

Supercritical extraction of buriti oil (*Mauritia flexuosa*) as an innovative approach to obtain natural food ingredients from the Amazon: a review

Extração supercrítica de óleo de buriti (*Mauritia flexuosa*) como uma abordagem inovadora para obtenção de ingredientes alimentares naturais da Amazônia: uma revisão

Extracción supercrítica del aceite de buriti (*Mauritia flexuosa*) como método innovador para obtener ingredientes alimentarios naturales de la Amazonia: una revisión

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ABSTRACT

The Amazon is rich in oil-bearing plant species, which possess valuable physicochemical, nutritional, and nutraceutical properties, with great technological and economic potential for various industrial applications. The buriti (*Mauritia flexuosa*) is one of the most relevant Amazonian fruits for the region due to its high levels of monounsaturated fatty acids, carotenoids, and tocopherols, demonstrating its high potential for use as an ingredient in the food industry. Although further investigations should be conducted to correlate the chemical composition with the biological benefits of regular consumption of buriti oil extracted with supercritical fluid, as well as to evaluate its characteristics and estimate possible applications, this technique has already been reported as economically viable for obtaining superior quality buriti oil. In this context, the aim of this research is to explore the supercritical extraction of buriti oil as an innovative approach for obtaining natural food ingredients from the Amazon.

Keywords: food, bioactive compound, supercritical fluid, technology.

RESUMO

A Amazônia é rica em espécies vegetais oleaginosas, que possuem valiosas propriedades físico-químicas, nutricionais e nutracêuticas, com grande potencial tecnológico e econômico para várias aplicações industriais. O buriti (*Mauritia flexuosa*) é um dos frutos amazônicos mais relevantes para a região devido aos seus altos níveis de ácidos graxos monoinsaturados, carotenoides e tocoferóis, demonstrando seu alto potencial para uso como ingrediente na indústria alimentícia. Embora mais investigações devam ser realizadas para correlacionar a composição química com os benefícios biológicos do consumo regular de óleo de buriti extraído com fluido supercrítico, bem como para avaliar suas características e estimar possíveis aplicações, essa técnica já foi relatada como economicamente viável para a obtenção de óleo de buriti de qualidade superior. Nesse contexto, o objetivo desta pesquisa é explorar a extração supercrítica de óleo de buriti como uma abordagem inovadora para obtenção de ingredientes alimentares naturais da Amazônia.

Palavras-chave: alimentos, composto bioativo, fluido supercrítico, tecnologia.

RESUMEN

La Amazonia es rica en especies vegetales oleaginosas, que poseen valiosas propiedades fisicoquímicas, nutricionales y nutraceuticas, con gran potencial tecnológico y económico para diversas aplicaciones industriales. El buriti (*Mauritia flexuosa*) es una de las frutas amazónicas más relevantes para la región debido a sus altos niveles de ácidos grasos monoinsaturados, carotenoides y tocoferoles, lo que demuestra su alto potencial de uso como ingrediente en la industria alimentaria. Aunque es necesario realizar más investigaciones para correlacionar la composición química con los beneficios biológicos del consumo regular de aceite de buriti extraído con fluido supercrítico, así como para evaluar sus características y estimar sus posibles aplicaciones, esta técnica ya ha sido reportada como económicamente viable para la obtención de aceite de buriti de calidad superior. En este contexto, el objetivo de esta investigación es explorar la extracción supercrítica del aceite de buriti como un enfoque innovador para la obtención de ingredientes alimentarios naturales de la Amazonia.

Palabras clave: alimentos, compuesto bioactivo, fluido supercrítico, tecnología.

1 INTRODUCTION

The Amazon biome is rich in oilseed plant species, which have valuable physicochemical, nutritional and nutraceutical properties, with great technological and economic potential for various industrial applications and the development of new products. Buriti (*Mauritia flexuosa*) is one of the Amazonian fruits of great relevance to the region due to its high nutritional value and presence of bioactive compounds, especially monounsaturated fatty acids, carotenoids and tocopherols. And it has aroused a growing interest in the market, which is increasingly looking for healthy and natural products, demonstrating its high potential to be used as a bioactive ingredient in the food industry (Bovi et al., 2017; Cândido et al., 2015; Freitas et al., 2017).

Extraction is an important step involved in the recovery of bioactive compounds from plant materials and among the various methods that can be applied to extract oils, extraction with supercritical fluid stands out. A unitary operation, where solvents, such as carbon dioxide (CO₂), are used above their critical points to extract soluble components from a mixture, allowing efficient removal of the substances of interest (Herrero et al., 2013; Ferreira et al., 2013). This technology has been developed in laboratories and industries around the world in several areas, the food industry being one of the most important that has made it stand out on the world stage due to the absence of solvents that are harmful to health and the environment (Braga; Gaspar and De Sousa, 2023).

Previous studies have already reported that extraction with supercritical fluid can be economically viable for obtaining buriti oil with superior quality when compared to other extraction methods. This is mainly due to variations in the operational parameters that the technique allows and which cause changes in the solubility of the supercritical fluid and consequently affect the yields and chemical compositions of the products generated (França et al., 1999; Chañi-paucar et al., 2021;

Ramos-Escudero et al., 2022). In this context, the objective of this research is to explore the supercritical extraction of buriti oil (*Mauritia flexuosa*) as an innovative approach to obtaining natural food ingredients from the Amazon.

2 THE BURITI (*Mauritia flexuosa*)

The buritizeiro, popularly known as buriti, is a palm tree native to the Amazon that belongs to the Arecaceae family. They are distributed throughout the northern region of South America, mainly in the Amazon region, in Peru, Bolivia, Colombia, Ecuador, Venezuela, Guyana and Brazil, where it is found in different states such as Amapá, Rondônia, Goiás, Bahia, Minas Gerais, Mato Grosso, Ceará and Maranhão, with greater predominance in Pará and Amazonas (Henderson et al., 1995; Virapongse et al., 2017).

Buriti has very specific and striking botanical characteristics that differentiate it from the other species of palm trees that make up the biodiversity that surrounds it. The harvest season runs from December to July, with maximum productivity in April. Adult specimens have a spherical crown with large leaves that can reach up to 6 meters in length, grouped between 10 and 20 leaves located in the terminal portions of the stem. The trunk is cylindrical and smooth, with a diameter that varies from 30 to 60 cm, and can reach up to 40 meters in height under favorable conditions, mainly in permanent or periodically flooded areas, as shown in Figure 1. Each palm tree produces an average of 8,000 fruits during its lifespan. life cycle, with an estimated production of 290 kg per year (Santos, 2005; Passos and De Mendonça, 2006).

Figure 1 – Buriti palm tree (*Mauritia flexuosa*) in a periodically flooded area.



In the Amazon, this species is of great cultural, environmental and economic importance. Practically all parts of the plant are used to produce different products, from handicrafts and toys to the construction of houses and bridges, serving as a source of subsistence for the local population. In addition to providing habitat and food for a wide range of wildlife (Brightsmith and Bravo, 2006; Lasso; Colonnello and Moraes, 2016; Castellanos et al., 2017).

Another important plant resource are its fruits with their red, hard and scaly skin, which covers a soft and oily pulp, which varies from yellow to reddish, depending on the stage of maturation and chemical profile, as shown in Figure 2. They have flavor and peculiar aroma and are consumed as food, especially by the local population, being a source of important nutrients due to their complex chemical composition. In the literature there are several studies that indicate that the edible part of the fruit contains macro and micro nutrients, such as carbohydrates, proteins, lipids, fiber, vitamins and minerals. In addition to monounsaturated fatty acids, phenolics, carotenoids and tocopherols, biologically active compounds that provide important health benefits (Lognay et al., 1987; Vásquez-Ocmín et al., 2009; Santos et al., 2013; Cândido et al., 2015; Santos et al., 2015).

Figure 2 – Buriti fruits (*Mauritia flexuosa*).



3 PHYSICAL-CHEMICAL PROFILE AND PROPERTIES OF BURITI OIL (*Mauritia flexuosa*)

The oil extracted from the pulp with buriti bark is the highlight product of this production chain, known for its functional properties related to high concentrations of fat-soluble compounds with biological activity, making it a promising raw material with potential applications in the food, pharmaceutical, cosmetics and others (Silva et al., 2009; Aquino et al., 2012; Santos et al., 2013). In general, its fatty acid profile is mainly composed of monounsaturated and unsaturated acids, with emphasis on oleic acid, followed by palmitic acid and linoleic acid, which indicates a good perspective in the use of this product for nutraceutical purposes. Furthermore, the low concentration

of polyunsaturated fatty acids gives buriti oil high oxidative stability (Darnet et al., 2011; Aquino et al., 2012; Aquino et al., 2015; Serra et al., 2018).

It also has a high content of carotenoids, a class of natural lipophilic pigments, responsible for the yellow-red color, as shown in Figure 3. These components are related to important physiological functions and actions, acting in the prevention of various diseases, due to their antioxidant capacity, protecting the cells and tissues against the harmful effects of reactive oxygen (ROS) and nitrogen species (RNS). The main carotenoid found in buriti is β -Carotene, a precursor of vitamin A, which can reach 70% of its composition, followed by α -carotene and lutein (Albuquerque et al., 2005; Rodrigues et al., 2012; Cândido et al., 2012; al., 2015; Bataglion et al., 2015; Tocopherols are fat-soluble compounds, found mainly in foods rich in polyunsaturated fatty acids, such as buriti. They are considered natural antioxidants with important biological activity. They have vitamin E activity, protecting the body against malfunction, particularly against cardiovascular diseases and cancer. The most common in buriti oil are α -tocopherol and β -tocopherol, with α -tocopherol being the most active form of vitamin E (Darnet et al., 2011; Freitas et al., 2017).

Figure 3 – Oil extracted from the pulp with skin of the buriti fruit (*Mauritia flexuosa*).



It is worth mentioning that the composition and, consequently, the nutritional value of crude oil may vary due to exogenous and endogenous factors, such as region, season, cultivation and management conditions, climate, type of soil, luminosity, stage of maturation, factors genetics etc. As well as the preparation of the sample and the extraction process used (Rosso and Mercadante, 2007; Barbosa et al., 2009; Silva et al., 2009; Milanez et al., 2016).

4 SUPERCRITICAL EXTRACTION

Technology involving supercritical fluids is a promising process for extracting and isolating high-value compounds from natural raw materials. It is a highly selective technique that avoids thermal degradation and the presence of toxic solvent residues in the extracts that can alter the desirable natural characteristics, especially due to low temperatures and the chemical properties of the solvents used (Brunner, 2005), which has achieved the interest of the food industry.

The fluids used in this type of extraction are in a supercritical state, that is, they are above the critical point, where they acquire physical and chemical properties intermediate between the liquid state and the gaseous state - density and diffusivity similar to a liquid and viscosity similar to a gas (Sovová et al., 2005; Sovová, 2012). In this condition, the fluids begin to present high diffusivity, high density and low viscosity, which results in high solvation power, making it easier to penetrate solid porous matrices, contributing to an increase in the mass transfer rate (Brunner, 2005; Herrero et al. al., 2006; Rosa et al., 2009).

Carbon dioxide (CO₂) is the fluid most used in supercritical extraction, especially in food processing, as it is considered safe (GRAS) and due to its physical-chemical properties and high adjustment power, which give it, as a solvent, the ability to easily change from gas to liquid and vice versa. Furthermore, it has a low temperature and critical pressure (T_c= 31°C and P_c= 72.9 bar), easy handling, miscible with other solvents, non-toxic, non-flammable, chemical inertness and relatively moderate cost. Pure supercritical carbon dioxide (SC-CO₂) is a lipophilic solvent, considered a non-polar substance. Therefore, non-polar organic compounds become well soluble, while polar compounds have reduced solubility in this solvent, which makes it an ideal solvent for application in vegetable oils (Rosa et al., 2009, Gil-Chávez et al., 2013 ; De Melo et al., 2014).

Temperature and pressure are operational parameters responsible for making a substance reach its supercritical state and directly influence the characteristics of the process and final products. Temperature is a critical parameter and its optimization is essential in order to avoid the degradation of heat-sensitive compounds (Brunner, 2005; Rosa et al., 2009; Cornelio-Santiago et al., 2017). Extraction by supercritical fluid involves high pressure rates, a preferred variable for adjustments, as it offers handling margins considerably greater than temperature, with the density of the fluid being the property most affected by pressure variations, which can give the supercritical fluid power of solvation approximate that of liquid solvents (De Melo et al., 2014). The dissolving power of a supercritical fluid depends on its density, which is strongly dependent on temperature and pressure conditions and can be easily changed with small variations in these parameters. The increase in pressure, at constant temperature, causes an increase in the density of the supercritical

fluid, increasing its solubilization power. Meanwhile, increasing temperature, at constant pressure, causes a reduction in the density of the fluid, reducing its solubilization power (Rosa et al., 2009).

In general, this unitary operation occurs in two steps. The first is extraction, where the solvent flows through the particles and comes into contact with the extractable components of the solid and dissolves them. And in the second, the raw material and substances dissolved in the supercritical solvent are separated, which, leaving the extractor, comes into contact with normal atmospheric conditions, causing the solvent and solutes to separate (Brunner, 1994; Brunner, 2005; Rosa et al., 2009). The supercritical extraction equipment basically consists of a high pressure pump, compressor, CO₂ cylinder, refrigeration bath, and a co-solvent pump. The solid samples, previously treated, are inserted into an extraction cell, which is then heated and pressurized until reaching pre-determined parameters, through the action of a high pressure pump, which allows the fluid in a supercritical state to travel through the system. and favor the separation and dragging of the compound of interest present in the solid matrix. Finally, the extractable compounds pass through a pipeline and are collected (Herrero et al., 2006).

5 SUPERCRITICAL EXTRACTION OF BURITI OIL (*Mauritia flexuosa*)

Meeting global demands for green food processing and naturally nutritious food products, supercritical technology has gained more and more attention. And over the years, it has been reported in the literature as an efficient method for obtaining oil from the buriti fruit, as briefly exemplified in Table 1.

Table 1: Information from the literature on the supercritical fluid extraction of buriti fruit (*Mauritia flexuosa*).

Parts of the plant	Compounds of interest	Reference
Pulp and peel	Pulp and peel Carotenoids, tocopherol, oleic, palmitic and linoleic acid	França <i>et al.</i> (1999)
Residue from the pressing process	Carotenoids	Prado <i>et al.</i> (2010)
Pulp	Oleic and palmitic acid	Cunha <i>et al.</i> (2011)
Pulp	Oleic and palmitic acid	Chañi-Paucar <i>et al.</i> (2021)
Pulp	Phenolics and flavonoids	Best <i>et al.</i> (2021)
Pulp	Phenolics and flavonoids	Best <i>et al.</i> (2022)
Pulp	Total oleic and palmitic acid, carotenoids, tocopherols, tocotrienols, sterol, polyphenols.	Ramos-Escudero <i>et al.</i> (2022)

Several authors have reported that oils extracted with supercritical fluid have superior quality when compared to other extraction methods. And optimizing this technique to obtain high yields, as well as the preservation of thermosensitive compounds, ensuring higher concentrations of bioactives, requires knowledge of both supercritical technology, as well as the raw material and the characteristics of the desired final products. Ramos-Escudero et al. (2022) evaluated the chemical composition of oil from three different morphotypes of *M. flexuosa* extracted by supercritical carbon dioxide by chromatography and identified high concentrations of carotenoids, tocopherols, tocotrienols, fatty acids and total polyphenols in all samples. However, important differences were observed between the samples in relation to their chemical composition and color parameters, even though the process conditions were the same, reinforcing that the characteristics of the raw material is also an important aspect that directly influences the final result.

The efficiency of supercritical extraction depends on the variation in fluid solubility and, consequently, on the selection of processing variables, such as pressure, temperature, solvent flow rate and extraction time, which are important and fundamental parameters for scaling up and for the industrial processing of *M. flexuosa* oil. França et al. (1999) evaluated the SC-CO₂ extraction of the pulp with the peel of immature buriti fruit and confirmed the effects of solvent flow, pressure and temperature on the mass transfer rate and, consequently, on overall yields. They also obtained an oily fraction with a high concentration of vitamins, mainly b-carotene. And the results evaluated by chromatography indicated that the extraction process was able to recover approximately 80% of the initial carotene content of the fruit. Chañi-Paucar et al. (2021) also observed the effects of processing variables in the extraction with supercritical fluid of the species originating from Peru and reported higher yields than those obtained in extraction with hexane and mechanical pressing, for example. The results also attest that changes in pressure and temperature did not affect the quality and fatty acid profile or the qualitative phytochemical profile of the extracted oil, but significantly affected the overall yields, probably due to the greater solubility achieved with the increase in the solvation power of the oil SC-CO₂ under the conditions studied.

Another advantage of supercritical extraction is the possibility of sequential integration with other processes to increase the yield and recovery of specific bioactive compounds, and thus generate products with unique characteristics. The first study carried out by Best et al. (2021) using the fruits of *M. flexuosa* showed that the sequential use of a SC-CO₂ extraction and a conventional solvent extraction provided total polyphenol and flavonoid contents 8.4 and 2.4 times higher, respectively, compared to the extracts obtained by conventional solvent extraction alone. Furthermore, two products with different characteristics were generated: extracts rich in oil and phenolics.

Studies have shown that supercritical fluid extraction (EFS) can be economically viable for obtaining plant extracts. However, it is important to study the economic viability of this technology, as investment costs are normally cited as the main reason why there are no industrial SFEs yet. Prado et al. (2010) studied the extraction with supercritical fluid of oils rich in carotenoids from three Amazonian palm trees, including buriti, and highlighted that the extraction time was the determining factor for the final concentration of carotenoids in the oils. The economic feasibility study, using literature data and experimental data to estimate the cost of manufacturing the oils, indicated that the costs of oils obtained by EFS, in general, were higher than those of pressed oils. However, it is known that oils obtained with supercritical technology are proven to be richer in carotenoids, which should determine higher sales prices and special uses for this product, highlighting its competitive advantage. Best et al. (2022) carried out an economic evaluation and sensitivity study of the by-products generated through two processes: a two-step sequential extraction process, combining EFS and a conventional extraction process with solvent and the conventional extraction process with isolated solvent. The authors reported that although the manufacturing cost in the process involving supercritical fluid was higher compared to the conventional technique, in the first process, two products of high nutraceutical and commercial value were obtained, showing that the process was more economically advantageous for obtaining of bioactive compounds on an industrial scale from *M. flexuosa*.

6 POTENTIAL APPLICATION OF BURITI OIL (*Mauritia flexuosa*) EXTRACTED WITH SUPERCRITICAL CO₂ IN THE FOOD INDUSTRY

The properties of buriti oil are already widely used for cosmetic applications, being produced and sold on a small and large scale for this purpose. However, even though the fruit and buriti oil also have excellent nutritional and functional characteristics, their food consumption is still limited to local communities where the fruit is abundant, mainly homemade or artisanal, in little processed foods, such as juices, jams, ice creams, wines and creams, adding little value to this raw material in this segment (Nascimento-Silva; Silva e Silva, 2020). And, taking into account that there is currently an increase in demand for innovative and healthy foods, with different compositions, including not only flavors, aromas and colors, but also nutritional and functional compounds with positive effects on health, the use of buriti oil in the food industry (Durães et al., 2006; Temelli, 2009).

Buriti oil extracted with SC-CO₂ has a unique color, aroma and flavor profile, characteristic of the fruit's pulp and skin, related to the concentration of bioactive compounds, especially carotenoids. Prado et al. (2010) reported that oils extracted with supercritical fluid had a more pronounced yellowish/reddish color when compared to pressed oils and reported a higher

concentration of carotenoids. This suggests that oils extracted with supercritical technology could be used as natural dyes to replace the commonly used artificial ones, as in addition to adding color to the product, it also adds high nutritional value. The study also suggested mixing it with other oils, such as soybean oil, to increase the population's intake of provitamin A.

The results found by Chañi-Paucar et al. (2021) and Ramos-Escudero et al. (2022) indicate promising potential for commercial applications of *M. flexuosa* oils, especially in the food industry, as a source of vitamins and natural antioxidants, which can be used in the development of functional foods and dietary supplements, for example. They also add that due to its fatty acid profile, especially high concentration of oleic acid, buriti oil can be incorporated as an alternative to improve the oxidative stability and shelf life of unstable, highly polyunsaturated oils.

Among the advantages of extraction with SC-CO₂ already reported in comparison to conventional methods, in addition to the high yield and high concentration of bioactive compounds, the absence of organic solvents, harmful to health and the environment, stands out, making the oil not toxic. And there is no need for additional refining processes, which end up causing undesirable changes in the oils. This process also allows for an increase in production scale to meet the greater demand that the market requires, preserving the biological properties and bioavailability of the compounds, making the development of new ingredients and products based on buriti viable (Brunner, 2005; De Melo et al., 2014).

7 CONCLUSION

Despite its nutritional and economic potential, there are still few studies related to the application of buriti pulp oil (*Mauritia flexuosa*) in food products. Supercritical fluid technology is an interesting approach to obtain food products with the special characteristics and properties to meet current market demands in accordance with consumer requirements and needs. And when applied to buriti fruit, it results in a high quality oil containing nutrients and compounds with biological activity, especially monounsaturated fatty acids, carotenoids and tocopherols, with great potential for the food industry. Further investigations must be conducted to correlate the chemical composition with the biological benefits of regular ingestion of buriti oil extracted with supercritical fluid, as well as to evaluate its characteristics and estimate possible applications, seeking to add commercial value to this very important species in the Amazon.

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DECLARATION OF CONFLICTING INTERESTS

The author(s) declare(s) that there is no conflict of interest.

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