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Functionality of lipid extracts obtained by green extraction from red pupunha (*Bactris gasipaes* Kunt)

Funcionalidade dos extratos lipídicos obtidos por extração verde da pupunha vermelha (*Bactris gasipaes* Kunt)

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The focus on diversity in the Amazon forest is related to fruits and oilseeds that have diverse nutritional and functional values in their composition and contribute to human health. Therefore, this research aims to study the functional constituents of lipid extracts obtained from peach palm (*Bactris gasipaes* Kunt) of the red variety obtained by green extraction with the assistance of ultrasound probe. The methodology followed established and internationally accepted standards, with comparative analyses of the quality of the oils, fatty acid profile by gas chromatography (GC), cardiovascular functionality indices and chemical profile by Fourier transform infrared spectroscopy (FTIR). The results obtained in this research demonstrate a yield equal to 9.81% on a dry basis, in addition to demonstrating high quality of the lipid extracts, presenting an acidity index equal to 1.85 mg KOH/g, a peroxide index equal to 2.75 mE/kg in of the limits established by Brazilian legislation. The fatty acid profile shows a high concentration of omega-9 (59.03%), an index of the ratio of hypocholesterolemic and hypercholesterolemic fatty acids equal to 2.45 and a predominance of unsaturated fatty acids, highlighting omega 9 (60.2 %), 6 (3.90%) and 3 (1.05%). FTIR spectra confirm a high presence of unsaturated fatty acids. Therefore, the data demonstrate benefits of extracting peach palm oil assisted by ultrasound, as it provides maintenance of nutritional and functional quality, keeping the constituents linked to the anti-inflammatory processes.
Keywords: lipid extracts, *Bactris gasipaes* Kunt, green extraction.

O enfoque para a diversidade da floresta amazônica está relacionado aos frutos e sementes oleaginosas que dispõem de valores nutricionais e funcionais diversificados em sua composição e contribuem para a saúde humana. Dessa forma, esta pesquisa tem a finalidade de estudar os constituintes funcionais dos extratos lipídicos obtidos da pupunha (*Bactris gasipaes* Kunt) da variedade vermelha obtidos por extração verde com assistência de ultrassom por sonda. A metodologia seguiu as normas estabelecidas e aceitas internacionalmente, sendo realizados análises comparativas da qualidade das frações lipídicas, perfil de ácidos graxos por cromatografia gasosa (CG), índices de funcionalidade cardiovasculares e perfil químico por espectroscopia de infravermelho por transformada de Fourier (FTIR). Os resultados obtidos nesta pesquisa demonstram rendimento igual a 9,81% em base seca, além de demonstrar alta qualidade do óleo apresentando índice de acidez igual a 1,85 mg KOH/g, índice de peróxidos igual a 2,75 mE/kg dentro dos limites estabelecidos pela legislação Brasileira. O perfil de ácidos graxos mostra alta concentração de ômega-9 (59,03%), índice da razão de ácidos graxos hipocolesterolêmicos e hipercolesterolêmicos igual a 2,45 e predominância de ácidos graxos insaturados, destacando-se os ômegas 9 (60,2%), 6 (3,90%) e 3 (1,05%). Os espectros de FTIR confirmam elevada presença de ácidos graxos insaturados. Sendo assim, os dados demonstram benefícios de extração do óleo da pupunha assistido por ultrassom, visto que confere manutenção da qualidade nutricional e funcional, mantendo os constituintes vinculados aos processo anti-inflamatórios.
Palavras-chave: extratos lipídicos, *Bactris gasipaes* Kunt, extração verde.

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1. INTRODUCTION

In recent decades, Brazil has been going through a nutritional transition, in which the high prevalence of malnutrition has given way to a greater occurrence of obesity and Chronic Noncommunicable Diseases (NCDs) – such as type 2 diabetes mellitus, cardiovascular diseases, among others – resulting from social, economic and cultural transformations [1]. According to the Ministry of Health (2021) [2], NCDs are the cause of half of the total deaths in the Brazilian population, recording 54.7% of deaths in 2019. Given this, the search for healthy and functional foods has gained notoriety in the current scenario, giving space to Amazonian palm fruits for their nutritional richness [3, 4].

The Amazon has a fruit industry internationally recognized for its abundance of peculiar flavors and colors, which brings with it new aspects of raw materials, sources of resources applicable in different sectors, such as: isolation of compounds, applications of extraction technologies, pharmaceuticals, among others. Furthermore, the same species can harbor different varieties and carry with it particularities of compounds, proportions, structures, colors, flavors, genetic differences and countless changes caused by successive hybridizations that can interfere in the composition of the products and by-products of these Amazonian food sources [5-7]

Among the varied fruit sources in the Amazon region, peach palm (*Bactris gasipaes*) stands out, which is a palm tree belonging to the Arecaceae family, reaching 20 meters in height and 15-25 centimeters in width in adult palms [7, 8]. Regarding its morphological characteristics, variations in shape, size, composition of the mesocarp, color of the fruit and pulp, as well as the percentage of oil can be observed [9].

Among the varieties of peach palms (*Bactris gasipaes*), the red peach palm stands out, which can have a diverse composition, with a content of lipids, proteins and carbohydrates that can vary according to the form in which it is presented (raw or cooked). One of the nutritional relevances is its quality parameters and organic functionality present, as well as the concentrations of polyunsaturated fatty acids, with emphasis on omega-9 (oleic acid), omega-6 (linoleic acid) and omega-3 (linolenic acid) according to recent research on the association of good lipid sources and improving the immune system. Furthermore, peach palm fruit also has a high content of carotenoids that have significant relevance for cardiovascular and cognitive health [4, 10-13].

Research revealing the potential of Amazonian fruits focuses largely on the isolation of food compounds. Such research has shown that the quality of materials extracted from plant sources, such as oilseeds, is strongly influenced by the use of different extraction techniques [14]. Among these, the most traditional forms with organic solvents stand out, especially those derived from petrochemical industries and their deleterious actions on the triad of man, raw material and the environment.

In this context, ultrasound-assisted extraction (UEA), using “green solvents”, is advantageous in minimizing losses in functional quality of bioactive constituents. With special emphasis on thermosensitive and photosensitive constituents, with less complex, faster techniques and with a good cost-benefit ratio, when compared to other forms of extraction such as solid-liquid extraction (Soxhlet), pressing, supercritical, microwave, and enzymatic [15]. In addition, UEA is based on three pillars of green chemistry: maintaining the quality of the isolated raw material and ensuring human and environmental health safety. Adding new fronts to a virtuous cycle of actions that bring together “technological innovations” with the most environmentally appropriate technological practice.

Given this, the relevance of the present work is justified by the need for more studies on the potential of Amazonian oilseeds in food, in addition to the interest in the search for new sources of vegetable oils with therapeutic functionalities. Therefore, this research aims to study the functional constituents of lipid extracts obtained from peach palm (*Bactris gasipaes* Kunt) of the red variety obtained by green extraction assisted by ultrasound with a probe.

2. MATERIAL AND METHODS

2.1 Raw material

This research is registered with access activity in the National System for Management of Genetic Heritage and Associated Traditional Knowledge (SisGen, AA5BEE7). This variety of the *Bactris gasipaes* plant is registered in the HF Professora Normélia Vasconcelos Herbarium under registration no. 4070.

Five kg of red peach (*Bactris gasipaes* Kunth) were purchased from the metropolitan region of Belém, referring to the 2022-2023 harvest. The samples were transported in Low Density Polyethylene (LDPE) plastic bags and stored in the Food Sciences Laboratory at UFPA at a temperature of 7 ºC.

2.2 Sample preparation

The fruits were cooked with water in a pressure cooker for 15 minutes, according to the traditional procedure carried out in Northern Brazil, followed by peeling with a stainless steel knife. The cooked peach palm pulps were subjected to freeze-drying (Solab, model SL-404B), crushed separately in a Willye knife mill (Fortinox brand, model Start FT 50) and underwent granulometric separation in a digital electromagnetic sieve shaker (Bertel, model VP-01, São Paulo, Brazil), vacuum packed (Scepter, model DZ-280) and stored away from light for subsequent analyses.

2.3 Extraction and yield of peach palm oil

Ultrasound-assisted extraction was carried out according to Ordóñez-Santos et al. (2019) [16] following the best parameters obtained in the optimization of peach palm oil extraction with ultrasound assistance. The solvent used in the extraction is based on the premise of green chemistry with 99.9% Ethanol, (M=46.07 g/mol) from the Synt brand. The pulps were crushed and weighed (5g) in an amber Erlenmeyer flask, using an analytical balance and adding the extraction solvent in a ratio of 1:5 (weight/volume). This mixture was subjected to an extraction process assisted by ultrasound with a probe using ultrasound equipment (Hilescher, model UP 100H) for 30 minutes with a frequency of 20 kHz and a temperature of 50 ± 2 °C. Then, the miscella resulting from the extraction was vacuum filtered and then separated in a rotary evaporator at a temperature of 50 ºC, obtaining the concentrated lipid fraction that was stored in an amber container at a temperature of 7 ºC. The was calculated as the ratio between the mass of lipid fraction extracted and the mass of pulp used.

2.4 Lipid fraction: quality parameters

To evaluate the quality of the oil, we took as a basis the requirements of Brazilian legislation according to normative instruction nº 87 of March 15, 2021 [17] for the acidity indices that will be evaluated using the Cd 3d-63 method and peroxides Cd 8-53 [18].

2.5 Analysis of the fatty acid profile

The fatty acids profile in lipid fraction was established by methyl esterification, in accordance with the methodological recommendation of the International Organization for Standardization ISO 5509 [19]. After phase separation, the collected supernatant was used in gas chromatography analysis (GC Varian 430 USA) equipped with a microcomputer using the Galaxie Chromatography software based on the following chromatographic conditions: fused silica capillary column SP®-2560 (Supelco, USA) (100 m long x 0.25 mm internal diameter) containing 0.2 μm polyethylene glycol.

The operating conditions were: fractional injection, ratio 50:1; column temperature at 140 °C for 5 min, programmed with an increasing rate of 4 °C per min up to 240 °C; carrier gas: helium, isobaric pressure of 37 psi, linear velocity of 20 cm/s; compensation gas: helium at 29 mL/min; injector temperature of 250 °C, (model Varian CP 8410) (autosampler); detector temperature of 250 °C. Qualitative composition was determined by comparing peak retention time with respective fatty acid profiles. The quantitative composition was carried out by area normalization, being expressed as a percentage of mass as established by the official Ce 1-62 method [20].

2.6 Functional quality of lipid fractions

The functionality of lipid fractions was established based on their respective chromatographic profiles using three composition indices: (1) atherogenicity index (AI), (2) thrombogenicity index (TI) according to Ulbricht, Southgate (1991) [21], and (3) the hypercholesterolemic ratio (HH) index defined by Santos-Silva et al. (2002) [22].

(Equation 1)

$$I.A = \frac{[(C12:0) + (4XC14) + (C16)]}{(\Sigma\ AGMI + \Sigma\ \omega - 6\ +\ \Sigma\ \omega - 3)}$$

(Equation 2)

$$I.T = \frac{(C14:0 + C16:0 + C18:0)}{[\ (0.5X\ \Sigma\ AGMI) + (0.5\ X\ \Sigma\ \omega 6)\ + (3X\ \Sigma\ \omega 3) + (\Sigma\ \omega 3/(\Sigma\ \omega 6)]}$$

(Equation 3)

$$H.H = \frac{(C18:1\omega 9 + C18:2\omega 6 + C20:4\omega 6 + C18:3\omega 3 + C20:5\omega 3 + C22:5\omega 3 + C22:6\omega 3)}{(C14:0 + C16:0)}$$

2.7 Infrared spectroscopy

Fourier Transform Infrared Spectroscopy (FTIR) analyzes on the lipid fraction were performed on a Perkin Elmer spectrometer, model Frontier 98737 (Waltham, MA, USA) at 25 °C in the wavenumber range 4000-400 cm^{-1}. Sample spectra was recorded by averaging 20 scans with 4 cm^{-1} resolution in transmission mode. The images were plotted in the Origin 8 program.

3. RESULTS AND DISCUSSION

3.1 Yield of red peach palm lipid fraction

The yield of red peach palm lipid fraction obtained by ultrasound-assisted extraction was on average 9.81% on a dry basis. When comparing this yield to data presented in other research with conventional forms of extraction with solvents considered non-green, such as those of Santos et al., (2020) [4] with hexane, the extraction yield using solid-liquid methods with a Soxhlet apparatus the average was 23.75% on a wet basis. In studies by Silva et al. (2020) [23] with extraction with petroleum ether solvent, the average was 11.75% on a wet basis.

Table 1: Physicochemical quality parameters of red peach palm lipid fraction.

Analysis	**Mean ± SD**	**Reference***
Acid value (mg KOH/g)	0.85 ± 0,55^a	4,0 mg KOH/g
Peroxide index (mEq/kg)	1,75 ± 0,35^a	15 mEq/kg

SD: Stantard Deviation; Source: Research Protocol, 2023.
*Normative Instruction No. 87 of March 15, 2021 (BRASIL, 2021) [17].

In relation to the quality standard expressed in Table 1, based on current legislation, the acidity and peroxide indices showed averages of 0.85 mg KOH/g and 1.75 mE/kg respectively, within the limits established by Brazilian legislation, with based on the requirements of quality and conservation standards for edible oils, following normative instruction nº 87 of March 15, 2021 [17] which establishes the maximum acidity and peroxide values for edible vegetable oils and fats, 4 mg KOH.g^{-1} and 15 mEq.kg^{-1}, respectively.

Comparing the results of this research with those of Santos et al. (2020) [4] who evaluated the quality standards of red peach palm oil, whose extraction procedure used was the solid-liquid method with a Soxhlet apparatus – they found the acidity value equal to 2.45 mg KOH/g and peroxide index equal to 5.47 mEq/kg. Therefore, even if they are within the values required by legislation, the increase in the acidity index may be related to the aggressiveness of the extraction method used in this study, which strengthens the idea that red peach palm oil obtained by assisted extraction by ultrasound presents better quality parameters when compared to the extraction method used by Santos et al. (2020) [4].

Such indices, such as acidity, are variables related to the nature and quality of the raw material, revealing the state of conservation of the oil, based on the deteriorating action of temperature, light and oxygen, elements that accelerate the decomposition of glycerides, accompanied by formation of free fatty acids. The peroxide index, in turn, consists of evaluating the initial stages of the oxidative process by determining the concentrations of hydroperoxide that are capable of oxidizing potassium iodide, quantifying its concentration. These indexes is the only ones legally defined in Brazil to determine the physical-chemical quality of oils and fats [17].

Differences in yield and quality results may be related to several factors, from origin, harvest, location, edaphoclimatic characteristics and mainly to the extraction method applied in this research, since extraction with green solvent, derived from renewable sources such as Sugar cane, is one of the pillars of green chemistry. The yield and quality indices evaluated may be reduced due to the lower aggressive power of the solvent on the lipoprotein membrane and the process of direct sonication on the membranes involving the peach palm pulp under study.

3.2 Fatty acid profile

The fatty acid profile patterns that make up this lipid fraction, its nutritional and functional quality based on estimates of protection with cardiovascular indices are presented in Table 2.

The data presented in the fatty acid profile shows that the saturated content highlights the presence of palmitic acid (26%), which influences the physical appearance, as the considered proportion of saturated fatty acids interferes with this aspect. This value found in our research was lower when compared to the data found by Santos et al. (2017) [24] and Santos et al. (2020) [4] in orange and red peach palm, with levels above 40%, which does not characterize these oils as solid at room temperature, since this content was less than 40%.

Among the unsaturated ones, the biggest highlight is the monounsaturated fatty acid omega-9 (oleic acid), with 59.03%, followed by the polyunsaturated fatty acids omega-6 (linoleic acid) and omega-3 (linolenic acid), with 3.90% and 1.05%, respectively. Considering the average amount of omega-6 (3.90%), the oil obtained from red peach palm pulp can be characterized as an intermediate source of this fatty acid, according to the categories listed by Santos et al. (2020) [25] and Rufino et al. (2020) [26]. When the omega-6 content of red peach palm (3.90%) is compared to other Amazonian species, we observed that it was higher than the levels found in buriti (2.9%) and tucumanzinho (2.6%), and the omega-3 was on average 1.05%, higher than that of these fruits analyzed by Santos et al. (2018) [27].

Table 2: Fatty acid composition (%) and functionality indexes of red peach palm lipid fraction.

Fatty acids (%)	**Red peach palm***	**Santos et al. (2020) [4]**
Saturated fatty acids (SFAs)		
Lauric C12:0	0.01	ND
Myristic C14:0	0.10	0.10
Palmitic C16:0	26.0	50.57
Arachidonic C20:0	0.17	ND
Monounsaturated fatty acids (MUFAs)		
Palmitoleic C16:1	10.01	3.39
Oleic C18:1	59.03	35.27
Polyunsaturated fatty acids (PUFAs)		
Linoleic C18:2	3.90	5.18
Linolenic C18:3	1.05	1.17
Σ SFAs	26.28	50.5
Σ MUFAs	69.04	38.66
Σ PUFAs	4.95	6.35
PUFAs/SFAs	0.18	0.125
Atherogenicity Index (A.I.)	0.35	1.10
Thrombogenicity Index (T.I)	2.13	2.04
Hypocholesterolemic and hypercholesterolemic ratio	2.45	0.84

*Data represents mean of duplicates.

Among the most important functions of essential fatty acids, we refer to the recommendations of the Food and Agriculture Organization of the United Nations (2010) [28], which states the need for an intake of omega 6 between 2.5-9% and omega 3 between 0.5-2%, as its adequate consumption helps regulate the inflammatory process, oxidative stress and endothelial function [29]. Considering the effects of fatty acids on human health, the importance of consumption and knowledge of these Amazonian fruit sources stands out.

The majority prevalence of approximately 74% of unsaturated fatty acids ratifies the nutritional and functional potential present in the red peach palm pulp, combined with the fact that the application of an extraction technology anchored in the principles of green chemistry, with environmentally suitable solvents, does not show negative insertions in the quality of its fatty acid profile when compared to other research with the same fruit, but with solvents that are harmful to the raw material, nature and humans [30].

In this sense, the maintenance of the nutritional and functional constituents of red peach palm is observed, with recognized anti-inflammatory action when observed its metabolic routes of conversion into docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), which regulate the production of prostaglandins that have protective action against platelet aggregation and inflammatory processes, in addition to arachidonic acid (AA) which, among others, give rise to eicosanoids, the main inflammatory mediators of lipid origin [31, 32]. Thus, foods known to contain essential fatty acids in these proportions are important as providers of greater anti-inflammatory protection [4, 31, 32].

The estimated indices of functional quality of the oil expressed in Table 2 show the positive effects of including fruits containing this composition in the usual diet for the body, the cardiovascular system and in preventing the development of NCDs. The atherogenicity index (A.I.) and the thrombogenicity index (I.T) estimate the functionality of the oil in relation to platelet aggregation and the prevention of the development of atherosclerosis and thrombosis; therefore, the lower the indexes, the better your response against heart disease [4]. In the present research, the averages were 0.35 for A.I. and 2.13 for T.I. When compared with the results obtained by Santos et al. (2020) [4] using a different extraction method (Table 2), we observed lower results for I.A and similar results for T.I, generally inferring better functional quality for oils extracted by ultrasound with green solvent.

The index of the ratio of hypocholesterolemic and hypercholesterolemic fatty acids has been related as a parameter for preventing cardiovascular health problems, directly interfering with cholesterol levels, helping to protect and being an adjunct in the treatment of coronary diseases; it is therefore inferred that the higher this index, the better its contribution to health [32]. In this research, the average value of this index was 2.45; if compared to the base oil as seen in Table 2, the result of this research is superior, indicating superior cardioprotective potential of this form of extraction.

3.3 Fourier transform infrared spectroscopy

Other chemical compounds can be visualized through specific chemical groups, spectral bands and vibration modes presented in Figure 1.

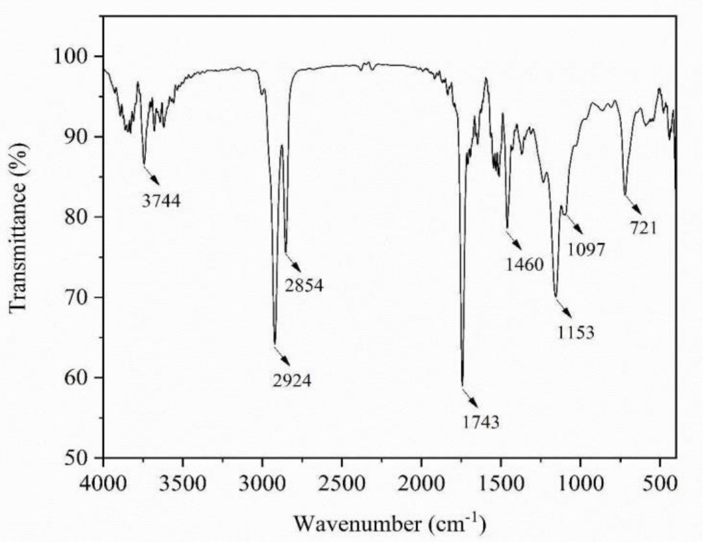

Figure 1: Fourier transform infrared spectroscopy.

The FTIR spectra of red peach palm lipid fraction obtained by ultrasound-assisted extraction shows absorption bands in high frequency ranges with variations in intensity, with prominent peaks 3744 cm^{-1}, 2924 cm^{-1} and 2854.cm^{-1} related to vibration stretching of methylene (-CH2), with different intensities. Other bands that varied between 1743.cm^{-1} and 1460 cm^{-1} are present with strong intensity and are characteristic of the carbonyl group (C=O), methyl esters, ketones and aldehydes frequently found in materials containing a long-chain fatty acid profile and are related to the stretching vibration of the triacylglycerol ester bond (– C=O) and bending vibration of the aliphatic groups CH_2 and CH_3 (– C–H), respectively [3, 9].

Highlight is given to the prominent bands at 1153 cm^{-1} and 1097 cm^{-1}, respectively, which are characteristic of the presence of carbonyl functional groups (C–O), esters, ethers and carboxylic acids. Its presence in high intensity is linked to its high number of oleic groups, as shown in the profile of fatty acids found in this oil (Table 2) with an average of 60%. The last prominent band is located around 721 cm^{-1} and is associated with the aliphatic chain of fatty acids linked to sequences of aromatic fatty acid rings and carbon-carbon bonds, confirming the high proportion of unsaturated fatty acids present in the profile of sample [3, 9].

4. CONCLUSION

The extraction method applied to the pulp of the red peach palm showed lower lipid fraction yields, however, they revealed a high-quality material, as demonstrated by the comparative analyzes expressed by the fatty acid profile.

The functionality estimated by the IT, IA and HH indices confirm the high antiatherogenic and antithrombogenic action, with a high hypocholesterolemic/hypercholesterolemic ratio based on the chromatographic profile of fatty acids, with a predominance of unsaturated fatty acids, mainly omega-3, 6 and 9.

The groups of organic compounds expressed in the infrared spectrum did not reveal interference from oxidative elements in the analyzed material, taking into account the green extraction method used. In addition, the high-frequency peaks confirmed the presence of functional groups referring to the presence of long-chain fatty acids, as demonstrated in the fatty acid profiles.

These data reinforce the need to continue research that optimizes new methods and extraction techniques for the isolation and analysis of materials that ensure that products are protected from oxidation, and that follow the precepts of green chemistry resulting in materials of high nutritional and functional quality, with supporting action in anti-inflammatory processes.

Thus, the application of UEA in the isolation of lipid fractions from red peach palm confirms the maintenance of the bioactive functional constituents in the isolated product, generating new possibilities for applications as inputs for pharmaceutical industries given its high concentration of anti-inflammatory constituents (omegas), in dermocosmetics with photoprotective action with its high levels of antioxidants (β-carotene), in food industries with its high concentration of macronutrients, among others. Thus, UEA can be applied, especially when it is desired to obtain high-quality raw material, without affecting human and environmental health, combining “technological innovations” with sustainability.

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