Journal of Food Measurement and Characterization (2018) 12:1284–1294
https://doi.org/10.1007/s11694-018-9742-3

ORIGINAL PAPER

Nutritional and chemical characterizations of fruits obtained from *Syagrus romanzoffiana, Attalea dubia, Attalea phalerata* and *mauritia flexuosa*

Caroline Honaiser Lescano[1] · Ivan Pires de Oliveira[1] · Fernando Freitas de Lima[1] · Débora da Silva Baldivia[2] · Priscilla Narciso Justi[1] · Claudia Andrea Lima Cardoso[3] · Jorge Luiz Raposo Júnior[1] · Eliana Janet Sanjinez-Argandoña[4]

Received: 13 December 2017 / Accepted: 31 January 2018 / Published online: 3 February 2018

Abstract

Several species of Arecaceae are widely distributed in tropical regions and are economically important as a source of vegetable oil and bioactive nutrients beneficial to health and human nutrition. In this work, the physical and chemical characteristics of the oils and fruits from *Syagrus romanzoffiana, Attalea phalerata, Mauritia flexuosa* and for the first time for *Attalea dubia* (Mart.) Burret were determined. All fruits were dimensioned according to the biometric analysis (size and mass). Nutritional analysis showed high levels of lipids, proteins, sugars and fibers, as well as Ca, Mg, K, Cu, Mn, Fe and Zn minerals. The composition of fatty acids showed the predominance of short and unsaturated fatty acids carbon chain. All fruits presented high content of polyphenols and carotenoids (except for *S. romanzoffiana*). Moreover, all fruits demonstrate antioxidant activity by direct capture of free radicals ABTS and DPPH. Finally, our results demonstrate that these fruits have a relevant concentration of nutrients and bioactive compounds with importance for human health. Such data open up promising prospects for the scientific exploration and use of these fruits as an alternative source to combat malnutrition as well as to compose formulations of food products with functional properties. Finally, our results demonstrate that these fruits present a relevant concentration of nutrients and bioactive compounds with importance for human health, with promising perspectives for the scientific exploration and use of these fruits as an alternative source to avoid malnutrition as well as to compose formulations of food products with functional properties.

Keywords Arecaceae's fruits · Vegetable oil · Food science · Functional foods · Nutraceutical

Introduction

Vegetable oils have been traditionally used by various cultures as food source, alternative medicine, cosmetic, and more recently in the chemical industry and as biofuels [1–3]. In South America, mainly in Brazil, there is a wide diversity of oleaginous species (native to different biomes, such as Amazon, Cerrado, Pantanal, others) and this area offers immense opportunities to increase agricultural production [4]. In the Cerrado region, which covers a large extent of the Brazilian territory, it is possible to find some species belonging to Arecaceae family that has attracted the attention of the scientific community, for example, *Syagrus romanzoffiana* (jerivá), *Attalea dubia* (Mart.) Burret (indaia), *Attalea phalerata* (bacuri) and *Mauritia flexuosa* (buriti), described in this paper [5–8]. For example, Arecaceae fruits stands out for its potential use in the production of biodiesel [9].

✉ Fernando Freitas de Lima
flfernando_@hotmail.com

[1] Faculty of Health Sciences, Federal University of Grande Dourados, Rodovia Dourados-Itahum, Km 12, PO Box 533, Dourados CEP 79804-970, Brazil

[2] Faculty of Biological and Environmental Sciences, Federal University of Grande Dourados, Dourados, MS, Brazil

[3] Course of Chemistry, University of Mato Grosso do Sul, Dourados, MS, Brazil

[4] Faculty of Engineering, Federal University of Grande Dourados, Dourados, MS, Brazil

Moreover, it has recently been shown that the fruits of Arecaceae present important biological activities such as anti-inflammatory properties (pulp oil from *Attalea phalerata*), hypoglycemic effect (*Syagrus romazoffiana*) [10], phtoprotective and neuroprotector effects (*Mauritia flexuosa*) [11]. These fruits are traditionally used in folk medicine, for example, the pulp oil of *Attalea phalerata* that is used as a hair tonic, anti-dandruff and pulmonary congestion, without cytotoxic effect [12]. The oil extracted from *Mauritia flexuosa* fruits is popularly used against burns and as a potent vermifuge and the fruits are used for the control of cholesterol, diabetes and inflammation. However, no data regarding the nutritional composition and the potential antioxidant action of *Attalea dubia* (Mart.) Burret fruits was found in the literature.

Fruits and kernels, in general, are known as good sources of dietary fiber, minerals, vitamins, and bioactive compounds [13]. The benefits derived from the consumption of these foods are diverse, and are widely highlighted in the literature [14, 15]. The species belonging to the Arecaceae family produce edible fruits, such as coconuts, which have a yellow/orange color pulp and kernels surrounded by a rigid endocarp. Arecaceae fruits are usually eaten raw (especially kernels) or as ice cream and juices (pulp mainly). Studies have shown that species belonging to the Arecaceae family are a rich source of bioactive compounds such as phenolics and carotenoids, specifically flavonoids and β-carotene [5–8, 16]. These compounds possess antioxidant properties which can be beneficially used to action, for example, free radicals, which are associated with aging and are involved in processes that unleash degenerative diseases [14, 15, 17]. In recent years an increasing number of studies have pointed out that there is a need to modify the eating habits of the Western population, since it is clear that the dietary habits in Western societies might lead to the development of obesity, dyslipidemia, diabetes, atherosclerosis, cancer and neurological diseases [18]. In addition, the addition of fruits from Arecaceae family into human nutrition can be beneficial in public policies against malnutrition.

The species belonging to the Arecaceae family are cultivated in tropical regions and are consumed by the local population. This study aimed to investigate the physical and chemical properties of these fruits in order to highlight their high nutritional and functional potential.

Materials and methods

Chemicals

Gallic acid, Folin–Ciocalteu reagent, ABTS (2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt), DPPH (2,2-diphenyl-1-picrylhydrazyl radical), Trolox (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) and potassium persulfate (di-potassium peroxodisulfate), were purchased from Sigma-Aldrich Chemical Company (St. Louis, MO). All the other chemicals used were of analytical grade.

Plant material and biometrical measurements

All species were collected in Mato Grosso do Sul state, between October and December of 2015 *Syagrus romanzoffiana* was collected in Dourados, *Attalea phalerata* in Bonito and *Attalea dubia* and *Mauritia flexuosa* in Campo Grande. All fruits were collected at harvest maturity selected according to the size and absence of damage, washed and then sanitized with aqueous solution of 0.66% (v/v) sodium dichloroisocyanurate dihydrate (content of active chlorine 3%). After biometrics measurements, fruits were pealed, pulped deseeded, and the different interested parts of these fruits were stored at − 5 °C until analysis.

The biometric characterization of fruits, besides providing taxonomic distinction between plant species, is an important tool for commercial applications through estimation of size and uniformity of samples. To determine the biometric parameters, 100 fruits of each species were used to limit the occurrence of the sample error and to guarantee reliable results for the analysis. The longitudinal and transversal diameters of 100 fruits were determined with the aid of a digital caliper (Mitutoyo). The mass of the whole fruit, peel (epicarp), pulp (mesocarp), endocarp and kernel, was determined using an analytical balance (Shimadzu-AUY220) using 100 fruits of sample set.

Nutritional composition

The pulp and kernel were characterized according to their moisture content determined by gravimetry in a greenhouse at 105 °C until constant weight and ash content by gravimetry in a muffle furnace at 550 °C [19]. Fat content was determined by Soxhlet method and carbohydrates according to the methods previously described [19]. Crude fiber was quantified by acid and alkaline hydrolysis, and protein content by quantifying total nitrogen, determined by the Micro–Kjedahl method [19].

Minerals nutrients

The mineral levels, such as macro and micro nutrients, were evaluated according to the traditional atomic spectrometry methodology. The samples were crushed and homogenized, followed by organic digestion using a mixture of hydrochloric acid and hydrogen peroxide, both concentrated, at high temperatures, solubilizing macro and microelements. The elements (Ca, Mg, K, Cu, Mn, Fe and Zn) were quantified by

spectrometry using an atomic absorption spectrophotometer (Varian-AA240FS) and acetylene gas. The quantification was performed by comparison to standard curves.

Fatty acids characterization

The pulp was previously dehydrated at 40 °C in a tray dryer (NG Scientific) with an air flow of 0.5 ms^{-1} for 72 h. Oil extraction was performed using Soxhlet method with hexane solvent [20]. Fatty acid characterization was performed by the trans methylation, using an ammonium chloride and sulfuric acid solution in methanol as esterifying agent. The treated samples were analyzed by gas chromatography (Agilent HP-6890), equipped with automatic sampler (HP-7683); split injector, 75:1 ratio; CP-SIL 88 capillary column (100 m × 0.25 mm i.d., 0.20 mm of film); and flame ionization detector (FID). The chromatographic conditions were performed according to Fernandes et al. with adaptations: initial temperature 120 °C/2 min, heating from 120 to 220 °C on a gradient rate of 2.2 °C/min and from 220 to 270 °C on a gradient rate of 2.0 °C/min; hydrogen carrier gas (flow rate of 1 mL/min); make-up gas, nitrogen at 30 mL/min; temperature detector, 270 °C; injection volume of 1 µL [21]. The identification of fatty acids was performed by comparing the standard retention time of fatty acids with those of the sample.

The detection limit was determined by injecting (n = 5) solutions of fatty acids of known concentration (0.1–100 µg/mL) and then decreasing the concentrations of the standards until detection of a peak with a signal/noise ratio of 3. The corresponding concentration was considered the minimal detectable concentration. The quantification limit was determined by performing the same methodology and, thus, the quantification limit was defined as the peak having a signal/noise ratio of 10.

The content estimation of the fatty acids (1–50 µg/mL) in the samples was performed by external calibration. Specimens with an analytic concentration exceeding the analytical curve were reassayed upon appropriate dilution of the samples. The results were expressed in g/100 g of sample.

The extraction efficiency was determined by analyzing aliquots of samples spiked with standards in the concentration of 20 µg/mL. The spiked samples were submitted to the same procedure as described in extraction of samples.

Total polyphenols and carotenoids

Total polyphenol content was determined according to the spectrophotometric method proposed by Folin–Ciocalteu, using gallic acid as standard. First, a solution was prepared (10 g sample + 50 mL acetone/water 70% v/v). Then, 0.5 mL of the solution was diluted in 2.5 mL of the Folin–Ciocalteu's reagent 10% v/v (diluted in water), and then 2.0 mL of sodium carbonate aqueous solution (7.5% v/v) was added. This solution was incubated in water bath at 50 °C for 15 min, and then cooled down using an ice bath. The absorbance readings at 760 nm were performed in a bench spectrophotometer (Varian Cary 50). The total carotenoids content was determined used 2.5 g of sample was macerated using acetone at 10 °C, it was added until extracting all the pigment, and then the mixture was vacuum filtered. The mixture was collected and transferred to a separatory funnel containing 40 mL of petroleum ether. After, the mixture was slowly washed with distilled water until complete removal of the acetone. Finally, the material was transferred into a volumetric flask and the volume completed with petroleum ether to final volume of 50 mL, and readings of absorbance at 450 nm were made in a bench spectrophotometer (Varian Cary 50).

Antioxidant activity by DPPH method

The DPPH radical-scavenging activities of oils were determined according to the method previously proposed by Brand-Wiliams et al. [22]. A volume of 0.5 mL of each sample was diluted in 0.5 mL of DPPH solution at 0.04 mmol/L and 1.5 mL of ethanol. The mixture was shaken and kept at room temperature e.g. 25 °C for 10 min. Antioxidant activity was measured by recording the absorbance intensity at 517 nm using a spectrophotometer (Varian Cary50), and ethanol was used as the blank.

Antioxidant activity by ABTS method

The ability of the oils to eliminate the ABTS free radicals was determined according to the conventional methodology proposed by Rufino et al. [23]. A standard curve was prepared using Trolox (6-Hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) in different concentrations (100, 500, 1000, 1500 and 2000 µmol/L). Reaction solutions, containing 30 µL of the oil and 3 mL of reagent (potassium persulfate at 2.45 mmol/L with ABTS at 7 mmol/L), were incubated at 30 °C for 6 min, and then the absorbance at 734 nm was read. The inhibition concentration was based on the Trolox standard curve and the results were expressed in µmol/L Trolox/g oil.

Statistical analyses

The results were expressed as mean ± standard deviation (SD). One-way ANOVA followed by the Tukey test was performed using GraphPad Prism (Version 6.0 - GraphPad Software, San Diego, CA) in order to evaluate possible differences between groups.

Results and discussion

Physical characterization of fruits

The biometric characteristics, dimensions and masses of parts of the fruits of *S. romanzoffiana, A. dubia, A. phalerata* and *M. flexuosa* are presented in Table 1. The fruit of *A. dubia* was the one that presented the largest transverse diameter (56.03 mm), followed by fruits of *M. flexuosa* (36.32 mm) and *A. phalerata* (30.65 mm), the lowest value was observed for *S. romanzoffiana* (28.21 mm). In terms of longitudinal diameter, the highest value was observed for *A. dubia* (63.65 mm), followed by *A. phalerata* (59.25 mm) and *M. flexuosa* (51.60 mm), and the smallest longitudinal diameter observed for *S. romanzoffiana* (24.27 mm). In summary, *S. romanzoffiana* is approximately spherical fruits, with great elongation (oval shape) for *A. phalerata, A. dubia* and *M. flexuosa*.

The comparison (dimensional and weight) can be easily visualized in Figs. 1 and 2. Figure 1 shows the shape of the fruits for each oleaginous species. The general form of the fruits is an oval geometry, with *S. romanzoffiana* more flattened and the others elongate. The smallest fruits are from *S. romanzoffiana* and the largest from *A. dubia*. It is interesting to note that the growth occurs mainly in the longitudinal axis compared to the transversal axis. This should be an easy criterion to identify the oleaginous species in function of the fruit, or to identify the origin of an unknown fruit.

Table 1 Biometric characteristics of the fruits from Arecaceae

Biometric parameter	*S. romanzoffiana*	*A. dubia*	*A. phalerata*	*M. flexuosa*
Transversal diameter (mm)	28.21 ± 1.15^{a}	56.03 ± 6.22^{b}	30.65 ± 1.36^{a}	36.32 ± 2.60^{a}
Longitudinal diameter (mm)	24.27 ± 1.40^{a}	63.65 ± 5.32^{b}	59.25 ± 1.42^{a}	51.60 ± 1.83^{a}
Whole fruit (g)	10.55 ± 1.06^{a}	98.20 ± 3.58^{b}	39.00 ± 3.76^{c}	55.75 ± 1.40^{d}
Peel (g)	*	27.30 ± 2.20^{a} *27.80%*	8.39 ± 1.44^{b} *21.51%*	14.36 ± 1.12^{c} *25.76%*
Pulp (g)	$6.97 \pm 0.9^{b,a}$ *66.07%*	12.70 ± 1.03^{a} *12.93%*	9.07 ± 2.33^{a} *23.26%*	$14.73 \pm 0.50^{c,a}$ *26.42%*
Seed (g)	2.73 ± 0.22^{a} *25.88%*	57.70 ± 2.51^{b} *58.76%*	18.58 ± 0.34^{c} *47.64%*	26.62 ± 0.92^{d} *47.75%*
Kernel (g)	0.85 ± 0.23^{a} *8.06%*	nd	2.42 ± 0.50^{b} *6.21%*	nd

Italic values indicate percentages express a ratio of each part of the fruit to the whole fruit weight

Values are means ± SD (n = 100). Mean values on the same line followed by different superscripts indicate significant differences ($p < 0.05$). Seed: sum of the kernel and its shell

nd not determined

*Very thin peel adhered to pulp

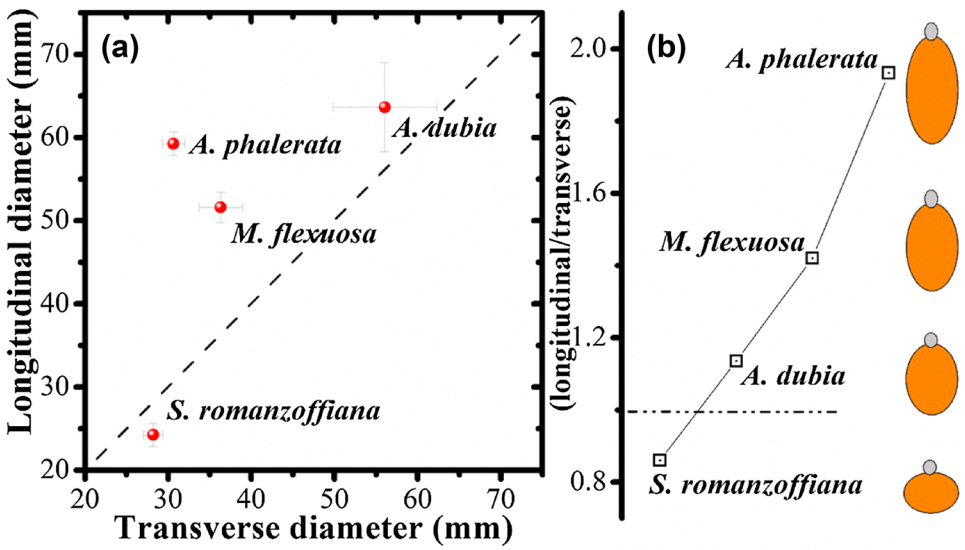


Fig. 1 Dimensions of the fruits from tropical oilseeds. **a** Longitudinal and transverse correlation to different species. **b** Relative diameter showing the fruits' form

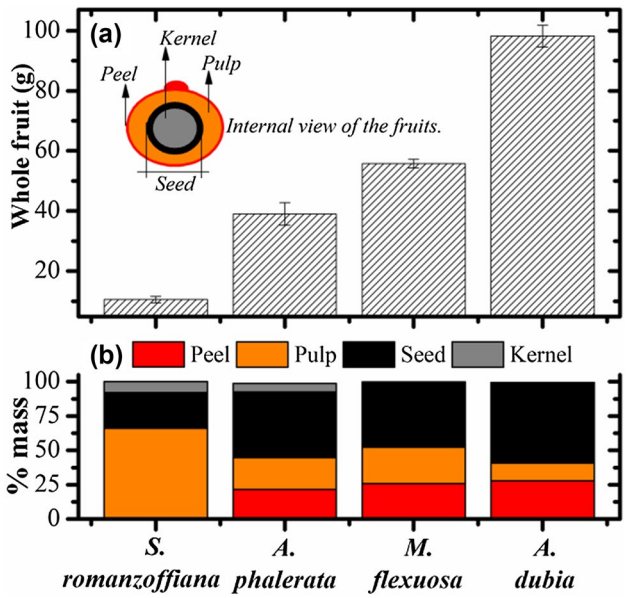


Fig. 2 Mass of the fruits and the percentage contributions of the constituent parts. **a** Mass of whole fruits and **b** fractioned in their specifics parts. Seed: sum of the kernel and its coating peel. (Color figure online)

Figure 2a presents the size of the fruits and the percentage distribution in their constituent parts. The largest of the *A. dubia* fruits also have larger mass, which is due to peel and its seed. In lighter and smaller fruits (*S. romanzoffiana*) the pulp represents most of the mass of the fruits and the heavier and larger fruits (*A. phalerata, A. dubia* and *M. flexuosa*) the seed (kernel sum and its coating shell) represents the major part of the mass of these fruits, besides a significant contribution of the peel.

In general, compared to the biometric values available in the literature, the fruits of *S. romanzoffiana* had slightly higher yield values when compared to those found by previous studies developed by Goudel et al. [24]. The fruits of *M. flexuosa* had pulp yield higher than those found in a previous study conducted by Barbosa et al. [25] and Carneiro et al. [26], and values similar to those determined by Carvalho et al. [27].

Nutritional composition

The knowledge of the nutritional characteristics of the fruits is of great relevance for understanding the nutritional and nutritional functions. The nutritional composition of the fruits is presented in Table 2. In fresh fruits, the average moisture content is between 65 and 95%, only the pulps of *S. romanzoffiana* (69.62%) and *M. flexuosa* (73.45%) have values within this range, the other fruits presented lower values, among which the lowest value was observed for *A. dubia*. The kernels that presented the highest moisture values were of *A. dubia* (19.64%) and *S. romanzoffiana* (18.29%). The content of fixed mineral residues for fruit pulp varied from 1.13% (*S. romanzoffiana*) to 2.91% (*A. dubia*), in addition, kernels showed variations between 1.28% (*A. dubia*) and 1.65% (*S. romanzoffiana*).

In relation to the Fats value, both fruit pulps and kernels presented high content, unlike most of the more traditional tropical fruits. In general, the kernels of the fruits present relative content of total fats higher than the one determined for the pulps. Specifically, the pulp with the highest percentage content of fats was *S. romanzoffiana* (21.67%), and lower content mainly for *A. dubia* (9.47%). The fruits with the highest fat content in the kernel were those with high fat content in the pulp *S. romanzoffiana* (40.68%). On the other hand, the lowest fat contents were obtained from *A. dubia* kernel (30.56%).

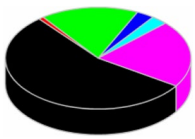
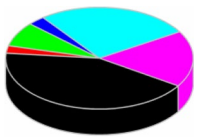
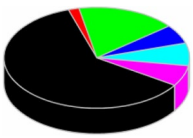
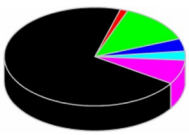
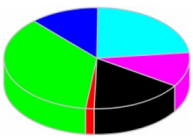
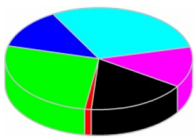
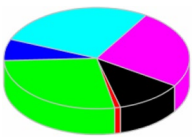
In general, the kernel of all fruits has a higher content of total proteins in relation to their respective pulps. The kernels with the highest protein content are the fruits of *S. romanzoffiana* (13.53%) and *A. dubia* (14.77%). The protein content in the pulps is lower for *A. dubia* (3.60%) and higher for *A. phalerata* (5.81%). In relation to the total sugar content, it is observed that the kernels present a higher amount of this nutritional constituent, mainly for *S. romanzoffiana* (25.85% in kernel and 3.70% in pulp) and *A. phalerata* (36.61% in kernel and 6.87% in pulp). It is worth noting the high amount of sugars in both parts of the fruits of *A. dubia*, above 30% in composition, in kernel (33.75%) and pulp (32.41%). These fruits present significant amounts of fiber, especially for *A. dubia* (21.72%) and *S. romanzoffiana* pulp (26.94%) and lower contents for *M. flexuosa* (8.32%) and *A. phalerata* (6.33%). In addition, the kernel of *A. phalerata* was the part of the fruit with greater percentage of fibers totaling 33.22%. Differences with values reported in previous studies might be attributed to soil, climatic conditions, collection period and other factors [20].

The physical and chemical characterization of those fruits is not sufficient to consider them with high nutritional value, since the bioavailability of the nutrients is essential to determine the nutritive value of the food [28]. However, the Cerrado fruits, here analyzed can considerably contribute to the recommended dietary intake, being alternative sources of several nutrients.

Minerals content

Table 3 shows the mineral composition of fruit pulp. Among the macronutrient elements, potassium had the highest concentration found in *A. dubia* (17.85 mg/g) and *S. romanzoffiana* (14.60 mg/g) pulps. It is interesting to observe that *A. dubia*, despite having high levels of potassium, has low contents of calcium and magnesium compared to other oilseeds. The fruits from *A. phalerata* were the only ones to present

Table 2 Nutritional composition of the fruits from Arecaceae. (Color table online)

Nutritional parameter (%)	*S. romanzoffiana*	*A. dubia*	*A. phalerata*	*M. flexuosa*
Moisture				
Pulp	69.62 ± 1.97[a]	51.61 ± 2.22[b]	57.91 ± 1.90[b]	73.45 ± 0.43[a]
Kernel	18.29 ± 0.01[a]	19.64 ± 1.44[a,b]	15.41 ± 0.47[a,c]	---
Fixed mineral residue				
Pulp	1.13 ± 0.13[a]	2.91 ± 0.02[b]	1.78 ± 0.16[c]	1.41 ± 0.15[a,c]
Kernel	1.65 ± 0.08[a]	1.28 ± 0.47[a]	1.33 ± 0.06[a]	---
Total fats				
Pulp	21.67 ± 0.10[a]	9.47 ± 0.59[b]	16.41 ± 0.23[c]	13.75 ± 0.56[d]
Kernel	40.68 ± 2.21[a]	30.56 ± 1.15[b]	36.01 ± 1.30[a,b]	---
Total proteins				
Pulp	3.88 ± 0.57[a]	3.60 ± 0.23[a]	5.81 ± 0.50[b]	4.30 ± 0.09[a,b]
Kernel	13.53 ± 0.96[a]	14.77 ± 0.51[a]	8.95 ± 1.31[b]	---
Total sugars				
Pulp	3.70 ± 0.69[a]	32.41 ± 0.76[b]	6.87 ± 1.23[a]	3.08 ± 0.66[a]
Kernel	25.85 ± 0.81[a]	33.75 ± 0.89[b]	36.61 ± 1.12[c,b]	---
Total fiber				
Pulp	26.94 ± 1.42[a]	21.72 ± 3.18[a]	6.33 ± 0.95[b]	8.32 ± 1.25[b]
Kernel	12.33 ± 1.86[a]	14.77 ± 0.51[a]	33.22 ± 1.20[b]	---
Summary diagram				
Pulp				
Kernel				–

Values are means ± SD (n = 3). Mean values on the same line followed by different superscripts indicate significant differences ($p < 0.05$). Summary diagram legend: black (moist); red (fixed mineral residue); green (total fats); blue (total proteins); cyan (total sugars); magenta (total fiber)

Table 3 Mineral contents in the pulp of Arecaceae fruits

Fruits Minerals	*S. romanzoffiana*	*A. dubia*	*A. phalerata*	*M. flexuosa*
Macronutrients				
Calcium (mg/g)	1.36 ± 0.03[a]	0.41 ± 0.02[b]	1.02 ± 0.06[c]	3.11 ± 0.05[d]
Magnesium (mg/g)	1.40 ± 0.03[a]	0.69 ± 0.02[b]	1.13 ± 0.03[c]	1.27 ± 0.09[a,c]
Potassium (mg/g)	14.60 ± 0.56	17.85 ± 0.37	< LQ	< LQ
Micronutrients				
Copper (µg/g)	< LQ	< LQ	3.02 ± 0.17	< LQ

Values are means ± SD (n = 3). Mean values on the same line followed by different superscripts indicate significant differences ($p < 0.05$). *LQ* limit of quantification: Zn 0.03 µg/g, Cu 0.09 µg/g, Fe 0.01 µg/g, K 0.1 mg/g

considerable amounts such as copper, manganese, iron and zinc micronutrients. Fruits from *M. flexuosa* presented high levels of manganese, a very important micronutrient in the formation of bones and an enzyme involved in amino acid, cholesterol and carbohydrate metabolism [29]. However, such fruit is poor in cooper and iron. A similar profile was found in fruits from *Acrocomia aculeate* [30–32].

Our results reinforce previous studies that mention Cerrado fruits as nutritional source of minerals, both for traditional feeding and for the control of malnutrition, for

example, that affects needy populations in tropical regions [33]. Fruit pulps can be considered as a source of minerals, since they present significant levels of some macro and micronutrients such as potassium, copper, iron and manganese. Such chemical elements participate in important cellular regulatory pathways and in the structural construction of proteins [34], which highlights the importance of ingestion of these micronutrients. On the other hand, mineral deficiency has been pointed out as favorable causes for several chronic diseases, such as cancer and obesity [35, 36]. It is known that the main cellular electrolytes in the human body are sodium, potassium, magnesium, phosphate and calcium in less amount, which are easily supplied by fruit intake as well as the intake of milk and its derivatives [37]. The Arecaceae family, which was investigated in this study, provides an alternative source of micro and macro nutrients. These results show how the consumption of these oleaginous plants could help to prevent degenerative diseases and malnutrition.

Fatty acids composition

The calibration curves were determined by linear regression with coefficients of determination between 0.9992 and 0.9996 for fatty acids. Recovery results were between 94.06 and 97.93% showing that the procedure employed was efficient with a relative standard deviation lower than ± 5. The detection limits were 5.0–8.5 µg/mL and quantification limits were 16.7–28.3 µg/mL for fatty acids (Table 4). The efficiency of each analytical procedure was evaluated by calculating the recovery values. Recovery results were between 91.17 and 94.62%, showing that the procedure employed was efficient in the extraction.

The fatty acids found in the pulp oil of four species of Arecaceae fruits are shown in Table 5. The oils are composed of saturated fatty acids (values ranging from 17.87 to 33.76%) and unsaturated fatty acids (values ranging from 66.02 to 81.26%). The content of saturated fatty acids is higher in fruits of *A. phalerata* (33.76%), followed by *A. dubia* (30.35%) while *M. flexuosa* fruits (17.87%) showed the lowest content. The palmitic acid is the most abundant saturated fatty acid in the pulp of all fruits, with contents varying from 16.12% (*M. flexuosa*) to 26.55% (*A. dubia*). All fruits presented significant levels of stearic acid (C18:0), contents ≥ 1%. It is intereseting to observe that significant amounts of lauric acid (C12:0) and myristic acid (C14:0) were found in *A. phalerata*, 4.88 and 4.15% of each fatty acid, respectively. Long chain saturated acids are only observed in small amounts in *S. romanzoffiana*, behenic acid (C22:0) 0.78% and lignoceric acid (C24:0) 1.15%.

The content of unsaturated fatty acids is higher in the fruits of *M. flexuosa* (81.26%), with lower contents for *A. dubia* (69.19%) and *A. phalerata* (66.02%). The fruits of

Table 4 LOD and LOQ of the fatty acids

Free fatty acids	LOD (µg/mL)	LOQ (µg/mL)
Caproic (C6:0)	5.0 ± 0.1	16.7 ± 0.2
Caprylic (C8:0)	5.7 ± 0.1	19.0 ± 0.1
Capric (C10:0)	5.0 ± 0.1	16.7 ± 0.3
Lauric (C12:0)	5.0 ± 0.1	16.7 ± 0.2
Myristic (C14:0)	5.7 ± 0.1	19.0 ± 0.4
Pentadecanoic (C15:0)	5.0 ± 0.1	16.7 ± 0.3
Palmitic (C16:0)	5.0 ± 0.1	16.7 ± 0.2
Palmitoleic (C16:1)	7.0 ± 0.3	23.3 ± 0.1
Margaric (C17:0)	5.0 ± 0.1	16.7 ± 0.1
Heptadecenoic (C17:1)	6.0 ± 0.1	20.0 ± 0.2
Stearic (C18:0)	5.0 ± 0.1	16.7 ± 0.4
Linoleic (C18:2)	7.0 ± 0.2	23.3 ± 0.3
α-linolenic (C18:3)	8.5 ± 0.1	28.3 ± 0.2
Arachidic (C20:0)	5.0 ± 0.1	16.7 ± 0.3
Gadoleic (C20:1)	6.0 ± 0.1	20.0 ± 0.3
Behenic (C22:0)	6.0 ± 0.2	20.0 ± 0.8
Lignoceric (C24:0)	7.0 ± 0.1	23.3 ± 0.5

Values are means ± SD (n = 3)

LOD limit of detection, *LOQ* limit of quantification

S. romanzoffiana presented saturated and unsaturated fatty acids contents in the approximate ratio of 1/4. It is interesting to observe that the pulps of all fruits presented high content of the monounsaturated oleic fatty acid (C18:1), with percentages above 50% for all fruits, except *S. romanzoffiana* (31.77%). However, *S. romanzoffiana* is the species with the highest levels of linoleic (C18:2, 26.32%) and alpha-linolenic (C18:3, 13.11%) polyunsaturated fatty acids. In addition, the other species had contents around 1% of alpha-linolenic acid. However, linoleic fatty acid can be found in significant contents in *A. dubia* (9.61%) and *A. phalerata* (12.71%).

Previous studies have demonstrated how unsaturated fatty acids have physiological benefits such as to the maintenance of the immune system in inflammatory processes [38], and are able to perform an antimicrobial action [39]. In this regard, it can be suggested that the consumption of the pulp oil of Arecaceae fruits, rich in those beneficial compounds, may play an important role in the prevention of chronic diseases and in inflammatory processes. These data corroborate with the study carried out by Hiane et al. [40] and for Coimbra and Jorge [41], for the Arecaceae family, where the pulps were rich in monounsaturated fatty acids.

Several medicinal properties have been attributed to the oils from Arecaceae, such as antibacterial, antifungal, antiviral, antiparasitic, antioxidant, hypoglycemic, immunostimulant, and hepatoprotective attributes, among others [39]. Such properties are often correlated with the constituent fatty acids together with secondary compounds such as

Table 5 Percentage composition of the fatty acids of the oil in the fruit pulps of Arecaceae

Free fatty acids saturated (%)	*S. romanzoffiana*	*A. dubia*	*A. phalerata*	*M. flexuosa*
Caproic (C6:0)	–	–	0.08 ± 0.01	–
Caprylic (C8:0)	–	–	0.57 ± 0.04	–
Capric (C10:0)	0.11 ± 0.01^{a}	0.18 ± 0.01^{a}	0.63 ± 0.05^{b}	0.11 ± 0.01^{a}
Lauric (C12:0)	0.42 ± 0.02^{a}	0.12 ± 0.01^{b}	4.88 ± 0.06^{c}	$0.11 \pm 0.01^{d,b}$
Myristic (C14:0)	0.45 ± 0.01^{a}	0.19 ± 0.01^{b}	4.15 ± 0.01^{c}	0.11 ± 0.01^{d}
Pentadecanoic (C15:0)	–	–	0.05 ± 0.00	–
Palmitic (C16:0)	22.47 ± 0.49^{a}	26.55 ± 0.52^{b}	20.48 ± 0.0^{c}	16.12 ± 0.04^{d}
Palmitoleic (C16:1)	0.39 ± 0.01^{a}	$0.78 \pm 0.02^{a,b}$	0.87 ± 0.01^{a}	$0.54 \pm 0.01^{a,c}$
Margaric (C17:0)	–	–	0.09 ± 0.04	–
Heptadecenoic (C17:1)	–	–	0.08 ± 0.01	–
Stearic (C18:0)	1.93 ± 0.02^{a}	2.48 ± 0.13^{b}	$2.31 \pm 0.01^{c,b}$	0.99 ± 0.01^{d}
Total saturated	27.72	30.35	33.76	17.87
Monounsaturated				
Oleic (C18:1)	31.77 ± 0.83^{a}	57.90 ± 1.22^{b}	51.07 ± 0.01^{c}	78.48 ± 0.91^{d}
Polyunsaturated				
Linoleic (C18:2)	$26.32 \pm .86^{a}$	9.61 ± 0.16^{b}	12.71 ± 0.02^{c}	1.78 ± 0.03^{d}
α-linolenic (C18:3)	13.11 ± 0.13^{a}	$0.79 \pm .02^{b,c,d}$	0.93 ± 0.00^{c}	0.78 ± 0.01^{d}
Arachidic (C20:0)	0.41 ± 0.01^{a}	0.57 ± 0.03^{b}	0.34 ± 0.01^{a}	0.12 ± 0.01^{c}
Gadoleic (C20:1)	0.33 ± 0.01^{a}	0.11 ± 0.01^{b}	$0.36 \pm 0.02^{a,c}$	0.28 ± 0.01^{a}
Behenic (C22:0)	0.78 ± 0.02^{a}	0.12 ± 0.01^{b}	$0.18 \pm 0.01^{c,d}$	0.20 ± 0.01^{d}
Lignoceric (C24:0)	1.15 ± 0.48^{a}	0.15 ± 0.01^{a}	0.22 ± 0.04^{a}	0.11 ± 0.01^{a}
Total polyunsaturated	39.43	10.40	13.64	2.56
Total unsaturated	71.92	69.19	66.02	81.86

Values are means ± SD (n = 3). Mean values on the same line followed by different superscripts indicate significant differences ($p < 0.05$)

polyphenols and carotenoids [42, 43]. A number of specific examples of biological activity associated with fatty acids can be mention such as the reduction in blood pressure observed with oleic acid, and the role of docosahexaenoic acid and eicosapentaenoic acid in the prevention of cardiovascular disease and cancer [44]. The beneficial effects associated with unsaturated fatty acids of plant origin motivate researchers to seek new sources of these biomolecules. As demonstrated by the present and also other studies, a great number of native species of tropical regions are rich in beneficial fatty acids, therefore their nutraceutical potential can be further explored.

The health benefits of Arecaceae oil include reducing the risk of arterial thrombosis and atherosclerosis, inhibiting of endocrine cholesterol biosynthesis, platelet aggregation and lowering blood pressure [43]. Specifically, fatty acids have been associated with benefits in coronary disease, especially polyunsaturated fatty acids [45–47].

Polyphenols, carotenoids and antioxidant activities

The content of total polyphenols in fruit pulps, shown in Table 6, is 197.0, 1092.0, 783.0 and 484.0 mg of GAE/100 g in the pulps of *S. romanzoffiana*, A. dubia, *A. phalerata* and *M. flexuosa*, respectively. In a previous work, Rufino et al. [23] found total polyphenol values of 755 mg GAE/100 g of pulp of juçara (*Euterpe edulis*), 454 mg GAE/100 g of açaí pulp (*Euterpe oleracea*) and 338 mg GAE/100 g of carnauba pulp (*Copernicia prunifera*), all of them belonging to the same Arecaceae family. These values are similar to those described in this paper, except for *S. romanzoffiana*, which has relatively low polyphenol content (197.0 mg GAE/100 g). It is worth noting that polyphenols are often associated with health promotion and prevention of diseases related to acute inflammation, cell differentiation, inactivation of pro-carcinogens, maintenance of DNA, protection against N-nitrosamines formation, estrogen metabolism, in addition to the well-known antioxidant effect due to their ability to neutralize free radicals [48, 49].

The analysis of the total carotenoid content in the fruit pulp varied widely, ranging from 1.12 to 636.79 µg/g, depending on the oil content, and the fruits of *M. flexuosa* presented the highest concentrations of carotenoids. This property must be correlated with the fact that this fruit is one of the major sources of provitamin A. On the other hand, the lowest levels were found in *S. romanzoffiana*. However, in general, fruits from Arecaceae are good sources of carotenoids. Regarding the biological effects

Table 6 Content of polyphenols compounds, carotenoids and antioxidant activities of pulps fruits from Arecaceae

Arecaceae fruits	Antioxidants compounds/activities			
	Total polyphenols (mg GAE/100 g DW)	Total carotenoids (μg/g DW)	Antioxidant activities	
			ABTS (μmol/L of Trolox/g oil)	DPPH (EC50) g sample/g DPPH
S. romanzoffiana	197.0 ± 0.10^{a}	1.12 ± 0.02^{a}	2.86 ± 0.53^{a}	45.81 ± 1.03^{a}
A. dubia	1092.0 ± 1.80^{b}	46.77 ± 0.16^{b}	45.36 ± 2.62^{b}	$1.30 \pm 0.02^{b,d}$
A. phalerata	783.0 ± 0.90^{c}	150.12 ± 0.11^{c}	$6.70 \pm 0.01^{c,d}$	33.24 ± 0.01^{c}
M. flexuosa	484.0 ± 1.60^{d}	636.79 ± 9.51^{d}	13.02 ± 1.15^{d}	1.86 ± 0.08^{d}

Values represent the mean ± SD (n = 3). The mean values within the same column followed by different superscripted letters indicate significant differences ($p < 0.05$)

GAE galic acid equivalent, *DW* dry weight

of carotenoids, these are considered as potent agents in reducing the risk of cancer, inflammation and in the treatment of atherosclerosis. These physiological activities have been attributed to their antioxidant properties, specifically, to the ability to sequester singlet oxygen and interact with free radicals [50, 51].

Free radical sequestration methods DPPH and ABTS can be used to evaluate the antioxidant activity of specific compounds or an extract/oil in a short period of time [52, 53]. The potential of the different samples to sequester free radicals was expressed as the final extract concentration required to inhibit the 50% oxidation (EC_{50}) of the DPPH radical. For the radical ABTS the values are expressed as the antioxidant capacity equivalent to 1 μmol/L of Trolox. The values obtained by the ABTS and DPPH methods indicate that *A. dubia* has the highest antioxidant activity (45.36 μmol/L of Trolox/g oil and 1.30 g sample/g DPPH) whereas *S. romanzoffiana* has the lowest antioxidant activity (2.86 μmol/L of Trolox/g oil and 45.81 g sample/g DPPH). Such result may be associated with its low polyphenols and carotenoids contents. Concerning the antioxidant activity of the other three species, they show intermediate values, *M. flexuosa* and *A. phalerata* (values from 6.70 to 13.02 μmol/L of Trolox/g oil). In general, the greatest antioxidant activities were found for *A. dubia* and *M. flexuosa*, which can be explained by the higher content of polyphenols content in the fruits of both species.

Bioactive components such as total polyphenols (phenolic and flavonoids) and carotenoids are important antioxidants which prevent chronic diseases [54]. There is a strong correlation between polyphenols and carotenoids content with antioxidant activity and pharmacological properties. As recently noticed, antioxidant activities and beneficial properties attributed to phenolic and carotenoid compounds may be due to a synergic action of various compounds present in different parts of the tropical fruits [55–57].

Conclusions

In conclusion, the results demonstrate that the fruits from *Syagrus romanzoffiana, Attalea dubia, Attalea phalerata* and *Mauritia flexuosa* (Arecaceae) present a rich and varied nutritional and mineral composition (Ca, Mg, K, Cu, Mn, Fe and Zn), where Mn was the major mineral among the evaluated ones. Moreover, fruit pulps have high concentrations of fatty acids important for health, such as oleic, linoleic and α-linolenic acids. Additionally, it was found that all fruits have high antioxidant activity, which is possibly related to the polyphenols and carotenoids contents. A general analysis of the results shows that these fruits are excellent sources of nutritional and bioactive compounds, indispensable for human nutrition. Therefore, it is suggested that the multimixture of these fruits can be used as an alternative source to avoid malnutrition as well as to compose formulations of food products with functional properties.

Acknowledgements The authors are grateful for financial support from CNPq, CAPES and FUNDECT. Especially Dr. Jorge Mancini Filho and Dr. Rosângela Pavan, researchers of School of Pharmaceutical Sciences–University of São Paulo.

Author contributions CHL performed the analysis and experimental design. IPO wrote and discussed the results. FFL performed the analysis and discussed the results. DSB performed the analysis. PNJ performed the analysis. CAC performed the quantification of fatty acids. JLRJ quantified the minerals. EJS performed the experimental design.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

1. H. Fukuda, A. Kondo, H. Noda, Biodiesel fuel production by transesterification of oils. J. Biosci. Bioeng. **92**, 405–416 (2001)

2. M. Kozłowska, E. Gruczyńska, I. Ścibisz, M. Rudzińska, Fatty acids and sterols composition, and antioxidant activity of oils extracted from plant seeds. Food Chem. **213**, 450–456 (2016)
3. C.E. Elson, R.B. Alfin-Slater, Tropical oils: nutritional and scientific issues. Crit. Rev. Food Sci. Nutr. **31**, 79–102 (1992)
4. T. Bruce, A. de Castro, R. Kruger, C.C. Thompson, F.L. Thompson, (2012) *Microbial Diversity of Brazilian Biomes. Genomics Applications for the Developing World* (Springer, New York) pp. 217–247
5. M. Moreira, M.P. Arrúa, A. Antunes, T. Fiuza, B. Costa et al., Characterization of *Syagrus romanzoffiana* oil aiming at biodiesel production. Ind. Crops Prod. **48**, 57–60 (2013)
6. B. Silva Ferreira, L. Pereira Faza, M. Le Hyaric, A comparison of the physicochemical properties and fatty acid composition of Indaiá (Attalea dubia) and Babassu (*Orbignya phalerata*) oils. Sci. World J. https://doi.org/10.1100/2012/532374, (2012)
7. C.E. Corrêa, E. Fischer, Santos, FAd, Seed banks on *Attalea phalerata* (Arecaceae) stems in the Pantanal wetland, Brazil. Ann. Bot. **109**, 729–734 (2011)
8. S.M. Silva, K.A. Sampaio, T. Taham, S.A. Rocco, R. Ceriani et al., Characterization of oil extracted from buriti fruit (Mauritia flexuosa) grown in the Brazilian Amazon region. J. Am. Oil Chem. Soc. **86**, 611–616 (2009)
9. E.C. Aguieiras, E.D. Cavalcanti-Oliveira, A.M. de Castro, M.A. Langone, D.M. Freire, Biodiesel production from *Acrocomia aculeata* acid oil by (enzyme/enzyme) hydroesterification process: use of vegetable lipase and fermented solid as low-cost biocatalysts. Fuel **135**, 315–321 (2014)
10. R.V. Ribeiro, I.G.C. Bieski, S.O. Balogun, D.T. de Oliveira Martins, Ethnobotanical study of medicinal plants used by Ribeirinhos in the North Araguaia microregion, Mato Grosso, Brazil. J. Ethnopharmacol. **205**, 69–102 (2017)
11. C. Zanatta, M. Mitjans, V. Urgatondo, P. Rocha-Filho, M. Vinardell, Photoprotective potential of emulsions formulated with Buriti oil (Mauritia flexuosa) against UV irradiation on keratinocytes and fibroblasts cell lines. Food Chem. Toxicol. **48**, 70–75 (2010)
12. F. Freitas de Lima, K. Traesel, F. Souza de Araújo, M.S. FA, H.V. SC et al., Study on the cytotoxic, genotoxic and clastogenic potential of attalea phalerata mart. ex Spreng. Oil pulp in vitro and in vivo experimental models. PLoS ONE. **11**, e0165258–e0165258 (2015)
13. N. Pellegrini, M. Serafini, S. Salvatore, D. Del Rio, M. Bianchi et al., Total antioxidant capacity of spices, dried fruits, nuts, pulses, cereals and sweets consumed in Italy assessed by three different in vitro assays. Mol Nutr Food Res. **50**, 1030–1038 (2006)
14. R.R. Watson, V.R. Preedy, *Bioactive Foods in Promoting Health: Fruits and Vegetables* (Academic Press, San Diego, 2009)
15. E. Ros, Health benefits of nut consumption. Nutrients **2**, 652–682 (2010)
16. J. Poetsch, D. Haupenthal, I. Lewandowski, D. Oberländer, Hilger T, Acrocomia aculeata—a sustainable oil crop. Rural **21**, 41–44 (2012)
17. J. Sosnowska, H. Balslev, American palm ethnomedicine: a meta-analysis. J. Ethnobiol. Ethnomed. **5**, 43 (2009)
18. MdF. Agra, F. PFd, J.M. Barbosa-Filho, Synopsis of the plants known as medicinal and poisonous in Northeast of Brazil. Revista Brasileira de Farmacognosia **17**, 114–140 (2007)
19. A. Lutz, *Óleos E Gorduras. Métodos Físicos-Quimicos Para Análise de Alimentos* (Instituto Adolfo Lutz, São Paulo 2008) pp. 589–625
20. C. Lescano, I. Oliveira, L. Silva, D. Baldivia, E. Sanjinez-Arg et al., Nutrients content, characterization and oil extraction from *Acrocomia aculeata* (Jacq.) Lodd. fruits. Afr. J. Food Sci. **9**, 113–119 (2015)
21. A.R.M. Fernandes, A.A.M. Sampaio, W. Henrique, R.R. Tullio, Oliveira, EAd et al., Composição química e perfil de ácidos graxos da carne de bovinos de diferentes condições sexuais recebendo silagem de milho e concentrado ou cana-de-açúcar e concentrado contendo grãos de girassol. Revista Brasileira de Zootecnia. https://doi.org/10.1590/S1516-35982009000400017, (2009)
22. W. Brand-Williams, M.-E. Cuvelier, C. Berset, Use of a free radical method to evaluate antioxidant activity. LWT-Food Sci. Technol. **28**, 25–30 (1995)
23. M.R. Maria do Socorro, R.E. Alves, E.S. de Brito, J. Pérez-Jiménez, F. Saura-Calixto et al., Bioactive compounds and antioxidant capacities of 18 non-traditional tropical fruits from Brazil. Food Chem. **121**, 996–1002 (2010)
24. F. Goudel, M. Shibata, C.M.M. Coelho, P.R.M. Miller, Fruit biometry and seed germination of *Syagrus romanzoffiana* (Cham.) Glassm. Acta Bot. Bras. **27**, 147–154 (2013)
25. R. Barbosa, A. Lima, M. Mourão Junior, *Biometria de frutos do buriti (Mauritia flexuosa LF-Arecaceae): produção de polpa e óleo em uma área de savana em Roraima* (Embrapa Amazônia Oriental-Artigo em periódico indexado (ALICE) 2010)
26. T.B. Carneiro, J.G. de Mello, Frutos e polpa desidratada Buriti (*Mauritia flexuosa* L.): aspectos físicos, químicos e tecnológicos. Revista Verde de Agroecologia e Desenvolvimento Sustentável **6**, 105–111 (2011)
27. C.A.R.V.A.L.H.O.J. de, MULLER, *C, Biometria e rendimento percentual de polpa de frutas nativas da Amazônia* (Embrapa Amazônia Oriental-Comunicado Técnico (INFOTECA-E) 2005)
28. H.R. El-Seedi, A.M. El-Said, S.A. Khalifa, U. Göransson, L. Bohlin et al., Biosynthesis, natural sources, dietary intake, pharmacokinetic properties, and biological activities of hydroxycinnamic acids. J. Agric. Food Chem. **60**, 10877–10895 (2012)
29. P. Trumbo, A.A. Yates, S. Schlicker, M. Poos, Dietary reference intakes: vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. J. Am. Diet. Assoc. **101**, 294–301 (2001)
30. M.R. Silva, D.B.C.L. Lacerda, G.G. Santos, D.M. de Oliveria Martins, Chemical characterization of native species of fruits from savanna ecosystem. Ciência Rural **38**, 1790–1793 (2008)
31. M.R. Silva, D.B.C.L. Lacerda, G.G. Santos, D.M. de Oliveria Martins, Caracterização química de frutos nativos do cerrado. Ciência Rural **38**, 1790–1793 (2008)
32. P.A. Hiane, P.A. Baldasso, S. Marangoni, M.L.R. Macedo, Chemical and nutritional evaluation of kernels of bocaiúva, *Acrocomia aculeata* (Jacq.) Lodd. Food Sci. Technol. (Campinas). **26**, 683–689 (2006)
33. A.M. Marin, E.M. Siqueira, S.F. Arruda, Minerals, phytic acid and tannin contents of 18 fruits from the Brazilian savanna. Int. J. Food Sci. Nutr. **60**, 180–190 (2009)
34. M.M. Harding, M.W. Nowicki, M.D. Walkinshaw, Metals in protein structures: a review of their principal features. Crystallogr. Rev. **16**, 247–302 (2010)
35. B.N. Ames, P. Wakimoto, Are vitamin and mineral deficiencies a major cancer risk? Nat. Rev. Cancer. **2**, 694 (2002)
36. O. Kaidar-Person, B. Person, S. Szomstein, R.J. Rosenthal, Nutritional deficiencies in morbidly obese patients: a new form of malnutrition? Obes. Surg. **18**, 1028–1034 (2008)
37. M. Clerici, L. Carvalho-Silva, Nutritional bioactive compounds and technological aspects of minor fruits grown in Brazil. Food Res. Int. **44**, 1658–1670 (2011)
38. A.R. Weatherill, J.Y. Lee, L. Zhao, D.G. Lemay, H.S. Youn et al., Saturated and polyunsaturated fatty acids reciprocally modulate dendritic cell functions mediated through TLR4. J. Immunol. **174**, 5390–5397 (2005)
39. M. DebMandal, S. Mandal, Coconut (*Cocos nucifera* L.: Arecaceae): in health promotion and disease prevention. Asian Pac. J. Trop. Med. **4**, 241–247 (2011)

40. P.A. Hiane, D. Bogo, M.I.L. Ramos, M.M. Ramos Filho, *Carotenóides pró-vitamínicos A e composição em ácidos graxos do fruto e da farinha do bacuri (Scheelea phalerata Mart.)* (2003)
41. M.C. Coimbra, N. Jorge, Characterization of the pulp and kernel oils from *Syagrus oleracea, Syagrus romanzoffiana*, and *Acrocomia aculeata*. J. Food Sci. https://doi.org/10.1111/j.1750-3841.2011.02358.x, (2011)
42. E. Tripoli, M. Giammanco, G. Tabacchi, D. Di Majo, S. Giammanco et al., The phenolic compounds of olive oil: structure, biological activity and beneficial effects on human health. Nutr. Res. Rev. **18**, 98–112 (2005)
43. D. Edem, Palm oil: biochemical, physiological, nutritional, hematological and toxicological aspects: a review. Plant Foods Hum. Nutr. **57**, 319–341 (2002)
44. C. Fazio, G. Piazzi, P. Vitaglione, V. Fogliano, A. Munarini et al., Inflammation increases NOTCH1 activity via MMP9 and is counteracted by eicosapentaenoic acid-free fatty acid in colon cancer cells. Sci. Rep. **6**, 20670 (2016)
45. D.J. Mcnamara, Dietary fatty acids, lipoproteins, and cardiovascular disease. Adv. Food Nutr. Res. **36**, 253–351 (1992)
46. Y. Watanabe, I. Tatsuno, Omega-3 polyunsaturated fatty acids for cardiovascular diseases: present, past and future. Expert Rev. Clin. Pharmacol. **10**, 865–873 (2017)
47. D. Swanson, R. Block, S.A. Mousa, Omega-3 fatty acids EPA and DHA: health benefits throughout life. Adv. Nutr. **3**, 1–7 (2012)
48. M.A. Timmers, J.L. Guerrero-Medina, D. Esposito, M.H. Grace, O. Paredes-López et al., Characterization of phenolic compounds and antioxidant and anti-inflammatory activities from mamuyo (Styrax ramirezii Greenm.) fruit. J. Agric. Food Chem. **63**, 10459–10465 (2015)
49. F. Shahidi, Functional foods: their role in health promotion and disease prevention. J. Food Sci. **69**, (2004)
50. D.B. Rodriguez-Amaya, Quantitative analysis, in vitro assessment of bioavailability and antioxidant activity of food carotenoids—a review. J. Food Compos. Anal. **23**, 726–740 (2010)
51. X.-R. Xu, Z.-Y. Zou, Y.-M. Huang, X. Xiao, L. Ma et al., Serum carotenoids in relation to risk factors for development of atherosclerosis. Clin. Biochem. **45**, 1357–1361 (2012)
52. L. Müller, K. Fröhlich, V. Böhm, Comparative antioxidant activities of carotenoids measured by ferric reducing antioxidant power (FRAP), ABTS bleaching assay (αTEAC), DPPH assay and peroxyl radical scavenging assay. Food Chem. **129**, 139–148 (2011)
53. P.C. Wootton-Beard, A. Moran, L. Ryan, Stability of the total antioxidant capacity and total polyphenol content of 23 commercially available vegetable juices before and after in vitro digestion measured by FRAP, DPPH, ABTS and Folin–Ciocalteu methods. Food Res. Int. **44**, 217–224 (2011)
54. J.W. Finley, Proposed criteria for assessing the efficacy of cancer reduction by plant foods enriched in carotenoids, glucosinolates, polyphenols and selenocompounds. Ann. Bot. **95**, 1075–1096 (2005)
55. J. Batista, A. Silva, C. Rodrigues, K. Costa, A. Oliveira et al., Avaliação da atividade cicatrizante do óleo de pequi (*Caryocar coriaceum* wittm) em feridas cutâneas produzidas experimentalmente em ratos. Arquivo do Instituto Biológico **77**, 441–447 (2010)
56. A.L. Miranda-Vilela, P.C.Z. Alves, A.K. Akimoto, G.S. Lordelo, M. de Nazare Klautau-Guimarães et al., Under increased hydrogen peroxide conditions, the antioxidant effects of pequi oil (*Caryocar brasiliense* Camb.) to decrease DNA damage in runners are influenced by sex, age and oxidative stress-related genetic polymorphisms. Free Radic. Antioxid. **1**, 27–39 (2011)
57. C.H. Lescano, R.D. Iwamoto, E.J. Sanjinez-Argandoña, C.A.L. Kassuya, Diuretic and anti-inflammatory activities of the microencapsulated *Acrocomia aculeata* (Arecaceae) oil on Wistar rats. J. Med. Food **18**, 656–662 (2015)