(year_{1 \text{ and } 2}) = -\frac{FC}{2} \quad (5)$$

$$NFC(year_3) = -WC \quad (6)$$

$$NFC(year_{4 \text{ to } 13}) = R - \text{taxes} \cdot (R - D) \quad (7)$$

$$NFC(year_{14 \text{ to } 23}) = R - \text{taxes} \cdot (R) \quad (8)$$

$$NFC(year_{24}) = R - \text{taxes} \cdot (R - WC) + WC \quad (9)$$

Calculus was performed using Brazilian currency. Direct and indirect fixed costs (FC) were calculated considering equipment and construction costs (expenses of construction, startup, electrical installations, pipes, among others) using considerations of Potrich et al. (2020). The equipment costs were obtained from suppliers. In case of the distillation column, fixed cost was obtained through ASPEN Plus simulation software (ASPENTECH, Bedford, USA) and the updated value converted to

Brazilian currency. In case of the evaporator, the six-tenth rule was applied (Williams, 1947). In this rule, the cost of equipment (EC_2) with a certain capacity is estimated based on the cost of other equipment with different capacity (EC_1) using Eq. 10, where f is the size factor of equipment 1 or 2, related to capacity, discharge, area, volume, etc. In this study, our reference was the equipment used by Potrich et al. (2020) for a plant of soybean oil extraction with ethanol.

$$EC_2 = EC_1 \left(\frac{f_2}{f_1} \right)^{0.6} \quad (10)$$

Variable costs were calculated based on data obtained from: i) interview, ii) composition of the Buriti fruit, and iii) literature data. For Scenario 2 (VAS), input and output streams were determined based on experimental data (oil extraction from buriti cake). Table 2 summarizes the global considerations of the economic feasibility analysis. The business was considered feasible if NPV was greater than zero within the period considered.

3. Results and discussion

3.1. Oil extraction from Buriti cake

Dried and milled semi-defatted cake's lipid and water content were determined, as well as granulometry results, which can directly influence extraction yield. Results revealed a residual oil content and water composition of 6.47 ± 0.05 % (m/m) and 1.97 ± 0.28 % (m/m), respectively. Considering that part of non-extracted oil by mechanical press remains adhered to cake, an additional step for further oil extraction from this residue could increase plant's production yield. Considering that water content negatively affects extraction performance, the drying of the cake is also essential for improving production yields. Particles diameters varied from 193.65 to 842.61 μm , being the main fraction (30 %, approximately) that with 387.30 μm , chosen for extraction. The smaller the particles, the bigger the contact area between solvent and particle for mass transfer. However, even though smaller particles are particularly suited for the process of mass transfer, they can make difficult the solvent's flow through equipment, depending on the extraction process: this is the case of percolation columns where particles with bigger diameter are preferable (Ferreira et al., 2022). In case of batch process, such as in mixers or agitated reactors, where solid movement is promoted by forced agitation, smaller particles are the best choice.

Fig. 3 present the results of the semi-defatted cake oil extraction kinetics with anhydrous ethanol, 95 % and 50 % hydrous ethanol where total lipids were measured during 24 h. Fig. 4 shows images of the extracts and raffinates obtained for all three solvents after those 24 hours of extraction. Results showed that anhydrous ethanol had the highest extraction of total lipids, reaching the highest lipid concentration in the micelle (oil + solvent) close to 4 h of extraction, that is, 1.54 % (m/m). After this peak, there is a decrease in total lipid concentration in the following hours, with a stable composition at around 1.0 % of total lipids in the extract (micelle). Similar phenomena occurred for 95 % and 50 % hydrous ethanol. In these cases, maximum extraction occurred after 1 or 2 hours, respectively for 50 % and 95 % (m/m) ethanol, with a

Table 2
Global considerations of the economic feasibility analysis.

Consideration	Values
Time for plant's construction*	2 years
Time of operation	20 years, 222 days/year
Minimum rate of attractiveness	11 %
Total taxes*	34 %
Depreciation	10 % Fixed Cost
Time of depreciation	10 years

* based on Potrich et al. (2020).

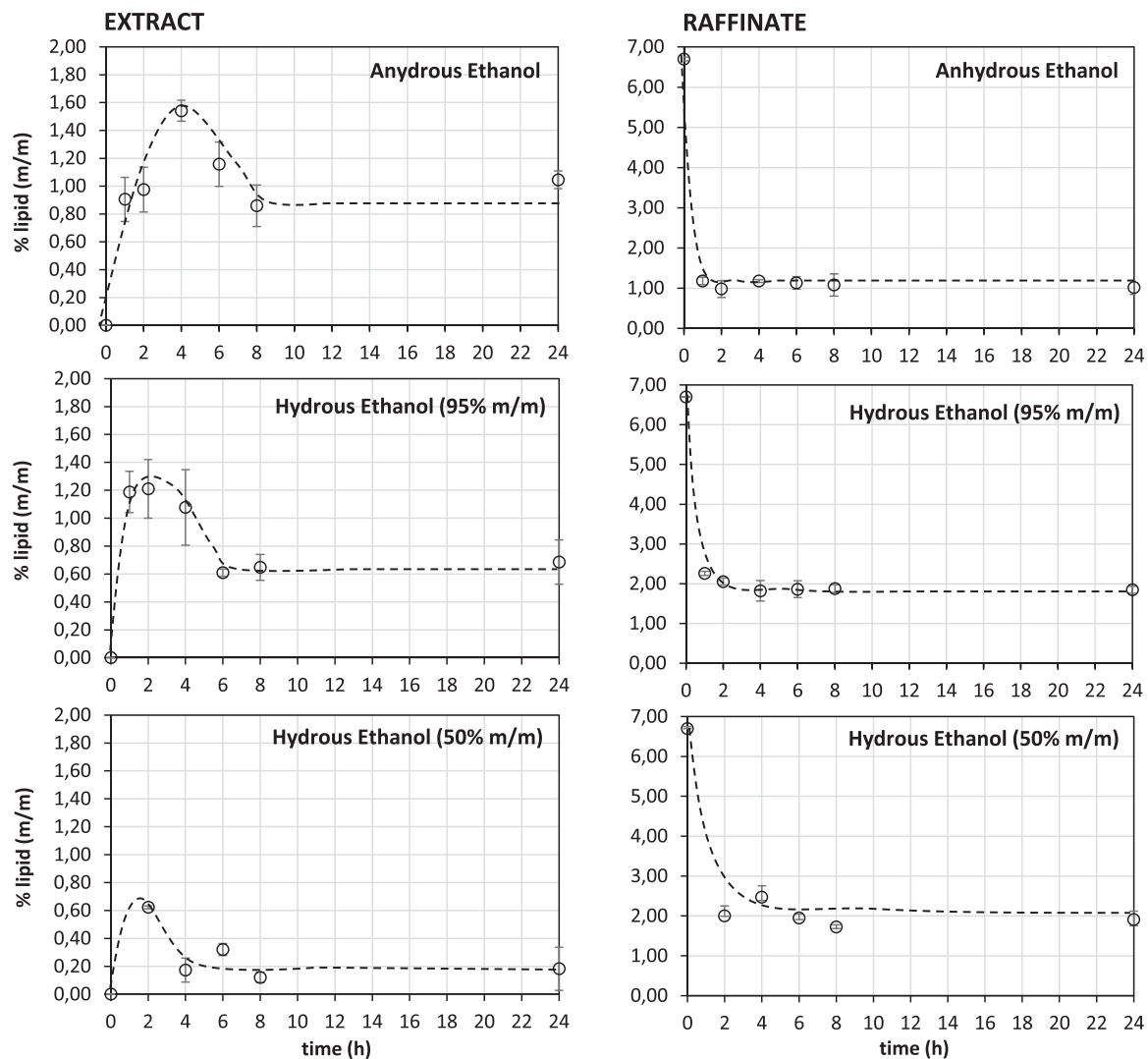


Fig. 3. Extraction kinetics (lipid content during extraction) for extract and raffinate streams (dashed lines are guide for the eyes).

decrease of lipid concentration in the extract after this period, respectively at 0.20 % and 0.60 % (m/m). Production yield for 95 % hydrous ethanol (43.3 %) was close to that obtained for anhydrous (48.2 %). In case of 50 % hydrous ethanol, yield was 1.3 %. This result showed a strong influence of water content in the solvent, negatively impacting the extraction's result.

The solid-liquid extraction kinetics could be explained by the mass transfer phenomena. [Sampaio Neto et al. \(2018; 2020\)](#) shows that the extraction process of a solid particle is a result of the mass transfer of the particle's solute (lipid) from the medium. A solid particle has two regions, that is: (i) the solid matrix itself, composed of "inert" material (fibers and other compounds) + oil and (ii) the particle's pores, spaces with direct access to the extraction medium. In the beginning of the extraction process, the oil concentration from the solid matrix is high in comparison to the solvent phase; as the extraction occurs, oil concentration from the solvent phase increases. The oil located in the particle's peripheral regions migrates to the solvent phase. Yet, the oil located in the particle's internal region migrates to the peripheral region as well as the pore region. In its turn, oil from the pores migrates directly to the solvent phase, given the established difference of concentration. Therefore, multiple simultaneous processes of mass transfer occur: i) from solid matrix to solvent phase (convection), ii) inside the solid matrix (diffusion), iii) from solid matrix to liquid phase inside the pore (convection), and iv) from liquid phase inside the pore to solvent phase

(convection). In the beginning of the process, concentration gradients are high, in a way that transfer rate is high. As the extraction process occurs, the lipid concentration gradient of the solid matrix and pores decreases, while the solvent phase's concentration rises, decreasing the gradient and the transfer rate.

This classic solid-liquid extraction behavior could be observed in the early hours of the kinetic curve (visually more explicit in the anhydrous ethanol kinetics, where extraction increases up to 4 h). However, as observed, after maximum extraction is established, a decrease in lipid concentration was observed. This profile could be explained probably due to buriti pulp's carbohydrates and proteins composition. [Cândido and Silva \(2017\)](#) show that wet buriti pulp can present 17.9 % for total carbohydrates, including dietary fibers, and 2.42 % for proteins. Therefore, considering drying and oil extraction, the concentration of these components is greater in the cake, with values reaching up to 7 % protein and 50 % total carbohydrates, approximately. In this case, after a peak of lipid extraction, the extraction of these compounds from solid matrix, probably reduced the relative concentration of total lipids in the extract. This could be related to ethanol's ability to extract compounds of greater polarity, that is the case of carbohydrates and proteins, as observed in other works in literature. [Baümle et al. \(2016\)](#) performed the ethanolic extraction of sunflower oil from sunflower collets, a solid material also rich in carbohydrates (close to 60 %). In this case, a high content of sugars in the extract was observed (105.66 g/kg) compared to

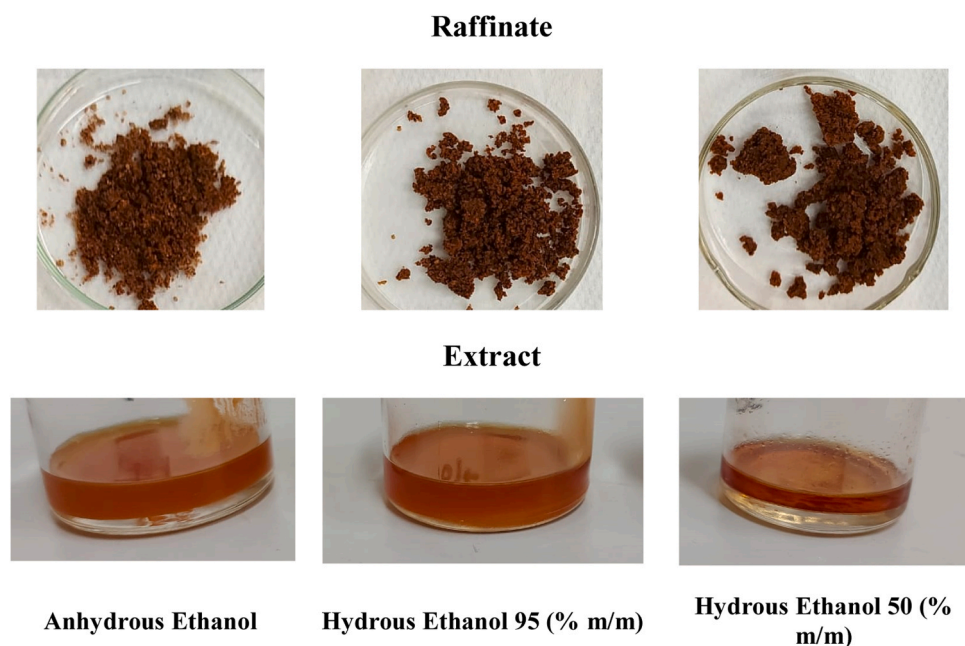


Fig. 4. Extracts and raffinate images after extraction.

no sugar extracted using hexane. Sawada et al. (2014) evaluated the extraction of soybean oil from soybean collets and showed that ethanol can also improve extraction of protein (up to 5.06 %), particularly in case of semi-defatted soybean cake, with lower oil content when compared to soybean (which is like the case here applied). Similar effects were also discussed by Sampaio Neto et al. (2020) for Babassu cake oil extraction, a solid material with lower content of lipids (close to 11 %) when compared to the raw material and a high fraction of protein and total carbohydrates. The lower relative lipid concentration in the cake probably promoted the accentuated decrease in lipid concentration during extraction. This was even more explicit for 50 % hydrous ethanol, that presented the lower lipid extraction. Indeed, by observing images of Fig. 4, the extract obtained by 50 % hydrous ethanol was slightly darker, probably due to the higher presence of other compounds, as mentioned, carbohydrates and proteins. Sawada et al. (2014) also showed that the presence of water improves protein extraction in case of semi-defatted soybean cake, corroborating to results here observed.

Another aspect was the high retention on solvent + oil micelle in the raffinate, especially in case of 50 % hydrous ethanol, that decreased the extraction yield. This was probably due to ethanol polarity, increasing the amount of adhered solution in solid matrix and preventing higher yields. Indeed, visually, solid matrix appears to be “moister” after extraction with 50 % ethanol with bigger solid clusters, when compared to anhydrous and 95 % hydrous ethanol, where smaller and lighter particles were obtained. As reported, interaction between cake’s oil and ethanol can be harmed with solvent’s water content, reducing the extraction ability. That is, the greater the water content, the higher solvent polarity, and the lesser the ability of ethanol for oil extraction, in a way that a competition with other solid’s components are established, i.e. carbohydrates and proteins, as previously commented.

Considering the practical application (scale-up) of this solvent extraction on an industrial scale, the lower the water content the higher the extraction yield. In this case, anhydrous or 95 % hydrous ethanol are the best choices, which was also observed by Sawada et al. (2014) in oil extraction from soybean semi-defatted cake, by Capellini et al. (2019), that performed lipid extraction from the residual sesame cake, by Magalhães et al. (2023) for peanut press cake and Bäumler et al. (2016), for obtaining sunflower oil from sunflower collets. Interestingly, Bäumler et al. (2016) and Aracava et al. (2022) also observed that the

use of ethanol as solvent can improve nutritional quality of the oils by increasing extraction of tocopherols. Aracava et al. (2022) also shows that the defatted cakes obtained by ethanol extraction are interesting for application in food or animal feed industry, due to not only the protein content of the cake obtained but also to the properties of the protein. It is important to highlight that, from an economic point of view, ethanol offers advantages for industrial purposes, considering its large-scale production in Brazil, predominantly occurring in the sugar-cane industry. Also, ethanol, similarly to hexane, a solvent mostly used by the soybean industry and other oilseeds to remove oil from solid matrices, has low volatility and, therefore, is easy to remove, facilitating cake purification and recovery for reuse. Together to the fact that ethanol presents a lower toxicity and easier handling when compared to that fossil-derived solvent, from a Circular Economy point of view, and in the context of Amazonian bioeconomy, the use of ethanol is an environmental advantage. Results obtained from the extraction kinetics also show that, for scale-up, due to the extraction of protein and carbohydrates, that decrease lipid concentration, the extraction should be stopped as soon as lipid content reaches its maximum, which occurred from 2 h in case of 95 % ethanol. Additionally, it is important to perform a subsequent and effective process of separation of extract from raffinate, which could be done, for example, with a filter press whose pressures can be applied for greater removal of the solution adhered to the solid matrix.

3.1.1. Characterization of buriti cake oils

The FA and TAG profile of the oils obtained from the extraction were obtained and compared to commercial buriti oil and literature data. Results are presented in Tables 3 and 4. Considering that for 50 % hydrous ethanol, extraction yield was quite low, this analysis was not performed. The FA profile shows that samples from commercial buriti oil presented a greater concentration of oleic acid, followed by palmitic acid, with a ratio between saturated and unsaturated FAs of 26 %. Some variation among pulp oils obtained by literature could be observed, particularly attributed, in this case, to seasonal and regional effects. Oils obtained in this work from cake presented a slightly higher concentration of saturated FA in a way that the ratio between saturated and unsaturated FAs was, on average, 40 %. This could be attributed to a combined effect between extraction, polarity of the solvent, and the matrix of the cake, enabling extraction of a different FA profile when

Table 3

FA profile for cake's oil and commercial Buriti oil (% m/m).

Fatty Acid		Pulp's oil*					Cake's oil	
		This work	[A]	[B]	[C]	[D]	Anhydrous Ethanol	Ethanol 95 %
C12:0	Lauric acid	0.21±0.08	0.03	-	0.06	-	0.7±0.2	2±1
C14:0	Myristic acid	0.4±0.2	0.08	0.5	0.11	0.02	0.6±0.2	1.2±0.7
C16:0	Palmitic acid	18.0±0.4	16.78	19.2	17.35	16.4	21±1	21.9±0.8
C18:0	Stearic acid	3.6±0.3	1.77	1.3	3.32	1.89	4.8±0.4	3.3±0.5
C18:1	Oleic acid	68.7±0.9	74.6	65.6	69.58	78.06	62±2	58.7±0.4
C18:2	Linoleic acid	6.9±0.6	4.94	4.9	7.31	1.69	6.7±0.1	9±3
C18:3	Linolenic acid	0.9±0.03	1.04	8.2	0.98	0.88	2.0±0.6	2.8±0.2
C20:0	Arachidic acid	0.16±0.01	-	-	0.20	0.11	0.35±0.01	0.3±0.1
C20:1	Eicosenoic acid	0.51±0.01	-	-	0.45	0.26	0.3±0.1	0.30±0.02
Others		0.69	0.76				1.27	0.96
SFA		22.52	19.42				28.35	28.86
MUFA + PUFA		77.48	80.58				71.65	71.14

* [A] Silva et al. (2009); [B] Speranza et al. (2016); [C] Freitas et al. (2017); [D] Mesquita et al. (2020)

Table 4

Probable TAG composition for Cake's oil and commercial Buriti oil (% m/m).

TAG		Pulp's oil*		Cake's oil	
		This work	[A]	Anhydrous	95 % Hydrous
OOO	Glyceryl 1,2,3-trioleate	30.87	39.73	22.04	18.15
POO	Glyceryl 1-palmitate-2,3-dioleate	29.87	31.98	29.60	26.61
OOLi	Glyceryl 1,2-dioleate-3-linoleate	9.18	7.93	7.20	8.12
POP	Glyceryl 1,3-dipalmitate-2-oleate	7.42	6.67	10.40	10.26
OPLi	Glyceryl 1-oleate-2-palmitate-3-linoleate	5.99	4.26	6.46	8.01
OOS	Glyceryl 1,2-dioleate-3-estearoil	5.89	3.13	6.38	4.01

* [A] Silva et al. (2009)

compared to cold pressed oils. Sampaio Neto et al. (2020), Magalhães et al. (2023) also showed that slight differences in the FA profile can occur for Babassu or Peanut residual cakes oils obtained by using ethanol, when compared to cold pressed oils. Bessa et al. (2017) and Sawada et al. (2014) found similar effects during ethanolic extraction of Rice Bran oil and Soybean collets when compared to extraction performed with hexane. These four matrices present different compositions with respect to lipids, total carbohydrates and proteins content, as well as oils with different fatty acid profiles, showing that this effect is independent to the matrix and FA composition. Ethanolic extraction can also enable access of more polar fatty compounds in the cake matrix, which is the case of medium-chain fatty acids, since polarity tends to increase as the FA carbon chain decreases (Marlina et al., 2020). In case of buriti, De Oliveira et al. (2017) showed that ethanolic extracts of Buriti fruit peels can present a high fraction of lauric acids but also palmitic acid, which, considering that residual peel can be presented in the matrix after pulping, can also explain the FA profile of the cake oils.

Regarding the TAG profile (Table 4), the most found TAGs were OOO and OOP with values greater than 20 % (m/m). Commercial samples presented a higher concentration of OOO, while cake's oil presented higher concentration of OOP, which could be related to a higher concentration of palmitic acid, corroborating to FAs' profile. This indicates that the oil retained in cake has a lipid profile somewhat different from that for pulp's oil, slightly richer in saturated compounds, especially palmitic acids and medium-chain FAs. Further, there is a mild difference between extracts obtained by 95 % ethanol and anhydrous, in a way that for 95 % hydrous ethanol a lower concentration of OOO and OOP, and a slightly higher concentration of other TAGs like POP, PPP, and those with myristic and lauric acids was observed. This could be because short-chain FAs present a higher polarity than longer-chain compounds,

as previously commented, being extracted more easily from the solid matrix. This different TAG composition could be also related, as already discussed, based on the work of De Oliveira et al. (2017), to the presence of peel or kernel residues on the pulp after pulping, which can elevate the concentration of saturated FAs on the cake, especially those with lower chains.

Melting and crystallization profiles are presented in Fig. 5. For all samples two main melting peaks were observed: one close to - 2°C, and another close to 8°C, approximately, with the end of melting close to 18°C. These peaks are related to the melting of two distinct groups of triacylglycerols. In fact, the profile of buriti oil's triacylglycerols presented approximately 30 % of OOO and POO, the remaining being mostly mono-, di- or triunsaturated TAG such as OOLi, POP, OPLi, and OOS. OOO β-form (more stable polymorphic form) melting occurs at 4.8°C whereas POO presents a β-form melting temperature at 18.5°C (Wesdorp, 1990). Considering the mixture of these major TAGs with other minor ones, it is expected that melting temperatures of the mixture's compounds are lower, which makes sense in the context of calorimetry analysis.

In DSC curves, peak's intensity (or area) could be related to the compound's mass. In case of commercial oil, the first peak's intensity is higher, which can corroborate to a higher concentration of OOO. However, for the oil obtained with anhydrous ethanol the opposite was observed, corroborating to TAG profile, where the ratio between POO and OOO was higher. For the 95 % hydrous ethanol samples, other peaks can be also observed, which could be probably related to the higher presence of lower-saturated-chain TAGs. In terms of physical properties, these significant differences on FA, TAG, melting, and crystallization profiles give rise to different oils for different technological applications in case of product formulation. Buriti's fatty acid profile is quite singular, when compared to classical crops, but also oils obtained from exotic fruits and seeds, considering the two main fatty acids of its profile, palmitic and oleic acid. This oil presents a slight similarity to the Rice Bran oil, whose composition in palmitic and oleic/linoleic acids are, respectively, close to 19 % and 75 % (Bessa et al., 2017). Otherwise, the oil obtained from the Buriti cake is quite like the Macauba pulp oil. Macauba (*Acrocomia aculeata*) is a fruit obtained from a palm tree that has gained notoriety in Brazil mainly considering their presence throughout the national territory but also due to be a crop with a high oil productivity, comparable to palm oil (Cabrera et al., 2022). Its fatty acid profile accounts for 21.8 % and 58.97 % of palmitic and oleic acid, respectively (Basso et al., 2014), similar to that obtained in this work for Buriti cake' oil: Macauba oil's TAG composition is close to 17.1 % OOO and 28.5 % POO, also like Buriti cake's oil, with 18.15 % and 26.61 % for OOO and POO, respectively. Macauba oil has been applied for several food applications, but also pharmaceutical and biodiesel production (Cabrera et al., 2022). Similarly, Buriti oil and its cake's oil showed a great potential not only in case of cosmetics, where it is mainly

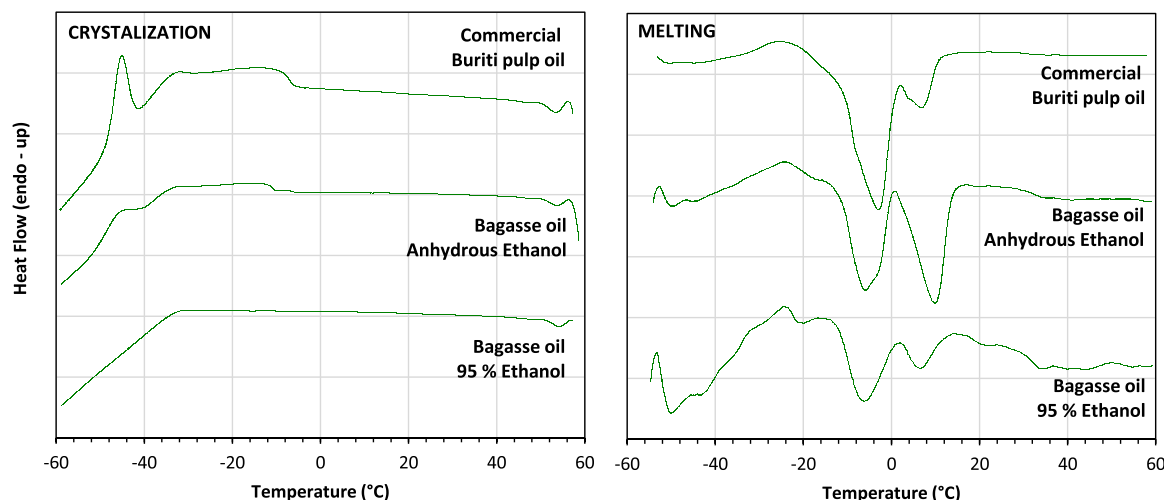


Fig. 5. DSC curves for cake's oil and commercial buriti pulp oil.

applied nowadays, but also for food, chemical and bioenergy industry.

3.2. Characterization and technical assessment of buriti oil production

The choice of processes for obtaining vegetable oils is extremely dependent on the matrix in which oil will be obtained as well as its overall quality. Indeed, factors such as cultivation or pre-processing stages can lead to oil's quality standards decreasing (Zhou et al., 2020), some of them demanded by national legislations. Considering this, preprocessing and processing stages for vegetable oil extraction and production were here described, focusing on the production practices of the buriti oil processing plant evaluated.

3.2.1. Preprocessing

Preprocessing steps begin with the fruit's harvest, where, subsequently, larger sized impurities, leaves, and branches are removed. In case of buriti, the fruit harvest is done in its ripening season, once a year: flowering of buriti occurs between December and April, and fruiting between December and June. In the region of the processing plant, harvest is manually done by workers/local residents, by climbing the trunks of fruit trees with or without the use of equipment for it where fruit bunches are extracted with the aid of machetes and fruit harvest nets. In this process, residual branches and leaves get mixed with the fruit. The harvest can take up days to be completed. Some regions are flooded, so fruits can fall directly into the water, which could result in quality loss by enzymatic hydrolysis. Until the transport of the fruits to the plant, there are no standard storage stages. After harvest, fruits are shipped to the processing plant, where they are selected, washed, and then stored in sanitized plastic bins under refrigeration.

In case of Buriti, oil is obtained from the fruit's pulp, like what occurs for palm or olive oils. Indeed, some fats and oils are obtained from plants' seeds, which is the case of other Amazonian oils such as Murumuru or Brazil nut (Pereira et al., 2019). Buriti pulping step is performed using a pulper that separates the pulp from fruits' shell and seeds: the resulting pulp is dried on drying tables that uses biomass burning for heat generation with a capacity of 250 kg per batch. Drying removes a big amount of water from the pulp, improving the oil extraction process. For oil extraction, dried pulp is stored away from direct light, humidity, and low temperature, which is a processing advantage for quality maintaining. When compared to other oilseeds, the preprocessing of Buriti for oil production is simpler: previously to extraction, soybean, corn, and rice bran, for example, are submitted to pelleting or laminations, so that oils are extracted more efficiently (Ferreira et al., 2022; Gasparetto et al., 2022).

3.2.2. Extraction

Depending on the vegetable matrix, oil extraction can be performed by different techniques. In general, continuous extraction can use expeller pressings, unpacked columns, with one or more stages, specific equipment, like *Rotocel*, with the use of solvents, being hexane the most common one for several types of commercial oils (such as soybean oil) (Gasparetto et al., 2022; Magalhães et al., 2023). Batch processes can be performed in hydraulic presses, or agitated reactors, using solvents as well. Extraction by pressing with *Expeller* is commonly found for oil extraction of different matrices but is not recommended for too "soft" raw material (without resistance to abrasion) or very hard seeds (with elevated resistance to abrasion) which could both affect the screw threads by excess of friction or torque. Buriti pulp extraction is performed in the processing plant by a tubular radial *Expeller*; this system is versatile for extraction of several matrices, like grains, seeds, almonds, and pulps. At this stage, despite this type of extraction is defined as "cold pressing", because no external heat source is applied, the pulp's temperature is slightly elevated due to internal friction in the equipment, which could cause quality loss by thermal degradation. After extraction, the oil is filtered in a filter press equipment and bottled in amber flasks, being stored away from direct light and in a refrigerated space.

3.2.3. Refine

Depending on the oil quality, affected by the characteristics of the raw material, harvest conditions, extraction process, and storage stages, the refine is a known practice in the vegetable oil industry. It employs techniques for removal of undesired compounds present in the extracted oil, as a result of the production chain, like phospholipids, acidity, pigments, or volatile and oxidizing compounds, that reduce oil quality, avoiding its use for food or other purposes. Oil quality standards are generally established by Regulatory Agencies, which, in Brazil, this is the case of ANVISA - Brazilian Health Regulatory Agency. According to ANVISA, for food applications, cold pressed vegetable oils should present maximum of 4.0 mgKOH/g for acidity and 15 meq/kg for peroxides. For refined oils, maximum values are 0.6 mgKOH/g and 10 meq/kg for acidity and peroxides, respectively (Brasil, 2021). In this case, values could be reached by degumming (removal of gum or phospholipids) (Dos Passos et al., 2022), neutralization or deacidification (removal of free fatty acids) (De Sa et al., 2022), bleaching or whitening (removal of compounds of color) and/or deodorization (for removal of undesired volatile molecules and other oxidizing compounds) (Gharby, 2022). Acidity percentage and phospholipid content determines the types of refining processes but also the final sensorial profile desired for the oil.

For oils in which color and odor are expected attributes as sensorial parameters - which is the case of olive or sesame oil, but also Amazonian

oils, like buriti - these steps are not performed, being the case of the Processing Plant evaluated. Therefore, according to ANVISA, in this case, the buriti oil is classified as cold pressed vegetable oil. In accordance with Mesquita et al. (2020), Buriti oil can presents high acidity content, in disagreement to Brazilian legislation, indicating the importance of Good Preprocessing Practices (GPP) or the introduction of “minimal” refining steps, with the removal of free fatty acids (FFA) avoiding its use for food purposes.

As a result of the questionnaire and, according to production detail previously introduced, Fig. 6 shows a diagram of processing sets of buriti oil production from the Processing Plant. The process presents a pre-processing stage where the harvest fruit is received, raw materials are washed for dirt removal, removal of rotten or open fruits (due to fall during harvest or transport), and separation of green fruits for ripening and future use. Next, before pulp removal, the fruits are sanitized with chlorinated water and dried naturally at room temperature. The clean ripe fruit goes through a stage of pulping with the use of an automated pulper. The pulp is spread in a thin layer on a drying table to facilitate humidity removal. Equipment uses wood/biomass for heat generation. Sequentially, the dried pulp is submitted to extraction and filtering. Semi-defatted cakes are removed and used as fertilizer, animal feed or redirected to burning. The oils are bottled in amber flasks for subsequent commercialization.

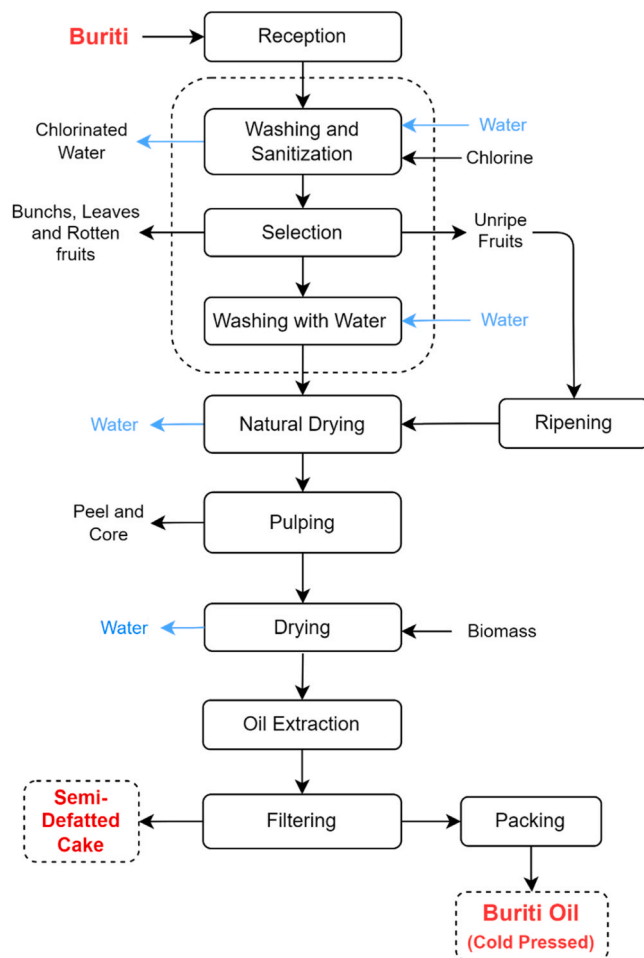


Fig. 6. Diagram of buriti oil processing, based on information obtained from the semi-structured interview.

3.2.4. Challenges for buriti oil quality maintenance

- **Fruit harvest:** At this stage, a critical point is the exposure of fruit to the environment's humidity and to high temperature, which could accelerate the process of oil degradation. The contact between fruit with water must be controlled, that is, keeping the fruit as dry as possible. Also, after harvesting and before processing, storage away from direct sunlight is key, with air circulation, preferably refrigerated and temperature-controlled environment. Lastly, storage time cannot be too lengthy, because, as time passes, the fruit tends to suffer oxidation and quality loss.
- **Fruit washing for removal of impurities:** This step can be critical regarding loss of fruit quality. It is mandatory avoid fruit exposure to humidity for too long as well as their damages such as shell rupture or cuts. Exposure of the fruit's interior to oxygen also accelerates oxidation reactions and quality loss. Whenever possible it is recommended to use forced-air ventilation for fruit drying after washing and sanitizing.
- **Pulping:** This process must be done as rapidly as possible to avoid prolonged exposure of the pulp to oxygen. Ideally, immediately afterwards, thermal inactivation of enzymes could be performed by applying a thermal process (heating), in case of the pulp is not promptly dried and extracted.
- **Oil extraction:** The parameters of the oil extraction by cold pressing with tubular radial expeller, in this case, should be carefully controlled, in a way that elevated temperature, promoted by equipment mechanical friction do not significantly affect oil quality. Temperature rising affects oil quality, resulting in the loss of thermosensitive compounds, like fat-soluble vitamins, antioxidants, aromatic compounds, and triacylglycerol degradation with the formation of FFAs and partial acylglycerols, increasing acidity and altering the physical properties for formulations. The pressing can be conducted at average pressure or, ideally, at a temperature-controlled environment (refrigerated). It is key to sanitize the press between extractions for removal of residues that can act on equipment oxidation, raising the next batch's organic load.
- **Process yield:** In case of vegetable oils, process yield is largely related to the extraction stage, with loss of neutral oil in the cake, the main residue. The use of higher pressures or sequential extractions can improve oil extraction, but attention to possible temperature damage is required. In addition to quantitative yield, low-quality oil commercially impacts business gains. It is worth emphasizing that the literature has focused efforts on detailing Amazonian oils and their benefits, whereas studies about oil quality and the use of residual cakes, that represent the majority of this industry's residue, have been little or barely tapped. In practice, the use of cake is relegated to crop fertilization (Bhomia et al., 2019) or energy production by combustion (Souza et al., 2020).
- **Storage:** The storage of oil in dark colored glass bottles, that prevent the contact of oil with light, and consequently, the deterioration of compounds sensitive to light, as well as use of refrigerated storage, lower to 25°C, are key for the maintenance of oil quality. In fact, one of the main components of oil pigmentation, the carotenoids, responsible for the identity of several Amazonian oils, like buriti, are highly unsaturated molecules with conjugated double bonds. According to Sampaio et al. (2017), these bonds are highly susceptible to degradation during processing and storage, resulting from the exposure to high temperatures, light, or pro-oxidant molecules. Another problem related to improper storage is TAG hydrolysis, in which compounds are hydrolyzed into smaller compounds, like diacylglycerols (DAG), monoacylglycerols (MAG), and FFAs (De Souza et al., 2024; Mesquita et al., 2020), precluding the use of oils for food purposes.

3.2.5. Modification of the production process with use of the semi-defatted cake for further oil production

Buriti oil processing was evaluated considering the circular economy theory. According to The [Ellen MacArthur Foundation \(2015\)](#) the circularity of a business can be mainly obtained from the introduction of what it calls “loops”. The production chain itself, from raw material to consumption is the “main loop”, in which product’s lifespan extension should be prioritize. “Reuse and redistribution” loops using mechanisms of “sharing, resale, or trade” should be introduced, as well as loops for “refurbishment” and “recycling” of side streams of the chain. In case all resources of the productive chain are reintroduced in the production stages of the original product, it is called that a closed loop is configured. The so-called *cradle to cradle* approach has this kind of loop as one of the most important ([Braungart et al., 2007](#)). In contrast to the closed loop, other scenarios are those called *open loop inside the same sector*, and *intersectoral open loop*. In this case, some products/streams of the main loop are redirected to another production chain. Some examples are streams of plastic and cardboard packaging sent to recycling, or organic residues used for composting ([Ng et al., 2020](#); [Weetman, 2019](#)). The interaction between production chains, despite not being able to promote the circular economy’s final goal considering a perfectly *closed loop*, is also an interesting strategy to reduce waste and boost sustainability, especially when it is not feasible to make too radical alterations in the chains, when there is not enough technology for total integration of the process or when the necessary modifications are not economically viable.

As previously mentioned, the main residue generated in Buriti oil processing is the cake obtained during dry pulp pressing. This cake represents nearly 90 %, in mass, of the process’ raw material: as it is a significant volume, this material is not disposed by the enterprise, but intended for animal feed, in local soil management practices or burning to generate heat. Considering that this material is already reused by the enterprise, in the local community, this practice can be characterized as a proposal within the circular economy perspective. This practice could be considered an *intersectoral open loop*, since the residue is used in other chains (animal or agricultural production). On the other hand, when used to heat generation for Buriti processing, a *closed loop* is obtained ([Ellen MacArthur Foundation, 2015](#); [Ng et al., 2020](#); [Weetman, 2019](#)).

Therefore, many circular production models are possible. In this case, it is important to evaluate possibilities that allow the best benefits for the enterprise. The ReSOLVE framework proposed by the [Ellen MacArthur Foundation \(2015\)](#) presents a set of possibilities or opportunities to create and improve production practices within the CE perspective. ReSOLVE is an acronym for Regenerate, Share, Optimize, Loop, Virtualize, and Exchange, i.e. production models or practices based not only on creation of loops, but also based on regeneration of the environment, sharing of facilities, processes or products, optimization of manufacturing practices, boosting production with less inputs, virtualization of processes through new technologies, and exchanging of high environmental impact materials. Together with the model based on creation of loops, probably the most applied in food production processes from the CE perspective, the use of other production models as well as hybrid models that incorporate more than one approach, has been presented in literature as an effective strategy to build a more environmental efficient and cost-competitive food sector ([Jabbour et al., 2021](#); [Tedesco et al., 2022](#); [Teigiserova et al., 2020](#)).

Specifically in the case of food processing, [Teigiserova et al. \(2020\)](#) provided a detailed assessment of strategies for managing residuals streams, both edible and nonedible, creating a guide for choosing the most environmentally efficient ones, taking into account the end-of-life of the product. In other words, these strategies, ordered hierarchically, are alternatives for increasing production efficiency, preventing losses and reducing the demand for waste management. In this context, the most preferable strategy for using edible waste is their use for manufacturing food for human consumption. This strategy is considered by the authors preferable over their use for animal feed or energy

generation, that could be performed using other streams inappropriate for human consumption.

Using the ReSOLVE framework and the hierarchy proposed by [Teigiserova et al. \(2020\)](#) for food waste management, this work proposes a new production model focused on using the semi-defatted Buriti cake in order to expand the circular nature of the enterprise. Considering that the cake has a residual oil content and represents a significant percentage of the input flow (fruit), the introduction of a step for extracting the residual oil from the cake is proposed. As mentioned previously, this strategy must be carried out using solvents. The extraction of industrial oils by using solvents is largely employed. Some examples are the extraction of soybean oil and olive cake oil. The most used solvent in industrial processes for oil removal from matrices is hexane, due to high production yields and facility for reintegration in the same process, despite its flammability, toxicity, and fossil fuel origin, restraining process’ sustainability. Ethanol, however, has been reported, as mentioned, by several studies as an alternative to hexane for extraction of oil from a different plethora of matrices for edible oil production ([Aracava et al., 2022](#); [Baümler et al., 2016](#); [Sampaio Neto et al., 2018](#); [Sawada et al., 2014](#); [Magalhães et al., 2023](#); [Ferreira et al., 2022](#); [Capellini et al., 2019](#); [Toda et al., 2023](#); [Bessa et al., 2017](#)). Ethanol differs from hexane considering its low toxicity and sustainable origin. In the context of Brazilian economy, high production and low cost of sugarcane ethanol makes this compound even more attractive. Moreover, considering that ethanol is a solvent with more polarity than hexane, it is also able to carry polar compounds, as previously discussed in experimental results of this work. This fact does not qualify as a negative aspect by itself; on the contrary, it enables the production of oils with specific characteristics, not obtained with the use of hexane, for example.

After the new oil extraction process, a defatted cake is obtained. This stream can be intended to several fates, including those already applied by the community for the semi-defatted material, such as animal feed or energy generation. However, defatted cakes from several other oilseeds have been evaluated as valued flour for food applications ([Aracava et al., 2022](#); [Capellini et al., 2019](#); [Navarro and Rodrigues, 2018](#)), meeting [Teigiserova et al. \(2020\)](#) proposals. This is because after lipid extraction, these cakes can present an improved content of protein, carbohydrates and dietary fibers: for dried Buriti pulp values can reach up to 11 % protein and 31 % dietary fibers ([Cândido and Silva, 2017](#); [Resende et al., 2019](#)).

Together with the cake, all other minor and non-edible streams of the ongoing buriti oil production were also reevaluated for their final destinations, and proposals of *closed loops* done. Strategies to improve oil quality were also provided. The modified flow chart is presented in [Fig. 7](#). The main changings are listed: (i) increasing oil extraction yields with oil extraction from semi-defatted cake and its residual obtained after filtering, using 95 % hydrous ethanol as solvent, as proposed in this work; (ii) recovery of ethanol through its evaporation from oil micelle, with the use of a natural circulation tubular evaporator and distillation for correction of the original water content of ethanol; (iii) recirculation of all output flows: the condensate of the reboiler from the distillation column, cooling water for condensation in the distillation column; destination of non-edible streams (pits, shells, stems, leaves, rotten fruits) for vapor generation in a boiler, and for energy supply for the drying table, and storage of chlorinated water for future cleaning of the industry. Defatted cake, after ethanol extraction, should be preferably used as flour for production of other products but, their destination to energy generation or animal feed can be also alternatives. For the improvement of oil quality, an additional stage is proposed after pulping: if drying is not rapidly performed, a thermal enzymatic inactivation step should be performed in a jacketed tank with indirect use of vapor.

Within the circular economy perspective, based on the strategies proposed by the ReSOLVE framework ([Ellen MacArthur Foundation, 2015](#)) and by the work of [Teigiserova et al. \(2020\)](#), when compared to the current enterprise, the proposed flowchart allows the increase in productivity of the main product (vegetable oil from Buriti fruit) and the

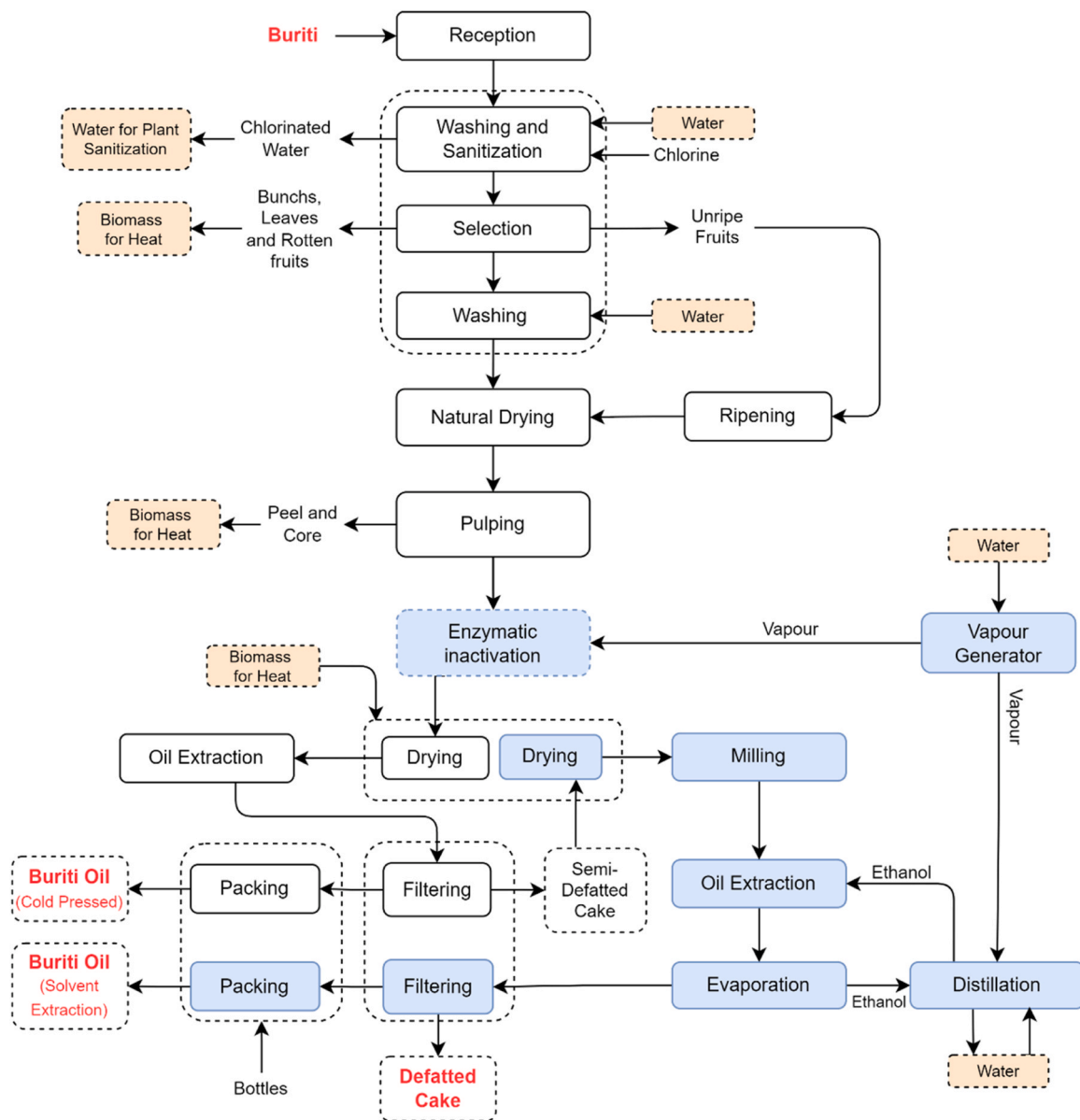


Fig. 7. Flowchart of the modified process, incorporating loops for reintegration of residual chains. Blue boxes are additional steps aggregated to the original flowchart. Red boxes are recycled streams.

generation of a new product (defatted flour), obtaining products with high added value. Furthermore, the new process considers that the solvent extraction stage uses input from a renewable source (ethanol) instead of a fossil solvent (hexane). Therefore, it covers more than one approach within the ReSOLVE framework: creation of a *closed loop* from the main residual stream (cake), optimization of the production process with increased production of added value products and more recycled/reused streams. Additionally, it also adopts a model based on the exchange of high-environmental impact inputs by using ethanol instead of hexane.

3.3. Economic evaluation

Tables 5–9 display equipment detailing and purchase prices, direct and indirect fixed costs of equipment installation and plant construction, and variable costs for both scenarios, that is: Business As Usual (BAU), i.e. the plant's current scenario, with disposal of semi-defatted cake, and Value Added Scenario (VAS), i.e. the scenario that considers cake reuse for further production of buriti oil. Other considerations applied to the

Table 5
Equipment purchases costs (Brazilian currency).

Stage	Equipament	BAU (\$)	VAS (\$)
Pulp Oil Extraction	Washing and Sanitization Tank	2,832.00	2,832.00
	Pulping Machine	45,400.00	45,400.00
	Drying Table	92,000.00	92,000.00
	Electric Press	19,620.00	19,620.00
	Filter Press	18,600.00	18,600.00
	Storage Tank	6,500.00	6,500.00
Cake Oil Extraction	Knife Mill	-	9,857.00
	Agitated Tank	-	19,200.00
	Evaporator (separation of ethanol from micelle)	-	34,067.25
	Distillation Column (ethanol rectification)	-	200,000.00
	Steam generator	-	23,500.00
Purchase Cost (PC)		184,952.00	471,576.25

Table 6
Equipment detailing.

Equipament	Description	Reference
Washing and Sanitization Tank	A304 Stainless Steel Tank for washing and sanitizing buriti fruits at the reception of the production process	Supplier
Pulping Machine	Electric pulping machine, manual feeding with motor drive. Structures in carbon steel, propellers and internal pulping set in stainless steel.	Supplier
Drying Table	Drying table with stainless steel perforated plate drying surface, thermally insulated for increased thermal efficiency. Use of firewood/biomass for heating.	Supplier
Electric Press	Electric press with a “radial tubular” type extraction system, consisting of a perforated pipe with an endless thread inside. Pressure is controlled by an external handle. The extract is expelled through the perforations so that where it is separated from the raffinate	Supplier
Filter Press	Filter Press in which product is pressurized between filter elements inside the filter plates.	Supplier
Storage Tank	A304 Stainless Steel Tank for storage of oil, water and solvent	Supplier
Knife Mill	Knife Mill for reduction of the size of Cake particles, with continuous flow grinding	Supplier
Agitated Tank	A304 Stainless Steel Jacketed Tanks with agitation system and temperature control using steam. For extraction of oil from semi-degreased cake and optionally for thermal treatment of the pulp for enzymatic inactivation.	Supplier
Evaporator (separation of ethanol from micelle)	Multitubular evaporator with natural circulation using steam for separation of the solvent from the micelle. Buriti oil and solvent are collected from the equipment and solvent is sent to a distillation column for water content rectification.	Potrich et al. (2020) applying Eq. 10 (for oil production flow)
Distillation Column (ethanol rectification)	Distillation column (carbon steel) with 20 stages, reflux rate of 4 for a flow rate of 250 liters/hour for rectification of hydrated ethanol 90–95 % ethanol (m/m). Total cost (ASPEN simulation) of USD 71,000. The currency was converted into Brazilian currency (Jan/2022) given R\$ 386,000. Due to the high cost, a maximum of BRL 200,000 was considered, considering the possibility of obtaining suppliers with lower prices, with less impact on the NPV	ASPEN Simulation
Steam generator	Vertical watertube steam generator using biomass/ firewood for generation of steam for evaporation, distillation, and extraction processes.	Supplier

Table 7
Direct and indirect fixed costs of installation.

Item	Multiplier	BAU (\$)	VAS (\$)	Reference (i)
Total Direct Cost of the Plant (TPDC)	$i (\times \text{PC})$			
Equipment Purchase Cost (PC)	1	184,952.00	471,576.3	Potrich et al. (2020)
Piping and Accessories	0.01	4715.80	4715.8	Potrich et al. (2020)
Electrical Installations	0.2	94,315.30	94,315.3	Potrich et al. (2020)
Construction and Structure	0.3	55,485.60	141,472.9	Potrich et al. (2020)
Insulation	0	0.00	0.00	Potrich et al. (2020)
Painting	0.05	23,578.80	23,578.8	Potrich et al. (2020)
Assembly, Testing and Start-up	0.25	46,238.00	117,894.1	Potrich et al. (2020)
Total (TPDC)		409,285.40	853,553.00	
Total Indirect Cost of the Plant (TPIC)	$i (\times \text{TPDC})$			
Engineering	0.3	256,065.90	256,065.90	Heinzle et al. (2006)
Construction	0.35	298,743.60	298,743.60	Heinzle et al. (2006)
Total (TPIC)		554,809.50	554,809.50	
Total Plant Cost (TPC) = (TPDC + TPIC)		964,094.90	1408,362.50	
Construction and Unforeseen Costs (CFC)	$i (\times \text{TPC})$			
Construction Services and Fees	0.06	84,501.70	84,501.70	Heinzle et al. (2006)
Contingencies	0.08	77,127.60	112,669.00	Heinzle et al. (2006)
Total (CFC)		161,629.30	197,170.70	
Total Plant Fixed Costs (TPC + CFC)		1125,724.20	1605,533.20	

Table 8
Inputs and outputs for daily processing of 1000 kg buriti.

Streams	Considerations	BAU kg/day	VAS kg/day
Buriti	3 % loss after sanitizing	970.0	970.0
Buriti pulp	30 % fruit	291.0	291.0
Dried buriti pulp	80 % wet pulp	232.8	232.8
Buriti oil	15 % wet pulp	43.7	43.7
Cake (wet)	Dried pulp – Extracted oil	189.2	189.2
Dried cake	90 % wet cake	-	170.2
Retained oil in Cake	7 % wet cake	-	11.9
95 % hydrous ethanol	solid:ethanol ratio 1:4	-	680.9
Extracted oil	90 % yield	-	10.7
Defatted cake	Cake – Extracted oil	-	159.5
Ethanol loss	5 % loss	-	34.0

calculations are described above.

- (i) For calculating direct and indirect installation costs, multipliers applied by Potrich et al. (2020) for the economic evaluation of a soybean oil processing plant, adapted from Heinzle et al. (2006) and Turton et al. (2009), were used. They considered that direct and indirect costs are proportional to equipment expenses. In this study, some fixed costs were considered independent from the scenarios. Some multipliers were also adapted to consider that a

Table 9
Variable costs for daily processing of 1000 kg buriti.

Cost	Considerations	BAU	VAS
		(\$)/ano	(\$)/ano
Biomass	No Cost	0.00	0.00
Worker	10 workers (1 minimum wage, 13 salaries)	157,560.00	220,584.00
Maintenance and Services	5 % Equipment Cost (PC)	9,247.60	23,578.81
Water	Maintenance cost (well) (+25 % in VAS)	5,000.00	6,250.00
Ethanol	Reposition (5 % losses) \$2.40/liter	0.00	18,140.20
Buriti	Acquisition price (\$2.16)	465,134.40	465,134.40
Package	Amber flasks, 500 ml \$4.00/flask	77,522.40	81,267.50
Electricity	Equipments and Installation	1,401.90	4,974.06
Others	10 % Variable Costs	71,586.63	81,992.90
TOTAL		787,452.93	901,921.91

soybean oil processing plant presents more structural complexity than Buriti plant.

- (ii) For variable costs, wood cost was not considered in both scenarios, given the use of biomass from buriti bunches or biomass

from local communities. Considering that water for plant's operation is obtained from well, an operational and maintenance cost of \$5000 per year was set, according to overall values applied for service providers. For electricity cost, it was considered equipment operating during 8 h per day at the plant's full capacity (daily processing rate of 5 tons), and a fee of \$0.69 kWh (Amazonas state energy provider, retrieved from Brazilian Electricity Regulatory Agency's platform, ANEEL, aneel.gov.br/relatorio-ranking-tarifas). For processing rates lower than 5 tons/day, electricity cost was considered linearly proportional. Acquisition cost of buriti fruit of \$2.16/kg was in accordance with National Supply Company's, CONAB, platform (conab.gov.br/info-agro/custos-de-producao). Concerning the solvent, a loss of 5 % per process was considered, at a cost of \$2.4/liter, according to a national sugar-cane database platform (observatorio-iadacana.com.br, prices and quotes for consumers). Moreover, since the current allocation for cake is its use as fertilizer, animal feed or burning, by local residents, this coproduct was not considered (at first) for sale.

- (iii) In case of salaries, 10 workers, or associates, were considered with a monthly income of a minimum wage, that is, \$1,212,00 (Brasil, updated in the beginning of 2022), with a total of 13 salaries per year (according to legislation). In case of VAS

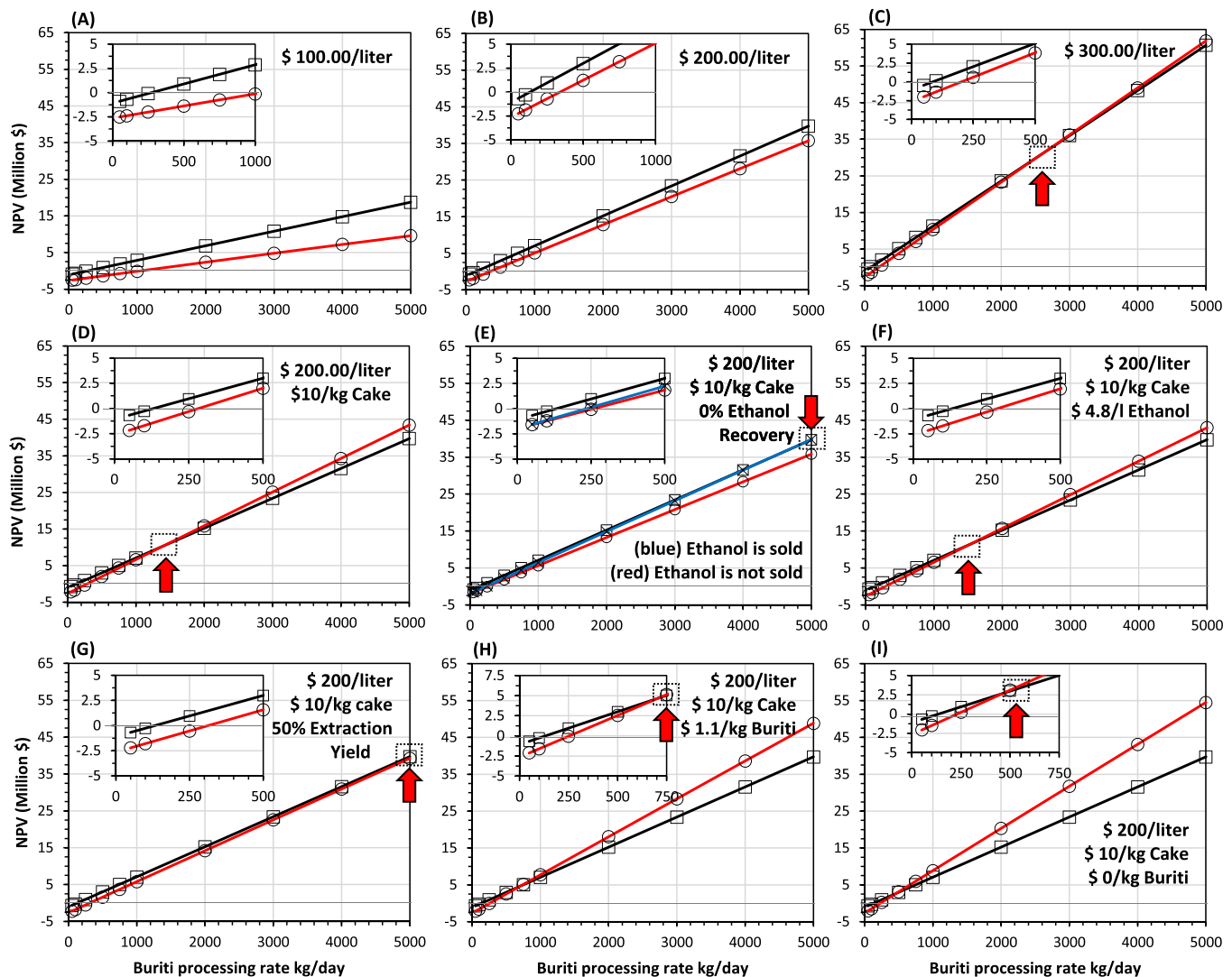


Fig. 8. Impact of daily buriti processing rate, ethanol recuperation, oil and cake prices as well as oil extraction yield in the Net Present Value (NPV) for BAU Scenario (black lines) and VAS Scenario (colored lines). Red arrows show “crossover” points, when VAS becomes more feasible than BAU.

scenario, 2 additional specialized workers were considered, due to the introduction of new processes and equipment, with a monthly income of two minimum wages.

- (iv) 222 days of processing per year were considered, that is, 252 business days minus 30 vacation days. It is important to note that buriti processing is seasonal, but a full year of work was considered (the plant processes other matrices for oil extraction).
- (v) A process yield of 90 % regarding extraction was considered. Moreover, as previously commented, the 95 % hydrous ethanol was considered due to facility for recovery and rectification.
- (vi) Working Capital was estimated at 15 % of the plant's total fixed cost, also according to Potrich et al. (2020).

Both scenarios were evaluated based on the NPV calculations for twenty years of business venture's activities and their results were compared. The analysis was performed assessing economic feasibility according to: (i) variation of buriti fruit's daily processing rate between 50 kg/day to 5 tons/day; and (ii) buriti oil's price range from \$100 to \$300 per liter. Results are presented in Fig. 8A to C.

Considering Buriti oil's sales prices of up to \$200 per liter (Fig. 8A and B), BAU scenario's NPV becomes positive "more quickly" with the increase of daily buriti fruit processing. In this case, BAU scenario was economically feasible for daily processing rates close to 150 kg/day with sales price of \$200 per liter, while for VAS this value was close to 400 kg/day. As the sale price decreases, the minimum daily processing rate for a cost-effective business venture increases up to 300 kg/day for \$100 per liter, approximately, for BAS, while for VAS, this value reaches 1 ton/day. Since NPV's increasing rate is higher for BAS than VAS, no "crossover" point was observed in these cases, i.e. a daily processing rate that VAS becomes more feasible. Some works in literature have already shown the economic feasibility of the use of agro-industrial byproducts for further extraction of biocompounds, aiming valorization of potentially valued residues but also meeting the principals of the circular economy framework. Da Porto et al. (2022) showed that, in the context of Wine processing, the installation of an additional plant to recover phenolic compounds using green solvents from the byproducts generated is a feasible strategy from the economic point of view. Tesfaye et al. (2021) also observed, in case of avocado processing, that the extraction of starch from waste seeds is similarly economically feasible in a short payback period, adding profitability to the ongoing venture, still providing a more sustainable perspective for the use of this residue, with the production of a high-value product.

With an increase of Buriti oil's sale price to \$300 per liter (Fig. 8C), the minimum daily processing rate decreases: for BAS, the minimum processing decreases to 75 kg/day, while for VAS, this value also decreases to 200 kg/day. By applying this higher price, a "crossover" point can be observed such that VAS becomes more economically feasible over BAS with a processing rate close to 2.5 ton/day. On the other hand, this hypothetical scenario does not meet the Amazonian plant's ongoing practices, considering the production of sociobiodiversity oils, with lower processing values and lower applied prices. Therefore, some sensitivity analyses were applied considering a price of \$200 per liter of Buriti oil, which is closer to market values.

The following sensitivity analyses were applied in order to verify the effect of some market or process variables in the feasibility of the VAS scenario: (i) sale of the defatted Buriti cake (Fig. 8D); (ii) no ethanol recovery after cake oil's extraction, i.e. 100 % of solvent is replaced for the next extraction (Fig. 8E); (iii) higher ethanol acquisition costs of \$4.80/kg (according to variations observed in a national sugar-cane database platform, observatoriocana.com.br) (Fig. 8F); (iv) buriti semi-defatted cake oil's extraction yield is 50 %, similar to the number obtained in laboratory tests (Fig. 8G); (v) lower buriti acquisition costs of \$1.1/kg (according to variation observed by National Supply Company, CONAB, in the period) or neglecting fruit's acquisition cost (Fig. 8H and I).

The BAU scenario consider that local residents usually use residual

semi-defatted cakes for some low valued practices such as for burning, animal feed or fertilizer, whose information was obtained in the questionnaire applied. In this case, since the community is saving on purchase of animal feed, fertilizer or biomass for burning, defatted cakes can be also considered as an indirect financial gain for the enterprise, despite the cooperative arrangement, as the management and productive model used, does not allow directly incorporate this effect into the cost analysis. However, as previously discussed the defatted cake obtained after residual oil extraction can be used as flour for food applications (Aracava et al., 2022; Capellini et al., 2019; Navarro and Rodrigues, 2018). Taking this into account, the defatted cake can be sold, and a price of \$10.00/kg was applied in the economic feasibility analysis to evaluate the effect of this market variable. This price is a hypothetical value, considering approximate values applied to defatted soybean meal (according to national institutes such as the Institute for Applied Economic Research, IPEA, or the National Supply Company, CONAB). However, considering the origin of this product, higher prices can be applied. Results can be observed in Fig. 8D.

The economic feasibility of VAS scenario was significantly improved with the sale of the defatted buriti cake. Considering that the price of defatted flour is \$10.00/kg the minimum daily processing necessary for the enterprise to reach its economic viability drops from 400 kg/day to 250 kg/day. Even with defatted cake sales, BAU scenario still presents a lower minimum processing rate to obtain a positive NPV value, close to 150 kg/day. However, flours sales could increase VAS scenario profitability when compared to the ongoing practice of allocating the Buriti cake for a low valued use, such as fertilizer or burning. In this case, despite BAU scenario reaches the profitability at lower daily processing values, the NPV increase rate of the VAS scenario was higher such that a "crossover" point was reached close to processing rates of 700 kg Buriti fruit per day. Cheng and Rosentrater (2019) and Lavenburg et al. (2021) that, in case of oil extraction from oleaginous raw materials, the economic feasibility analysis is essential as it can show profitability scenarios mainly related to the use of the defatted cakes. Cheng and Rosentrater (2019) shows that, for the extraction of soybean oil by mechanical pressing, the residual cake plays a key role in the profitability of the business, so that, considering some fluctuations related to market issues, oil and cake can contribute, respectively, with 25 % and 75 % of enterprise return. In other words, in case of soybean oil, the sale of cake is essential for enterprise viability, especially in case of high production scales, which corroborates with the results observed here.

The effect of solvent (ethanol) costs on venture's profitability was observed by evaluating additional scenarios. The first of them suppose that no recovery of ethanol is performed. No recovery of the solvent implies a decrease of fixed costs, with the non-acquisition of a distillation column (valued at \$200,000), but with expressive increase in variable cost, with the purchase of ethanol. In this case, two cases were evaluated, such that the evaporated solvent (ethanol) can be sold at half-price or no solvent is sold. Results are in Figure E. When compared to the previous scenario (Figure D) where ethanol is recovery, VAS's minimum Buriti processing rate for positive NPV did not alter significantly, being close to 250 kg/day and still higher than BAU. However, differently from previous case, as buriti processing rate increases, the NPV of VAS scenario is still lower than BAU's NPV, that is, no solvent recovery makes cake's oil recovery economically unfeasible. With the Evaporate Solvent sales, venture becomes more feasible when compared to BAU scenario at processing rates higher than 5 ton/day. This means that, despite the high fixed costs for adapting a processing unit for oil extraction from the cake, due to the high price of the rectification column, corresponding to 42 % of VAS fixed costs, it is fundamental to consider solvent recovery. Chea et al. (2020) present a comprehensive analysis on the effect of solvent recovery on the economic viability of industrial processes. In fact, chemical processes are characterized by the high use of solvents in the most diverse applications. The authors show that, when compared to classic waste management strategies for solvents streams, such as incineration, recovery is the best strategy from both economic and

environmental point of view, considering that solvent recycling prevents unwanted environmental emissions.

The impact of the solvent on ventures' feasibility was also evaluated by considering that ethanol's purchase price is \$4.8 per liter, twice the value first considered (\$2.4 per liter). Indeed, as mentioned, ethanol prices can largely vary according to sugar-cane Brazilian market (as observed in the national sugar-cane database platform observatorio.iadacana.com.br) which can, consequently, impact venture's profitability. Fig. 8F shows the results for this analysis. When compared to VAS scenario where 95 % of ethanol is recovery and purchased at \$2.4 per liter (Fig. 8D), the increase in ethanol prices did not significantly affect VAS profitability, that becomes more feasible than BAU at processing rates close to 750 kg/day (according to the "crossover" point). This could be mainly attributed to the effect of ethanol recovery: no recovery of ethanol makes the solvent responsible for 33 % of the variable costs, approximately. Otherwise, by applying solvent recovery, the purchase of lost ethanol (5 %) makes this input responsible for only 2,6 % of the variable costs.

As experimentally observed, lab-scale yields were around 50 %, especially due to a high extract retention on the cake, which, industrially can be overcome by applying press filtration: in this case, a sensibility analysis was applied considering this lower extraction yield. Fig. 8G shows the results. Regarding yield's reduction from 90 % to 50 %, the VAS scenario was also unfeasible when compared to BAU, that is, VAS's NPV is always lower than BAU, for daily processing up to 5 ton/day. Close to 5 ton/day, a "crossover" point is observed. This result shows that it is key to boost the extraction process' yield, which could be mitigated industrially, as previously mentioned, with the use of the filter press.

Fig. 8H and I show another sensitivity analysis applied on Buriti fruit purchase costs. According to the National Supply Company, CONAB (conab.gov.br/info-agro/custos-de-producao) Buriti fruit's prices can vary due to seasonal or regional effects, but also, and mainly, due to climate changes. In this case, the effect of decreasing the Buriti fruit's purchase price was evaluated, considering half-price (\$1.1/kg). Fig. 8H shows that Buriti's price largely impacts venture's feasibility such that at a minimum processing rate of approximately 750 kg of buriti/day, VAS scenario becomes more profitable than BAU. Indeed, Buriti's purchase costs are responsible for almost 8 % of total variable costs. Still, Fig. 8I shows a hypothetical scenario where the enterprise has no cost for Buriti acquisition. This considers a reality where the enterprise itself owns Buriti exploitation: since Buriti is obtained from extractive production, costs could be neglected. This is the scenario that presents the faster return on investment, surpassing BAU's scenario at processing rates close to 500 kg/day and with a positive NPV at processing rates close to 200 kg per day.

Results show that adapting the processing plant to incorporate practices related to the circular economy is possible under some conditions. The price of buriti oil significantly affects the profitability of the enterprise. The sale of the defatted cake is crucial to enable these modifications. Increasing the price of the cake is possible and can significantly improve venture's profitability. This could be performed by boosting studies that justify its use in applications with higher added value, due to its nutritional characteristics, and according to several works that have already shown that defatted flours obtained from nuts and seeds can be used in applications such as baking, biscuits or food supplements (Aracava et al., 2022; Capellini et al., 2019; Navarro and Rodrigues, 2018). Buriti's purchase price is also key to the project's economic viability. Considering that the enterprise itself can be responsible for the extraction of Buriti, neglecting its acquisition costs, becomes the best scenario. Also, despite the high fixed costs related to the incorporation of high-cost equipment for ethanol recovery, this practice is essential from an economic, but also sustainability point of view. These modifications not only comply with the principles of the circular economy but, additionally, make it possible to add value to the main residue from the processing of buriti pulp, the residual

semi-defatted cake obtained after cold pressing, increasing the profitability of the enterprise.

4. Conclusion

The CE perspective was applied in this work to evaluate strategies within the Buriti processing chain, focusing on the valorization of its main residue, the semi-defatted cake obtained after oil production. As an alternative to the ongoing practice, i.e. use of this residue for animal feed or burning, a solvent extraction process using ethanol was successfully evaluated for further oil production from this solid matrix, also providing a new value-added material (defatted cake) improved in proteins and carbohydrates. In a large-scale scenario, the lab-scale extraction yield could be boosted by filter pressing, avoiding oil retention in the cake or by continuous extraction. Presence of carbohydrates and proteins, due to ethanol polarity, were also discussed, and process scale-up should consider a proper process time to improve extracts' lipid content. When compared to cold pressed oil, the cake's oil slightly differs in terms of FA profile, with a higher saturated FA content, resulting in a lipid for different technological applications when compared to pulp oil. It is interestingly similar to Macauba pulp oil, an important Brazilian crop, used in food, chemical and bioenergy industry.

This strategy was further evaluated in the context of an Amazonian Buriti processing plant, as a case study. Besides creation of this *closed loop*, from a CE perspective, and within the ReSOLVE framework, other strategies were considered to improve venture's sustainability, such as process optimization and use of low environmental impact inputs. In this context, Good Harvesting and Preprocessing Practices (GHP and GPP) were observed as key to improving oil quality, avoiding losses due to high acid/peroxide oils, improving processes yields. A low humidity environment, postharvest rapid destination to processing plant, proper storage and pulp enzymatic inactivation are the main recommendations in this case. Cake's oil extraction scale-up also demands the acquisition of specialized equipment, especially for solvent recovery, that in this work was focused on ethanol as a greener alternative to hexane.

Lastly, according to the NPV's assessment, this new scenario (VAS) is feasible in some processing and market conditions, such as daily buriti processing rate close to 750 kg/day, Buriti oil prices at \$200/liter and a defatted cake flour sold at \$10/kg. This scenario can be boosted by lower Buriti fruit prices or considering self-exploitation of the fruit by the enterprise (fruit at no costs), decreasing processing rates. Also, the ethanol recovery cycle was economically essential for venture's feasibility. It is important to mention that the ongoing venture's practice is already aligned with the CE perspective. However, this work suggests that, despite the feasibility of the new scenario is dependent on the increase of the current venture's production status and obtaining of higher quality and value-added products, the new strategies here discussed could enhance the current practice on the CE context, with the valorization of the Buriti chain.

Therefore, future studies should address the valorization of defatted flour, evaluating their application in high-value products for food or specialized animal nutrition, which could increase its price and venture's profitability. Still, considering the high fixed costs for equipment acquisition, and the demand for specialized processes, studies on the impact of public policies and scientific research in the valorization of extractive production chains in the Brazilian Amazonian region are essential. It is important to mention that, in case of the evaluated plant, the business was a result of public national funding and technical support of non-governmental organizations and scientific institutions. This shows that, for installation of processing plants of Amazonian raw-materials, in the context of Bioeconomy development, income generation, mitigation of deforestation, and uncontrolled use of natural resources, public policies are fundamental, associating financial funding for plant installation but also technical support, without which economic feasibility of local business at an industrial scale would not be possible. This could promote not only the valorization of the Buriti

(*Mauritia flexuosa*) chain, one of the most important products from Brazilian socio-biodiversity, from a socio-economical point of view, but also could boost the whole Bioeconomy of Brazilian biomass.

CRediT authorship contribution statement

Gonçalves Maria Luiza M B B: Writing – original draft, Validation, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Gonçalves Daniel:** Visualization, Methodology, Investigation, Formal analysis. **Sampaio Neto Oscar Z:** Visualization, Validation, Methodology, Conceptualization. **Meirelles Antonio J A:** Supervision, Resources, Project administration, Funding acquisition. **Batista Eduardo A C:** Supervision, Resources, Project administration, Funding acquisition. **Sampaio Klicia A:** Visualization, Supervision, Resources, Project administration, Investigation, Conceptualization. **Maximo Guilherme J:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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