Plant Foods for Human Nutrition (2019) 74:141–148
https://doi.org/10.1007/s11130-018-0710-1

ORIGINAL PAPER

Non-conventional Tropical Fruits: Characterization, Antioxidant Potential and Carotenoid Bioaccessibility

Paulo Berni [1] · Stephanie S. Campoli [1] · Talita C. Negri [1] · Nataly M. V. de Toledo [1] · Solange G. Canniatti-Brazaca [1]

Published online: 15 January 2019

Abstract

Eleven non-conventional tropical fruits were evaluated regarding their nutritional value, antioxidant potential, carotenoid contents and bioaccessibility. The fruits were chosen due to their spread through the Brazilian territory: araçá-boi, jaracatiá, cambuití, seriguela, capeba, pitangatuba, pitanga, buriti, acerola, dovialis and abricó-da-praia. Results have shown that these fruits are in general, *i.e.* depending on the fruit, rich sources of dietary fibers and minerals, high in moisture, and low in proteins. Twelve carotenoids were analyzed by HPLC-DAD and results ranged from 0.04 to 104 μg/g wet weight. Xanthophylls stood out, being higher than carotenes for araçá-boi, seriguela, pitangatuba and dovialis. Bioaccessibility varied both between fruits and carotenoids ranging from 2 to 75%. Although the fruit matrix effect, xanthophylls were more bioaccessible than carotenes, while lycopene and γ-carotene presented the poorest bioaccessibility. The present study is fundamental to expand the knowledge about the fruit properties, carotenoids bioaccessibility and potential benefits for health, as well to preserve natural resources and encourage the intake of new fruits for human nutrition.

Keywords Brazilian native fruit · Bioavailability · Xanthophylls · Carotenes · *In vitro* digestion

Introduction

The great biodiversity found in South American biomes, especially the ones inside Brazilian territory (such as Atlantic Forest, *Cerrado* and Amazon Forest), represents an important source of new plants for human nutrition, flavors and materials for food industry [1]. Tropical fruits such as araçá-boi (*Eugenia stipitata*), jaracatiá (*Jaracatia spinosa*), cambuití (*Sageretia elegans*), seriguela (*Spondias purpúrea*), capeba (*Odontocarya acuparata*), pitangatuba (*Eugenia selloi*), pitanga (*Eugenia uniflora*), buriti (*Mauritia flexuosa*), acerola (*Malpighia emarginata*), dovialis (*Dovyalis abyssinica*) and abricó-da-praia (*Mimusopsis comersonii*) are widespread in Brazilian territory, and according to the Reflora program and herbarium [2] some of these fruits are native from biomes of Brazil (araçá-boi, jaracatiá, cambuití, capeba, pitangatuba, pitanga and buriti), while others were introduced in Brazil and now can naturally occur, specially at southeast and northeast regions and along to the Brazilian coast. Seriguela, pitanga, buriti and acerola already have commercial production and distribution in Brazil for internal consume *in natura* and for agroindustry processing in pulp, extracts (for cosmetics and supplements), oil (buriti), jelly and other products. There are efforts for improvement of the commercial production and agroindustry of araçá-boi, jaracatiá, and dovialis. However, these fruits are still integrating only local markets, ecotourism and ethnic foods [3].

Increasing biodiversity of fruits in diet could improve human health due to carotenoids and other bioactive compounds, but many fruits still not being produced or consumed, probably due to unfamiliarity of consumers, mainly from urban areas. For example, it was demonstrated that some underutilized fruits from Southeast Asia can provide similar or higher amounts of total carotenoids and β-carotene than popular fruits commercialized in Malaysia [4]. There are still limited studies on the nutritional value of unconventional fruits, especially regarding their bioactive compounds. This make difficult their disclosure for stimulating consumption. Positively, pioneer studies, like the present one, are detecting the great potential of unconventional tropical fruits from

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11130-018-0710-1) contains supplementary material, which is available to authorized users.

✉ Paulo Berni
paulo.berni@usp.br

[1] Department of Agri-food Industry, Food and Nutrition, Luiz de Queiroz College of Agriculture, University of São Paulo, Avenida Pádua Dias, 11, Piracicaba, SP 13416-900, Brazil

Brazil as source of bioactive compounds with high antioxidant activities [1, 5]. These researches are essential for exploring the potential of certain fruits for integrating diets, improve health and serve as new raw-material for food technology.

Conversely, it was demonstrated great amounts of pro-vitamin A carotenoids in buriti [6], identified a diversity of carotenes (*e.g.* lycopene) and xanthophylls (*e.g.* rubixanthin) in pitanga [7] and provided evidence that araçá-boi could be used as nutraceutical ingredient in the production of functional foods due to its carotenoid pattern [8]. The genus *Eugenia* has presented many fruits with high antioxidant activity against biological radicals and anti-inflammatory properties [1]. Acerola presents very high antioxidant activity due to its high contents of vitamin C and polyphenols [9]. Nutritional value of tropical fruits is interest to local communities that ingest these fruits regularly, for example, buriti can be source of minerals, fibers, vitamin A and important fat acids in the diet [10].

Carotenoids are among the most important compounds in fruits that provide the mentioned health benefits. In plants, they are responsible for yellow to red color in fruits that also stimulate the palate in humans. Carotenes and xanthophylls occur in the plants in several different forms: water soluble complexes with proteins; esterified with fat acids; solubilized in lipids. The human digestion and absorption of carotenoids suffer influence of the carotenoid species, the fruit matrix, their chemical state, the amount ingested and absorption modifiers. These factors can be studied by *in vitro* methodologies (including *in vitro* digestion) and allows to estimate their bioaccessibility, *i.e.* the amount of the carotenoid released from the food matrix during digestion and made available for absorption [11, 12]. Therefore, this research aimed to expand the knowledge about the nutritional value, antioxidant potential, carotenoids composition and bioaccessibility of unconventional tropical fruits from Brazil. This new approach encourages the inclusion of these fruits into human diet, promoting nutritional benefits, as well as presenting new fruits that could be used for innovation on food product development.

Materials and Methods

Reagents Violaxanthin (VioX), lutein (Lut), all-*trans*-α-carotene (α-C), all-*trans*-β-carotene (trans-βC), all-*trans*-γ-carotene (trans-γ-C) and all-*trans*-lycopene (Lyc) standards for HPLC, and also the enzymes for *in vitro* digestion were purchased from Sigma-Aldrich (St Louis, MO, USA). Only chromatographic grade organic solvents were used for carotenoid extraction and HPLC analysis (Tedia, Fairfield, OH, USA). All other reagents were of analytical grade.

Fruit Samples The tropical fruits (Supplementary material) were chosen due to their availability, yield, yellow to red color of their pulps when mature, and that are native and/or well adapted to Brazilian climate. Araçá-boi, jaracatiá, cambuití, seriguela, capeba, pitangatuba, dovialis and abricó-da-praia were collected in the Sítio de Frutas Raras at Campina do Monte Alegre, SP, Brazil (−23.5359370, −48.5124060). Whole and ripe fruits were collected, washed and transported in Styrofoam boxes with ice. Ripe pitanga and acerola were harvested from the orchard located at the Luiz de Queiroz College of Agriculture (ESALQ), Piracicaba, SP, Brazil. Buriti pulp was produced by the co-op Sertão Veredas (Chapada Gaúcha, MG, Brazil). The farmers collected ripe Buriti fruits, peeled them, added warm water, and crushed them to separate the seeds and pulp, which was frozen shipped in dark plastic bags of 500 g to Piracicaba, SP. Excepting buriti, the fruits were processed in the Department of Agri-food Industry, Food and Nutrition (LAN/ESALQ). They were selected, sanitized with sodium hypochlorite (200 ppm/10 min) and pulped. Araçá-boi, jaracatiá, seriguela, capeba, pitangatuba and dovialis had their seeds discarded and their pulp with the peel were homogenized with liquid nitrogen in an analytic mill (A11 Basic Mill IKA, Germany). Cambuití was pulped in the same way, however the seeds have not been removed, since they are too small and are ingested when they are eaten. Abricó-da-praia had their seeds and skin removed, and since its pulp is very soft, it was only mashed and stored. Whole pitanga and acerola were pulped in a juicer (Philips Walita, China) and their seeds were retained by the juicer sieve. All samples were stored in 50 mL tubes with blanket of nitrogen gas, sealed, packed in black bags and stored frozen at −25 °C until the analysis and *in vitro* digestions.

Proximate Composition AOAC [13] protocols were used for moisture (AOAC 930.04), ash (AOAC 930.05) and protein (AOAC 978.04) analysis. Lipid content was determined by gravimetry after solvent extraction [14]. The insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) were determined by enzymatic-gravimetric method [15]. Available carbohydrates were calculated by difference following AOAC [13] recommendation: 100 - (weight in grams [protein + fat + water + ash + dietary fiber] in 100 g of food).

Antioxidant Potential by ABTS and DPPH The analysis was performed according to described in Rufino et al. [9] for extractions and antioxidant assays. Briefly, samples were extracted with solution of MeOH 50% (60 min) at room temperature, centrifuged (24,500 *g* for 15 min; NOVATECNICA®, NT 835, Piracicaba, SP, Brazil) and supernatants were collected. Residues were extracted with acetone solution 70% (60 min) at room temperature and supernatants were collected after centrifuging again. Both extracts were combined and the volume was adjusted to 100 mL with distilled water. The ABTS and DPPH analysis were done as described elsewhere [9].

Carotenoid Extraction and Saponification The extraction of carotenoids was performed as described by Kimura et al. [16]. Briefly, homogenized aliquots (0.2–1 g, depending of the fruit color) were extracted with cold acetone (7 °C) until colorless. The extracts were filtered under vacuum and partitioned in separatory funnel to petroleum ether. Saponification step was carried out to hydrolyze the xanthophylls esters. The extracts were kept 16 h in the dark mixed with a solution of KOH (10%) in methanol containing 0.01% of BHT and a blanket of N_2. Then, the extracts were washed five times with distilled water and completely dried under N_2 flux. Carotenoids from micellar fraction were extracted as described in Berni et al. [17]. In summary, aliquots of 5–10 mL were agitated 1 min in vortex with 10 mL of THF/MeOH (1:1, *v/v*) followed by addition of 10 mL of hexane and then centrifugated at 800 *g* for 10 min at 4 °C. The upper layer was collected, saponified and dried. Extracts were resuspended in MeOH:MTBE (1:1, *v/v*) and then filtered (PTFE 0.22 μm) before injection into the HPLC system.

Carotenoid Analysis by HPLC-DAD Fruit carotenoids were analyzed by HPLC-DAD system (Shimadzu® LC-20A Prominence, Kyoto, Japan) with a polymeric YMC™ C30 column (150 × 4.6 mm, 5 μm particle size). The analytic condition was described by Kimura et al. [16] and consisted in use MeOH and MTBE as mobile phase in linear gradient starting at 90:10 (MeOH:MTBE) to 40:60 in 60 min, returning to initial conditions and kept for 15 min; flow rate was 0.8 mL/min; column temperature was 30 °C; injection volume ranged 10 – 60 μL. Standard curves of VioX, Lut, α-C, *trans*-βC, *trans*-γ-C and Lyc were performed. For identifying carotenoid without its respective standards, we compared their diode array absorption spectra and elution order with the certified reference material (CRM485) reported in Kimura et al. [16]. ZeaX, β-CX, 9-cis-βC,13-cis-βC and 15-cis-βC were calculated using the *trans*-βC standard, since they carry the same chromophore and similar max absorption peak (λmax). Cis-γ-C was calculated using the *trans*-γ-C curve.

Carotenoid Bioaccessibility by *In vitro* Digestion *In vitro* digestions were carried out according to Garret et al. [18]. Briefly, fruit samples were homogenized with a solution of basal salts (NaCl 120 mol/L, $CaCl_2$ 6 mmol/L and KCl 5 mmol/L). Excepting buriti, it was added 2% (*w/w*) of soybean oil to the fruit samples as minimum lipids needed for mixed micelles formation. Artificial saliva containing 106 units/mL of α-amylase (Sigma® A3176) was added (6 mL) for simulating the oral phase. The pH was adjusted to 2.5 and 2 mL of pepsin solution (Sigma® P7000; 50,000 units/mL) was added for simulating the gastric phase (1 h, 37 °C). The pH was raised to 6 to stop the gastric phase, then 3 mL of bile extract solution (Sigma® B8631; 40 mg/mL) and 2 mL of pancreatin (Sigma® P1750, 4000 units/mL) and lipase (Sigma® L3126, 1000 units/mL) solution were added. Final pH was adjusted to 6.5. Aliquots of the digesta were centrifuged at 5000 x *g*, 60 min, 4 °C until aqueous phase separation. The upper phase obtained contains the mixed micelles formed with the bioaccessible carotenoids. The ratio between carotenoids from mixed micelles and the initial content predicts their % bioaccessibility.

Statistical Analysis Analyses were done in triplicate and data was tested for significant differences using ANOVA and Tukey's test ($p < 0.05$). The software Statistica 13© (Dell Inc., USA) was used.

Results and Discussion

Proximate Composition

Proximate composition is presented in (Table 1). Buriti presented the highest lipid value (19.2%) and lowest moisture (63.2%), and therefore, it was estimated the most caloric fruit in this study. The buriti presents great potential for extraction of oil that can be used by food, cosmetics and pharmaceutical industries [10]. Pitanga and araçá-boi demonstrated the highest moisture content (93.8 and 93.4%, respectively), which may be interesting for the manufacture of their juices, since they can present high yield due to the high amount of water. In addition, the consumption of juices, such as the pitanga, is indicated because it may contribute to anti-inflammatory effects [19]. The jaracatiá was the fruit that presented the highest ash content (1.78%), which indicates a considerable amount of minerals that should be explored by other studies. The protein content is frequently low in fruits; and in this study, the highest values were found from jaracatiá and acerola, around 1%. Regarding soluble and insoluble fibers, abricó-da-praia presented the highest concentration of these components (0.99% for SDF and 14.12% for IDF). The regular fiber intake is important to increase stool weight and to reduce transit time through the intestinal tract, which may help to prevent or relieve constipation [20], besides to affect the digestion and bioaccessibility of nutrients. For carbohydrates, fruits as seriguela, pitanga and abricó-da-praia recorded higher values probably due to its high amount of sugars since these are considered the sweetest fruits among those studied (Table 1).

Antioxidant Potential by ABTS and DPPH

In relation to the antioxidant potential, acerola and cambuití highlighted in both assays, DPPH and ABTS

Table 1 Proximate composition results for the non-conventional tropical fruits

Fruits	Moisture (%)	Protein (%)	Ash (%)	Lipids (%)	SDF* (%)	IDF* (%)	Carbohydrates (%)
Araçá-boi	93.4[1a2]	0.41[c]	0.21[g]	0.24[c]	0.10[f]	2.78[e]	2.91[f]
Jaracatiá	82.4[e]	1.03[a]	1.78[a]	0.24[c]	0.45[c]	4.50[d]	9.63[cd]
Cambuití	80.5[f]	0.48[c]	0.48[ef]	0.69[c]	0.15[ef]	6.56[c]	11.13[bc]
Seriguela	77.4[g]	0.47[c]	0.62[d]	0.26[c]	0.80[b]	3.05[e]	17.43[a]
Capeba	88.4[c]	0.23[d]	0.58[de]	0.68[c]	0.10[f]	0.30[f]	9.68[cd]
Pitangatuba	93.8[a]	0.17[d]	0.10[h]	0.43[c]	0.09[f]	0.99[f]	4.40[ef]
Dovialis	88.6[c]	0.19[d]	0.66[d]	0.42[c]	0.23[def]	0.53[f]	9.38[d]
Acerola	91.2[b]	1.08[a]	0.31[g]	0.53[c]	0.24[def]	1.14[f]	5.45[e]
Abricó-da-praia	69.5[h]	0.71[b]	1.20[b]	1.17[b]	0.99[a]	14.12[a]	12.28[b]
Buriti	63.2[i]	0.68[b]	0.92[c]	19.20[a]	0.39[cd]	9.94[b]	5.70[e]
Pitanga	83.5[d]	0.62[b]	0.42[f]	0.40[c]	0.28[de]	2.71[e]	12.07[b]

Mean ($n = 3$), fresh basis. Different letters in the column correspond to significant difference ($p < 0.05$) between fruits. SF: soluble fibers; ISF: insoluble fibers. * Soluble dietary fiber – SDF and insoluble dietary fiber – IDF

(Fig. 1). The highest result observed for cambuití in the ABTS assay (Fig. 1) can be explained by its polyphenolic composition. Furthermore, its antioxidant potential by ABTS was also higher than other Brazilian fruits reported [9]. The antioxidant potential in fruits can be determinated by the presence of compounds such as vitamin C in acerola, flavonoids in pitanga and araçá (*Psidium guineenses*), and monomeric anthocyanins in açaí [21]. Besides that, other components such as phenolic compounds also contribute to antioxidant properties, as observed by Rufino et al. [9] for yellow mombin (*Spondias mombin*), cashew apple (*Anacardium accidentale*), umbu (*Spondias tuberosa*) and açaí (*Euterpe oleracea*). All the other fruits analyzed remained in a similar extent for Trolox equivalents in both tests (DPPH and ABTS). The ranged observed of 1.77–7.8 μM Trolox/g (DPPH) and 8.6–39 8 μM Trolox/g (ABTS) also are in agreement to the literature [8, 9, 21]. Other studies have been showing high antioxidant potential for Brazilian native fruits and identifying some fruits as sources of bioactive compounds which can be interesting due to their health benefits [1, 5].

Carotenoid Analysis by HPLC-DAD

Overall observation on the carotenoid content of analyzed tropical fruits (Table 2) demonstrates that carotenoids with provitamin A activity are the majority – *trans*-βC, α-C, β-CX, 9-*cis*-βC, 13-*cis*-βC, 15-*cis*-βC. The *trans*-βC was presented in every sample and was the main carotenoid of eight fruits from the 11 analyzed. Pitangatuba, seriguela and dovialis present xanthophylls as the major carotenoids, specifically β-CX. This profile of carotenoid distribution among tropical fruits is well demonstrated by the Database of carotenoid contents published by Dias et al. [23], where *trans*-βC is reported in almost all tropical and subtropical fruits listed, followed by large presence of xanthophylls, especially β-CX and Lut, while lycopene occurs only in some fruits. Pitanga and buriti results for carotenoids analysis are not presented in

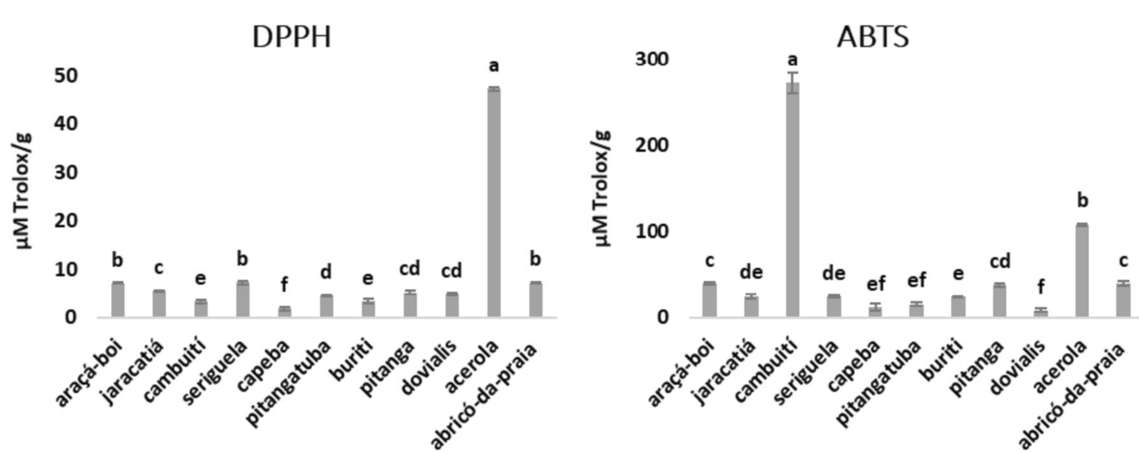

Fig. 1 DPPH and ABTS assays of non-conventional tropical fruits. Results are equivalents of Trolox (μM/g). Different letters correspond to significant difference ($p < 0.05$) between fruits

Table 2 Carotenoid composition of non-conventional tropical fruits

Fruits	trans-βC*		α-C		β-CX		9-cis-βC		13-cis-βC		15-cis-βC	
	Total	Bioac.	Total	Bioac.	Total	Bioac.	Total	Bioac.	Total	Bioac.	Total	Bioac.
Araçá-boi	2.10^{c}	0.29^{b}	0.65^{b}	0.30^{c}	2.44^{d}	0.35^{d}	0.18^{cd}	0.04^{c}	0.16^{c}	0.03^{c}	0.11^{d}	0.05^{c}
Jaracatiá	10.60^{b}	1.91^{b}	1.55^{b}	0.09^{de}	0.53^{ef}	0.04^{e}	0.39^{cd}	0.03^{c}	0.85^{bc}	0.02^{c}	0.63^{bcd}	0.02^{c}
Cambuití	0.70^{c}	0.07^{b}	0.36^{b}	ND	0.05^{e}	0.01^{e}						
Seriguela	2.89^{c}	0.84^{b}	0.97^{b}	0.23^{cd}	5.94^{c}	1.29^{c}	0.07^{d}	ND	0.13^{c}	0.03^{c}	0.08^{d}	0.02^{c}
Capeba	104.10^{a}	32.60^{a}	47.50^{a}	14.85^{a}	13.99^{a}	3.20^{a}	18.37^{a}	7.01^{a}	12.10^{a}	6.05^{a}	8.81^{a}	3.69^{a}
Pitangatuba	3.35^{c}	1.11^{b}	2.45^{b}	0.69^{b}	4.48^{c}	1.89^{b}	1.83^{b}	0.47^{b}	1.56^{b}	0.53^{b}	1.29^{b}	0.49^{b}
Dovialis	2.40^{c}	0.25^{b}			9.00^{b}	1.25^{c}	0.90^{c}	ND	0.70^{bc}	0.04^{c}	0.30^{cd}	0.04^{c}
Acerola	11.70^{b}	1.52^{b}	1.24^{b}	0.06^{e}	1.92^{de}	0.22^{de}	0.73^{cd}	ND	1.44^{b}	0.05^{c}	1.19^{bc}	0.04^{c}
Abricó-da-praia	0.11^{c}	0.01^{b}	0.04^{b}	0.01^{e}								

Fruits	VioX		Lut		ZeaX		trans-γ-C		cis-γ-C		Lyc		RAE*(μ/100 g)
	Total	Bioac.	Total	Bioac.	Total	Bioac.	Total	Bioac.	Total	Bioac.	Total	Bioac	
Araçá-boi	1.04^{b}	0.24^{b}	1.60^{b}	0.15^{d}	0.55^{b}	0.25^{c}							31.5
Jaracatiá			0.33^{ef}	0.03^{de}									104.8
Cambuití			0.59^{de}	0.10^{c}									7.5
Seriguela			1.63^{b}	0.80^{b}	0.22^{b}	ND							54.2
Capeba	30.98^{a}	2.07^{a}	2.21^{a}	1.64^{a}	19.41^{a}	4.93^{a}	11.00	0.42	7.3	0.25	6.20	0.14	1290
Pitangatuba	4.36^{b}	0.69^{b}	0.84^{cd}	0.40^{c}	4.44^{b}	1.37^{b}							76.3
Dovialis													65.4
Acerola			1.00^{c}	0.03^{e}									235
Abricó-da-praia			0.16^{f}	0.06^{d}									1.08

Mean ($n = 3$). Results are expressed in μg/g of wet weight. Different letters in the column correspond to significant difference ($p < 0.05$) between fruits. ND = Not Detected. *Abbreviations: all-*trans*-β-carotene (*trans*-βC); all-*trans*-α-carotene (α-C); β-cryptoxanthin (β-CX); respectively 9, 13 and 15-*cis*-β-carotene (9-cis-βC, 13-cis-βC and 15-cis-βC); violaxanthin (VioX); lutein (Lut); zeaxanthin (ZeaX); all-*trans*-γ-carotene (trans-γ-C); *cis*-γ-carotene (*cis*-γ-C); all-*trans*-lycopene (Lyc); retinol activity equivalents (RAE) calculated according to FAO [22]

this manuscript because they were selected for food product development. Capeba is the fruit presenting the higher contents of all carotenoids that were identified and calculated. Also, *trans*-γ-C, *cis*-γ-C and lyc were identified in capeba, these are uncommon carotenes in fruits. A very small peak similar to lycopene also were noted in pitangatuba fruit. However, the absorbance spectrum was not clear and the amount was too low for adequate identification and calculation.

The values of *trans*-βC found (Table 2) coincide with the ranges presented at Dias et al. [23] for acerola, seriguela and araçá-boi. The other seven fruits were not found at this database. No data was found in the literature about the carotenoid content of jaracatiá, cambuití, capeba, pitangatuba and abricó-da-praia. We assume this is the first time that these fruits have their carotenoid composition reported. It is important to consider that variations in the carotenoid content may occur due to factors such as ripening, sunlight incidence and soil composition [11]. The RAE (retinol activity equivalent) was calculated according to FAO [22] and shows that the consumption of these fruits would contribute to the vitamin A intake, excepting cambuití and abricó-da-praia (Table 2). The consumption of 100 g of capeba would surpass 100% of RDI (recommended daily intake) of 450 μg/d RAE for children 4–6 years of age [22].

Carotenoid Bioaccessibility by *In vitro* Digestion

Results of bioaccessibility (%), *i.e.* the efficiency of micellarization of carotenoids as the ratio of the initial amounts in fresh fruits and their bioaccessible fraction, are present in Fig. 2. Digested capeba demonstrated the highest bioaccessible amounts of all carotenoids. Among the fruits that most provide bioaccessible carotenes the first are capeba and jaracatiá, Brazilian native fruits, followed by seriguela and acerola, exotic fruits. Pitangatuba appear, after capeba, as a greater provider of bioaccessible xanthophylls (the sum of β-CX, VioX, Lut and ZeaX). It was not found studies that determined bioaccessibility of carotenoids from these fruits, and then we compared the bioaccessible contents with other common tropical fruits. While capeba provide about 33 μg/g for *trans*-βC and 3 μg/g for β-CX in the bioaccessible fraction, oranges provided 0.02 μg/g for *trans*-βC and 0.04 μg/g,

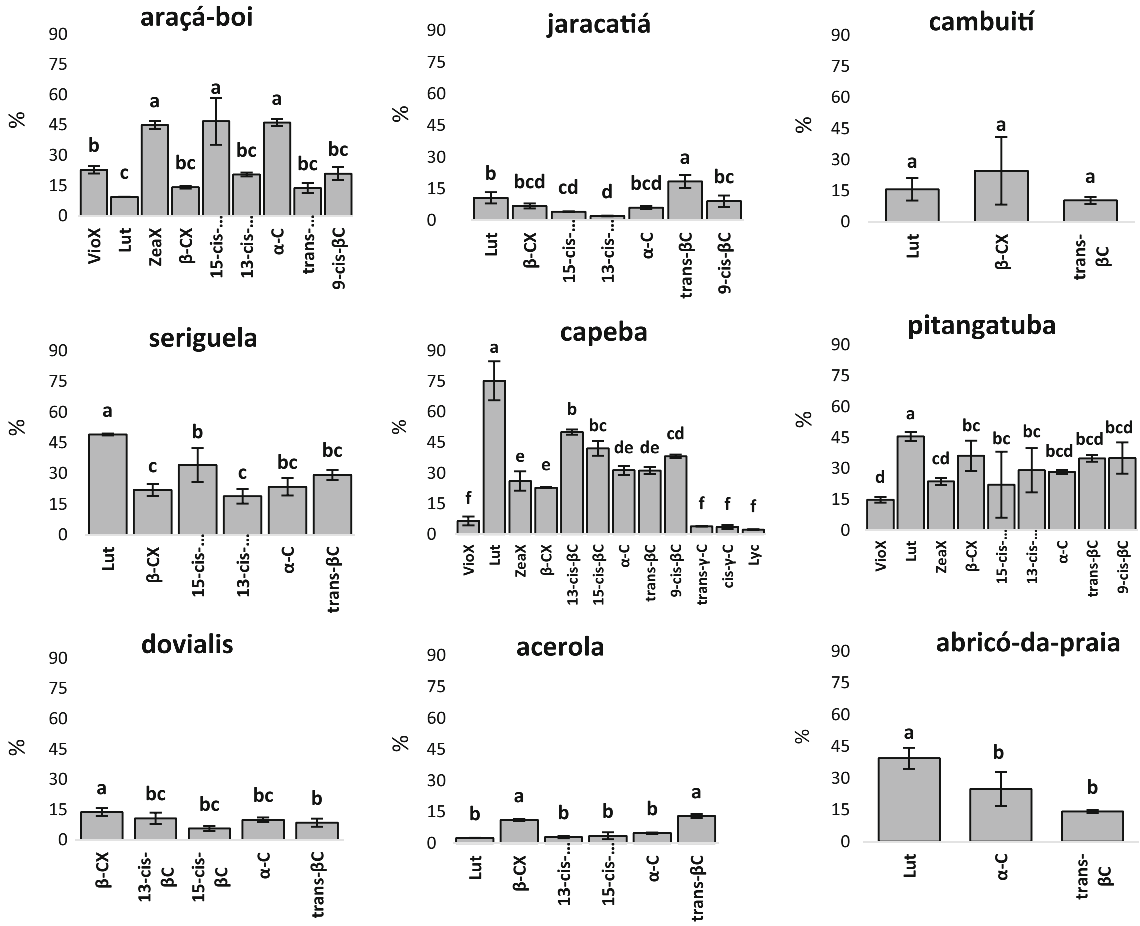

Fig. 2 Bioaccessibility of carotenoids of non-conventional tropical fruits ($n = 3$). Results are the ratio between the carotenoid from fresh fruits and the amounts micellarized after *in vitro* digestions (%). Different letters correspond to significant difference ($p < 0.05$) between carotenoids. For the abbreviation definitions please see Table 2

mandarins 0.1 μg/g for *trans*-βC and 1.8 μg/g [24], mango 8.9 μg/g for *trans*-βC and papaya 2.4 for *trans*-βC [25]. A water and pulp beverage (50:50, *v/v*) made with caja (*Spondias mombim*), that is also a tropical fruit native in Brazil and from the same genus of seriguela, formed mixed micelles during *in vitro* digestions containing: 0.06 μg/g of *trans*-βC, 0.06 μg/g of α-C, 0.15 μg/g of β-CX, 0.08 μg/g of Lut and 0.03 ZeaX, not considering the esterified xanthophylls [26]. Therefore, our data of bioaccessible amounts in the mixed micelles after *in vitro* digestions are slightly higher than the found in literature, which can be explained by the greater initial content in the fresh tropical fruits analyzed.

The carotenoid bioaccessibility of digested fruits was presented in the Fig. 2. For the araçá-boi fruit, ZeaX, 15-*cis*-βC and α-C were ~45% bioaccessible, being at least 25% higher than the other carotenoids. Jaracatiá had low carotenoid bioaccessibility – ranging from 2% for 13-*cis*-βC to 18% for *trans*-βC – when compared to the other fruits. No significant differences were observed between the bioaccessibility of Lut, β-CX and *trans*-βC from cambuití. Seriguela presented a range of 18 to 49% bioaccessibility, being Lut the most bioaccessible. The *in vitro* digestion of capeba revealed 75% of Lut bioaccessibility followed by the *cis*-βC isomers (38–50%), α-C and *trans*-βC (~31%), β-CX and ZeaX (22–26%), and finally the Lyc, *trans*-γ-C, *cis*-γ-C and VioX had the lowest bioaccessibility (2–6%). Pitangatuba presented the lowest bioaccessibility for VioX (15%) and the highest for Lut (45%). For dovialis the bioaccessibility was 13% for β-CX, 8% for *trans*-βC followed by the other carotenes, but not significantly. Acerola had very low bioaccessibility of its carotenoids, being β-CX and *trans*-βC the most efficiently incorporated into mixed micelles, with 11 and 13%, respectively. Finally, abricó-da-praia presented Lut as the most bioaccessible (39%), α-C (24%) and *trans*-βC (14%).

These results were consistent with literature for the range of bioaccessibility of several carotenoids from many different fruits [25, 27–29], and in the prevalence of bioaccessible xanthophylls [30] than carotenes [31], and in relation to the low bioaccessibility of Lyc and VioX [27, 29]. It is important to mention that the *cis* isomers of *trans*-βC and *trans*-γ-C found in the micellar phase could be affected by the carotenoid extraction and saponification steps, since at this stage the carotenes are already released and can suffer stress during this long analysis period, despite all the precautions that were taken (BHT, light protection and room temperature controlled 26 °C). Other studies that analyzed the bioaccessibility of carotenoids from tropical fruits reported values of 8.2% for *trans*-βC, 3.4% for Lyc [32] and 35% for *trans*-βC in papaya; and 24% - 39% of *trans*-βC for mango [25]. Lycopene bioaccessibility both for tomatoes and papaya was <5% when analyzed by the same *in vitro* digestion protocol [31]. Therefore, it was observed that in plant foods the carotenoid bioaccessibility can be affected by factors such as food matrix, maturity and growing conditions.

Conclusions

Eleven non-conventional tropical fruits were studied as new plants for human nutrition. Some of these fruits have their proximate composition and carotenoid contents reported for the first time. The fruits presented relative high contents of IDF, excepting capeba, pitangatuba, dovialis and acerola. Noteworthy, buriti presented 19.2% of lipids. Acerola and cambuití demonstrated antioxidant potential much higher than the other fruits in the ABTS assay. Jaracatiá, seriguela, capeba, pitangatuba and acerola highlighted due to their carotenoid diversity and concentration. *In vitro* digestions results showed variations between fruits mainly because their food matrix, although generally xanthophylls were more bioaccessible than carotenes, and Lyc have very low bioaccessibility. The scientific knowledge together with the commercial exploitation of tropical fruits, especially the Brazilian natives, can stimulate sustainable development, better food habits, protection against biopiracy and the innovation in food systems.

Acknowledgements This work was supported by the São Paulo Research Foundation – FAPESP trough research funding [grant #2015/15507-9] and PhD scholarships for Paulo Berni [grant #2014/15119-6] and Nataly Toledo [grant #2014/14049-4]. We thank Helton Muniz, from *Sítio de Frutas Raras,* for his extreme efforts to grow and protect the Brazilian native fruits, provide samples and help with his accurate knowledge about botany.

Compliance with Ethical Standards

Conflict of Interest All authors declare they have no conflict of interest.

Ethical Approval This article does not contain any studies with human or animal subjects.

References

1. Infante J, Rosalen PL, Lazarini JG et al (2016) Antioxidant and anti-inflammatory activities of unexplored Brazilian native fruits. PLOS ONE 11:e0152974. https://doi.org/10.1371/journal.pone.0152974
2. Flora do Brasil 2020 (2018). Jardim Botânico do Rio de Janeiro. http://floradobrasil.jbrj.gov.br. Accessed 09 July 2018
3. Negri TC, Berni PRA, Canniatti-Brazaca SG (2016) Nutritional value of native and exotic fruits from Brazil. Biosaúde 18:82–96
4. Khoo HE, Ismail A, Mohd-Esa N et al (2008) Carotenoid content of underutilized tropical fruits. Plant Foods Hum Nutr 63:170–175
5. Betta FD, Nehring P, Seraglio SKT et al (2018) Phenolic compounds determined by LC-MS/MS and *in vitro* antioxidant capacity of Brazilian fruits in two edible ripening stages. Plant Foods Hum Nutr 73:302–307
6. Rosso VV, Mercadante AZ (2007) Identification and quantification of carotenoids, by HPLC-PDA-MS/MS, from Amazonian fruits. J Agric Food Chem 55:5062–5072
7. Porcu MO, Rodriguez-Amaya DB (2008) Variation in the carotenoid composition of the lycopene-rich Brazilian fruit *Eugenia uniflora* L. Plant Foods Hum Nutr 63:195–199
8. Garzón AA, Narváez-Cuenca CE, Kopec RE et al (2012) Determination of carotenoids, total phenolic content, and antioxidant activity of arazá (*Eugenia stipitata* McVaugh), an Amazonian fruit. J Agric Food Chem 60:4709–4717
9. Rufino M, Alves RE, Brito ES et al (2010) Bioactive compounds and antioxidant capacities of 18 non-traditional tropical fruits from Brazil. Food Chem 121:996–1002
10. Cândido TLN, Silva MR (2017) Comparison of the physicochemical profiles of Buriti from the Brazilian Cerrado and the Amazon region. Food Sci Technol 37:78–82
11. Rodriguez-Concepcion M, Avalos J, Bonet L et al (2018) A global perspective on carotenoids: metabolism, biotechnology, and benefits for nutrition and health. Prog Lipid Res 70:62–93
12. Eggersdorfer M, Wyss A (2018) Carotenoids in human nutrition and health. Arch Biochem Biophys 652:18–26
13. Association of Official Analytical Chemists (1995) Official methods of analysis of the association of official analytical chemists, 16th edn. AOAC, Washington
14. Bligh EG, Dyer EJ (1959) A rapid method of total lipid extraction and purification. Can J Biochem Physiol 37:911–917
15. Li BW, Cardozo MS (1992) Nonenzimatic-gravimetric determination of total dietary fiber in fruits and vegetables. J AOAC Int 75:372–374
16. Kimura M, Kobori CN, Rodriguez-Amaya DB, Nestel P (2007) Screening and HPLC methods for carotenoids in sweet-potato, cassava and maize for plant breeding trials. Food Chem 100:1734–1746
17. Berni P, Chitchumroonchokchai C, Canniatti-Brazaca SG et al (2014) Impact of genotype and cooking style on the content, retention, and bioaccessibility of β-carotene in biofortified cassava (*Manihot esculenta* Crantz) conventionally bred in Brazil. J Agric Food Chem 62:6677–6686
18. Garrett DA, Failla ML, Sarama RJ (1999) Development of an *in vitro* digestion method to assess carotenoid bioavailability from meals. J Agric Food Chem 47:4301–4309
19. Josino Soares D, Walker J, Pignitter M et al (2014) Pitanga (*Eugenia uniflora* L.) fruit juice and two major constituents thereof exhibit anti-inflammatory properties in human gingival and oral gum epithelial cells. Food Funct 5:2981–2988
20. Slavin J (2013) Fiber and prebiotics: mechanisms and health benefits. Nutrients 5:1417–1435
21. Stafussa AP, Maciel GM, Rampazzo V et al (2018) Bioactive compounds of 44 traditional and exotic Brazilian fruit pulps: phenolic compounds and antioxidant activity. Int J Food Prop 21:106–118

22. FAO/OMS. Human vitamin and mineral requirements. In: Report 7th joint FAO/OMS 491 Expert Consultation, Bangkok, Thailand. Food and Agriculture Organization, Rome, Italy, 2001
23. Dias MG, Olmedilla-Alonso B, Hornero-Méndez D et al (2018) Comprehensive database of carotenoid contents in Ibero-American foods. A valuable tool in the context of functional foods and the establishment of recommended intakes of bioactives. J Agric Food Chem 66:5055–5107
24. Rodrigo MJ, Cilla A, Barberá R, Zacarías L (2015) Carotenoid bioaccessibility in pulp and fresh juice from carotenoid-rich sweet oranges and mandarins. Food Funct 6:1950–1959
25. Veda S, Platel K, Sirinivasan K (2007) Varietal differences in the bioaccessibility of β-carotene from mango (*Mangifera indica*) and papaya (*Carica papaya*) fruits. J Agric Food Chem 55:7931–7935
26. Costa GA, Mercadante AZ (2018) *In vitro* bioaccessibility of free and esterified carotenoids in cajá frozen pulp-based beverages. J Food Compos Anal 68:53–59
27. Schweiggert RM, Mezger D, Schimpf F et al (2012) Influence of chromoplast morphology on carotenoid bioaccessibility of carrot, mango, papaya, and tomato. Food Chem 135:2736–2742
28. Dhuique-Mayer C, Borel P, Reboul E et al (2007) β-Cryptoxanthin from citrus juices: assessment of bioaccessibility using an *in vitro* digestion/Caco-2 cell culture model. Br J Nutr 97:883–890
29. Jeffery JL, Turner ND, King SR (2012) Carotenoid bioaccessibility from nine raw carotenoid-storing fruits and vegetables using an *in vitro* model. J Sci Food Agric 92:2603–2610
30. O'Sullivan L, Ryan L, O'Brien N (2007) Comparison of the uptake and secretion of carotene and xanthophyll carotenoids by Caco-2 intestinal cells. Brit J Nutr 98:38–44
31. Rodrigues DB, Chitchumroonchokchai C, Mariutti LRB et al (2017) Comparison of two static *in vitro* digestion methods for screening the bioaccessibility of carotenoids in fruits, vegetables, and animal products. J Agric Food Chem 65:11220–11228
32. Mashurabad PC, Palika R, Jyrwa YW et al (2017) Dietary fat composition, food matrix and relative polarity modulate the micellarization and intestinal uptake of carotenoids from vegetables and fruits. J Food Sci Technol 54(2):333–341