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Macro and trace element compositions and physicochemical parameters of guajiru fruits (*Chrysobalanus icaco* l.) from two Brazilian states

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ABSTRACT

Chrysobalanus icaco L. is a tree found in America and Africa. In Brazil it can be found in the biome along the coast. It has great food potential and its fruits, named guajiru, are consumed by fishing communities *in natura* and processed as jams and jellies. However, the literature on this tree species is limited. This study aims to describe the element contents and physicochemical characteristics of the *C. icaco* fruits from two regions in Brazil and investigate if they influence its sensory characteristics. The fruits were collected in the Northeastern region of Brazil in Maracajaú, State of Rio Grande do Norte (RN) and in Salvador, Bahia (BA). The morphometric characteristics, color, texture, and sensory analyses were carried out on the fruits *in natura*, and the physicochemical analyses and mineral profile on the pulp homogenized with the peel. The mineral profile showed K > Na > Mn > Mg > Ca > Fe > Mn > Cu > Zn > Ni > Cr, varying from 206 mg/100g (K) to 0.87 μg/100 g (Cr). The fruits from RN presented higher levels of trace and macronutrients, which affected the sensory characteristics, mainly the flavor, and led to better acceptance of these samples as compared to those from BA. The results suggest that *C. icaco* fruits present a good nutritional profile and sensory acceptance and hence their commercialization could be stimulated as a table fruit or mixed with other fruits.

1. Introduction

Fruits are nutritional sources of importance to the human diet because of their chemical composition and beneficial effects on human health. Due to their contents of phytochemicals, some of which have antioxidant properties, fruits and vegetables play an essential role in the prevention of chronic diseases such as diabetes, cardiovascular diseases, and cancer [1,2].

Several studies have pointed out the need for a diet rich in fruits in order to achieve an adequate daily consumption of vitamins, anthocyanins, tannins, and macro and trace elements [2–4]. The nutritional composition and mineral content depend on the

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particularities of each species and the genetic variation between plant specimens and these factors define the organoleptic attributes and physicochemical properties resulting from the metabolic activities [5]. In addition to the genetic factor, differences can also be derived from the type of cultivation and degree of maturation, mainly due to the edaphoclimatic conditions of each region [5].

Brazil has native fruit plants with high economic potential, such as pineapple (*Ananas comosus* L.), cajá (*Spondias mombin* L.), guava (*Psidium guajava* L.), passion fruit (*Passiflora edulis Sims*) and cashew (*Anacardium occidentale* L.). According to Oliveira et al. [2], the country stands out due to its rich biodiversity, representing 20% of the world's flora. Despite being the third largest fruit producer in the world, only 24% of the Brazilian population reach the minimum value of 400 g of daily intake recommended by the World Health Organization (WHO) [6]. Some of the characteristics that refer to the quality of the food are decisive aspects for consumption. The freshness, firmness, aroma, flavor, nutritional value, and appearance form a set of characteristics that lead the individual to consume a determined fruit [1,7].

In Brazil, fruits are usually consumed as desserts [6]. The country's natural food resources can act in a complementary way in the diet since, besides being of easy economic access, they have great acceptance and high nutritional potential but there are still plenty of food sources yet to be fully explored, such as novel fruits [2].

Guajiru is the edible fruit harvested from the trees of the *Chrysobalanus icaco* L. species, also popularly known as abajeru, ariu, ajuro, and maçãzinha-da-praia [8]. *C. icaco* L. is part of the *Chrysobalanaceae* botanical family, and the genus *Chrysobalanus* covers two other species: *C. venezuelanus* and *C. cuspidatus*, but only *C. icaco* has Pan-American distribution, occurring from Florida to South America and even on the African continent [9].

C. icaco is a native species, typical of coastal dunes. In Brazil, it is distributed in forests in the Northern Amazon biome, and in the coastal biome known as the restinga, located from the Southeastern to Northeastern regions of the country [9]. A previous study showed that the fruit pulp contained a substantial amount of trace elements with antioxidant activity, mainly copper (Cu), chromium (Cr) and selenium (Se) [10]. In another study by Venancio et al. [11], its richness in anthocyanins was demonstrated, these being responsible for a cytotoxic action in cancer cells and an anti-inflammatory effect in non-tumor cells of the human colon, therefore having a nutraceutical potential.

Despite these interesting findings, the *C. icaco* fruits are not usually commercialized and are rarely investigated, despite their extensive distribution throughout the world [8,10,12]. Thus, they are presented as novel food sources that should have their nutritional potential assessed in order to be inserted on the Brazilian and international markets. More investigation on this fruit species is necessary, since information on its nutritional and mineral composition could promote food safety, help provide healthy diets for consumers and enhance its future commercialization. Knowledge of the nutritional composition of native fruits, such as *C. icaco*, may encourage their consumption and production [4].

Considering that the chemical composition and mineral contents of plants are directly influenced by the type of soil and environment in which they grow [3] and in view of the limited amount of research on the fruits of *C. icaco*, this study aims to investigate the physicochemical, mineral and sensory attributes of *C. icaco* fruits from two regions in Brazil.

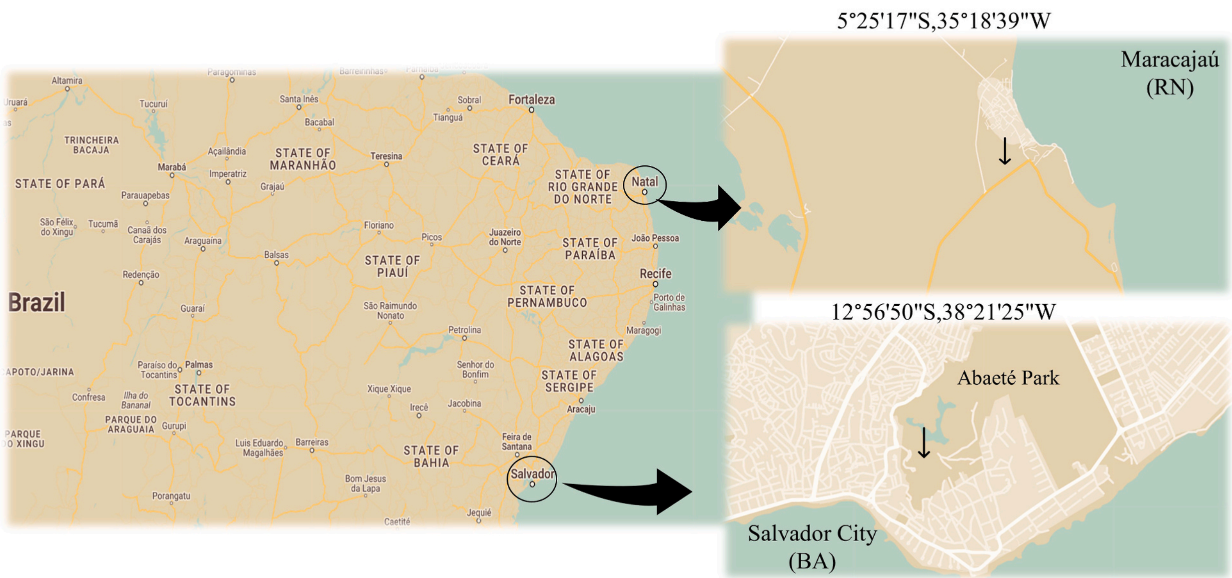

Fig. 1. Geographical locations of the *C. Icaco* fruit collection sites. Developed with the help of the legacy JSON styling wizard (mapstyle.withgoogle.com).

2. Material and methods

2.1. Material sampling locations

The *C. icaco* fruits were obtained from two native forest areas in the coastal region of Brazil, one from the dunes of Maracajaú – RN, 52 km from the State capital Natal (5° 25′17″S, 35°18′39″ W), here referred to as RN, and the other from the dunes of the Abaeté Park in Salvador - Bahia (12°56′50″ S, 38°21′25″ W), here called BA (Fig. 1). The collection site for each locality was established with the help of a key informant, a resident from the local community. Botanical material testimonies were also collected. The two sites were selected based on convenience, the first one in the State of Bahia because this is our region and the second in the State of Rio Grande do Norte, since we have collaborators in this northeastern region of Brazil, and it represents a restinga biome for comparison.

2.2. Methods

2.2.1. Sample collection

The fruits were collected manually from both locations in February 2018. At each location about 200 fruits were harvested at the mature stage, when they present a dark red to purple color, since they are not climacteric fruits. The *C. icaco* fruits collected were placed in plastic bags, identified, put in iceboxes, and transported to the laboratory.

Sixty fruits with no mechanical injury or damage caused by animals were selected from each collection site (n = 60), washed with ultrapure water (Mili-Q® system, Millipore-Merck) and the following physical parameters evaluated: fruit, seed and pulp masses; length and maximum diameter of the fruits and seeds, and the calculated yield, pulp thickness, color, and texture. All analyses were carried out in the Laboratory of Toxicology (LabTox) and Laboratory of Sensory Analysis of the Faculty of Pharmacy of the Federal University of Bahia, Brazil.

The same fruits were used with the peel, but with the seeds removed (pulp) to determine the pH value, total soluble solids (TSS), total titratable acidity (TTA), TSS/TTA ratio, water activity (wa), and the proximate and trace element compositions. Three replicates of each pulp were analyzed for all the physicochemical parameters (n = 3). For the sensory analysis, a further sixty fruits from each location were selected (n = 60), sanitized, dried, and served to the volunteers.

2.2.2. Physicochemical parameters

The length and diameter of the *C. icaco* fruits were measured using a digital caliper with an accuracy of 0.01 mm. The weights of the fruit, seeds, and pulp were measured with the aid of an analytical balance. The pH of the samples was determined using a digital benchtop pH-meter (Orion®, Thermo Equip.). The TSS value was determined using a digital refractometer (Atago, model master T), and the results expressed in °Brix, the TTA by manual titration, and the results expressed in percentage [13] and the water activity using the equipment AQUALAB (model CX2, Decagon Devices). For each fruit, the physical parameters were evaluated in triplicate and the results expressed as the average ± standard deviation.

2.2.3. Proximate composition

The proximate composition analyses were carried out in triplicate and followed the methods established by AOAC [14]. To determine the moisture content, the *in natura* pulps were weighed and dried in an oven at 105 °C to constant weight. The dried pulp samples were weighed, charred using a Bunsen flame, and calcined in a muffle furnace at 550 °C to determine the ash content (Method 923.03).

The total protein content was determined using the Kjeldahl method (Method 920.152), multiplying the total nitrogen content by the conversion factor of 5.75, the value used for vegetable proteins according to RDC n° 360/2003 [15]. The lipid content was determined using the Bligh-Dyer method, which consists of a cold extraction using a mixture of solvents (chloroform and methanol). The total carbohydrate content was determined from the difference between 100 g of the product and the sum of the values found for ash, moisture, lipids, and proteins, as described by AOAC [14].

2.2.4. Texture and instrumental color analysis

The mechanical assay of the fruits was carried out using an SMS/P6 probe in a model TA texture analyzer (Stable Micro Systems®). The operating conditions were as follows: pre-test velocity, test, and post-test of 10.0 mm/s; compression distance of 4.0 mm; 5.0 g trigger force and 5″ time. An 8 mm diameter dubbing drill plate and a 4 mm probe were used. The drilling force (firmness) was expressed in Newtons (N).

The CIELAB system ($L\ a^*\ b^*$) was used to analyze the fruit color, where L represents brightness in percentage from 0 to 100 (0-dark, 100-total brightness) on the vertical axis, a^* and b^* represent the chromatic coordinates from green to red (- to +) on the horizontal axis and blue to yellow (- to +) on the vertical axis, respectively (Hunter diagram). A previously calibrated Chroma Meter CR-5 colorimeter (Konica Minolta ®) was used to measure these variables in the fruits (three replicates per fruit).

2.2.5. Determination of macro and trace element compositions

A mass of approximately 0.25 g of dehydrated pulp was weighed directly into the PTFE (Polytetrafluoroethylene) tubes of the microwave digester oven, 4 mL of spectrographic-grade concentrated nitric acid added, and left to stand open for 15 min in the exhaustion hood. After sealing appropriately, the tubes were transferred to the microwave digester (MARS-6, CEM®, USA) and subjected to complete mineralization following the built-in protocol for vegetable material (Potency of 1030–1800 W for 40 min at

200 °C, cooling down for 15 min). After reaching room temperature in the exhaustion hood, the mineralized samples were volumetrically transferred into 15 mL polypropylene graduated tubes and completed to 10 mL with ultrapure water [3].

The macro and trace elements were determined by atomic emission spectrometry for the elements potassium (K) and sodium (Na) (AES - Varian Spectra AA 55B, Mulgrave Victoria, Australia), and atomic absorption spectrometry (FAAS) in the flame mode for magnesium (Mg), calcium (Ca), iron (Fe), zinc (Zn), and copper (Cu), using a fuel rich air-acetylene flame. The wavelengths for K, Na, Mg, Ca, Fe, Zn, and Cu were 422.7 nm; for Zn 213.9; and for Cu 324.8, respectively. The metals analyzed in an AAS graphite furnace (GFAAS) (Varian Spectra AA 240FGZ, Mulgrave Victoria, Australia), with their respective wavelengths were Mn (279.5 nm), Cr (357.9 nm), Se (196.0 nm), Mo (313.3 nm), and Ni (232.0 nm). Supplementary Table S1 shows the other equipment parameters such as the lamp current, slit width, and heating program applied for each metal. Matrix modifier solutions were used for Mn (0.5% $Mg(NO_3)$ in 0.2% nitric acid) and for Cr (0.1% Triton X-100 in 0.2% nitric acid). External calibration curves were used for all elements, with the exception of Se for which a standard addition calibration procedure was applied. The values found for the concentrations of each element in mass/volume (mg or μg/L) were transformed into mass/mass (mg or μg kg^{-1}) and corrected for the mean value for moisture found in each sample. All the results found for macro and trace elements were expressed in both mg or μg 100 g^{-1} wet weight (w/w) and per dry weight (d/w) for comparison with other studies. For quality assurance purposes, certified reference materials (CRM) NIST rice flour 1468a and NIST apple leaves 1515 (National Institute of Standard and Technology, USA) and reagent blanks were analyzed along with each batch, and all samples were analyzed in duplicate.

2.2.6. Sensory Analysis

A total of sixty potential consumers received the duly balanced and codified fruit samples, presented monadically, along with their respective acceptance and purchase forms. The tests were carried out in individual booths in the UFBA Sensory Analysis Laboratory. The tasters were recruited from the Faculty of Pharmacy and filled in a sociodemographic questionnaire after signing the Informed Consent Term. The study was approved by the research ethics committee of the Federal University of Bahia (No. 2349854). The charts followed the affective acceptance method with a ten-point hybrid hedonic scale [16,17].

Table 1
General characteristics of *C. icaco* fruits according to the origin.

Main parameters		BA			RN			
Dimensions		Mean		SD	Mean	SD		p-value
Fruits								
	Total mass (g)	423.06		1.57	354.42	1.13		<0.001
	Length (cm)	2.73		0.14	2.64	0.13		<0.001
	Diameter (cm)	2.54		0.15	2.41	0.16		<0.001
Seeds								
	Total mass (g)	99.80		0.17	98.84	0.15		0.002
	Lenght (cm)	1.91		0.14	1.99	0.11		0.001
	Diameter (cm)	1.27		0.08	1.22	0.07		0.001
Pulp								
	Mass (g)	310.61		0.77	252.79	1.04		<0.001
	Thickness (cm)	0.41		0.12	0.32	0.08		0.022
	Yield (%)	73.42		0.39	71.33	0.10		0.001
Pulp		**BA**			**RN**			
	Physicochemical parameters	**Mean**		**SD**	**Mean**	**SD**		**p-value**
	pH	5.44		0.11	5.03	0.02		<0.001
	TSS (°Brix)	10.93		0.30	13.33	0.11		<0.001
	TTA (%)	1.15		0.08	1.58	0.05		0.002
	TSS/TTA	9.55		0.85	8.48	0.34		0.112
	Wa (%)	97.83		0.45	97.77	0.45		0.865
	Nutrients							
	Energy (kcal)	60.04		1.44	73.12	0.29		<0.001
	Moisture (%)	84.73		0.26	81.29	0.06		<0.001
	Ashes (%)	0.49		0.01	0.64	0.2		<0.001
	Total carbohydrate (%)	14.27		0.23	17.33	0.03		0.002
	Lipid (%)	0.19		0.09	0.17	0.03		0.746
	Protein (%)	0.31		0.04	0.56	0.05		0.003
Physical pameters								
Whole fruits		**BA**			**RN**			
Firmness (N)		**Med**	**Min**	**Max**	**Med**	**Min**	**Max**	**p-value**
		45.38	28.69	64.07	46.02	28.39	92.64	0.80
Color								
L*		23.02	17.70	34.04	24.85	19.98	37.16	<0.001
a*		22.15	12.70	26.48	20.41	15.53	25.10	0.73
b*		6.44	2.73	11.47	4.42	2.62	9.13	<0.001

Values expressed in mean and standard deviation, Student's *t*-test with significance of $p < 0.05$. Values expressed in Median (Med), Minimum (Min) and Maximum (Max), Mann-Whitney *U* test with significance of $p < 0.05$.

2.2.7. Data analysis

The results were expressed as the mean, standard deviation, and the minimum and maximum values. The data were checked for distribution. The Student's t-test was used to verify differences according to the origin of the fruit for those with parametric distribution, and the Mann-Whitney *U* test for non-parametric data. In addition, a bivariate analysis using Pearson's correlation coefficient and the Hierarchical Grouping Analysis (AHA) were applied to verify which physicochemical parameters were associated with the sensory aspects. A heatmap plot was obtained with this data to illustrate the hierarchical groups. All the tests were applied at a significance level of $p < 0.05$ and the statistical software packages IBM SPSS statistics v.23, and Minitab,v.17 were used for all analyses.

3. Results

3.1. Physicochemical parameters

In this study the *C. icaco* fruits presented a length/diameter (l/d) ratio close to one, reaffirming their rounded shape. In general, the sizes ranged from 2.38 to 3.10 cm in length, 2.13–2.92 cm in diameter, and the pulp thickness values from 0.16 to 0.74 cm. However, some differences were evident between the fruits from Bahia and those from Rio Grande do Norte. The *C. icaco* fruits from BA were larger with 28% thicker pulp and 23% higher yield, and the average seed diameter values were also higher (Table 1).

As expected, the TTA was higher for lower pH values. There was no difference in the TSS/TTA ratios according to fruit origin, that is, the fruits had similar harvesting points. The water activity also presented no significant difference, regarded as high for both locations.

In general, the pulp yield was high, with an average of 71.3% for RN and 73.4% for BA. As shown in Table 1, the pulps were classified as low acid according to the Food and Drug Administration (FDA) [18] classification, with pH values above 4.6. The *C. icaco* fruit pulp from BA had a higher pH and lower TSS than that from RN. The *C. icaco* fruit pulp from RN presented a value of 13.33 °Brix.

3.2. Proximate composition

The pulp from the *C. icaco* fruits from BA showed a higher moisture content and lower ash, protein and carbohydrate contents. No difference in the lipid contents were observed between the regions and consequently, the pulp from BA had a lower energetic value than that from RN. The proximate compositions for the *C. icaco* fruit pulps from BA and RN revealed low protein and lipid concentrations.

3.3. Texture and instrumental color analyses

No significant difference was observed between the samples concerning the values for maximum compression reached in the first cycle (firmness). Regarding the color scale, the fruits showed a higher value for red color (+a^*) and a low mean value for yellow coloring (+b^*), resulting in a more violet than orange appearance. The fruits were similar for the red color scale (a^*), but there were differences for the L* and b* parameters. The *C. icaco* fruits from RN were lighter than those from BA, showing greater luminosity and a less intense yellow color than the fruits from BA.

3.4. Macro and trace element composition

3.4.1. Analytical methods for the quality assurance of metals

The data in Table 2 summarizes the quality assurance results for the analytical methods used to determine the metals. In general, they had values for precision ranging from 2.8 to 28.7% and the accuracy for the determination of all elements ranged between 75 and 115.1%. The procedural limit of detection (LOD) for each element was calculated as 3 × SD of the reagent blank readings (n = 6). The LODs for Na, K, and Ca were set at 0.24, 1.1, and 0.38 μg g^{-1}, respectively; and for Fe, Zn, and Cu the LODs were set at 1.56, 0.96, and

Table 2
Metal analysis quality assurance results.

Elements	CRM	Certified value (mg kg^1)	Obtained value (mg kg^{-1})	Precision (%)	Accuracy (%)	LOD (mg kg^{-1})	LOQ (mg kg^{-1})
Na	Apple leaves	24.4 ± 2.1	23.40 ± 1.17	5.0	95.9	0.24	0.79
K	Rice flour	1282 ± 11	1169 ± 9	7.7	91.2	1.1	3.5
Ca	Rice flour	118.4 ± 3.1	112.9 ± 3.5	3.1	95.0	0.38	1.2
Mg	Rice flour	559 ± 10	548 ± 2.5	4.5	98.0	0.85	2.5
Cu	Apple leaves	71.6 ± 1.6	68.5 ± 1.12	2.8	95.7	0.13	0.56
Fe	Rice flour	7.42 ± 0.44	7.66 ± 0.31	3.6	103.2	1.56	5.15
Mn	Rice flour	19.2 ± 1.8	19.43 ± 0.08	2.9	101.2	0.08	0.26
Cr	Apple leaves	0.3[a]	0.28 ± 0.02	7.1	93.3	0.04	0.11
Mo	Rice flour	1.45 ± 0.05	1.35 ± 0.22	4.9	93.0	0.23	0.76
Ni	Apple leaves	0.91 ± 0.12	0.68 ± 0.09	15	75	0.03	0.09
Se	Apple leaves	0.365 ± 0.029	0.42 ± 0.012	28.7	115.1	0.004	0.013
Zn	Apple leaves	1424 ± 46	1445 ± 39	2.7	101.5	0.96	3.17

[a] Uncertainty not specified.

0.13 μg g^{-1}, respectively. Finally, for Mn, Cr, Se, Mo, and Ni they were set at 0.08, 0.04, 0.004, 0.23, and 0.03 μg g^{-1}, respectively.

Twelve elements were quantified for the metal profile, of which K, Na, Mg, and Ca were in the majority (Table 3). The concentrations of Se and Mo in the *C. icaco* fruits from BA and RN were below the detection limits of the analytical methods. The concentrations of Ca, Fe, Ni, and Cr were about ten times smaller than the values for dry mass presented by Aguiar et al. [10].

Significant differences were only observed between the *C. icaco* fruit pulps from BA and RN for four elements on a dry weight basis. The Na and Cr contents in the *C. icaco* fruit pulps from BA were higher and the Mn and Ni contents lower than those found in the *C. icaco* fruits from RN. The number of significant differences amongst the macro and trace element contents increased on a wet weight basis.

Table 4 shows the recommended daily intakes for each mineral and the contributions made by 100 g portions of the BA and RN *C. icaco* fruits. A daily intake of 100 g of *C. icaco* fruit from BA or RN provides the following percentages of the recommended intakes: 12% and 16% respectively for Cu, 6% and 7% respectively for Mg, and approximately 4% for K for both locations.

According to Table 5, significant correlations were found for all the macro and trace elements, except for Zn and Na, with the pH, ATT, TSS, carbohydrate, and protein contents. The higher the mineral content, the higher the carbohydrate and protein contents, given their positive correlation coefficients, except for Cr.

Considering the pH value, the macro and trace elements K, Mg, Ca, Fe, Mn, Cu, and Ni were shown to be negatively correlated, and consequently positively correlated with the acidity as well as with the TSS. Chromium did not follow this profile, since its correlation with pH was positive and negative for acidity and TSS (Table 5). Cr was the only mineral with a higher concentration in the BA sample, establishing its strong relation with these parameters, since the BA sample had a lower TSS content, lower acidity and higher pH value.

3.5. Sensory Analysis

The dendrogram (Fig. 2) shows that the appearance had more significant dissimilarity with the scores for odor and flavor, in more significant proportions, and with those for texture to a lesser extent. The scores for flavor and odor followed a similar pattern, so they were in the same group.

The best acceptance scores were attributed to appearance, followed by texture, with no significant difference in the analysis of variance with Tukey's post-test between the acceptance scores for these attributes ($p = 0.166$), and the lowest scores were attributed to odor and flavor with averages around 6.0, also with no significant difference ($p = 0.533$) between these characteristics that least pleased potential consumers.

The acceptability of the attribute of appearance for the *C. icaco* fruits had an average value higher than the descriptor "neither liked nor disliked". Regardless of their origin, the fruits were considered to have a good appearance (Table 6), despite differences observed between the samples from BA and RN in the size, pulp thickness, and color (Table 1). In addition, the data only show a significant difference between the acceptances of the *C. icaco* fruit samples from the two localities for flavor, with greater acceptability for the *C. icaco* fruits from RN. No difference was evident for the attribute of texture, as there was no difference in firmness between the fruits from BA and RN, as shown in the data in Table 1.

The tasters reported the absence of a marked taste for both fruit samples, defining them as "just sweet", and the taste and texture were compared to those of Jambo fruits. The tasters were dissatisfied with the thickness of the pulp, and terms such as "little pulp" or "little flesh" were reported. The tasters described a slight astringency in the BA fruits.

Fig. 3 indicates the groupings of the multivariate statistical analyses presented in the form of heatmaps. Fig. 3a groups the fruit

Table 3
Macro and trace element profile of *C. icaco* fruits in samples from two Brazilian locations (this study) plus from Rio de Janeiro, Brazil [10].

	Dry weight					*p*-value	Wet weight				*p*-value
	RJ	BA		RN			BA		RN		
	Mean	Mean	±SD	Mean	±SD		Mean	±SD	Mean	±SD	
Macroelements (mg/100 g)											
K	1620	1095	40	1102	112	0.920	**167**	**5.96**	**206**	**21**	**0.036**
Na	**870**	**416**	**9.2**	**332**	**17**	**0.002**	63	1.40	62	3.27	0.515
Mg	181	167	5.7	162	6.2	0.447	**25**	**0.88**	**30**	**1.17**	**0.004**
Ca	289	25	0.5	36	5.6	0.081	**3.82**	**0.75**	**6.68**	**1.06**	**0.042**
Microelements (mg/100 g)											
Fe	12.6	1.66	0.22	2.13	0.23	0.060	**0.25**	**0.03**	**0.40**	**0.04**	**0.010**
Mn	**2.10**	**1.15**	**0.09**	**1.64**	**0.04**	**0.001**	**0.17**	**0.01**	**0.31**	**0.01**	**<0.001**
Zn	0.80	0.63	0.18	0.59	0.07	0.733	0.09	0.03	0.11	0.01	0.473
Cu	1.87	0.71	0.04	0.76	0.05	0.269	**0.11**	**0.06**	**0.14**	**0.09**	**0.006**
Trace elements (μg/100 g)											
Cr	**890**	**8.00**	**1.00**	**4.67**	**0.58**	**0.007**	**1.22**	**0.15**	**0.87**	**0.11**	**0.032**
Se	59	<0.40	–	<0.40	–	–	<0.40	–	<0.40	–	–
Mo	0.01	<0.23	–	<0.23	–	–	<0.23	–	<0.23	–	–
Ni	**370**	**29**	**1.15**	**44**	**2.65**	**0.001**	**4.48**	**0.18**	**8.23**	**0.49**	**<0.001**

Note: Reference data for mineral content in fruits from Rio de Janeiro (RJ) was obtained by Aguiar et al. [10]. Student's t-test, for samples from Bahia (BA) and Rio Grande do Norte (RN).
LD: Detection Limit.

Table 4
Percentage of recommended daily intake of minerals for a portion of *C. icaco* fruits from two locations in Brazil.

Elements	RDI	RDI percentage per serving of *C. icaco* fruit	
		BA	**RN**
(mg/100 g)			
K	4700	3.6	4.4
Na	1500	4.2	4.1
Mg	400	6.3	7.5
Ca	1000	0.4	0.7
Fe	8	3.1	5.0
Zn	11	0.8	1.0
Cu	0.9	12.2	15.6
(μg/100 g)			
Cr	35	3.5	2.5

Note: RDI values obtained from Food and Nutrition Board, Institute of Medicine, National Academies.

Table 5
Pearson's correlation coefficients among element profile, physicochemical parameters and centesimal composition of *C. icaco* fruits.

Elements	pH	TSS	TTA	Protein	Lipid	Carbo hydrate
	−0.859	0.864	0.798	0.875	−0.216	0.844
	0.029*	0.027*	0.057	0.022*	0.681	0.035*
Na	0.300	−0.346	−0.285	−0.558	0.200	−0.324
	0.563	0.502	0.585	0.250	0.704	0.531
Mg	−0.953	0.910	0.990	0.889	−0.387	0.943
	0.003**	0.012*	0.001**	0.018*	0.449	0.005**
Ca	−0.904	0.889	0.917	0.814	−0.124	0.921
	0.013*	0.018*	0.010*	0.049*	0.815	0.009**
Fe	−0.931	0.902	0.956	0.824	−0.286	0.933
	0.007**	0.014*	0.003**	0.044*	0.582	0.007**
Mn	−0.985	0.972	0.951	0.972	−0.190	0.977
	<0.001**	0.001**	0.004**	0.001**	0.719	0.001**
Zn	−0.330	0.230	0.468	0.430	−0.585	0.296
	0.523	0.661	0.349	0.395	0.222	0.569
Cu	−0.956	0.939	0.936	0.871	−0.234	0.947
	0.003**	0.005**	0.006**	0.024*	0.655	0.004**
Cr	0.867	−0.868	−0.860	−0.812	0.244	−0.875
	0.025*	0.025*	0.028*	0.050*	0.641	0.022*
Ni	−0.973	0.976	0.946	0.971	−0.154	0.983
	0.001**	0.001**	0.004**	0.001**	0.771	<0.001**

*significant correlation at the 0.05 level; ** significant correlation at the 0.01 level.

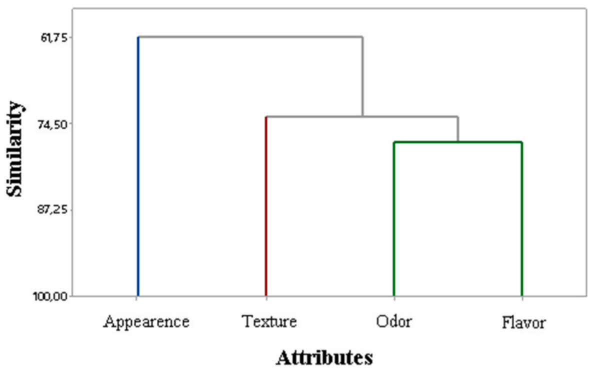

Fig. 2. Dendogram for the sensory attributes found in the acceptance tests for the *C. icaco* fruits from both locations.

samples according to their physical and sensory parameters, indicating that samples in the same cluster present remarkable similarity considering the analyses carried out. On the other hand, the main differences between the fruits can be perceived in the heatmap for the parameters *a, *b (color) and acceptance of taste. The acceptance of the texture of the samples also differed, although the same was not perceived in the physical measurement of firmness using the texturometer.

Fig. 3b associates the physicochemical parameters with the metals in both fruits, showing similar behavior to that seen in the heatmap of Fig. 3a, with a single cluster of samples. However, differences can be observed between the samples for the parameters of

Table 6
Sensory acceptance for *C. icaco* fruits from two localities in Brazil.

Attribute	BA		RN		
	Mean	±SD	Mean	±SD	p-value
Appearance	7.09	2.26	7.43	1.76	0.369
Texture	6.39	2.30	7.00	2.05	0.130
Odor	5.97	1.54	6.37	1.79	0.189
Flavor	5.30	2.41	6.31	2.49	0.025

Student's t-test *p*-value.

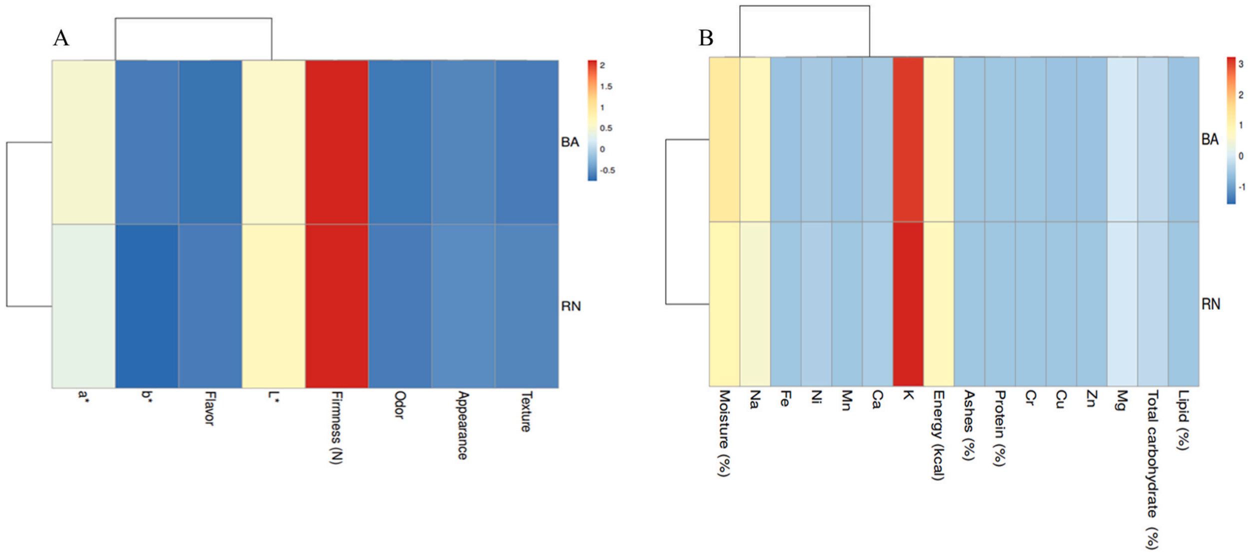

Fig. 3. Multivariate analysis in the form of a heatmap of the *C. icaco* fruit samples regarding their physical and sensory attributes (a) and physicochemical and metal parameters (b).

moisture, Na, Ni, and K. This result suggests that edaphoclimatic conditions, as well as the cultivation mode and the chemical composition of the soil, are factors that can determine the quality of the *C. icaco* fruits from the two different regions.

4. Discussion

In this study, the macro and trace element compositions and other relevant physicochemical characteristics of the *C. icaco* fruits from two locations in Brazil were evaluated. A sensory test was also applied, where the tasters ranked the fruits according to distinct parameters. The composition of the fruits influenced the acceptance of the flavor, the attribute which obtained lower scores when compared to attributes such as appearance, odor, and texture. Regarding the place of origin, the samples from Rio Grande do Norte were more accepted and richer in trace and macro elements.

The values for length were comparable with those reported in the study developed by Simón, Mares, Sanchéz, & Martinéz [19], who described *C. icaco* fruit as oblong and cited a length range of 2–4 cm for fruits from Mexico. In Brazil, Santana, Rêgo, & Silva [20] found *C. icaco* fruits with average lengths of 2.91 cm and diameters of 2.95 cm for fruits harvested in the State of Paraíba in the Northeastern region, larger than the fruits mentioned in this study. The thicker pulp of BA fruits can be justified by the fact that the *C. icaco* fruits from RN are smaller, with less mass, and seeds with longer mean lengths than fruits from BA, thus reflecting the proportional difference in pulp yield between the two locations. The greater turgescence of the fruits from BA as compared to those from RN is probably due to the difference in moisture content.

Corroborating with the values for yield of about 70% found for the *C. icaco* fruits from RN and BA, Aguiar et al. [10] also obtained a 71% yield for *C. icaco* fruits collected in Rio de Janeiro (RJ), Brazil. According to Carvalho & Müller [21] in a study with 50 fruit species from the Amazon region, values of between 61% and 80% are categorized as high yield. The authors described a yield of 65.8% in pulp (without peel) for *C. icaco* fruits and Santana et al. [20] suggested that the high pulp yield is one of the characteristics that makes it possible to consume the fruit *in natura*.

The total soluble solids content of 13.33° Brix found for the *C. icaco* fruits from RN favors consumption of this fruit. According to data reported by Schiassi, Souza, Lago, Campos, & Queiroz [22], who studied the pulp of *Annona crassiflora Mart.*, this value for TSS is considered elevated. According to Damodaran et al. [5], fruits with a lower water content tend to concentrate sugars and acids and, consequently, present higher soluble solids contents, which is linked to the sweetness aspect of the food and hence to the likelihood of a consumer choosing the food, since this is directly proportional to its degree of sweetness.

The data obtained by Aguiar et al. [10] for the pH (5.64) and TSS (10 °Brix) of *C. icaco* fruits corroborate with the current results, suggesting the viability for *in natura* consumption or its industrialization. The total soluble solids content is related to the proportion of sugar, as evidenced by the higher total carbohydrate content in the RN fruits. The above authors, in their study with *C. icaco* fruits from Rio de Janeiro, observed lower TSS values for the pulp, in relation to the total carbohydrate content (13.43%) and higher in relation to the energy value when compared to the BA pulp. On the other hand, they found higher protein (0.68%) and lipid contents (0.85%) than the BA and RN samples. Similar data for the total caloric value of 54.5 Kcal for the *C. icaco* fruits from BA was reported by Franco [23] for fruits of the same species.

As far as the element composition is concerned, Clerici & Carvalho-Silva [24] emphasized the nutritional value of the macro and trace elements in seasonal fruits consumed by the population, but not commercialized on a large scale, such as pink jambo (*Eugenia malaccensis* L.) and jaboticaba (*Myrciaria cauliflora* Berg.), both species presenting 0.1% of lipids in their compositions, equal to the percentage observed in the *C. icaco* fruits from BA and RN; and proteins between 0.6% for jaboticaba and 0.9% for pink jambo, values close to or higher than those found in the current study for RN *C. icaco* fruits.

The energy values of the species cited by Clerici & Carvalho-Silva [24] were lower than those of the *C. icaco* fruits from BA and RN, of 27.00 and 58 kcal/100 g for pink jambo and jaboticaba, respectively. In addition to their nutritional characteristics, Damodaran et al. [5] argue that the lipids, proteins, and carbohydrates contribute to defining attributes such as the texture and taste of a food.

According to Salinas-Hernández et al. [7], firmness is an important parameter to determine the post-harvest quality of a fruit, its consumer acceptance, and, consequently, its market value. According to research with fresh fruits, Farcuh, Rivero, Sadka, & Blumwald [25], analyzing plums (*Prunus salicina* L.), found a value of 35 N, a value considered low for firmness when compared to the *C. icaco* fruits. However, the values presented here are similar to the average value of 43.3 N reported for peaches (*Prunus persica* L.) by Denoya et al. [26].

Concerning the water activity, the value found for the *C. icaco* fruits from BA and RN showed their potential for degradability and susceptibility to deterioration by microorganisms [5] and consequent loss of firmness. In their post-harvest study with *in natura C. icaco* fruits from the region of Cartagena, Colombia, Diaz-Gomez et al. [27] found a shelf life of three days at an average temperature of 28 °C.

As well as firmness, the color also interferes in the determination of freshness, the appearance, and the shelf life of fruits and vegetables. The color of fruits depends on pigments such as anthocyanins and carotenoids, with anthocyanins being responsible for colors such as blue, purple, violet, magenta, red, and orange; and carotenoids responsible for yellow, red, and orange colors [5]. Brito et al. [28] observed in their studies that *C. icaco* fruits contained substantial amounts of anthocyanins. The same was perceived by Vargas-Simón, Soto-Hernández, & Rodríguez-González [29], who determined two specific groups of anthocyanins that separate red *C. icaco* fruits from purple *C. icaco* fruits. Such studies corroborated the fact that higher mean values for the coloration parameters were found on the scale for red ($+a^*$) than for yellow ($+b^*$). Sereno et al. [4] studied cocona (*Solanum sessiliflorum* Dunal) and found good correlations between carotenoids and the color parameters, the values obtained for cocona being higher for yellow (63.40) when compared with the data reported in the current study. However, there are no studies in the literature comparing the pigment contents with the instrumental color analysis for *C. icaco* fruits, and hence it cannot be inferred that the *C. icaco* fruits present fewer carotenoids due to their low values for the yellow tone as compared to the cocona fruits, which are orange.

The development of fruit quality characteristics such as appearance, shape, size, color, aroma, and flavor is due to the specific functions that each essential element plays in the metabolic processes of the fruits [30]. These macro and trace elements also contribute to the nutritional quality, storage, and post-harvest conservation of the fruit [31] and it was evident that, with the exception of Cr, the concentrations of all the macro and trace elements were higher in the RN pulp than in the BA pulp. Aguiar et al. [10] analyzed *C. icaco* fruits collected in Rio de Janeiro (RJ) and found the same qualitative standard for the macro and trace element composition. However, the amounts were higher than those reported in this study, especially for Ca, Fe, Ni, and Cr when compared on a dry-weight basis. Franco [23] found values of 50 and 0.30 mg/100 g for Ca and Fe, respectively, in the composition of table fruits of this same species.

The concentrations of Se and Mo in the *C. icaco* fruits from BA and RN were below the limits of detection of the analytical methods applied. However, Aguiar et al. [10] reported concentrations of 1.0 μg/100 g for Mo and 59 μg/100 g for Se using the ICP-MS (inductively coupled plasma mass spectrometry) technique, which is about x10 to x20 more sensitive than the method used in this study. The variation in mineral content, as expressed in the dry mass, was evident in the study by Mir-Marqués et al. [3] with persimmon fruits (*Diopsyros kaki* L.) from seven distinct regions in Spain, where the mean values for the mineral contents in the fruits from the different localities varied up to ten times for certain macro and trace elements such as Na and Ni.

The values found for K in the *C. icaco* fruits from BA and RN on a dry weight basis, when compared to values reported for green banana flour (1475 mg/100 g) [32], were 30% lower. The same difference was observed when comparing the K values in the RN sample with that in apple banana (264 mg/100 g fresh mass) [33]. In their studies with bananas, Pereira & Maraschin [34] reported high potassium contents showing a beneficial effect on human health, mainly on the regulation of blood pressure. It should be noted that the mineral composition of the fruits depends on the soil fertility conditions in each region, since the elements are absorbed from the soil [3].

For example, Lester, John, & Makus [35] reported the influence of applying K to the soil on cultivars of fruits such as apple, banana, kiwi, nectarine, and papaya. They showed that the application of this mineral to the soil increased some characteristics of the fruits, mainly the size and firmness and also increased the sugar content, consequently interfering positively on the sensory quality. However, these influences did not occur in the same manner for all the fruit species cited.

Several studies have shown that mineral supplementation with elements such as K, Ca, Mn, Ni, Zn, Cu, Fe, Mo, and Se, in different cultivars (papaya, apple, strawberry, and tomato) with the correct balance, may increase the macronutrients and improve fruit quality, such as increasing the sugar content and size, changing the acidity, color and texture, as well as resulting in productivity gains, important characteristics for the consumer market. Guo-Yi, Xin-Zhong, Yi, Xue-Feng, & Zhen-Hai [36], working with apple trees, reported that K and Ca were among the main macro and trace elements associated with fruit quality, and found evidence of a positive correlation between the K/Ca ratio and the amounts of soluble solids.

The data presented are evidence that visual characteristics such as shape, color, and size may influence product acceptance. Salinas-Hernández et al. [7] in a sensory study with post-harvest mangoes showed a strong positive correlation between the sensory attributes of flavor and sweetness. The higher pH value, TSS content, and total carbohydrates may have contributed to a better acceptance of the flavor of the RN fruit.

Souza et al. [12] and Fellipe [8] reported that *C. icaco* fruits had an unattractive flavor, and they also mentioned their low economic value in Brazil, therefore being consumed in the form of sweets, jams, preserves, and jellies. However, Fonseca-Kruel & Peixoto [37], in an extractive community on the coast of Rio de Janeiro State, Brazil, reported that fishermen valued the use and commercialization of *C. icaco* fruits and emphasized the nutritive value and pleasant taste, besides the medicinal uses of their leaves. Likewise, Fellipe [8] reported that *C. icaco* fruits were widely consumed in coastal regions, due to their color and appearance.

The results of the present study indicate the potential application of the *C. icaco* fruits on the food market, considering the overall good sensory scores and the physicochemical/element profiles. The different mineral, physicochemical and sensory profiles of the fruits harvested in RN and BA show that they could be consumed and processed in different manners, which may incite the development of new studies.

The Northeast region of Brazil is known to have a relevant income from the production of tropical and native fruits, such as *Genipa americana* L., *Spondias tuberosa*, *Spondias bahiensis*, and *Eugenia uniflora* L. Some of these fruits have been extensively studied and can even be considered as functional foods due to their bioactive compound contents [38]. Native plants and their fruits are increasingly being pursued by consumers and processing industries [38]. Therefore, the research organs need to promote more studies, such as the present one, regarding their characterization, testing possible uses for native plants, such as the *C. icaco* fruits. By highlighting the interesting nutritional potential of *C. Icaco*, the present study may stimulate the development of novel food products, such as beverages, liqueurs, and jams, which could provide additional income for the producers of this plant and help with their subsistence, food security, and overall economy in the region [39]. Furthermore, it is also suggested that the possible functional properties of *C. icaco* fruits need to be assessed due to the increasing market relevance for functional foods worldwide [40].

5. Conclusions

The present study showed that the *C. icaco* fruit is a good source of trace elements, especially copper. Regarding its total carbohydrates and energy value, it resembles other fruits better known by the population, despite having low protein and lipid contents. The samples of fruits obtained from Rio Grande do Norte (RN) presented higher ash contents and consequently the macro and trace elements were found at higher levels than in the fruits from Bahia (BA), except for chromium. No differences were found for Na and Zn according to origin. The differences observed were related to the protein, carbohydrate, and total soluble solids contents, and the pH value and acidity, and the fruit composition of the influenced the acceptance with respect to flavor. The *C. icaco* fruits from Rio Grande do Norte were more accepted and richer in macro and trace elements. Overall, the fruits from both regions represent a potential for usage by the food industry. Therefore, further studies should be developed in order to evaluate possible uses for the *C. icaco* fruits as ingredients in the food industry, which may help increase the income of its producers and enhance the knowledge of such a plant by the scientific community and the population.

Author contribution statement

Ynayara Joane de Melo Rodrigues; Nathália Ribeiro dos Santos: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Pedro Paulo Lordelo Guimarães Tavares: Analyzed and interpreted the data; Wrote the paper.

MARIA EUGÊNIA DE OLIVEIRA MAMEDE: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

José Antônio Menezes Filho: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e20291.

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