



Evaluation of quality parameters, physicochemical and bioactive properties of licuri oil (*Syagrus coronata*)

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ABSTRACT

This study aimed to conduct a comprehensive analysis of licuri (*Syagrus coronata*) oil, exploring its composition, quality parameters, bioactive profile, and physicochemical properties. Licuri oil was extracted by cold pressing from mature fruits and subjected to extensive chemical characterization, including lipid, protein, water content, peroxide value, acidity, trace metals, carboxylic acid, total polyphenol, carotenoids and tocopherols. The oil's lipid profile, including fatty acid, and triacylglycerol profile was also determined. Antioxidant capacity was determined by DPPH radical scavenging assay (IC₅₀), melting and crystallization behaviors were examined via differential scanning calorimetry (DSC), complete rheological profile was assessed through stress – strain curves, and oil's oxidative stability determined by Rancimat apparatus. The analysis revealed that licuri oil has favorable characteristics, such as low water content (0.54 %), peroxide value within regulatory limits (5.83 mEq/kg), and low free fatty acid content (0.09 %). It is a rich source of lauric acid (45.01 %), with significant amounts of myristic (13.2 %), caprylic (12.34 %), and oleic acid (10.79 %), similar to coconut or palm kernel oils, largely applied in industry. The predominance of triglycerides derived from lauric acid contributes to its functionality, including an interesting melting and rheological profile, making it suitable for various food and cosmetic applications. Additionally, licuri oil exhibits a significant content of phenolic compounds (196.73 µg CAE/g) and tocopherols (7.79 µg/g), leading to improved oxidative stability (30.09 h at 110 °C), and antioxidant capacity, thus making licuri oil a healthier alternative to conventional oils.

1. Introduction

The Caatinga region, an exclusive semiarid biome in Brazil, is recognized for its ecological and cultural richness, hosting a unique biodiversity that has adapted to the extreme conditions of this environment (Noutcheu et al., 2024). *Syagrus coronata* (Martius) Beccari, commonly known as licuri, is a native palm that plays a pivotal role in

the economy and sustenance of rural communities in the region (Souza et al., 2021) due to the high content of oil and protein present in the seed of its fruit (Neves et al., 2023). The extraction of licuri oil is carried out from the almond, the seed of the licuri fruit, which is particularly rich in saturated fatty acids (Guimarães et al., 2021). The most common extraction method is mechanical pressing, using an expeller press or a hydraulic press, which applies pressure to the seeds to extract the oil.

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This extraction process aligns with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 12, which aims to ensure responsible consumption and production patterns, as pressing without chemical solvents has a lower environmental impact. Furthermore, the valorization of licuri as a native resource and its exploitation by small local communities is related to SDG 8 (Decent Work and Economic Growth), as it promotes job creation and agricultural production diversification, while stimulating the local economy (Faria et al., 2025).

Previous studies have shown that licuri almond has a high oil content, ranging from 49 to 60 %, and its richness in saturated fatty acids such as lauric, myristic, and caprylic acids. The presence of lauric acid is critical due to its associated bioactive properties, including antimicrobial and antioxidant effects (Lisboa et al., 2020). Studies have also explored the antibacterial potential of licuri oil, demonstrating activity against *Staphylococcus aureus* strains with varying resistance profiles, thus positioning it as a potential alternative in combating infections, especially given the rising threat of antibiotic resistance (Santos et al., 2019; Souza et al., 2021).

Licuri has long been used in traditional medicine and local cuisine and is a critical food source for the region's wildlife. Recent studies have significantly advanced the understanding of licuri oil and its diverse applications. Menezes et al. (2024) analyzed the volatile compounds in both cooked green and naturally ripe licuri almonds. They found that limonene was prevalent in ripe almonds, while aldehydes and alcohols were more common in cooked almonds, indicating that both could be valuable for enhancing flavor and aroma in food products. Moreira et al. (2024) investigated the production of ester bioaromas in licuri oil using lipase-mediated alcoholysis, which resulted in an oil with antimicrobial properties against bacteria such as *Staphylococcus hominis* and *Corynebacterium xerosis*. Barbosa et al. (2024) demonstrated that licuri oil possesses significant antinociceptive and anti-inflammatory effects, reducing pain and inflammation in mice without showing oral toxicity. Fernandes et al. (2022) explored the use of licuri agroindustrial waste for producing a corrosion inhibitor, achieving 91 % efficiency in protecting mild steel surfaces.

Despite these findings on nutritional and therapeutic potential of licuri oil, significant gaps remain in the full characterization of licuri oil physicochemical and bioactive properties, essential information for comparison with other vegetable oils already known on the market and, therefore, the development of new process and products. In this context, this work presents a systematic and detailed characterization of 3 main aspects of licuri oil: i) Assessment of oil quality parameters, related to raw-material (lipids, water, protein, carbohydrate, and ash content), as well as process and storage conditions (color, peroxide value, acidity, trace metals, and carboxylic acid profile); ii) Characterization of lipids and bioactive compounds (fatty acids, acylglycerols, tocopherols, polyphenols, and carotenoids), directly impacting oil properties and applications; iii) Determination of physicochemical properties (rheological, melting and crystallization profiles, antioxidant capacity and oxidative stability), related to food, cosmetic or pharmaceutical applications. Furthermore, data here obtained can significantly contribute to increase the knowledge about natural resources of Brazilian Cerrado, promoting, consequently, their sustainable exploitation and the biome preservation.

2. Material and methods

2.1. Material

The licuri oil used in this study was kindly provided by the Cooperativa Produtores e Agroextrativistas Frutos da Terra (Coopefrut), Miguel Calmon, Bahia, Brazil. The licuri fruits were manually harvested in October 2023. Maturity was determined based on the external appearance of the fruits, specifically when the husk (epicarp) turned fully yellow, indicating optimal ripeness. After harvesting, damaged or immature fruits were manually selected and removed. The almonds were then separated from the fruits using a knife, and the oil was

extracted by cold pressing using a Radial Tubular system (model ERT 60III, Scott Tech, Brazil), performed at ambient temperature (approximately 28 °C).

For quality parameters and bioactive profile analyses, the following materials were used: Ultrapure water (Millipore Direct-Q3 UV, Millipore Corporation, USA); Folin-Ciocalteu reagent (Dinâmica, Brazil); methanol (95 % grade, ACS, Brazil); ethyl acetate (95 % grade, Synth, Brazil); sodium carbonate (Na_2CO_3) (95 % grade, Dinâmica, Brazil); caffeic acid (98 % grade, Sigma-Aldrich, USA); and hexane (99 % grade, J.T. Baker, USA). Additionally, 2,2-diphenyl-1-picrylhydrazyl (DPPH) (Sigma-Aldrich, USA); sodium hydroxide (95 % grade, ACS, Brazil); sodium chloride (99.5 % grade, Sigma-Aldrich, USA); a 15-component fatty acid methyl esters (FAME) mix (Sigma-Aldrich, USA); tetradecane (99 % grade, Sigma-Aldrich, USA); pyridine (99.9 % grade, Sigma-Aldrich, USA); *N*-bis(trimethylsilyl)trifluoroacetamide (BSTFA) (Sigma-Aldrich, USA); ammonium hydroxide (28 %, 95 % grade, J.T. Baker, USA); and isopropanol (99 % grade, Sigma-Aldrich, USA) were also employed. For lipid class analysis, the esterifying reagent solution used in the preparation of the fatty acid profile consisted of ammonium chloride (95 % grade, Exodo, Brazil), sulfuric acid (98 % grade, Qhemis, Brazil), and methanol (99.9 % grade, Sigma-Aldrich, USA). The tocopherol standards included γ -, α -, and δ -tocopherol, as well as γ -, α -, and δ -tocotrienol (Merck, USA). A syringe filter with a hydrophilic PTFE membrane (0.45 μm pore size, 25 mm diameter, Analítica, Brazil) was used for extract preparation.

2.2. Assessment of composition and oil quality parameters

2.2.1. Composition, peroxide and acidity values

Lipids, water content, peroxide value and titratable acidity were determined according to the American Oil Chemists' Society (AOCS, 2017) standards. The lipid content was assessed utilizing an automated extractor (XT15 model, ANKOM Technology, USA) and a dryer (Dryer HCl Filter model, ANKOM Technology, USA), following the AOCS Method Am 5-04. Water content was determined according to Ca 2e-84 method by Karl Fisher (870 KF Titrino plus, Metrohm, Switzerland); peroxide value was determined according to Cd 8b-90 method; titratable acidity was performed with an automatic titrator (848 Tritino plus, Metrohm, Switzerland) and expressed in free fatty acids (FFA) content according to Cd 3d-63 method. Protein and ash content were determined following methodologies from the Association of Official Analytical Chemists (AOAC, 1998). The protein content was determined using the Kjeldahl method (method 988.05), while ash content was determined by incineration in a muffle furnace (method 940.26). The carbohydrate content was calculated by subtracting the sum of lipid, water, protein, and ash contents from 100. Analyses were performed in triplicate and presented alongside their standard deviations.

2.2.2. Trace metals

Trace metals were analyzed in triplicate following the guidelines outlined in American Society for Testing and Materials method D5185-18 (ASTM, 2018). The quantification of inorganic elements was conducted using axial measurements in a dichroic spectral combiner (ICP OES 5100 SVDV, Agilent Technologies, Japan). The operational parameters included a plasma power of 1.5 kW, argon flow rate set at 15 L/min, auxiliary argon flow at 0.4 L/min, nebulization flow maintained at 0.45 L/min, and a stabilization time of 15 s. Wavelengths of 317.93 nm, 259.94 nm, 280.27 nm, and 213.62 nm were utilized for the determination of calcium, iron, magnesium, and phosphorus, respectively.

2.2.3. Color

Color measurement was performed using Lovibond colorimeter (Lovibond PFX995, Tintometer, United Kingdom), following the AOCS Cc13e-92 method (AOCS, 2017), measuring color on Lovibond RYBN scale through visual comparison of the licuri oil with Lovibond filters (R

to red index, Y to yellow index, B to blue index, and N to neutral index).

2.2.4. Carboxylic acid profile

The carboxylic acid profile, related to oil degradation during process and storage, was performed in triplicate and presented alongside their standard deviations. Carboxylic acids were determined according to the methodology described by Souza et al. (2017), using an ion chromatograph (model 940 Professional IC Vario, Metrohm, Switzerland), equipped with a Metrosep Organic Acid 250–7.8 column (250 × 7.8 mm), pre-column with the same internal composition of the main column, and an automatic sampler model 858 Metrohm. For the extraction of carboxylic acids, approximately 10.0 g of sample were weighed into a falcon tube, and 20 mL of ultrapure water were added. The tube was placed on a vortex mixer (model Genius 3, IKA, Brazil) and mixed for 1 min. Then, the tube was placed in a thermostatic bath at 85 °C for 30 min. Finally, the tube was transferred to an ultrasonic bath (model USC 2800 A, Unique, Brazil) at 25 °C for 20 min. After phase separation, the aqueous phase was collected with disposable syringe and needle, filtered through a filter, and transferred to the chromatograph's 11 mL vial for injection.

2.2.5. Fourier-transform infrared spectroscopy (FT-IR) spectra

Oil's FT-IR spectra were obtained using a Fourier-transform infrared spectrometer (Cary 630 FTIR, Agilent, USA), equipped with a temperature-controlled Attenuated Total Reflectance (ATR) sample holder accessory with ZnSe crystal MicromATR (Czitek, Danbury, CT - USA). The licuri oil samples were maintained at room temperature prior to analysis to ensure liquidity and homogeneity. A small amount of sample (approximately 2 drops) was then applied onto the heated ZnSe crystal MicromATR. The spectra were collected over different time periods, covering the range of 4000 to 650 cm^{-1} .

2.3. Lipids and bioactive compounds profile

2.3.1. Fatty acids, mono- di- and triacylglycerol composition

The fatty acids profile and lipid class composition were performed in triplicates and presented alongside their standard deviations. Fatty acid profile was assessed through gas chromatography following the Ce 1–62 method outlined by the AOCS (2017). Utilizing a gas chromatograph (model 7890B, Agilent, USA) equipped with a flame ionization detector (FID) and a capillary column (Agilent model DB-WAX) boasting dimensions of 30 m in length, 0.25 mm in internal diameter, and a film thickness of 0.25 μm , the analysis was conducted. Helium served as the carrier gas at a flow rate of 25 mL/min. The column temperature program was as follows: an initial ramp from 50 °C to 120 °C at 15 °C/min, with a 15-min hold; followed by an increase of 4 °C/min until 200 °C, with a 3-min hold; and a final increase of 4 °C/min until 250 °C. The licuri oil were transesterified in FAME, according to Hartman and Lago (1973) with adjustments. Briefly, 50 mg of oil was mixed with 4 mL of 0.5 N sodium hydroxide in methanol. The test tube was tightly sealed to prevent leaks and heated in a boiling water bath for 8 min, or until the solution became clear. After cooling rapidly in an ice bath, 5 mL of esterification reagent was added, and the mixture was reheated in the water bath for 5 min. The tube was cooled again in an ice bath, and 4 mL of saturated sodium chloride solution was added. The mixture was vigorously shaken for 30 s, followed by the addition of 5 mL of hexane and another round of vigorous shaking. After resting, the upper organic phase containing the FAME was collected for injection into the gas chromatograph. Peak identification was achieved through comparison of retention times with fatty acid methyl ester standards.

Determination of monoacylglycerols (MAG) and diacylglycerols (DAG) via gas chromatography adhered to the methodology outlined in the AOCS method Cd 11-b-91 (AOCS, 2017). The same gas chromatograph was employed, utilizing a capillary column (model Agilent DB-5HT) with dimensions of 15 m in length, 0.32 mm in internal diameter, and a film thickness of 0.10 μm . Helium was the carrier gas at a flow

rate of 5 mL/min. The column temperature program started at 60 °C with a 1-min hold, followed by an increase of 10 °C/min until 360 °C, with a 15-min hold. Approximately 50 mg of oil was weighed, and 100 μL of a tetradecane solution (internal standard) in pyridine was added, along with 300 μL of BSTFA. The mixture was placed in a derivatization tube, shaken, and heated at 70 °C for 20 min. After cooling, 50 μL of the reaction mixture was diluted with 1 mL of hexane and injected into the gas chromatograph. Quantification of MAG and DAG content was conducted through extrapolation from the calibration curves and summation of retention time areas. Triacylglycerol (TAG) content was subsequently derived by deducing 100 from the calculated values of MAG, DAG and FFA content.

The determination of TAGs compositions was conducted following a combinatorial analysis approach as outlined by Antoniosi Filho et al. (1995) using Matlab version 6.0. This method relied on a model of random distribution of fatty acids in glycerol. The content of trisaturated TAGs (Tri-STAG) was considered as 60.79 %, as described by Liu et al. (2019) for coconut oils.

2.3.2. Tocols profile

The tocopherols analysis was performed in triplicate and presented alongside their standard deviations. Tocopherols were determined using ultra-high performance liquid chromatography with -electrospray ionization and -mass spectrometer detector (UHPLC/ESI/MS) (Waters Acquity, USA), as outlined by Ansolin et al. (2017). For the UHPLC analysis, a C18 column (model UPLC BEH C18, Waters Acquity, USA) with dimensions of 130 Å pore size, 1.7 μm particle size, 2.1 mm internal diameter, and 50 mm length was employed. The mobile phase consisted of methanol: water: ammonium hydroxide (99:1:0.1 v/v/v) and isopropanol. Samples of licuri oil were diluted at 8000 $\mu\text{g/mL}$ in isopropanol before analysis. Instrument control and data acquisition were performed using MassLynx software. The obtained correlation coefficients were greater than 0.99, indicating the method's suitable linearity.

2.3.3. Total polyphenol and carotenoids content

The total polyphenol content was assessed using the Folin-Ciocalteu reagent method. Samples of licuri oil were processed to obtain extracts using methanol and ethyl acetate as solvents, following established protocols from Haiyan et al. (2007) and Szydłowska-Czeriak et al. (2008), with suitable adaptations. Briefly, 3 g of oil were mixed with methanol and ethyl acetate in 50 mL Falcon tubes and homogenized using an orbital shaker (Novatecnica, Brazil) at 200 rpm for 1 h. The mixture was then centrifuged (Hettich, Rotina 380 R, Germany) at 10,000 rpm for 10 min. A 1 mL aliquot of the supernatant was reacted with 0.5 mL of Folin-Ciocalteu reagent for 3 min, followed by the addition of 1 mL of 10 % saturated Na_2CO_3 solution and 7.5 mL of ultrapure water. After homogenization, the mixture was left to react for 1 h before measuring the absorbance at 725 nm using a UV-Vis spectrophotometer (Thermo Scientific, Orion AquaMate 8000, USA). A calibration curve was prepared using caffeic acid solutions at concentrations of 12.5, 25, 50, 100, and 200 $\mu\text{g/mL}$, yielding the calibration equation (absorbance x concentration): $y = 0.0104x + 0.0953$ ($R^2 = 99.50$ %). The analytical blank consisted of methanol, ethyl acetate, Folin-Ciocalteu reagent, Na_2CO_3 solution, and ultrapure water mixed in the same proportions as the samples. Analyses were performed in triplicate, and results were expressed as μg of Caffeic Acid Equivalent (CAE) per gram of oil (μg CAE/g).

The total carotenoids concentration in licuri oil was assessed via UV-Vis spectrophotometer (Orion AquaMate 8000 UV-vis, Thermo Scientific, USA) at 446 nm, employing a methodology adapted from Rodriguez-Amaya (2001). Approximately 2 g of licuri oil was diluted in hexane to obtain 5 mL of extract volume, and the total carotenoid content (in μg β -carotene/g of sample) was calculated using the Eq. (1).

$$\text{Total carotenoids } (\mu\text{g } \beta\text{-carotene/g}) = \frac{A \cdot V \cdot 10^6}{A_{1\text{cm}}^{1\%} \cdot m} \quad (1)$$

where A is the absorbance at 446 nm, V is the extract volume in mL, $A_{1\text{cm}}^{1\%}$ is the absorption coefficient of β -carotene in hexane (2590), and m is the oil sample mass in grams. The results were expressed as μg of β -carotene equivalents per gram of oil.

2.4. Physicochemical properties

Viscosity measurements were conducted using a rheometer (AR1500ex, TA Instrument, United States). The experiments were conducted across a range of shear rates from 1 to 300 s^{-1} at four temperatures, 25 °C, 45 °C, 65 °C and 85 °C. The calculation of viscosity was carried out using Newton's law equation. The shear stress to shear rate data was analyzed using linear regression to fit Newton's model. The slope obtained from the linear regression indicates the kinetic viscosity (η) at each temperature.

2.4.1. Melting and crystallization profile

Differential scanning calorimetry (DSC) was used to analyze the melting and crystallization behavior of licuri oil. The equipment (2920 DSC, TA Instruments, USA) was calibrated with pure indium (TA Instruments), naphthalene, cyclohexane, and decane (purity >99.9 %, Sigma-Aldrich). A 5.00 ± 0.01 mg sample of oil was sealed in an aluminum pan and scanned at a rate of 5C/min to ensure stability according to Pereira et al. (2019). To induce crystallization, the sample was heated to 70 °C for 10 min, then cooled to −70 °C at the same rate to create the crystallization curve. Subsequently, it was reheated to 70 °C to generate the melting curve. The thermograms were analyzed using Universal Analysis 2000 software (TA Instruments, New Castle, USA) to determine peak temperatures (T_{peak}) for both crystallization and melting curves.

2.4.2. Oxidative stability index

The oxidative stability of the samples was evaluated using accelerated lipid oxidation with the Rancimat equipment, following the Cd 12b-92 method (AOCS, 2017). Oil samples (5 g) were heated on an electric block, while clean, dry, filtered air was passed through them at a flow rate of 9 L/h. The volatile organic acids released from the samples were collected in distilled water, and the conductivity of the water was monitored to assess oxidation progress. The oxidation induction time (OIT), representing the time until a sharp increase in conductivity, was determined at temperatures of 110, 120, 130, and 140 °C by identifying the intersection of the baseline with the tangent to the conductivity curve. The Arrhenius equation was employed to illustrate the effect of temperature on lipid oxidation rate (Eq. 2). The activation energy and pre-exponential factors were calculated from the slopes and intercepts of the regression lines generated by plotting $\ln(k)$ vs. $1/T$ using least squares linear regression, respectively. The kinetic rate constant (k, h^{-1}) was obtained as the inverse of OIT:

$$\ln(k) = \ln A - (E_a/RT) \quad (2)$$

where k is the reaction rate constant, A is the pre-exponential factor, E_a is the activation energy, R is the molar gas constant, and T is the absolute temperature.

2.4.3. Antioxidant capacity

Antioxidant capacity was determined using the DPPH free radical scavenging method, following adapted protocols from Valavanidis et al. (2004) and Espin et al. (2000). Samples were prepared by mixing 2.4 g with 8 mL ethyl acetate in a 15 mL Falcon tube, then homogenized using a vortex shaker (model Genius 3, IKA, Brazil). Reaction mixtures with a fixed DPPH concentration (1×10^{-4} mol/L) and varying sample volumes (0, 100, 200, 400, 600, and 800 μL) were prepared in 15 mL Falcon

Table 1

Composition and quality parameters in licuri oil.

Variables	Results
Composition (% by mass)	
Lipids	98.18 ± 0.19 %
Water content	0.54 ± 0.05 %
Protein	nd
Ash	0.29 ± 0.04 %
Carbohydrates	0.99 %
FFA	0.09 ± 0.01 %
Peroxide value	5.83 ± 0.81 mEq/kg
Carboxylic acid profile	
Formic acid	nd
Acetic acid	nd
Propionic acid	nd
Butyric acid	nd
Valeric acid	nd
Hexanoic acid	nd
Heptanoic acid	nd
Octanoic acid	nd
Trace metals	
Calcium (Ca)	12.10 ± 0.20 mg/kg
Iron (Fe)	0.20 ± 0.01 mg/kg
Magnesium (Mg)	8.68 ± 0.01 mg/kg
Phosphorus (P)	32.20 ± 0.01 mg/kg
Color measurement	
R	1.13 ± 0.15
Y	3.70 ± 0.17
B	0.00 ± 0.00
N	0.10 ± 0.00

mEq: milliequivalent; FFA: free fatty acids; nd: not detected; CAE: caffeic acid equivalent; R: red index; Y: yellow index; B: blue index; N: neutral index; η : kinematic viscosity; $\pm$: standard deviation.

tubes. Absorbance was measured at 517 nm after 30 min using a UV–Vis spectrophotometer (model Orion AquaMate 8000 UV–vis, Thermo Scientific, USA). Curves of DPPH reduction (%) as a function of sample concentration (mg/mL) were constructed and results were expressed as Inhibitory Capacity (IC_{50}) – mg/mL.

3. Results and discussion

3.1. Composition and quality parameters

Table 1 presents composition and quality parameters, including trace metals and carboxylic acid profile for licuri oil. The results indicate that licuri oil has a relatively high lipid content, comprising approximately 98.18 ± 0.19 % of the composition, along with insignificant levels of protein and ash, which is consistent with expectations for a vegetable oil. Additionally, the oil exhibits a relatively low water content, with an average of 0.54 ± 0.05 %, which is positive for its stability and shelf life. The carbohydrate content (0.99 %), calculated by difference, represents the remaining components after deducting the other constituents. While it is uncommon to find carbohydrates in commercial oils, their presence in licuri oil may be associated with traces of plant matter, such as fruit or seed residues during the extraction process.

With an average peroxide value of 5.83 ± 0.81 mEq/kg, the oil falls within the regulatory thresholds stipulated by Brazilian legislation (values below 15 mEq/kg). This adherence to standards is attributable to appropriate storage practices and minimal exposure to oxygen and light, mitigating the risk of peroxidation common in vegetable oils (Santos et al., 2020; Serra et al., 2019). Commercial crude vegetable oils often contain FFA at levels up to 5 %, resulting from cellular damage to plant tissue during harvesting, storage, transportation, or processing, posing challenges for the edible oil industry, requiring removal through refining. Damage can be caused by factors like bruising, freeze-thaw cycles, hot/humid conditions, or microbial activity (Nguy, et al., 2022). Licuri oil exhibits low FFA content (0.09 ± 0.01 %), suggesting minimal cellular damage and supports the notion of good oil quality and

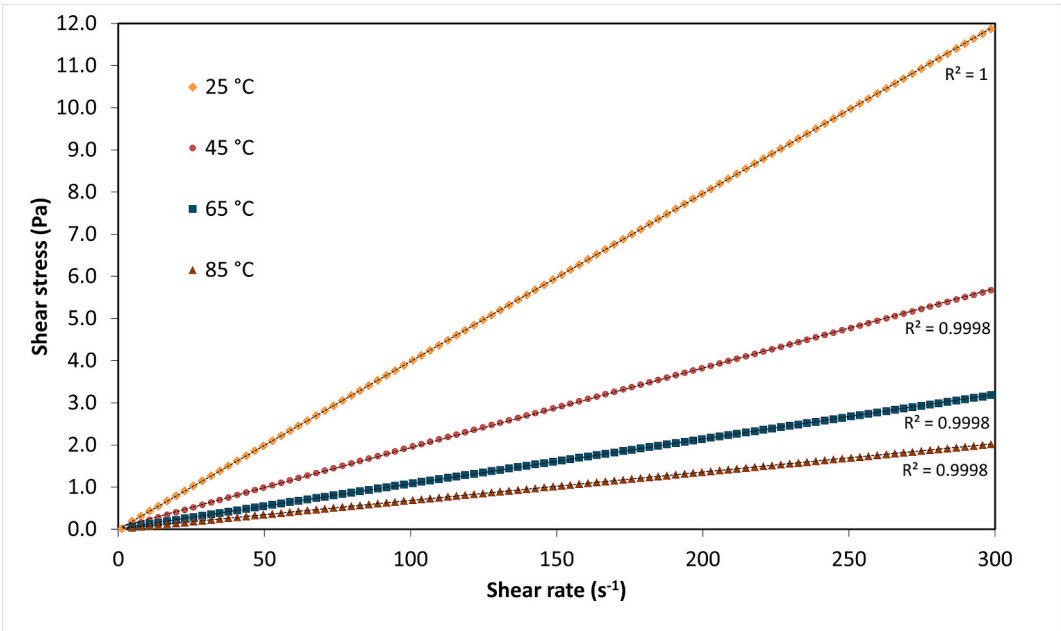


Fig. 1.. Relation between shear stress and shear rate of licuri oil at 25 °C, 45 °C, 65 °C, and 85 °C.

no need to refining, as FFAs serve as indicators of oil degradation, particularly in crude oils (Wei et al., 2019).

The color analysis results indicate that licuri oil has a low average value of yellow color (3.70 ± 0.17 on a scale of 0 to 70 in Y). In general, the yellow color can be attributed to the presence of certain pigments or compounds such as carotenoids. Licuri oil also exhibits relatively low red and neutral hues, with average values of 1.13 ± 0.15 (on a scale of 0 to 70 in R) and 0.10 ± 0.00 (on a scale of 0 to 3.9 in N), respectively. This suggests that the oil has a predominantly light color, with little presence of pigmentation. It is important to emphasize that a light color is a desirable quality attribute in crude oils, indicating the non-occurrence of oxidation and darkening reactions during the process (Bauer et al., 2020).

The quality and acceptability of licuri oil can be also significantly influenced by the presence of metals, responsible for increasing the oxidation rate of the oils and impacting freshness and storage capacity. Environmental factors contribute to metal contamination, with elements in soil, water and air affecting the composition of oils (Souza et al., 2022). Calcium, iron, magnesium, and phosphorus were detected in licuri oil at average concentrations of 12.10 ± 0.20 mg/kg, 0.20 ± 0.01 mg/kg, 8.68 ± 0.01 mg/kg, and 32.20 ± 0.01 mg/kg, respectively.

Notably, licuri oil exceeds the recommended phosphorus limit of 5 mg/kg in vegetable oil, indicating the need for physical refining to ensure compliance with quality standards. In fact, the phosphorus content is seen as an impurity in vegetable oils since it can cause darkening of the oil, result in off flavors, and impose difficulties on the oil downstream processing (Pereira et al., 2019).

The analysis of the carboxylic acid profile in licuri oil revealed the absence of detection of all analyzed compounds, including formic, acetic, propionic, butyric, valeric, hexanoic, heptanoic, and octanoic acids. This absence can be interpreted as a positive indicator regarding the stability of licuri oil. Carboxylic acids are the final product of the degradation and deterioration of vegetable oils over time, indicating the level of lipid oxidation. Therefore, the non-detection of these compounds suggests that licuri oil may not have an influence on the lipid oxidation processes initiated. The results agree with the low level of peroxide found.

Fig. 1 presents the FT-IR spectra for licuri oil. It is possible to notice that the main bands were at 1743 cm^{-1} , attributed to stretching vibration of C=O ester groups, associated with the presence of glycerides classes, main constituents of vegetable oils; 2920 cm^{-1} and 2851 cm^{-1} characteristic of asymmetrical and symmetrical stretching vibration of

Table 2
Fatty acids profile and lipid class composition (% by mass) in licuri oil.

Fatty acids	This work	Literature							
		Antoniassi et al., 2022	Bauer et al., 2013	Guimarães et al., 2021		Alves et al., 2019	Iha et al., 2014	Mean	σ
State in Brazil	Bahia	Bahia	Bahia	Pernambuco		nd	Alagoas		
Caprylic Acid (C8:0)	12.34 ± 0.03	9.2	9.8	12.1	na	10.5	13.0	10.9	1.6
Capric Acid (C10:0)	7.43 ± 0.05	6.6	6.4	6.8	9.2	6.6	8.0	7.3	1.1
Lauric acid (C12:0)	45.01 ± 0.44	46.1	45.2	42.8	44.6	45.2	48.0	45.3	1.7
Myristic Acid (C14:0)	13.22 ± 0.04	14.6	14.8	14.2	19.0	14.9	14.0	15.3	1.9
Palmitic Acid (C16:0)	5.94 ± 0.05	6.5	7.1	6.6	10.0	7.2	5.0	7.1	1.7
Stearic Acid (C18:0)	2.45 ± 0.05	3.5	3.1	2.3	3.8	3.8	2.0	3.1	0.8
Oleic Acid (C18:1, N9)	10.79 ± 0.02	10.3	12.3	11.2	13.4	7.7	7.0	10.3	2.5
Linoleic Acid (C18:2, N6)	2.51 ± 0.01	2.8	2.8	2.9	nd	4.2	3.0	3.1	0.6
Others	0.31								
SFA	86.39	86.7	86.9	84.75	86.56	84.4	88	85.86	
MUFA	10.79	10.3	12.3	11.23	13.44	7.7	7	10.99	
PUFA	2.51	2.78	2.8	2.89	nd	4.2	3	3.17	

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; TAG: triacylglycerol; DAG: diacylglycerol; MAG: monoacylglycerol; $\pm$: standard deviation. na = not analysed, nd = not identified; σ = standard deviation for the values from literature.

CH₂ groups, respectively, indicating the presence of saturated hydrocarbon chains in the oil molecule, thus reaffirming the predominant composition of saturated fatty acids such as lauric acid in licuri oil; 1154 cm⁻¹ and 1109 cm⁻¹ referring to bending vibration of the CH₂ groups and stretching vibration of the C—O ester groups, respectively; 1465 cm⁻¹ attributed to scissoring vibration of the CH₂ and CH₃ groups, suggesting the presence of aliphatic hydrocarbons in the oil molecule; and 720 cm⁻¹ related to overlapping of the CH₂ rocking vibration and the out-of-plane bending vibration of cis-disubstituted olefins. The FT-IR analysis can be used, together with other analytical techniques, as an oil's fingerprint, confirming its identity and adulteration practices, not observed in this case. Also, it confirms their predominant composition in fatty acids, mainly composed by saturated and medium-chain fatty acids, but also oleic acid, whose results will be presented and discussed later (Aktar & Adal, 2019; Barbosa et al., 2022; Quiñones-Islas et al., 2013).

3.2. Lipids and bioactive compounds profile

3.2.1. Fatty acid and triacylglycerol profile

Table 2 shows the content of fatty acids and lipid class composition in licuri oil. Lauric acid appears as the predominant fatty acid, constituting 45.01 ± 0.44 % of the total, followed by myristic acid with 13.22 ± 0.04 % and caprylic acid with 12.34 ± 0.03 %. The results are in line with those found by Antoniassi et al. (2022) when evaluating the fatty acid profile of licuri oil (46.10 ± 1.10 % lauric, 14.60 ± 1.00 % myristic, and 9.20 ± 2.60 % caprylic).

In comparison with the study by Bauer et al. (2013), which analyzed refined and pressed licuri oil samples, the lauric acid content (43.4 % for refined and 44.2 % for pressed) and myristic acid content (13.89 % for refined and 14.45 % for pressed) are similar. However, the oleic acid content found (10.79 ± 0.02 %) was lower compared to both oils analyzed (12.83 % for refined and 12.08 % for pressed). Since the extraction method is the same, this difference may be related to intrinsic characteristics of the fruit, including the geographical location from which it was sourced, which could influence the fatty acid profile of the oil. Other fatty acids present include capric acid (7.43 ± 0.05 %), palmitic acid (5.94 ± 0.05 %), and stearic acid (2.45 ± 0.05 %), indicating that it is an oil rich in saturated fatty acids (SFA) (86.39 %). Oleic (10.79 ± 0.02 %) and linoleic acid (2.51 ± 0.01 %), mono- (MUFA) and polyunsaturated (PUFA) fatty acids, represent 13.30 % of licuri's fatty acid profile.

It is worth noting that licuri oil shares a similar composition to coconut oil (*Cocos nucifera*), which also has high levels of medium-chain fatty acids (MCFA), such as lauric acid (approximately 49.0 %), and myristic acid (approximately 8.0 %) (Boateng et al., 2016; Prasanna et al., 2024). It also presents resemblance with palm kernel oil (Sehgal et al., 2021), composed of up to 53.2 % and 19.3 % of lauric and myristic acid, respectively, and babassu oil (*Attalea speciosa*), containing 47.75 % lauric acid and 14.22 % myristic acid (Bauer et al., 2020). These lipids are commonly called lauric fats due to their high composition in lauric acid, whose physical properties allows the development of several food application, which is the case of cocoa butter substitutes (Norazlina et al., 2021), confectionery products, toppings and fillings for cookies or cakes, spreads, milk fat alternatives for margarines, vegan ice creams and cheese analogues ((Prasanna, et al., 2024; Sehgal & Sharma, 2021). Lauric fats are also recognized by their antimicrobial and moisturizing properties (Moreira et al., 2024), allowing cosmetic applications, such as in body creams, shampoos, balms and soaps (Verma et al., 2024). The high SFA value are responsible for products with good resistance to oxidation, stability at high temperatures and long shelf-life (Sakaino et al., 2022; Viidanoja, 2015). From a nutritional point of view, fats rich in MCFA, have been also recognized by their therapeutic effects and health benefits, when compared to longer-chain fats, such as in ketogenic diets, treatment of gastrointestinal disorders, body weight loss and LDL-cholesterol decrease (Pereira et al., 2023; Nimbkar et al., 2022;

Table 3

Triacylglycerol composition (% by mass) in licuri oil.

Molecular weight (g/mol)	TAG code	Concentration (%)
721.16	LaOLa	12.65
639.01	LaLaLa	10.79
582.90	LaLaCp	9.31
665.05	CpOLa	8.55
610.96	LaLaC	8.24
667.06	LaLaM	7.11
749.21	LaOM	6.26
693.10	COLa	6.22
695.12	LaLaP	4.07
554.85	CpLaC	3.68
526.80	CpCpLa	3.15
777.26	LaOP	3.09
719.14	LaLLa	2.97
723.17	LaLaS	2.11
663.03	CpLLa	2.03
636.99	CpOC	1.59
608.94	CpOCp	1.58
747.19	LaLM	1.55
691.09	CLLa	1.48
805.32	LaOS	1.41
751.22	PPLa	0.80
775.25	LaLP	0.78
498.74	CpCpC	0.58
Mono-UTAG		50.16
Di-UTAG		0.00
Tri-STAG		49.84

La: lauric acid; O: oleic acid; Cp: caprylic acid; C: capric acid; M: myristic acid; P: palmitic acid; L: linoleic acid; S: stearic acid; Mono-UTAG: monounsaturated triacylglycerols; Di-UTAG: diunsaturated triacylglycerols; Tri-STAG: Trisaturated triacylglycerols.

Dayrit, 2014; Sandhya et al., 2016), and together with MUFA and PUFA, reduced risks of cardiovascular diseases and alleviation of skin and allergic conditions (Baum et al., 2012). Therefore, the unique licuri oil's FA profile allows not only important technological applications with high added value, but also development of products with specific nutritional or therapeutic functionalities.

Licuri oil demonstrated notable lipid class composition, with TAG comprising most of its constituents (94.93 ± 0.12 %). This high proportion of TAG is indicative of the oil's quality, aligning with standards observed in high-quality vegetable oils, which typically contain over 90 % TAG. Further analysis revealed minor constituents within licuri oil, including DAG and MAG, which were found at concentrations of 4.03 ± 0.02 % and 0.95 ± 0.05 %, respectively, also contributing to the technological and functional properties of licuri oil (Serra et al., 2019).

Table 3 presents TAGs composition of licuri oil. Results show that this oil is composed of 49.84 % Tri-STAG and 50.16 % Mono-UTAG. In addition, TAGs mainly derive from lauric acid, with 19 of the 23 different TAGs. Among the identified TAG codes, the most abundant were LaOLa (12.65 %), LaLaLa (10.79 %), and LaLaCp (9.31 %). The predominance of LaOLa and LaLaLa suggests a significant presence of lauric, but also a mild contribution of oleic acid in the TAG composition, similar to Bauer et al. (2020) for babassu oil. Other prominent TAG species in the product include CpOLa (8.55 %), LaLaC (8.24 %), LaLaM (7.11), and LaOM (6.26 %), indicating a substantial contribution of other MCFA, i.e. caprylic, capric and myristic acids.

In the natural TAG molecule, fatty acids attach to specific positions within the glycerol structure. These positions are identified by stereospecific numbering, known as *sn-1*, *sn-2*, and *sn-3*. As anticipated, licuri oil exhibits 13 TAGs containing oleic and linoleic acid predominantly at the *sn-2* position, a characteristic typical of vegetable oils (Alfieri et al., 2018). Similar to coconut oil, lauric acid in licuri oil is uniformly distributed across all three stereospecific positions. The stereospecific arrangement and lengths of fatty acid chains at *sn-1*, *sn-2*, and *sn-3* positions within TAG species dictate the fate of dietary fat during digestion

Table 4

Bioactive compounds present in licuri oil.

Compound	Results
Tocols profile	
γ-tocopherol	nd
α-tocopherol	0.49 ± 0.01 µg/g
δ-tocopherol	nd
α-tocotrienol	4.73 ± 0.06 µg/g
γ-tocotrienol	2.57 ± 0.04 µg/g
δ-tocotrienol	nd
Total phenolic content	196.73 ± 0.34 µg CAE/g
Total carotenoids	0.47 ± 0.01 µg β-carotene/g

nd: not detected; ±: standard deviation.

and absorption. Pancreatic and lipoprotein lipases predominantly hydrolyze fatty acids at the *sn*-1 and *sn*-3 positions, yielding FFA and MAG at *sn*-2 (Karupiah & Sundram, 2007).

3.2.2. Bioactive compounds

Table 4 presents the total polyphenolic and carotenoid content, as well as the tocols profile. When compared to other oils, licuri oil presents a significant content of phenolic compounds ($196.73 \pm 0.34 \mu\text{g CAE/g}$), surpassing the content found in other widely consumed oils such as extra virgin olive oil ($142.27 \pm 2.75 \mu\text{g CAE/g}$), coconut oil ($8.92 \pm 0.66 \mu\text{g CAE/g}$), sunflower oil ($11.60 \pm 2.36 \mu\text{g CAE/g}$), and flaxseed oil ($24.49 \pm 3.57 \mu\text{g CAE/g}$). This result is promising, highlighting the relevance of licuri oil in terms of antioxidant properties and oil stability (Rodilla et al., 2023). The total carotenoid content in licuri oil ($0.47 \pm 0.01 \mu\text{g } \beta\text{-carotene/g}$), while relatively low, is significant when compared to regional oils and fats such as murumuru fat, cupuassu fat, bacuri fat, babassu oil, and Brazil nut oil, which do not exhibit carotenoid content (Serra et al., 2019). Carotenoids are recognized for their antioxidant properties and potential health advantages, which encompass anti-inflammatory and anticancer effects. They play a crucial role in eye health, acting as antioxidants that protect against light damage and potentially reducing the risk of age-related macular degeneration (AMD) and cataracts. Large-scale epidemiological studies have established a strong correlation between diets abundant in carotenoids, and decreased risks of specific diseases such as cancer and heart disease (Young & Lowe, 2018).

Licuri oil exhibited a total tocols content of $7.79 \mu\text{g/g}$, with α-tocopherol present at a concentration of $0.49 \pm 0.01 \mu\text{g/g}$, comparable to that found in coconut oil ($0.50 \mu\text{g/g}$) (Rizvi et al., 2014). Tocols, including tocopherols and tocotrienols, play a crucial role in preventing

lipid oxidation, thereby extending the storage life of almonds (Wen et al., 2020). This antioxidant, a form of vitamin E, protect cell membranes from oxidative damage, particularly vital in the immune system, cellular proliferation, and apoptosis regulation (Tucker and Townsend, 2005). Additionally, the presence of α-tocotrienol and γ-tocotrienol, predominant compounds in licuri oil, at concentrations of $4.73 \pm 0.06 \mu\text{g/g}$ and $2.57 \pm 0.04 \mu\text{g/g}$, respectively, further enhances its nutritional profile. Tocotrienols, structurally similar to tocopherols but possessing additional unsaturated bonds, exhibit enhanced antioxidant properties and demonstrate neuroprotective effects and the ability to inhibit cancer cell growth (Comitato et al., 2017).

3.3. Physicochemical properties

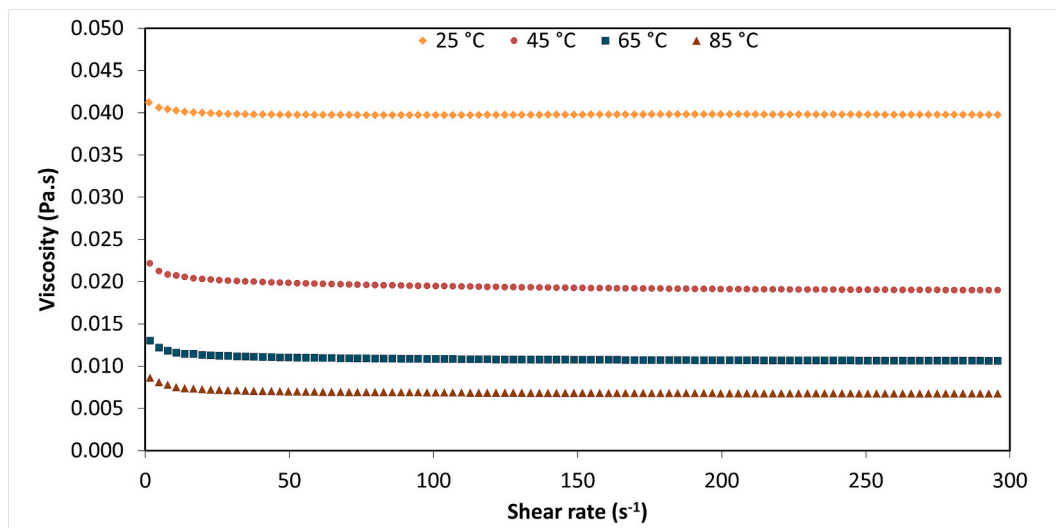
3.3.1. Rheology profile

Fig. 2 presents the results of shear stress and shear rate measurements of licuri oil at different temperatures: 25 °C, 45 °C, 65 °C, and 85 °C. It can be observed that the shear stress increases linearly with shear rate at all temperatures, indicating a typical Newtonian behavior, as expected for vegetable oils. All results from Fig. 2 yielded R^2 values >0.99 , indicating a strong linear relationship between shear stress and shear rate. Additionally, it is notable that the shear stress decreases as the temperature increases while maintaining a constant shear rate (Hashempour-Baltork et al., 2018), as shown for kinematic viscosity in Table 5 (0.0398 Pa.s at 25 °C, 0.0191 Pa.s at 45 °C, 0.0107 Pa.s at 65 °C, and 0.0068 Pa.s at 85 °C). This phenomenon can be attributed to the increased thermal motion among the oil molecules, reducing intermolecular forces, facilitating flow, and consequently reducing viscosity (Foster & Ferrier, 1979), as illustrated in Fig. 3. Thus, with viscosity generally constant at all tested temperatures, this oil exhibits consistent Newtonian behavior within the speed range of 0 to 300 s^{-1} (Abedinzadeh et al., 2016). The viscosity of oils is a fundamental property in various industrial applications, including fluid flow and heat transfer unit operations in the food industry. Operations such as mixing,

Table 5

Kinematic viscosity in licuri oil.

Temperature (°C)	η (Pa.s)
25	0.0398
45	0.0191
65	0.0107
85	0.0068

**Fig. 2..** Relation between viscosity and shear rate of licui oil at 25 °C, 45 °C, 65 °C, and 85 °C.

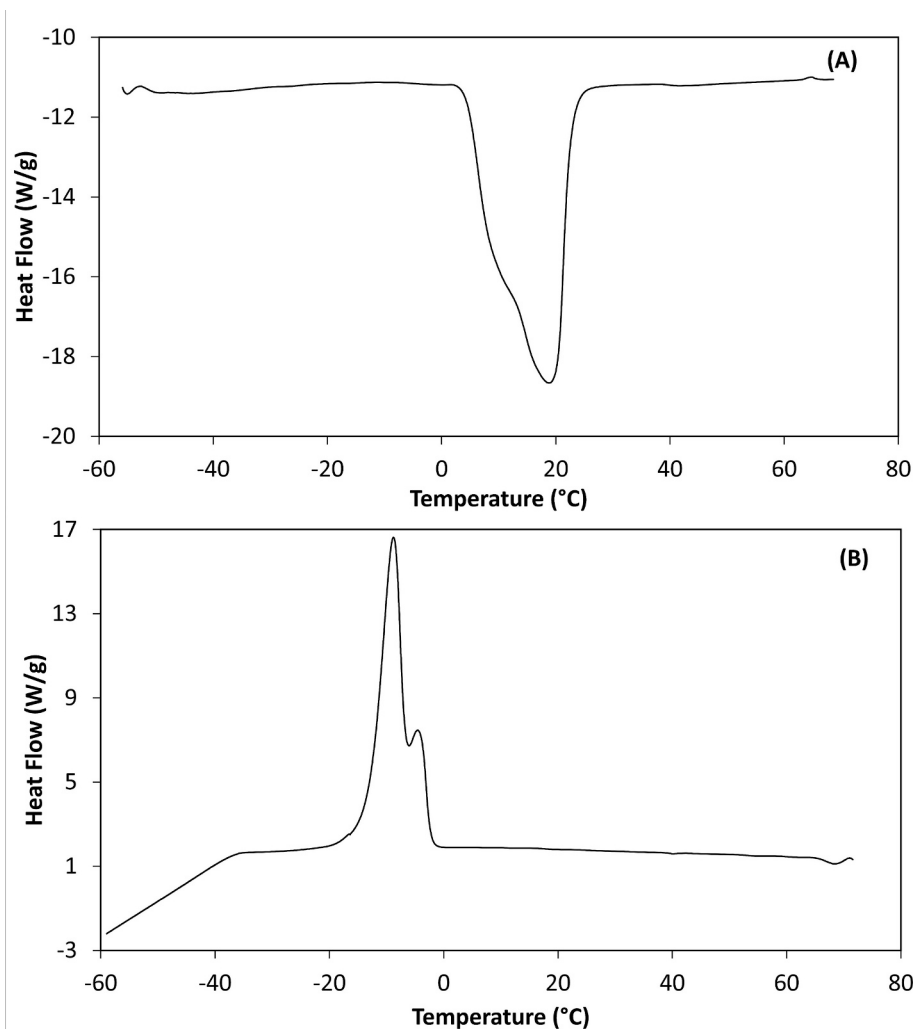


Fig. 3.. Melting (A) and crystallization (B) profile of licuri oil.

pumping, transportation, and frying rely directly on the rheological characteristics of oils to ensure efficiency and quality of final products (Diamante & Lan, 2014).

3.3.2. Melting and crystallization profile

FA and TAG profiles not only reveal the composition in licuri oil but are also mainly related to its physical properties, especially in case of melting and crystallization behavior. In case of licuri oil, the presence of Mono-UTAGs combined with the predominant presence of TAGs with MCFA results in a product with liquid consistency, close to room temperature, but possibly presenting a small solid phase fraction, depending on storage conditions (McCarty & DiNicolantonio, 2016). This can be seen in Fig. 4, which shows the melting and crystallization curve of licuri oil. According to the heating and cooling curves obtained, oil's melting and crystallization temperatures occurred at 19.08 °C and -7.03 °C, respectively (peak top temperatures). Although only a single peak was observed in the melting curve, at least two separated peaks were observed in the crystallization curve. As previously observed, licuri oil presents 2 main groups of TAGs in its composition, Mono-UTAG like LaOLA (with melting temperature of 16.5 °C), and Tri-STAG like LaLaLa or LaLaM (with melting temperatures ranging from 42 to 47 °C) (Wesdorp, 1990). During cooling, Tri-STAG starts their crystallization, leading to a first crystallization peak (around -5 °C), followed by a second crystallization peak of greater intensity (-7 °C), probably related to Mono-UTAG. During heating, on the other hand, the melting events of

these 2 groups overlapped, leading to a monomodal melting, occurring in a range between 0 and 27 °C. Pardaui et al. (2017), Aragão & Maximo (2024) and Pereira et al. (2019) showed that, according to the melting behavior, Amazonian fats can present multiple melting events or a single melting profile, like what was here observed. Multiple events are related to heterogenous TAGs profiles, i.e. presence of different fractions of Mono- Di or Tri-UTAGs, such as observed for pracaxi (*Pentaclethra macroloba*), Brazil nut (*Bertholletia excelsa*) or bacuri (*Platonia insignis*) fats/oils. Otherwise, fats like, tucuma kernel (*Astrocaryum aculeatum*), murumuru (*Astrocaryum murumuru*), palm kernel or coconut presents a more homogenous TAG profile, mainly composed by Tri-STAG and/or Mono-UTAG, like licuri oil. The single melting peak, in this case, could be attributed, according to Pereira et al. (2019) to favorable chemical interactions among similar classes of TAGs, which favor the packing of molecules in the crystalline network of the solid phase, leading to the fusion of all fractions at the same time. This behavior is quite interesting for the previously mentioned industrial applications, leading to products that are completely solids at low temperatures or completely liquid at higher temperatures, improving stability of the formulations (Pereira et al., 2019; Aragão & Maximo, 2024).

3.3.3. Oxidative stability

Rancimat data was collected to determine the oxidation induction time (OIT) isothermally at four distinct temperatures (110, 120, 130, and 140 °C), as outlined in Table 6. These results reveal a decrease in

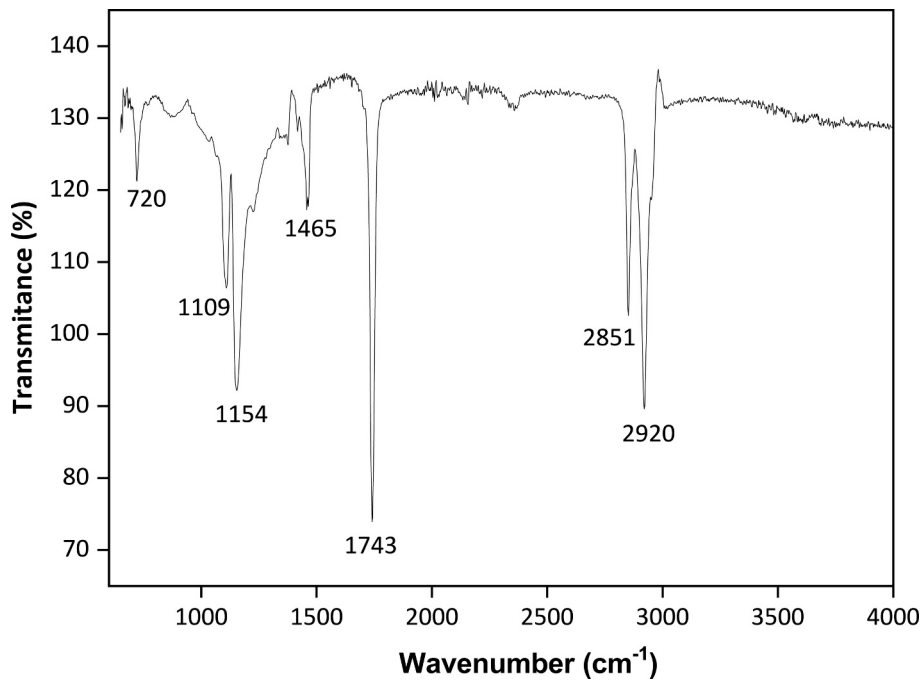


Fig. 4.. Infrared spectroscopy of licuri oil.

Table 6
Oxidative stability index and Arrhenius equation parameters in licuri oil.

Temperatures (°C)	OIT (h)	k _{OIT} (10 ⁻³ /h)
110	30.09 ± 0.42	33.23
120	14.08 ± 0.01	71.02
130	7.03 ± 0.16	142.25
140	3.65 ± 0.06	274.35
Arrhenius equation parameters		Value
Intercept		25.65 ± 0.21
Slope		-11,128 ± 85
R ²		0.99983
E _a (kJ/mol)		92.5 ± 0.3
A _{OIT} (10 ¹² h ⁻¹)		0.138

OIT: oxidation induction time; k_{OIT}: reaction rate constants (1/OIT); ±: standard deviation. Ea: activation energy; A_{OIT}: frequency factor.

OIT values (30.09 ± 0.42, 14.08 ± 0.01, 7.03 ± 0.16, and 3.65 ± 0.06, respectively) with rising temperatures. As previously mentioned, the reaction rate constant (*k*) was derived from the reciprocal of OIT for each temperature, representing lipid oxidation of the samples, as observed across different temperature settings. These results indicate an increase in *k* with higher temperatures, signifying accelerated lipid oxidation.

Utilizing *k* value to assess lipid oxidation rate against temperature, a direct correlation was established. The ln(*k*) vs. 1/*T* curve generated for licuri oil is depicted in Fig. 5, with the slope used to compute the activation energy (*Ea*) and the intercept used for the frequency factor (*A_{OIT}*), also listed in Table 6. Notably, the curve displayed an exceptional coefficient of determination (*R*² > 0.99). Oxidation is a multifaceted process leading to various oxidation products and intermediates, each with its own rate constant. The overall *Ea* reflects the cumulative impact of all activation energies involved during oxidation (Adhvaryu et al., 2000).

Lipid oxidation at different temperatures may follow distinct steps or reaction pathways, influenced by the reactivity of prooxidants, such as trace metals and carboxylic acid, previously measured, and antioxidants, such as tocopherols, carotenoids and polyphenolic compounds.

Additionally, oil temperature influences oxygen solubility in vegetable oils, decreasing by approximately 25 % for every 10 °C increase in temperature (Aktar & Adal, 2019; Robertson, 2000). Thus, predictive results may entail uncertainties and errors, serving as only approximate values. The calculated Arrhenius *Ea* of 92.5 kJ/mol is detailed in Table 6 for licuri oil. Previous studies on lipid oxidation kinetics for refined oils reported *Ea* values for various oils, including canola (88.45–89.94 kJ/mol), soybean (79.66–92.42 kJ/mol), sunflower (63.81–90.74 kJ/mol), corn (77.78–88.14 kJ/mol), and olive (89.5–101.8 kJ/mol) (Adhvaryu et al., 2000; Farhoosh et al., 2008; Gharby et al., 2016). Licuri oil exhibits stability comparable to other oil sources, as evidenced by the data presented, in line with low prooxidants compounds and high antioxidant bioactives found.

3.3.4. Antioxidant capacity

Regarding antioxidant capacity, the results showed an average of 60.43 ± 3.26 mg/mL. Nobre et al. (2018), found an average of 3517.01 ± 77.07 mg/mL for babassu oil (*Orbignya phalerata* Mart.) and 704.21 ± 25.14 mg/mL for buriti oil (*Mauritia flexuosa*). Although it is in the lower range, it is important to note that lower values indicate a greater ability to reduce the DPPH radical, suggesting a good antioxidant potential of licuri oil, which is also in line with the content of tocopherols, carotenoids and polyphenolic compounds. These compounds, supported by epidemiological studies, not only contribute to oil's oxidative stability, preventing its degradation, but also, to their ability in free radicals scavenging, oxidative stress and cells damaged prevention. They have been also largely employed in the context of chronic diseases treatments (Gutiérrez-Grijalva et al., 2016). Therefore, licuri oil is, indeed, a promising ingredient in food and cosmetic industries. Supported by its particular antioxidant ability, licuri oil could be employed as: i) a healthier alternative to conventional oils, helping preservation of nutritional or functional integrity of products during process or storage, due to improved stability for storage or high temperatures applications, such as for backing, frying or roasting (Kochhar, 2016); ii) a dietary supplement for immune system (Mishra et al., 2024); iii) an anti-inflammatory product, in treatments such as for acne or psoriasis (Khanal, et al., 2024); iv) an adjuvant in cancer treatments, whose potential could be boosted by synergistic blends with other oils (Burin

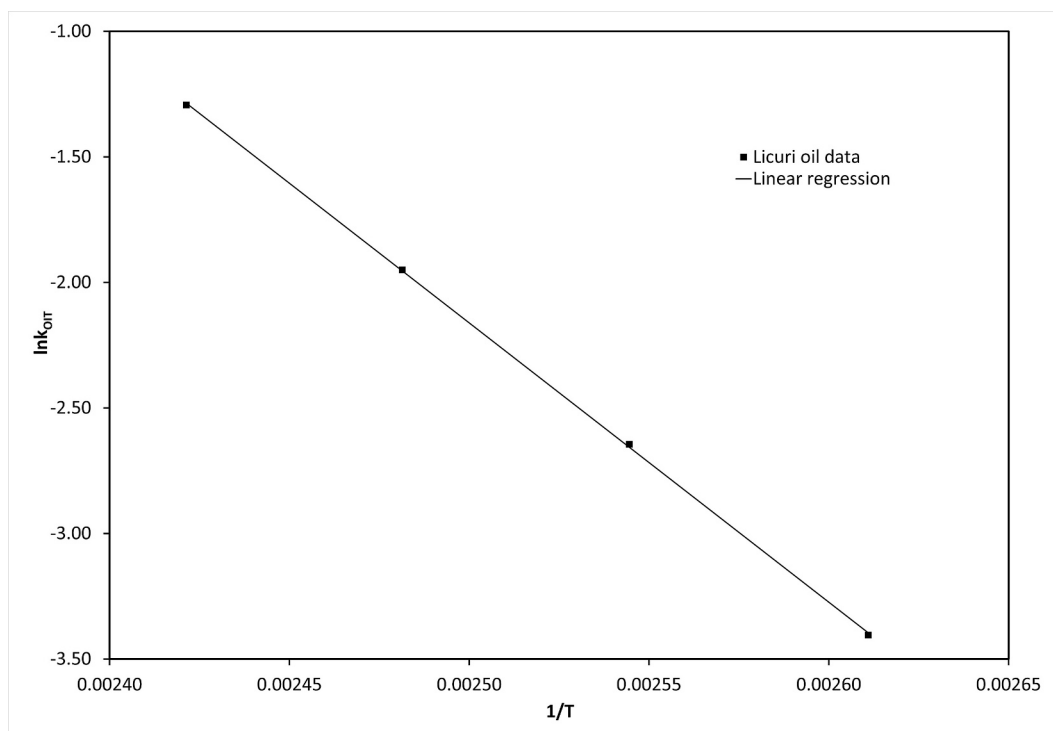


Fig. 5.. Relation between $\ln(k)$ and $1/T$ curve generated for lipid oxidation rate of licuri oil.

et al., 2022; Hashempour-Baltork, et al., 2016); v) an ingredient in skin care formulations, due to anti-aging effects, improving skin elasticity and firmness (Khanal et al., 2024; Mishra et al., 2024).

4. Conclusions

This work could elucidate important quality parameters, bioactive profile and physicochemical properties related to the development of new process and products. The characterization revealed favorable compositional attributes, including low water and carboxylic acid values, related to degradation during process and storage and, as well as peroxide and free fatty acid values within regulatory limits. Trace metals values, including phosphorous content, despite low, indicate that minimal refining process could improve oil quality. Moreover, the presence of essential nutrients such as phenolic compounds and tocopherols underscores its potential health-promoting and great antioxidant properties, also verified. The predominance of lauric acid and TAGs derived from this acid, further enhances its high oxidative stability and functionality, especially considering its melting, crystallization and rheological profile, positioning licuri oil as a promising ingredient in various industrial applications, such as for production of cocoa butter replacers, margarines or cheese analogues, fillings and spreads, but also body creams, moisturizers, or dermatological creams, not only with nutraceutical or therapeutic appeal, but also aligned with the growing trends in natural, sustainable, and health-focused formulations.

CRedit authorship contribution statement

Gabriel Sthefano Lourenço Pereira: Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Patrícia Tonon de Souza:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Grace Kelly Mizuno Flozino:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Rafael Fernandes Almeida:** Writing – original draft, Formal analysis, Data curation, Conceptualization. **Dhayna**

Oliveira Sobral: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Marcelo Antonio Morgano:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Wilton Rogério Lustri:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Silmara Cristina Lazarini:** Methodology, Formal analysis, Data curation, Conceptualization. **Pedro Paulo Corbi:** Validation, Resources, Methodology, Formal analysis. **Antonio José de Almeida Meirelles:** Resources, Funding acquisition. **Guilherme José Maximo:** Writing – review & editing, Validation, Supervision, Software, Resources, Conceptualization. **Eduardo Augusto Caldas Batista:** Supervision, Resources, Funding acquisition. **Klicia Araujo Sampaio:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation.

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.

References

- Abedinzadeh, S., Torbati, M., & Azadmard-Damirchi, S. (2016). Some qualitative and rheological properties of virgin olive oil-apple vinegar salad dressing stabilized with xanthan gum. *Advanced Pharmaceutical Bulletin*, 6(4), 597–606. <https://doi.org/10.15171/apb.2016.074>
- Adhvariy, A. T. A. N. U., Erhan, S. Z., Liu, Z. S., & Perez, J. M. (2000). Oxidation kinetic studies of oils derived from unmodified and genetically modified vegetables using pressurized differential scanning calorimetry and nuclear magnetic resonance spectroscopy. *Thermochimica Acta*, 364(1–2), 87–97. [https://doi.org/10.1016/S0040-6031\(00\)00626-2](https://doi.org/10.1016/S0040-6031(00)00626-2)
- Aktar, T., & Adal, E. (2019). Determining the Arrhenius kinetics of avocado oil: Oxidative stability under rancimat test conditions. *Foods*, 8, 236. <https://doi.org/10.3390/foods8070236>
- Alfieri, A., Imperlini, E., Nigro, E., Vitucci, D., Orrù, S., Daniele, A., ... Mancini, A. (2018). Effects of plant oil Interesterified Triacylglycerols on Lipemia and human health. *International Journal of Molecular Sciences*, 19, 104. <https://doi.org/10.3390/ijms19010104>
- Alves, A. Q., da Silva Jr, V. A., Góes, A. J. S., Silva, M. S., de Oliveira, G. G., Bastos, I. V. G. A., ... Alves, A. J. (2019). The fatty acid composition of vegetable oils and their potential use in wound care. *Advances in skin and wound care*, 32(8), 1–8. <https://doi.org/10.1097/01.ASW.0000557832.86268.64>
- Ansolin, M., Souza, P. T., Meirelles, A. J. A., & Batista, E. A. C. (2017). Tocopherols and tocotrienols: An adapted methodology by UHPLC/MS without sample pretreatment steps. *Food Analytical Methods*, 10, 2165–2174. <https://doi.org/10.1007/s12161-016-0768-z>
- Antonias, R., Miranda, P. C., Ferreira, G. F., Vieira, T. M. F. S., Freitas, S. C., & Matsuura. (2022). Nutritional evaluation of Syagrus coronata kernels and development of cookies prepared with cassava flour and licuri kernels. *Food Science and Technology*, 42, Article e69720. <https://doi.org/10.1590/fst.69720>
- Antoniosi Filho, N., Mendes, O. L., & Lanças, F. M. (1995). Computer prediction of triacylglycerol composition of vegetable oils by HPLC. *Chromatographia*, 40, 557–562. <https://doi.org/10.1007/BF02290268>
- AOAC. (1998). *Official method of analysis* (15th ed.). Washington DC: Association of Official Analytical Chemists.
- AOCS. (2017). *Official methods and recommended practices of the American oil Chemists' Society*. Champaign: American Oil Chemists' Society.
- Aragão, V. C., & Maximo, G. J. (2024). Thermophysical properties of blends composed of Amazonian fats and soybean oil. *Food Research International*, 177, Article 113911. <https://doi.org/10.1016/j.foodres.2023.113911>
- ASTM. (2018). *ASTM standard D5185-18, standard test method for multielement determination of used and unused lubricating oils and base oils by inductively coupled plasma atomic emission spectrometry (ICP-AES)*. West Conshohocken: ASTM International.
- Barbosa, B. V. D. R., de Alves, J. V. O., Costa, W. K., da Aguiar, I. F. S., Galvão, L. R. L., da Silva, P. M., ... dos Correia, M. T. S. (2024). Almond fixed oil from *Syagrus coronata* (Mart.) Becc. Has antinociceptive and anti-inflammatory potential, without showing oral toxicity in mice. *Journal of Ethnopharmacology*, 331, Article 118283. <https://doi.org/10.1016/j.jep.2024.118283>
- Barbosa, N. V., Santos, L. B., Seguchi, L. J., Silva, B. C., Carvalho, T. L., Wanderley Neto, E. T., & Silva, M. R. A. (2022). Rapid assessment of transformer insulating vegetable oil quality using FTIR spectroscopy and chemometrics. *Química Nova*, 45, 994–1003. <https://doi.org/10.21577/0100-4042.20170914>
- Bauer, L. C., Damásio, J. M. A., Silva, M. V., Santana, D. A., Gualberto, S. A., & Simionato, J. I. (2013). Chemical characterization of pressed and refined licuri (*Syagrus coronata*) oils. *Acta Scientiarum*, 35(4), 771–776. <https://doi.org/10.4025/actascitechnol.v35i4.20251>
- Bauer, L. C., Santos, L. S., Sampayo, K. A., Ferrão, S. P. B., da Fontan, R. C. I., Minim, L. A., ... Bonomo, R. C. F. (2020). Physicochemical and thermal characterization of babassu oils (*Orbignya phalerata* Mart.) obtained by different extraction methods. *Food Research International*, 137, Article 109474. <https://doi.org/10.1016/j.foodres.2020.109474>
- Baum, S. J., Kris-Etherton, P. M., Willett, W. C., Lichtenstein, A. H., Rudel, L. L., Maki, K. C., ... Block, R. C. (2012). Fatty acids in cardiovascular health and disease: A comprehensive update. *Journal of Clinical Lipidology*, 6(3), 216–234. <https://doi.org/10.1016/j.jacl.2012.04.077>
- Boateng, L., Ansong, R., Owusu, W. B., & Steiner-Asiedu, M. (2016). Coconut oil and palm oil's role in nutrition, health and national development: A review. *Ghana Medical Journal*, 50, 189–196.
- Burin, M. A., Ferronato, C., Amorim, M. P., Pereira, L. M., Bilibio, D., Bender, J. P., & Priamo, W. L. (2022). Extraction of Pecan nut (*Carya illinoensis*) oil using different techniques and its antitumor potential in human cancer cells. *The Journal of Supercritical Fluids*, 179, Article 105409. <https://doi.org/10.1016/j.supflu.2021.105409>
- Comitato, R., Ambra, R., & Virgili, F. (2017). Tocotrienols: A family of molecules with specific biological activities. *Antioxidants*, 6, 93. <https://doi.org/10.3390/antiox6040093>
- Dayrit, F. M. (2014). The properties of lauric acid and their significance in coconut oil. *Journal of the American Oil Chemists' Society*, 92, 1–15. <https://doi.org/10.1007/s11746-014-2562-7>
- Diamante, L. M., & Lan, T. (2014). Absolute viscosities of vegetable oils at different temperatures and shear rate range of 64.5 to 4835 s⁻¹. *Journal of Food Processing*, 2014, Article 234583. <https://doi.org/10.1155/2014/234583>
- Espin, J. C., Soler-Rivas, C., & Wichers, H. J. (2000). Characterization of the Total free radical scavenger capacity of vegetable oils and oil fractions using 2,2-Diphenyl-1-picrylhydrazyl radical. *Journal of Agricultural and Food Chemistry*, 48, 648–656. <https://doi.org/10.1021/jf9908188>
- Farhoosh, R., Niazmand, R., Rezaei, M., & Sarabi, M. (2008). Kinetic parameter determination of vegetable oil oxidation under Rancimat test conditions. *European Journal of Lipid Science and Technology*, 110(6), 587–592. <https://doi.org/10.1002/ejlt.200800004>
- Fernandes, C. M., de Oliveira, P. C. O., Pina, V. G. S. S., Peixoto, B. S., Massante, F. F., Veloso, ... & Ponzio, E. A. (2022). Pyrolysis of *Syagrus coronata*: Transforming agroindustrial waste into a new environmentally sustainable corrosion inhibitor. *Sustainable Chemistry and Pharmacy*, 29, 100751. <https://doi.org/10.1016/j.scp.2022.100751>
- Faria, D. C., de Queiroz, M. E. L. R., & Novaes, F. J. M. (2025). Direct Hot Solid-Liquid Extraction (DH-SLE): A High-Yield Greener Technique for Lipid Recovery from Coffee Beans. *Plants*, 14(2), 185. <https://doi.org/10.3390/plants14020185>
- Foster, L. L., & Ferrier, L. K. (1979). Viscometric characteristics of whole soybean milk. *Journal of Food Science*, 44(2), 583–590. <https://doi.org/10.1111/j.1365-2621.1979.tb03841.x>
- Gharby, S., Harhar, H., Mamouni, R., Matthäus, B., & Charrouf, Z. (2016). Chemical characterization and kinetic parameter determination under Rancimat test conditions of four monovarietal virgin olive oils grown in Morocco. *OCL*, 23(4), A401. <https://doi.org/10.1051/ocl/2016014>
- Guimarães, J. S., Shiosaki, R. K., & Mendes, M. L. M. (2021). Licuri (*Syagrus coronata*): características, importâncias, potenciais e perspectivas do pequeno coco do Brasil. *Desenvolvimento e Meio Ambiente*, 58, 169–192. <https://doi.org/10.5380/dma.v58i0.68852>
- Gutiérrez-Grijalva, E. P., Ambriz-Pérez, D. L., Leyva-López, N., Castillo-López, R. I., & Heredia, J. B. (2016). Review: Dietary phenolic compounds, health benefits and bioaccessibility. *Archivos Latinoamericanos de Nutrición*, 66, 87–100.
- Haiyan, Z., Bedgood, D. R., Jr., Bishop, A. G., Prenzler, P. D., & Robards, K. (2007). Endogenous biophenol, fatty acid and volatile profiles of selected oils. *Food Chemistry*, 100(4), 1544–1551. <https://doi.org/10.1016/j.foodchem.2005.12.039>
- Hartman, L., & Lago, R. C. (1973). Rapid preparation of fatty acid methyl esters from lipids. *Laboratory Practice*, 22, 475–476.
- Hashempour-Baltork, F., Torbati, M., Azadmard-Damirchi, S., & Savage, G. P. (2016). Vegetable oil blending: A review of physicochemical, nutritional and health effects. *Trends in Food Science & Technology*, 57, 52–58. <https://doi.org/10.1016/j.tifs.2016.09.007>
- Hashempour-Baltork, F., Torbati, M., Azadmard-Damirchi, S., & Savage, P. T. (2018). Chemical, rheological and nutritional characteristics of sesame and olive oils blended with linseed oil. *Advanced Pharmaceutical Bulletin*, 8, 107–113. <https://doi.org/10.15171/apb.2018.013>
- Iha, O. K., Alves, F. C., Suarez, P. A., de Oliveira, M. B., Meneghetti, S. M., Santos, B. P., & Soletti, J. I. (2014). Physicochemical properties of *Syagrus coronata* and *Acrocomia aculeata* oils for biofuel production. *Industrial Crops and Products*, 62, 318–322. <https://doi.org/10.1016/j.indcrop.2014.09.003>
- Karupiah, T., & Sundram, K. (2007). Effects of stereospecific positioning of fatty acids in triacylglycerol structures in native and randomized fats: A review of their nutritional implications. *Nutrition & Metabolism*, 12(4), 6. <https://doi.org/10.1186/1743-7075-4-16>
- Khanal, A., Giri, J., Dall'Acqua, S., & Adhikari, R. (2024). Vegetable oils-based cosmetics. In *In Vegetable Oil-Based Polymers and their Surface Applications* (pp. 139–161). Elsevier. <https://doi.org/10.1016/B978-0-12-822189-1.00002-7>
- Kochhar, P. (2016). Thermal stability of fats for high temperature applications. In Thomas A. B. Sanders (Ed.), *Functional Dietary Lipids* (pp. 103–148). Woodhead Publishing. <https://doi.org/10.1016/B978-1-78242-247-1.00005-3>
- Lisboa, M. C., Wiltshire, F. M. S., Fricks, A. T., Dariva, C., Carriere, F., Lima, A. S., & Soares, C. F. (2020). Oleochemistry potential from Brazil northeastern exotic plants. *Biochimie*, 178, 96–104. <https://doi.org/10.1016/j.biochi.2020.09.00203>
- Liu, R., Guo, X., Cheng, M., Zheng, L., Gong, M., Chang, M., Jin, Q., & Wang, X. (2019). Effects of chemical refinement on the quality of coconut oil. *Journal of Food Science and Technology*, 56, 3109–3116. <https://doi.org/10.1007/s13197-019-03810-w>
- McCarty, M. F., & DiNicolantonio, J. J. (2016). Lauric acid-rich medium-chain triglycerides can substitute for other oils in cooking applications and may have limited pathogenicity. *Open Heart*, 27, Article 000467. <https://doi.org/10.1136/openhrt-2016-000467>
- Menezes, A. V., Souza, D. A., Lima, D. P., Leite Neta, M. T. S., Almeida-Souza, T. H., dos Rodrigues, R. N. S., ... de Montezano, I. M. C. (2024). Fatty acids and volatile compounds of cooked green licuri (*Syagrus coronata*) and naturally ripe licuri almonds from native flora, popularly consumed in Brazil. *Food Research International*, 191, Article 114735. <https://doi.org/10.1016/j.foodres.2024.114735>
- Mishra, S., Anand, S., & Pandey, A. (2024). *Vegetable Oils in Pharmaceutical Industry. Oils and Fats as Raw Materials for Industry* (pp. 231–265). <https://doi.org/10.1002/9781119910558.ch9>
- Moreira, R. C., Leonardi, G. R., & Bicas, J. L. (2024). Lipase-mediated alcoholysis for in situ production of ester bioaromas in licuri oil for cosmetic applications. *Journal of Biotechnology*, 392, 25–33. <https://doi.org/10.1016/j.jbiotec.2024.09.010>
- Neves, G. F., Motoike, S. Y., Kuki, K. N., Montaya, S. G., Cruz, C. D., & De Sousa, W. V. (2023). Genetic diversity of *Syagrus coronata* and principal component analysis of phenotypic traits: a palm from the Brazilian semiarid biome. *Biodiversity and Conservation*, 32, 4275–4293. <https://doi.org/10.1007/s10531-023-02689-6>
- Nguy, L. H., Hien, L. T. M., & Dao, D. T. A. (2022). Effect of some cultivation factors and extraction methods on Terminalia catappa L. seed oil. *International Journal of Food Science*, 2022(1), Article 1356092. <https://doi.org/10.1155/2022/1356092>
- Nimbkar, S., Leena, M. M., Moses, J. A., & Anandharamakrishnan, C. (2022). Medium chain triglycerides (MCT): State-of-the-art on chemistry, synthesis, health benefits

- and applications in food industry. *Comprehensive Reviews in Food Science and Food Safety*, 21(2), 843–867. <https://doi.org/10.1111/1541-4337.12926>
- Nobre, C. B., Sousa, E. O., Camilo, C. J., Machado, J. F., Silva, J. M. F. L., Filho, J. R., ... Costa, J. G. M. (2018). Antioxidative effect and phytochemical profile of natural products from the fruits of “babaçu” (*Orbignia speciosa*) and “Buriti” (*Mauritia flexuosa*). *Food and Chemical Toxicology*, 121, 423–429. <https://doi.org/10.1016/j.fct.2018.08.068>
- Norazlina, M. R., Jahurul, M. H. A., Hasmadi, M., Mansoor, A. H., Norliza, J., Patricia, M., ... Fan, H. Y. (2021). Trends in blending vegetable fats and oils for cocoa butter alternative application: A review. *Trends in Food Science & Technology*, 116, 102–114. <https://doi.org/10.1016/j.tifs.2021.07.016>
- Noutcheu, R., Oliveira, F. M. P., Wirth, R., Tabarelli, M., & Leal, I. R. (2024). Chronic human disturbance and environmental forces drive the regeneration mechanisms of a Caatinga dry tropical forest. *Perspectives in Ecology and Conservation*, 22, 79–92. <https://doi.org/10.1016/j.pecon.2024.01.002>
- Pardauil, J. J. R., Molfetta, F. A., Braga, M., Souza, L. K. C., Filho, G. N. R., & Costa, C. E. F. (2017). Characterization, thermal properties and phase transitions of amazonian vegetable oils. *Journal of Thermal Analysis and Calorimetry*, 127, 1221–1229. <https://doi.org/10.1007/s10973-016-5605-5>
- Pereira, E., Fernandes, J., Gonçalves, R., Pinheiro, A. C., Duarte, M. S., Alves, M. M., ... Vicente, A. A. (2023). Evaluating the in vitro digestion of lipids rich in medium-chain fatty acids (MCFAs) using dynamic and static protocols. *Food Chemistry*, 406, Article 135080. <https://doi.org/10.1016/j.foodchem.2022.135080>
- Pereira, E., Ferreira, M. C., Sampaio, K. A., Grimaldi, R., de Meirelles, A. J. A., & Maximo, G. J. (2019). Physical properties of Amazonian fats and oils and their blends. *Food Chemistry*, 278, 208–215. <https://doi.org/10.1016/j.foodchem.2018.11.016>
- Prasanna, N. S., Selvakumar, M., Choudhary, N., & Raghavarao, K. S. M. S. (2024). Virgin coconut oil: wet production methods and food applications—a review. *Sustainable Food Technology*, 2(5), 1391–1408. <https://doi.org/10.1039/d4fb00093e>
- Quinones-Islas, N., Meza-Márquez, O. G., Osorio-Revilla, G., & Gallardo-Velazquez, T. (2013). Detection of adulterants in avocado oil by mid-FTIR spectroscopy and multivariate analysis. *Food Research International*, 51, 148–154. <https://doi.org/10.1016/j.foodres.2012.11.037>
- Rizvi, S., Raza, S. T., Ahmed, F., Ahmad, A., Abbas, S., & Mahdi, F. (2014). The role of vitamin E in human health and some diseases. *Sultan Qaboos University Medical Journal*, 14, 157–165.
- Robertson, G. L. (2000). Shelf life of packaged foods, its measurements and prediction. In A. L. Brody, & J. B. Lord (Eds.), *Developing new food products for a changing marketplace* (pp. 329–353). Lancaster (UK): Tech-nomic Publishing.
- Rodilla, S. D., Martínez-Pineda, M., Yagüe-Ruiz, C., & Vercet, A. (2023). Evaluation of phenolic compounds, antioxidant activity and pigment content in emerging and traditional plant-based oils in Mediterranean gastronomy. *International Journal of Gastronomy and Food Science*, 33, Article 100771. <https://doi.org/10.1016/j.ijgfs.2023.100771>
- Rodríguez-Amaya, D. B. (2001). *A guide to carotenoid analysis in foods* (Vol. 71). Washington: ILSI Press.
- Sakaino, M., Sano, T., Kato, S., Shimizu, N., Ito, J., Rahmania, H., Imagi, J., & Nakagawa, K. (2022). Carboxylic acids derived from triacylglycerols that contribute to the increase in acid value during the thermal oxidation of oils. *Scientific Reports*, 12, Article 12460. <https://doi.org/10.1038/s41598-022-15627-3>
- Sandhya, S., Talukdar, J., & Bhaishya, D. (2016). Chemical and biological properties of Lauric acid: A review. *International Journal of Advanced Research*, 4, 1123–1128. <https://doi.org/10.21474/IJAR01/952>
- Santos, B. S., Macedo, C. B. F., Adelson, A. N. J. J., Brust, F. R., Bezerra Silva, P. C., Rocha, S. K. L., ... Guedes Paiva, P. M. (2019). Antistaphylococcal activity of *Syagrus coronata* essential oil: Biofilm eradication and in vivo action on *Galleria mellonella* infection model. *Microbial Pathogenesis*, 131, 150–157. <https://doi.org/10.1016/j.micpath.2019.04.009>
- Santos, O. V., Gonçalves, B. S., da Macêdo, C. S., Conceição, L. R. V., Costa, C. E. F., Monteiro Júnior, O. V., ... da Lannes, S. C. S. (2020). Evaluation of quality parameters and chromatographic, spectroscopic, and thermogravimetric profile of Pataúá oil (*Oenocarpus bataua*). *Food Science and Technology*, 40, 76–82. <https://doi.org/10.1590/fst.01619>
- Sehgal, S., & Sharma, V. (2021). Palm/Palm Kernel (*Elaeis guineensis*). In B. Tanwar, & A. Goyal (Eds.), *Oilseeds: Health Attributes and Food Applications*. Singapore: Springer. https://doi.org/10.1007/978-981-15-4194-0_6
- Serra, J. L., da Rodrigues, A. M. C., Freitas, R. A., de Meirelles, A. J. A., Darnet, S. H., & Silva, L. H. M. (2019). Alternative sources of oils and fats from Amazonian plants: Fatty acids, methyl tocols, total carotenoids and chemical composition. *Food Research International*, 116, 12–19. <https://doi.org/10.1016/j.foodres.2018.12.028>
- Souza, P. T., Ansolin, M., Batista, E. A. C., Meirelles, A. J. A., & Tubino, M. (2017). Kinetic of the formation of short-chain carboxylic acids during the induced oxidation of different lipid samples using ion chromatography. *Fuel*, 199, 239–247. <https://doi.org/10.1016/j.fuel.2017.02.093>
- Souza, R. M., Toloza, C. A. T., & Aucélio, R. Q. (2022). Fast determination of trace metals in edible oils and fats by inductively coupled plasma mass spectrometry and ultrasonic acidic extraction. *Journal of Trace Elements and Minerals*, 1, Article 100003. <https://doi.org/10.1016/j.jtemin.2022.100003>
- Souza, T. G. S., Silva, M. M., Feitoza, G. S., Alcântara, L. F. M., Silva, M. A., Oliveira, A. M., ... Chagas, C. A. (2021). Biological safety of *Syagrus coronata* (Mart.) Becc. fixed oil: Cytotoxicity, acute oral toxicity, and genotoxicity studies. *Journal of Ethnopharmacology*, 272, Article 113941. <https://doi.org/10.1016/j.jep.2021.113941>
- Szydlowska-Czerniak, A., Dianoczki, C., Recseg, K., Karlovits, G., & Szyk, E. (2008). Determination of antioxidant capacities of vegetable oils by ferric-ion spectrophotometric methods. *Talanta*, 76(4), 899–905. <https://doi.org/10.1016/j.talanta.2008.04.055>
- Tucker, J. M., & Townsend, D. M. (2005). Alpha-tocopherol: Roles in prevention and therapy of human disease. *Biomedicine & Pharmacotherapy*, 59, 380–387. <https://doi.org/10.1016/j.biopha.2005.06.005>
- Valavanidis, A., Nisiotou, C., Papageorgiou, Y., Kremli, I., Satravelas, N., Zinieris, N., & Zygalki, H. (2004). Comparison of the radical scavenging potential of polar and lipid fractions of olive oil and other vegetable oils under normal conditions and after thermal treatment. *Journal of Agricultural and Food Chemistry*, 52, 2358–2365. <https://doi.org/10.1021/jf030491h>
- Verma, K., Kaushik, P., Chugh, R., Kaur, G., & Kathuria, D. (2024). Cosmeceutical applications of natural oils and fats. In *Specialized Plant Metabolites as Cosmeceuticals* (pp. 239–256). Elsevier. <https://doi.org/10.1016/B978-0-443-19148-0.00011-5>
- Viidanoja, J. (2015). Determination of short chain carboxylic acids in vegetable oils and fats using ion exclusion chromatography electrospray ionization mass spectrometry. *Journal of Chromatography A*, 1383, 96–103. <https://doi.org/10.1016/j.chroma.2015.01.032>
- Wei, W., Sun, C., Jiang, W., Zhang, X., Hong, Y., Jin, Q., ... Yang, Z. (2019). Triacylglycerols fingerprint of edible vegetable oils by ultra-performance liquid chromatography-Q-ToF-MS. *LWT*, 112, Article 108261. <https://doi.org/10.1016/j.lwt.2019.108261>
- Wen, Y., Xu, L., Xue, C., Jiang, X., & Wei, Z. (2020). Assessing the Impact of Oil Types and Grades on Tocopherol and Tocotrienol Contents in Vegetable Oils with Chemometric Methods. *Molecules*, 25(21), 5076. <https://doi.org/10.3390/molecules25215076>
- Wesdorp, L. H. (1990). *Liquid – multiple solid phase equilibrium in fats*. Thesis. Netherlands: Delft University of Technology.
- Young, A. J., & Lowe, G. L. (2018). Carotenoids - Antioxidant properties. *Antioxidants*, 7(2), 28. <https://doi.org/10.3390/antiox7020028>