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Quality characteristics and thermal behavior of buriti (*Mauritia flexuosa* L.) oil

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SUMMARY: This work reports a complete characterization of buriti oil. Physicochemical properties were determined according to AOCS methodologies and thermophysical properties were measured using a controlled stress rheometer and a digital electronic density meter. β-carotene and tocopherol contents were obtained using HPLC systems. Fatty acids and acylglycerol classes were determined using GC and HPSEC systems, respectively, while triacylglycerol composition was estimated using the software PrOleos. Thermal behavior (crystallization and melting) was analyzed using a DSC. The results attested high levels of total carotenoids with β-carotene as the major one; total tocopherols contained α- and β-tocopherols which accounted for 91% of the total; and monounsaturated fatty acids were mainly represented by oleic acid. The results showed close agreement between density and viscosity of buriti and olive oils. The crystallization and melting peaks occurred at -43.06 °C and -2.73 °C, respectively. These properties enable Buriti oil to be recommended as an excellent alternative for enriching foods with bioactive compounds.

KEYWORDS: *β-carotene; Carotenoids; Monounsaturated fatty acid; Oleic acid; Tocopherols; Triunsaturated triacylglycerols*

RESUMEN: ***Parámetros de calidad y comportamiento térmico del aceite de buriti*** **(Mauritia flexuosa *L.*).** En este trabajo realiza una completa caracterización del aceite de buriti. Las propiedades fisicoquímicas se llevaron a cabo de acuerdo con las metodologías AOCS y se midieron las propiedades termo-físicas usando un reómetro de esfuerzo controlado y un medidor de densidad electrónico digital. Se obtuvieron los contenidos de β-caroteno y tocoferol utilizando HPLC. Los ácidos grasos y las diferentes clases de acilgliceroles se determinaron utilizando GC y HPSEC, respectivamente, mientras que la composición de triacilglicéridos se estimó utilizando el software PrOleos. El comportamiento térmico (cristalización y fusión) se analizó utilizando un DSC. Los resultados ponen de manifiesto altos niveles de carotenoides totales con β-caroteno como mayoritario, tocoferoles totales, con α- y β-tocoferoles que representan el 91% del total, y ácidos grasos monoinsaturados representados principalmente por ácido oleico. Hay una estrecha relación entre la densidad y la viscosidad del aceite de buriti y las de los aceites de oliva. Los picos de cristalización y de fusión se dan a -43,06 °C y -2,73 °C, respectivamente. Estas propiedades permiten que el aceite de Buriti sea recomendado como una excelente alternativa para enriquecer alimentos con compuestos bioactivos.

PALABRAS CLAVE: *Ácido graso monoinsaturado; Ácido oleico; β-caroteno; Carotenoides; Tocoferoles; Triglicéridos triinsaturados*

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1. INTRODUCTION

The Arecaceae family native palm trees are one of the most important plant resources in the Amazon region. Their fruits are a source of high-quality vegetable oils which are not only alternative foods for the local population, but constitute important sources of oils and fats with potential applications in food, pharmaceutical, cosmetic and other industries (Santos *et al.*, 2013). Due to their chemical composition, the oils obtained from these palm trees are considered new sources of high-added-value phytochemicals (Santos *et al.*, 2015).

Buriti (*Mauritia flexuosa* L.) is one of the Amazon's native palms belonging to the Arecaceae family, and it is a long-lived, single-stemmed, dioecious palm that can reach 30–40 m in height. It usually grows in permanent or periodically flooded areas along rivers, forests and savannas in northern-central Brazil, where it plays a major role in ecology, economics, and culture throughout most areas of its occurrence. Its fruit has a hard, scaly red bark that covers a soft and oily pulp; its color varies from dark yellow to reddish after complete ripeness. Extraction by cold pressing yields about 45 kg of buriti oil from 1000 kg of ripe fruits, which is considered as an Amazonian resource for cosmetic, food and pharmaceutical purposes (Albuquerque *et al.*, 2005; Silva *et al.*, 2009; Speranza *et al.*, 2016; Virapongse *et al.*, 2017).

Oils are complex mixtures containing a wide range of compounds. Apart from the major class of triacylglycerols, the unsaponifiable fraction is constituted by different groups of components, such as hydrocarbons, waxes, sterols, tocopherols and carotenoids. A complete characterization of the unsaponifiable fraction is of great interest, since the nutritional value of edible oils depends on the content and composition of biologically active compounds present in this oil fraction (Santos *et al.*, 2013). Additionaly, the characterization of oils is of big interest to predict thermophysical properties, such as density and rheological parameters (Santos *et al.*, 2005). The specific composition of different oils makes the determination of physical properties essential to provide a well-designed processing system (Steffe, 1996).

Buriti oil is an important source of energy and vitamins and has some similarities to palm oil, such as its reddish-yellow color and its flavor (Pardauil *et al.*, 2017; Pesce *et al.*, 2009). However, buriti oil presents a high concentration of monounsaturated fatty acids, with values higher than those found in olive oil or in Brazil nuts, which are foods known for their oil with high nutritional quality due to the monounsaturated fatty acid properties of reducing blood total and LDL-cholesterol (França *et al.*, 1999; Silva *et al.*, 2009). In addition, the low concentration of polyunsaturated fatty acids gives buriti oil a high oxidative stability (Silva *et al.*, 2009). Buriti oil contains β-carotene in higher concentrations than foods widely consumed by Brazilians, such as guava, pitanga, papaya, passion fruit, carrots and other fruits from the Amazon region, including palm nuts, peach palm and tucumã (Rodriguez-Amaya, 1996; De Rosso and Mercadante, 2007). In addition, buriti oil presents high levels of tocopherols, making it a reliable source of antioxidant compounds (Bataglion *et al.*, 2015).

Carotenoids are a diversified group of lipophilic components, and β-carotene is a provitamin A compound with 100% theoretical activity (Rodriguez-Amaya, 1996; McClements *et al.*, 2007). The prevention of cancer, heart disease and macular degeneration are among the beneficial health effects that are attributed to carotenoids due to their association with antioxidant activity (Alquezar *et al.*, 2008; Meléndez-Martínez *et al.*, 2007). Tocopherols are important antioxidants and present vitamin E activity, especially α-tocopherol (De Greyt and Kellens, 2005).

Considering the high nutritional value of buriti oil and the growing interest of consumers for healthier products, its use in the food industry could be interesting (Bovi *et al.*, 2017). In this context, this work aimed to carry out a complete characterization of buriti oil, including its physicochemical and thermophysical properties, β-carotene and tocopherol contents, fatty acid and acylglycerol classes, as well as its thermal behavior (crystallization and melting).

2. MATERIALS AND METHODS

2.1. Chemicals

Hexane, acetonitrile, trimethylamine, methanol, ethyl acetate, isopropanol and tetrahydrofuran, all HPLC grade, were obtained from Dinâmica (Diadema, Brazil), J. T. Baker (Phillipsburg, USA) or Vetec (Rio de Janeiro, Brazil). The samples and solvents were filtered through Millipore (Billerica, USA) membranes (0.22 and 0.45 μm) prior to HPLC analysis. Sodium hydroxide, potassium hydroxide, methanol, petroleum ether and ethyl ether were obtained from Labsynth (Diadema, Brazil) or Dinâmica (Diadema, Brazil) and were of analytical grade. Standards of β-carotene and tocopherols were obtained from Sigma-Aldrich (St. Louis, USA).

2.2. Buriti oil

Six liters of crude buriti oil (Amazon Oil^{TM}) were obtained in Ananindeua city, Pará state, in the Brazilian Amazonian region and stored at -30 °C until analysis.

The characterization of buriti oil was carried out by physicochemical analyses, thermophysical

properties, β-carotene and tocopherols contents, fatty acids and acylglycerol classes and thermal analyses (crystallization and melting).

2.3. Physicochemical analyses

The physicochemical characteristics of buriti oil were assessed by the determination of free acidity (expressed in equivalent of oleic acid) and peroxide, iodine, saponification and refractive indexes, according to AOCS (2009). All the analyses were carried out in triplicate.

2.4. Determination of thermophysical properties

Rheology and density of crude buriti oil were determined in triplicate at 25 ºC.

***Rheology*.** A controlled stress rheometer, model ARG2 (TA Instruments, New Castle, USA), was used to carry out steady state flows with cone-plate geometry (52 μm gap). The shear rate varied from 0.1 s^{-1} to 500 s^{-1}, and the mean shear stress was acquired through the data acquisition system. Then, the resulting rheograms were fitted to Newton model to provide the viscosity value.

***Density*.** The density was determined using a digital electronic density meter (model DMA 4500-M, Anton Paar, Austria), in which approximately 10 mL of crude buriti oil were used for each run. After establishing the temperature, the density values were provided by the equipment.

2.5. Determination of carotenoids and tocopherols in buriti oil

***Carotenoids*.** The content of β-carotene in buriti oil was determined by high performance liquid chromatography coupled to a diode array detector (HPLC-DAD). Before the injection into the HPLC system, the crude buriti oil was submitted to saponification in 10% KOH in methanol for 14-16 hours, followed by a liquid-liquid partition using petroleum ether:ethyl ether (1:1, v/v) and the alkali was removed by washing with distilled water (De Rosso and Mercadante, 2007). The carotenoid extract was injected into a Shimadzu HPLC (Kyoto, Japan) equipped with quaternary pump (LC-20AT) with a 10 μL loop, on-line degasser, auto sampler (SIL-20A) and a DAD detector (SPD-M20A). The compounds were separated on a C18 Shimpack VP-ODS column (250 mm x 4.6 μm) using, as mobile phase, a linear gradient of acetonitrile (0.05% triethylamine):methanol:ethyl acetate from 60:20:20 to 60:0:40 in 43 minutes and maintaining this proportion for 17 min. The flow rate was 1 mL/min, the column temperature was set at 29 °C and the chromatograms were processed at 450 nm (Silva *et al.*, 2014). β-carotene was identified according to the following combined information: elution order on C18 column, co-chromatography with authentic standard, and UV–Vis spectrum [λ_{max}, spectral fine structure (%III/II), peak *cis* intensity (%AB/AII)] compared with the data available in the literature (De Rosso and Mercadante, 2007). The β-carotene was quantified (in triplicate) by HPLC-DAD, using external seven-point analytical curves (in duplicate) with all-*trans*-β-carotene standard (0.547–35.0 μg/mL). Total carotenoids were considered as the sum of the carotenoid peak areas in the chromatogram obtained.

***Tocopherols*.** The tocopherol profile and total tocopherols in buriti oil were determined according to AOCS Ce 8-89 methodology (AOCS, 2009), using the high performance liquid chromatography coupled to fluorescence detector. Before the injection into the HPLC system, the crude buriti oil was solubilized in hexane (1% w/v). The samples were injected into a Perkin Elmer SERIES 2000 HPLC, under the following chromatographic conditions: isocratic pump Perkin Elmer 250; fluorescence detector Shimadzu RF-10 AXL with excitation-290 nm and emission-330 nm; Merck analytical column 250 x 4 mm Li Chrosorb Si 60*5μm coupled to compatible guard column; mobile phase: 99:1 hexane/isopropanol (filtered and degased for 10 minutes in an ultrasonic bath), flow 1.0 mL/min; injected volume of 20.0 μL. The individual tocopherols were identified by elution order on the analytical column compared with external authentic standards and quantified (in triplicate) using external analytical curves with authentic standards. Total tocopherols were considered as the sum of the individual tocopherol concentration.

2.6. Fatty acid composition and acylglycerol classes

The determination of the fatty acid composition was performed on a gas chromatograph with capillary column - CGC Agilent 6850 Series GC System, after esterification using the Hartman and Lago (1973) method. The fatty acid methyl esters were separated according to the AOCS Ce 1-62 method (AOCS, 2009) on capillary column DB-23 Agilent (50% cyanopropyl-methylpolysiloxane) with dimensions: 60 m, φ int: 0.25 mm, 0.25 μm film. Oven temperature 110 °C-5 min, 110-215 °C (5 °C/min), 215 °C-24 min; detector temperature 280 °C; injector temperature 250 °C; helium drag gas; split ratio 1:50; injected volume of 1.0 μL. The qualitative composition was determined by comparing peak retention times with those of respective fatty acid standards. Mustard oil was used as standard. The quantitative composition was determined by the peak percentage area.

The buriti oil acylglycerol classes were determined by high performance size exclusion chromatography (HPSEC) using liquid chromatograph Pelkin Elmer

Series 200; refractive index detector Waters 2414; two columns, being 1 - JORDI GEL DVB 300 x 7.8 mm, 500 Å and 2 - JORDI GEL DVB 300 x 7.8 mm, 100 Å; mobile phase tetrahydrofuran; flow rate 1 mL/min; injected volume 20.0 µL. The sample was solubilized in tetrahydrofuran at 1.0% concentration. The acylglycerol separation mechanism by the HPSEC technique occurs through the molecular size difference among compounds present in the reaction enviroment. In this case, the elution order is triacylglycerols, diacylglycerols, monoacylglycerols and free fatty acids.

2.7. Triacylglycerol composition and triacylglycerol classes

The buriti oil triacylglycerol composition was estimated using the software PrOleos, based on the hypothesis of 1,3-random-2-random distribution, which predicts triacylglycerols' molar percentage present in vegetable oils, from the fatty acid composition (Antoniosi Filho *et al.*, 1995). This software is available in the plataform "https://lames.quimica.ufg.br/p/4035-material-didatico". The triacylglycerol classes were estimated by triacylglycerol composition.

2.8. Crystallization and melting

Thermal analysis for buriti oil crystallization and melting behavior was performed by differential scanning calorimetry using DSC 8000 (Pyris Series, Perkin Elmer) at 80 °C for 10 min, 80 at -80 °C (5 °C/min), -80 °C for 10 min, -80 to 80 °C (5 °C/min).

3. RESULTS AND DISCUSSION

3.1. Physicochemical and thermophysical analyses

The buriti oil used was crude, and due to this fact a higher percentage of free fatty acids was observed (Table 1) compared to refined oils. For example, Ribeiro *et al.* (2009) reported 0.03% FFA for refined soybean oil. The peroxide index is related to the oil oxidative state and not to its characterization itself. Santos *et al.* (2013) found 7.4 meq O_2/kg for buriti oil and reported this value within expected ranges for crude oils of good quality. The saponification and iodine values are related only to specific characteristics of each vegetable oil, such as chain length and unsaturation number (Pardauil *et al.*, 2017). Both the iodine and saponification indexes found for buriti oil were similar to those found in the literature, being 73 g/100 g and 193 mg KOH/g, respectively (Lognay *et al.*, 1987). The refractive index found for buriti oil (Table 1) was the same as previously reported in the literature (Albuquerque *et al.*, 2005; Silva *et al.*, 2009).

With respect to rheology, buriti oil showed Newtonian behavior as expected in the literature for oils (Steffe, 1996). It was characterized by the linear dependence between shear rate and shear stress with R^2>0.9999 and null intercept. Newtonian viscosity presented close values to the ones published by Santos *et al.* (2005) for different vegetable oils. In the same way, the viscosity of buriti oil was comparable to the values found by Ribeiro *et al.* (2017) for different commercial olive oils. These olive oils had a very similar fatty acid composition to buriti oil, which also resulted in close agreement between buriti and olive oil densities. Besides being an indicative of degradation, such properties are useful for the correct design of oil pumping, settling and filtration (Bonnet *et al.*, 2011).

3.2. β-carotene and tocopherol contents

Buriti oil presented high contents of carotenoids (686.89 mg/kg), with β-carotene as the major compound, accounting for 74% of total carotenoids (506.84 mg/kg), which imparts the oil its orange-red color. Godoy and Rodriguez-Amaya (1994) emphasize that buriti is a very important pro-vitamin A source, since its content in β-carotene is much higher than that found in most of Brazilian fruits. Crude palm oil shows total carotenoids of 608.39 mg/kg (Ferreira *et al.*, 2006), which is similar to the crude buriti oil in our study. In addition, natural sources of this carotene are of great interest because only 2% of commercial β-carotene is naturally produced (Dufossé *et al.*, 2005; Ribeiro *et al.*, 2011; Speranza *et al.*, 2016).

Buriti crude oil was reported with a high amount of total carotenoids by Lognay *et al.* (1987) (1730 mg/kg), Albuquerque *et al.* (2005) (1707 mg/kg) and Silva *et al.* (2009) (1003 mg/kg) with β-carotene present as the principal component.

De Rosso and Mercadante (2007) reported the identification and quantification of carotenoids in buriti pulp by HPLC-DAD using a C_{30} column and coupled to a mass spectrometer (APCI ionization source), and presented β-carotene as the major carotenoid (72%), followed by 13-*cis*-β-carotene (12%), 9-*cis*-β-carotene (3.6%), γ-carotene (2.9%) and *cis*-γ-carotene (1.9%) and a total carotenoid

TABLE 1. Physicochemical and thermophysical characteristics of buriti oil

Oil characteristics	Results
Free acidity (%)	3.99±0.01
Peroxide index (meq O_2/kg)	6.86±0.38
Iodine index (g/100 g)	76
Saponification index (mgKOH/g)	193
Refractive index (25 °C)	1.46±0.01
Viscosity (mPa·s)	66.01
Density (kg/m³)	909.33±0.01

content of 513.87 mg/kg. Santos *et al.* (2015) investigated the carotenoid composition in buriti oil by HPLC-DAD. The authors reported a total carotenoid content of 54.81 mg/kg with β-carotene as the principal carotenoid (55%), followed by *cis*-β-carotene (31%), lutein (6%) and *cis*-lutein (3%).

Although in our study other carotenoid peaks were observed in the chromatogram of the crude buriti oil sample, it was not possible to perform the identification by the HPLC-DAD analysis, since *cis* and *trans* isomer separation were not efficient and the *cis* peaks were present at very low intensity. In the chromatogram (Figure 1) it is possible to notice the carotene peaks and β-carotene peak with the biggest area.

Concerning the tocopherol profile, which can be seen in Table 2, buriti oil presented a content of total tocopherols of 104.14 mg/100 g. The principal tocopherol was β-tocopherol (48%) followed by α-tocopherol (43%), in this way, they were present in similar amounts and represented 91% of total tocopherols.

Lognay *et al.* (1987) and Albuquerque *et al.* (2005) reported similar values for total tocopherols, but Lognay *et al.* (1987) presented the α-tocopherol as the major component (48.1%) while (β + γ)-tocopherol represented 48.3%. Silva *et al.* (2009) and Santos *et al.* (2013) reported high values for total tocopherols at 152 mg/100g and 156.7 mg/100 g, respectively. While Silva *et al.* (2009) presented β-tocopherol as the major component (45%) followed by α-tocopherol (40%), Santos *et al.* (2013) presented α-tocopherol as the major component (70%) followed by β-tocopherol (30%). These results reinforce the fact that buriti oil has a promising potential as a dietary source due to its high vitamin E content (Santos *et al.*, 2013). Such difference in reported values of unsaponified matter might be due to fact that the composition and, consequently, the nutritional value of crude buriti oil vary with the variability and/or ripening stage, the region of provenance and extraction process (Santos *et al.*, 2015; Silva *et al.*, 2009).

3.3. Fatty acid composition and acylglycerol classes

Buriti oil presented higher levels of unsaturated fatty acids than saturated fatty acids, being oleic acid the main fatty acid in buriti oil (69.58%) followed by palmitic acid (17.35%) (Table 3). Similar compositions were also related by other authors (Escriche *et al.* 1999; Albuquerque *et al.*, 2005; Silva *et al.*, 2009; Bataglion *et al.*, 2015).

The profile of fatty acids found in buriti oil revealed a good source of monounsaturated fatty acids. According to Speranza *et al.* (2016), a great interest has been placed on oils that contain these fatty acids. High oleic and low linoleic fatty acid contents help to make them more resistant to oxidation than most oils.

From the point of view of nutritional and food industries, in general, oleic acid is the most abundant omega-9 fatty acid in food and one of the most commonly found fatty acids in nature. It is monounsaturated, considered fundamental for beneficial properties in the reduction of LDL-cholesterol oxidation, besides being a precursor for the production of most other polyunsaturated fatty acids and hormones (Syed, 2012; Watkins and German, 2008; Angelis, 2001).

Regarding the acylglycerol classes, the most abundant compounds are triacylglycerols (88%) (Table 4). Such result was similar to that reported in the literature; 92.6% of triaclylglycerols and the content of diacylglycerols, monoacylglycerols and free fatty acids were about 5% for buriti crude oil (Lognay *et al.*, 1987).

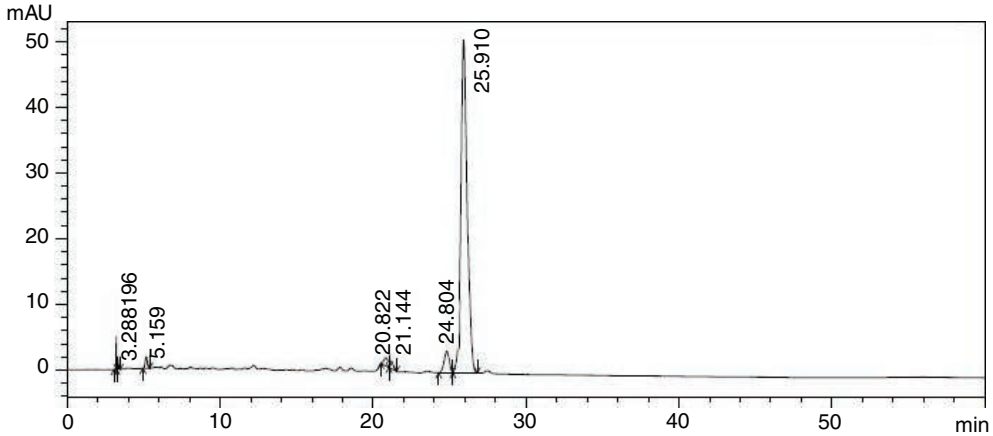

FIGURE 1. Chromatogram (processed at 450 nm), obtained by HPLC-DAD, of carotenoids from buriti oil.

Table 2. Tocopherol profile of buriti oil

Tocopherol	Content (mg/100 g)	% Total Tocopherol
α-tocopherol	44.89±7.84	43.11
β-tocopherol	50.13±7.42	48.13
γ-tocopherol	3.63±0.59	3.49
δ-tocopherol	5.49±0.74	5.27
Total	104.14±0.01	

Table 3. Composition of fatty acids of buriti oil

	Fatty acids	Mean (%)
C12:0	Lauric acid	0.06±0.02
C14:0	Myristic acid	0.11±0.02
C15:0	Pentadecanoic acid	0.06±0.03
C16:0	Palmitic acid	17.35±0.07
C16:1	Palmitoleic acid	0.24±0.01
C17:0	Margaric acid	0.09±0.01
C17:1	Heptadecenoic acid	0.07±0.01
C18:0	Stearic acid	3.32±0.02
C18:1	Oleic acid	69.58±0.15
C18:2	Linoleic acid	7.31±0.02
C18:3	Linolenic acid	0.98±0.01
C20:0	Arachidic acid	0.20±0.01
C20:1	Gadoleic acid	0.45±0.01
C22:0	Behenic acid	0.07±0.01
C24:0	Lignoceric acid	0.11±0.04
Saturated		21.37±0.17
Unsaturated		78.63±0.17

Table 4. Acylglycerol classes in buriti oil composition

Acylglycerol classes	Mean (% total lipids)
Triacylglycerols	88.33±1.16
Diacylglycerols	8.02±0.74
Monoacylglycerols + Free fatty acids	3.65±0.42

3.4. Triacylglycerol composition and triacylglycerol classes

The predominant triacylglycerols were OOO, POO, OLO and POP, representing 80.12% of the total (Table 5). It was observed that the composition of triacylglycerols in buriti oil was extremely homogeneous, considering the low fatty acid variability of this matrix, given the high contents in oleic and palmitic acids followed by linoleic acid. This fact also justifies the large percentage of triunsaturated (U_3) and diunsaturated (SU_2) triacylglycerols in the buriti oil composition of triacylglycerol classes (Table 6).

Table 5. Triacylglycerol composition of buriti oil

	Triacylglycerol	% (normalized)
C48:0	PPP	0.55±0.01
C50:1	POP	6.54±0.06
C50:2	PLP	1.03±0.04
C52:1	POS	2.53±0.02
C52:2	POO	26.41±0.06
C52:3	PLO	5.89±0.01
C52:4	PLnO	1.10±0.01
C54:2	SOO	5.37±0.02
C54:3	OOO	35.99±0.15
C54:4	OLO	11.20±0.05
C54:5	OLnO	2.64±0.01
C56:3	OGaO	0.75±0.01

P = palmitic acid, O = oleic acid, L = linoleic acid, S = stearic acid, Ln = linolenic acid, Ga = gadoleic acid.

Santos *et al.* (2013) determined the buriti oil triacylglycerol profile by HPCL reporting results for OOO (39.8%), POO+PLS (35.9%) and POP (10.2%) and by GC reporting results for OOO (35.6%), POO (38.8%) and POP (9.4%). These similar results could confirm the good accuracy of the PrOleos software, in which, Speranza *et al.* (2016) obtained a similar triacylglycerol profile for buriti oil.

Antoniosi Filho (1995) and Lognay *et al.* (1987) also found that OOO, POO and POP were the predominant triacylglycerols in the buriti oil analized, but they did not observe OLO as one of the predominant ones, reporting that it corresponded to 1.1 and 1.8% of total triacylglycerols, respectively.

3.5. Crystallization and melting

The crystallization temperature range was observed between -58.54 and 1.16 °C, with the peak at -43.06 °C. In turn, the melting temperature range was observed between -24.51 and 18.52 °C, with the peak at -2.73 °C. The crystallization and melting curves can be seen in Figure 2.

Because buriti oil is a mixture of triacylglycerols, crystallization and melting are observed in a temperature range, but not at a specific temperature. This is due to the fact that triunsaturated triacylglycerols present crystallization and melting points different from diunsaturated, monounsaturated and trisaturated triacylglycerols as a consequence of the different degrees of unsaturation.

It is interesting to note that the crystallization range did not coincide with the melting range, which is a common behavior in oils as a result of the different triacylglycerol arrangements when oil is liquid or solidified.

Buriti oil has approximately 90% of triunsaturated and diunsaturated triacylglycerols, and these have lower crystallization points than monounsaturated and trisaturated ones. When oil is liquid and the temperature is gradually reduced, monounsaturated and trisaturated triacylglycerols are melted in diunsaturated and triunsaturated and these last ones crystallize at a lower temperature. This behavior justifies a low crystallization range.

On the other hand, when buriti oil is solidified, triacylglycerols are arranged in a more organized way, which makes the melting range higher than the crystallization and melting transitions of highly polyunsaturated fatty acids followed by the melting of monounsaturated fatty acids and a small fraction of saturated fatty acids (Pardauil *et al.*, 2017). Pardauil *et al.* (2017) reported a similar crystallization curve and according to these authors and Tan and Che Man (2000), crystallization curves are reproducible and simpler than melting curves due to the oil crystallization being influenced only by chemical composition and not by the initial crystalline state which is a consequence of the polymorphism phenomena of natural oils, and this cannot be established unequivocally by DSC measurements.

Crystallization and melting curves also depend on fatty acid composition. Usually, oil samples with a high degree of saturation show higher temperatures of crystallization and melting profiles than oils with a high degree of unsaturation (Pardauil *et al.*, 2017).

The triunsaturated triacylglycerols, prevalent in buriti oil, present melting points from −14 to 1 °C and they are important for the softness and lubricity of products at room temperature. In addition, the diunsaturated triacylglycerols, with melting points from 1 to 23 °C, are important for the oral properties and mechanical-performance of products at room temperature (O'Brien, 2009; Rodrigues and Gioielli, 2003; Bessler and Orthoefer, 1983; Speranza *et al.*, 2016).

TABLE 6. Triacylglycerol classes in the composition of buriti oil

Triacylglycerol classes	%
S_3 (SSS)	0.55±0.01
S_2U (SUS)	10.10±0.12
SU_2 (SUU)	38.77±0.08
U_3 (UUU)	50.58±0.20

S = saturated acylglycerol, U = unsaturated acylglycerol.

4. CONCLUSIONS

Concerning the presented results, the buriti oil characterization attested its high quality due to high levels of carotenoids and tocopherols, with β-carotene and β-tocopherol being the principal ones in their classes, and monounsaturated fatty acids with oleic acid as the major one. In this way, crude buriti oil demonstrated a high potential to be used as a bioactive ingredient for foodstuff. Furthermore, its physicochemical and thermophysical characterization is useful for developing promising products and designing new processes.

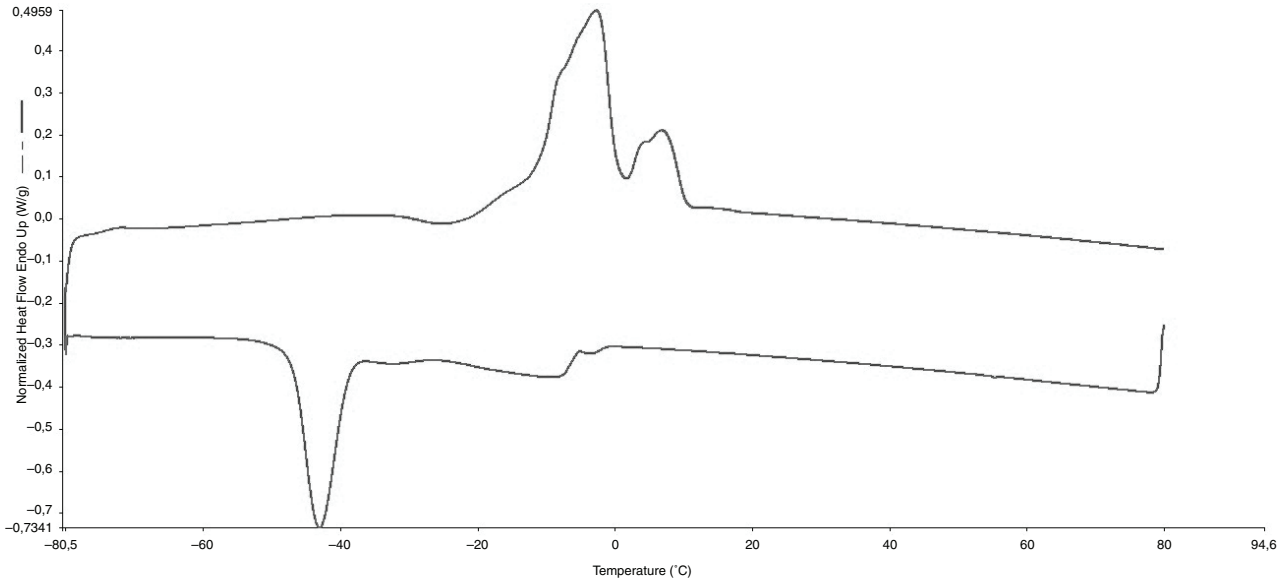

FIGURE 2. Thermogram of buriti oil with melting curve (above) and crystallization curve (below).

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