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Nutritional potential of Red Jambo fruit: dietary fibers, minerals, antioxidant potential, and bioaccessibility of phenolic compounds

Potencial nutricional da fruta Jambo vermelho: fibras dietéticas, minerais, potencial antioxidante e bioacessibilidade de compostos fenólicos

Potencial nutricional de la fruta Jambo rojo: fibras dietéticas, minerales, potencial antioxidante y bioaccesibilidad de compuestos fenólicos

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Abstract
Red jambo (RJ) is used by traditional medicine to treat diabetes, so far there are no reports on the relationship of its fiber content with monosaccharide composition and the bioaccessibility of the phenolic compounds. The aim of this study was to characterize the nutritional profile, minerals, the composition of sugars, the antioxidant potential, and the phenolic compounds accessibility of the fruit edible parts (pulp and peel). Considering the edible fraction, the major minerals were manganese, iron, magnesium, and zinc, suggesting that they can contribute to the recommended daily intake for adults. The monosaccharide composition showed that both the pulp and the peel have as main composition glucose (50.1% and 68.4%) and uronic acids (38.4% and 20.6%), respectively. Also, the contents of bioactive compounds and the antioxidant potential of the fruit are relatively high in the pulp and peel fractions, mainly for DPPH assay. Moreover, fourteen phenolic compounds were identified. Among them, p-coumaric and trans-cinnamic acids showed the highest bioaccessibility. We suggest the use of RJ in new nutraceutical and food products since it is a natural source of compounds with natural antioxidants.
Keywords: *Syzygium malaccense*; Monosaccharide composition; Mineral profile; In vitro digestion; Nutraceutical.

Resumo
O Jambo Vermelho (JV) é usado pela medicina tradicional no tratamento do diabetes, até o momento não há relatos sobre a relação do seu conteúdo de fibra com a composição dos monossacarídeos e a bioacessibilidade dos compostos fenólicos. O objetivo deste estudo foi caracterizar o perfil nutricional, minerais, a composição de açúcares, o potencial antioxidante e a acessibilidade aos compostos fenólicos das partes comestíveis da fruta de JV (polpa e casca). Considerando a fração comestível, os principais minerais foram manganês, ferro, magnésio e zinco, sugerindo que pode contribuir para a ingestão diária recomendada para adultos. A composição dos monossacarídeos mostrou que tanto a polpa quanto a casca têm como principal composição glicose (50,1% e 68,4%) e ácidos urônicos (38,4% e 20,6%), respectivamente. Além disso, os teores de compostos bioativos e o potencial antioxidante da fruta são relativamente elevados na polpa e na casca, principalmente pelo ensaio DPPH. Além disso, quatorze compostos fenólicos foram identificados. Entre eles, os ácidos p-cumárico e transcinâmico apresentaram a maior bioacessibilidade. Sugerimos o uso de JV em novos produtos nutracêuticos e alimentícios por ser uma fonte natural de compostos com antioxidantes naturais.
Palavras-chave: *Syzygium malaccense*; Composição de monossacarídeos; Perfil mineral; Digestão *in vitro*; Nutracêutico.

Resumen
El Jambo Rojo (JR) es utilizado por la medicina tradicional para tratar la diabetes, hasta el momento no existen informes sobre la relación de su contenido de fibra con la composición de monosacáridos y la bioaccesibilidad de los compuestos fenólicos. El objetivo de este estudio fue caracterizar el perfil nutricional, los minerales, la composición de azúcares, el potencial antioxidante y la accesibilidad a compuestos fenólicos de las partes comestibles del fruto (pulpa y piel). Considerando la fracción comestible, los principales minerales fueron manganeso, hierro, magnesio y zinc, lo que sugiere que puede contribuir a la ingesta diaria recomendada para adultos. La composición de monosacáridos mostró que tanto la pulpa como la cáscara tienen la composición principal glucosa (50,1% y 68,4%) y ácidos urónicos (38,4% y 20,6%), respectivamente. Además, el contenido de compuestos bioactivos y el potencial antioxidante de la fruta son relativamente altos en la pulpa y las cáscaras, principalmente según el ensayo DPPH. Además, se identificaron catorce compuestos fenólicos. Entre ellos, los ácidos p-cumárico y transcinámico mostraron la mayor bioaccesibilidad. Sugerimos el uso de JR en nuevos productos nutracéuticos y alimenticios ya que es una fuente natural de compuestos con antioxidantes naturales.
Palabras clave: *Syzygium malaccense;* Composición de monosacáridos; Perfil mineral; Digestión *in vitro*; Nutracéutico.

1. Introduction

Red jambo (RJ) belongs to the Myrtaceae family and is scientifically known as *Syzygium malaccense* (L.) Merr. & L.M. Perry. This fruit can be found in several regions of the world, we can consume both pulp and fruit peel, with pulp is white, thick, and juicy, marked by acid and palatable taste, similar to the taste of apples. However, despite its various forms of use, the fruit is still little explored. Until then, some compounds in this fruit have been reported, such as macronutrients, some micronutrients, and some bioactive compounds, mainly anthocyanins (Reynertson et al., 2008; Batista et al., 2016; Nunes et

al., 2016; Peixoto et al., 2016; Batista et al., 2017; Batista et al., 2020; Farias et al., 2020).

The search for foods of natural origin rich in bioactive compounds and antioxidant properties is increasingly being preferred by the food industry as sources of natural antioxidant ingredients. They attract attention because these natural components with antioxidant properties have great potential in food preservation, and can be used to reduce or replace the addition of synthetic preservatives (Maqsood et al., 2020).

So, bioactive compounds have antioxidant properties that make them nutraceuticals attractive. But, at the same time, although studies have reported the antioxidant activity and some phenolic compounds of RJ (Reynertson et al., 2008; Nunes et al., 2016; Batista et al., 2017), we believe that it is important to evaluate more of the nutritional composition and bioaccessibility of these phenolic compounds present in this fruit. Therefore, this study aims to evaluate the nutritional profile, minerals, the composition of sugars, and the antioxidant potential of pulp and peel of *S. malaccense*, identify the profile of phenolic compounds, estimate the *in vitro* bioaccessibility and intestinal uptake of the phenolic compounds of the edible portion of the fruit.

2. Methodology

2.1 Sample

RJ was collected in Brazil, and a voucher was left at the Municipal Botanical Museum of Curitiba, Paraná, Brazil (nº MBM- 379581, respectively). The research is registered under nº 010004/2015-7 (CNPq – Brazil). Mature fruits were peeled manually, and pulp and peel were separated, frozen (-18 °C), lyophilized, and stored under vacuum.

2.2 Nutritional Composition

2.2.1 Physicochemical composition

Moisture, ash, pH, and titratable acidity were determined by official AOAC methods (AOAC 2000; AOAC 2005). Total soluble solids (TSS) were read in a digital refractometer (AIQ, RTD-95, São Paulo,' BR).

2.2.2 Monosaccharide composition

2.2.2.1 Pre-Treatment

Samples (20 mg) were pre-treated in an ice bath with H_2SO_4 72% (w/w) for 1 h, then hydrolyzed with 8% H_2SO_4 at 100 ºC for 15 h (Saeman, Moore, Mitchell, & Millet, 1954). The hydrolysate was filtered and divided into four aliquots: one was used to determinate de total carbohydrate content; the second one was used for quantification of uronic acids contents; the third one was used for determination of uronic acids identity; the last one was neutralized with $BaCO_3$, the insoluble material was removed by filtration and the solution was reduced, acetylated and analyzed for neutral monosaccharide composition.

2.2.2.2 Neutral monosaccharide quantification

After hydrolysis with 8% sulfuric acid at 100 ºC for 15 h (Saeman et al., 1954) and neutralization with $BaCO_3$ and removal of the insoluble material by filtration, the solution was then reduced with $NaBH_4$ (4°C for 72h) (Sassaki et al., 2008; Wolfrom & Thompson, 1963a) and acetylated overnight with acetic anhydride (Ac_2O)-pyridine (1:1, v/v, 1 mL) in room temperature (Wolfrom & Thompson, 1963b). The resulting alditol acetates were extracted with $CHCl_3$, and analyzed in a Thermo Scientific Trace GC Ultra gas chromatograph with a mixture of He, N_2, and compressed air as carrier gas at 1 mL min-1, using a DB-225-MS column (0.32 mm internal diameter x 30 m x film thickness 0.25 µm) programmed from 100°C to

230°C at a heating rate of 60 °C min-1. The alditol acetates were identified by their retention time profiles, compared with standards.

2.2.2.3 Quantification and determination of uronic acids identity

The colorimetric m-hydroxybiphenyl method was used to quantify the uronic acid content (Blumenkrantz and Asboe-Hansen, 1973), using galacturonic acid as standard. The uronic acids' identity was determined by anion exchange chromatography coupled with pulsed amperometric detection (HPAEC-PAD). After hydrolysis, the sample was filtered through a 0.22 μm membrane, injected in a Thermo Scientific Dionex ICS-5000 chromatograph (Thermo Fisher Scientific, USA) with CarboPac PA20 column (3 × 150 mm) using a gradient of 0,5 M NaOH and 1 M NaOAc as eluent (Modified from Nagel, Sirisakulwat, Carle, & Nei-dhart, 2014) in N_2 atmosphere in a flow of 0.2 ml/min at 24°C. Analyses were carried out in triplicate. ChromeleonTM7.2 Chromatography Data System software was used to analyze the collected data.

2.2.3 Mineral profile

The total mineral content was determined according to the official method recommended by the AOAC (2005, no. 999.10). Aliquots of 10 g of pulp and peel were incinerated at (550 ± 5) °C for 5 h. Ashes from the pulp and peel fractions were submitted to dry digestion, and solubilized with nitric acid (8%w/w); finally, they were diluted in 25 mL volumetric flasks with ultra-pure water. The determination of minerals was carried out using a Varian 720-ES (Palo Alto, CA, USA) inductively coupled plasma optical emission spectrometer (ICP-OES) equipped with an axial view. The calibration standards were prepared in nitric acid at 0.5% (w/w). The range of linearity was evaluated by the linear regression coefficient of the calibration curves.

2.3 Antioxidant activity

The lyophilized fruit was dissolved in methanol: water (50:50) (v/v), according to Rufino et al. (2007). After homogenization, the extracts were centrifuged at 2000 *rpm* for 15 minutes. The supernatants were reserved and the acetone: water precipitated (70:30) (v/v) reextracted. Subsequently, the anterior supernatants were added to that obtained in the first extraction and made up to 100 mL with distilled water. The extraction solvent was removed using a rotary evaporator.

We tested two different methods, the DPPH (2,2-diphenyl-1-picril-hydrazil) radical scavenging activity assay, and Ferric reducing antioxidant power (FRAP) assay. For DPPH, a methanol solution containing 0.06 mmol L^{-1} DPPH was prepared and stored at 20°C for later use. We prepared the working solution by diluting the stock solution of DPPH (0.06 mmol L^{-1}) in methanol until we obtained a solution with an absorbance of approximately 0.980 ± 0.02 at 515 nm (Brand-Williams et al., 1995; Rufino et al. 2011).

For FRAP, we mixed 200 μL of the extract with 200 μL of $FeCl_3$ (3 mmol L^{-1} in 5 mmol L^{-1} citric acid) in a tube and incubated it for 30 minutes in water bath at 37°C. Then, TPTZ solution (3.6 mL) was added and the mixture was vortexed. After exactly 10 minutes, a Hewlett–Packard spectrophotometer was used to read the absorbance (620 nm). The model of the equipment was HP 8452A (Cheadle Heath, Stockport Cheshire, United Kingdom. Results were expressed in equivalent Trolox μmol $100g^{-1}$ of the lyophilized sample (Benzie and Strain 1996).

2.4 Phenolic compounds

Total phenolic compounds were evaluated by spectrophotometry using the Folin-Ciocalteau's reagent (Zielinski; Kozlowska, 2000; Pires et al, 2017). To determine the profile of phenolic compounds the process of extracting followed the methodology described by Rufino et al. (2010). About 0.5 g of each fraction was added to 20 mL of methanol/water (50:50,

v/v) and exposed to an ultrasonic bath, 40 kHz, for 30 min, (SINGLE, model USC-1800, Brazil), at 25 °C. Afterward, the fractions were centrifuged at 6000 *g* for 15 minutes (model SL-701, Solab, São Paulo, Brazil). The remaining residue was extracted with 20 mL of acetone/water (70:30, v/v) and resubmitted to the ultrasonic bath and centrifugation. Finally, the extracts were placed in a 50 mL volumetric flask and the volume was completed with deionized water.

The solvent used in the extraction was removed using a rotary evaporator (Fisatom 802, São Paulo, Brazil), and 1 mL aliquot of extracts was filtered through a 0.45 μm (PTFE) syringe filter. It was then used for the analysis of the profile of phenolic compounds.

Phenolic compounds were separated and identified by the LC-20 AT High-Performance Liquid Chromatography (Shimadzu Corporation, Japan) equipped with a photodiode array detector (DAD). The separation was performed on a C18 column (SUPELCOSIL ™ LC-PAH, 250 mm x 4.6 mm ID, 5 μm particle size, Sigma-Aldrich) with an elution gradient of (A) water/2 % of acetic acid (v/v) and (B) 2:1 (v/v) acetonitrile/methanol as follows: 90 % A in 0 min, 88 % A in 3 min, 85 % A in 6 min, 82 % A in 10 min, 80 % A in 12 min, 70 % A in 15 min, 65 % A in 20 min, 60 % A in 25 minutes, 50 % A in 30-40 min, 75 % A in 42 min, and 90 % A in 44 min. The flow rate was 1.0 mL/min and the column temperature was maintained at 40 °C with an injection volume of 20 μL. The total run time was 50 minutes (DUTRA et al., 2017). Separated compounds were monitored at three different wavelengths (254 nm, 280 nm, and 320 nm). We analyzed a total of fourteen compounds: ferulic acid, caffeic acid, myricetin, vanillic acid, catechin, kaempferol, rutin, synaptic acid, syringic acid, quercetin, 4-hydroxybenzoic acid, salicylic acid, p-coumaric acid, and trans-cinnamic acid. The following reagents were obtained from Sigma-Aldrich (St. Louis, Missouri, USA). The quantification of individual phenolic compounds was projected into their detected peak areas, which were calculated through the LabSolutions software version 5.42 SP4 Copyright (Shimadzu Corporation), versus calibration, and then we determined the quantification curves.

2.5 Bioaccessibility

The physiological gastrointestinal digestion simulation process was performed in three phases: oral, gastric, and intestinal, including dialysis. This procedure was based on Rodríguez-Roque et al. (2013) with modifications by Dutra et al. (2017). To evaluate bioaccessibility, we used the fruit as a whole (the proportion of 71% of the pulp and the peel to 29%), since the fruit is generally consumed in its entirety.

2.5.1 Gastric and intestinal digestion

Aliquots of 10 g of fruit lyophilized were mixed with 50 mL of water and 5 mL of saline solutions (2.38 g Na_2HPO_4, 0.19 g KH_2PO_4, 8 g NaCl, and 200 U L^{-1} amylase). The mixture was stirred for 10 minutes in a water bath at 37 ± 2 °C at 95 rpm. To simulate gastric digestion, the fruit fraction was acidified to pH 2.0 with 1 mL of porcine pepsin preparation (13 mg of pepsin in 5 mL of 0.1 mol L^{-1} HCl). The final volume of 5 mL was then incubated at 37 ºC, shaking at 95 rpm for 1 hour to simulate gastric digestion. At the end of the gastric digestion, the mixture was immediately cooled in an ice bath and 1 mL aliquots were removed and stored at -18 °C. The remainder of the sample was digested in the small intestine, and cellulose dialysis membrane segments (12.000 Da cutoff molecular weight) were filled with 25 mL of $NaHCO_3$ (0.5 mol L^{-1}). The dialysis membrane contained 0.5 mol L^{-1} of $NaHCO_3$ to titrate the gastric digestion to a pH of 7.5.

Aliquots of 20 mL of the gastric stage were placed in polyethylene tubes, in which the dialysis membranes were completely immersed until reaching a pH of 5.0. Afterward, 5 mL of pancreatin (0.12 g) and the bile salts glycodexicolate (40 mg in 1 mL saline), taurodeoxycholate (25 mg in 1 mL saline), and taurocholate (40 mg in 1 mL saline) were added to each tube. Then, the fruit fractions were incubated on a shaker (95 rpm) at 37°C for 2 hours to complete the intestinal phase.

2.5.2 Calculation of bioaccessibility (%)

The percentage of bioaccessibility was expressed according to Equation (1). The calculation was based on the concentration released in the digestion process and the concentration in the fruit.

Bioaccessibility (%) = (BC dialyzed/ BC non-digested) × 100 *(1)*

Note: BC dialyzed: concentration of the phenolic compound in the dialyzed portion; BC non-digested: phenolic concentration of the compound in the fruit.

2.6 Statistical analysis

All variables were reported as mean ± standard deviation (SD) of three replicates, except monosaccharide composition which was performed in percentage (%). The results were compared by the one-way analysis of variance (ANOVA) and the Student's t-test ($p < 0.05$). Data analysis was performed using the software STATISTICA 12.0 (Statsoft Inc., Tulsa, OK, USA) and GraphPad Prism 6.0 (San Diego, CA).

3. Results and discussion

3.1 Nutritional profile

3.1.1 Physicochemical characterization

The physicochemical characterization of the edible fraction (pulp and peel) of RJ had previously been reported by Gibbert et al. (2021), but in this study, the fruit fractions were separated and characterized individually. Still, the results are similar, (Table 1), and both pulp and peel have an expressive percentage of total soluble solids and high amounts of carbohydrates.

Table 1 – Physicochemical characterization of lyophilized pulp and peel of Red Jambo.

Parameter	Pulp	Peel	p-value
Moisture (g $100g^{-1}$)	11.9 ± 0.25^a	11.8 ± 0.05^a	0.34
Fixed mineral residue (g $100g^{-1}$)	4.76 ± 0.01^a	4.83 ± 0.17^a	0.85
Protein (g $100g^{-1}$)	1.83 ± 0.03^b	3.97 ± 0.05^a	0.003
Fats (g $100g^{-1}$)	1.30 ± 0.02^b	2.41 ± 0.16^a	0.005
Carbohydrates (g $100g^{-1}$)	49.79 ± 0.007^a	44.04 ± 0.21^b	0.001
Total dietary fiber (g $100g^{-1}$)	30.42 ± 0.32^a	32.95 ± 0.21^b	0.042
pH	3.75 ± 0.01^b	3.84 ± 0.005^a	0.031
Total soluble solids % (°Brix)	7.76 ± 0.003^b	9.87 ± 0.003^a	0.002
Titratable acidity (g citric acid)	0.47 ± 0.02^b	0.88 ± 0.82^a	0.011
Brix/Acidity (TSS/CA)	16.87 ± 1.22^a	14.02 ± 0.88^b	0.040
Total Energy Value (kcal)	218,18	213,73	-

Note: Mean ± standard deviation (SD) of lyophilized pulp and peel fractions. Different superscript letters on the same line denote significant differences between results (Student's t-test, $p < 0.05$). Source: Authors.

3.1.2 Monosaccharide Composition

Since RJ has an expressive carbohydrate content, the monosaccharide composition was carried out, and the fruits' pulp showed to be composed mainly of glucose (Glc, 50.1%), followed by uronic acids (38.4%), arabinnose (Ara, 3.8%), xylose (Xyl, 2.7%), and mannose (Man, 2,0%), with minor amounts of galactose (Gal, 1.9%), rhamnose (Rha, 0,8%) and fucose (Fuc, 0.2%) (Table 2). Wild red jambo fruits' peel was mainly composed of glucose (Glc, 68.4%), followed by uronic acids (20.6%), arabinnose (Ara, 3.2%), xylose (Xyl, 2.5%), and galactose (Gal, 2,5%), with minor amounts of mannose (Man, 1.9%), rhamnose (Rha, 0,7%) and fucose (Fuc, 0.2%) (Table 2). Until the moment, no articles are reporting the monosaccharide composition of pulp and peel of fruits from the Myrtaceae family without an extraction method.

Table 2 - Monosaccharide composition of pulp and peel of Red Jambo.

Fraction	Monosaccharide composition (%)[a]							
	Uronic Acids[b]	Rha	Fuc	Ara	Xyl	Man	Gal	Glu
Pulp	38.4	0.8	0.2	3.8	2.7	2.0	1.9	50.1
Peel	20.6	0.7	0.2	3.2	2.5	1.9	2.5	68.4

[a]% of peak area of monosaccharide composition relative to the total peak area, determined by GLC. [b]Uronic acids, determined using the *m*-hydroxybiphenyl method (Blumenkrantz and Asboe-Hansen, 1973). Source: Authors.

Galacturonic acid was identified by HPAEC-PAD as the majority of uronic acid present in both RJ pulp and peel. The presence of galacturonic acid was reported in other fruits from the Myrtaceae family as *Syzygium jambos* (Tamiello et al., 2018) and this acid in a large proportion indicates a predominance of pectins in these samples.

3.1.3 Mineral profile

The minerals found in higher amounts in RJ were potassium (215.07 mg $100g^{-1}$ pulp and 242.59 mg $100g^{-1}$ peel), phosphorus (54.24 mg $100g^{-1}$ pulp and 85.95 mg $100g^{-1}$ peel), magnesium (21.98 mg $100g^{-1}$ pulp and 22.66 mg $100g^{-1}$ peel), and calcium (21.45 mg $100g^{-1}$ pulp and 21.53 mg $100g^{-1}$ peel). Only copper, iron, potassium, magnesium, manganese, sodium, zinc, and phosphorus presented significant differences between pulp and peel ($p < 0.05$) (Table 3).

Table 3 – Concentration of minerals in the pulp and peel of lyophilized Red Jambo.

Mineral	Pulp	Peel	p-value*	RDA females	RDA males
	mg 100g^{-1}			mg 100g^{-1}	
K	215.07 ± 0.89^{b}	242.59 ± 0.02^{a}	0.68	4700	4700
P	54.24 ± 0.64^{b}	85.95 ± 4.42^{a}	0.032	700	700
Mg	21.98 ± 0.82^{b}	22.66 ± 0.42^{a}	0.047	320	420
Ca	21.45 ± 0.14^{a}	21.53 ± 0.56^{a}	0.92	1000	1000
Na	8.72 ± 0.54^{b}	9.22 ± 0.05^{a}	0.036	1500	1500
Fe	0.94 ± 0.009^{a}	0.56 ± 0.03^{b}	0.045	8	18
Zn	0.82 ± 0.03^{a}	0.46 ± 0.01^{a}	0.028	11	8
Mn	0.37 ± 0.002^{a}	0.36 ± 0.01^{b}	0.049	2.3	1.8
Cu	0.33 ± 0.009^{a}	0.30 ± 0.03^{b}	0.047	0,9	0,9
Se	<0.10 ± 0.06^{a}	<0.10 ± 0.01^{a}	-	0,05	0,05
Al	1.81 ± 0.20^{a}	1.09 ± 0.19^{a}	0.71	ND	ND
Cr	< 0.10 ± 0.008^{a}	<0.10 ± 0.004^{a}	-	0,035	0,025
Ni	< 0.10± 0.09^{a}	< 0.10 ± 0.02^{a}	-	ND	ND

Different superscript letters on the same line denote significant differences between fractions (Student's t-test, p <0.05). RDA: Recommended Dietary Allowances for adults aged 31-50 (Food and Nutrition Board, 2004). ND: Not determined. Source: Authors.

Fruits are generally important sources of minerals, especially potassium and magnesium. Potassium is a mineral required in the human body as it aids the maintenance of the osmotic pressure, water balance, and acid-base balance of the organism. Besides, it has an important role in the transfer of ATP phosphate to pyruvic acid, contributing to muscular contraction control. Also, some of these minerals found in the fruit have an antioxidant function (zinc, selenium, and copper), that is, they can reduce and/or stop the formation of free radicals (Mergedus et al., 2015) and may contribute to reducing the inflammatory profile. In fact, the anti-inflammatory effect has already been proven in another fruit from the same family as RJ (Qamar et al., 2021).

On the other hand, by comparing the minerals found in greater quantities with the reference brought from Recommended Dietary Allowance / RDA (Table 3), it can be emphasized that potassium, the main mineral present in RJ, reaches less daily RDA than manganese, iron, magnesium, and zinc. Previously, manganese was the eighth mineral present in the fruit, now analyzing the conversion according to RDA, which has a percentage of almost 20% for males and 15% for females, standing out among the first. Magnesium is found mainly in fruits like blackberry, pineapple, and strawberry; Besides being present in seafood, some grains, and some vegetables. This mineral has several functions, ranging from the activation of

enzymes involved in the synthesis of connective tissue, to the regulation of glucose (FOOD AND NUTRITION BOARD, 2004).

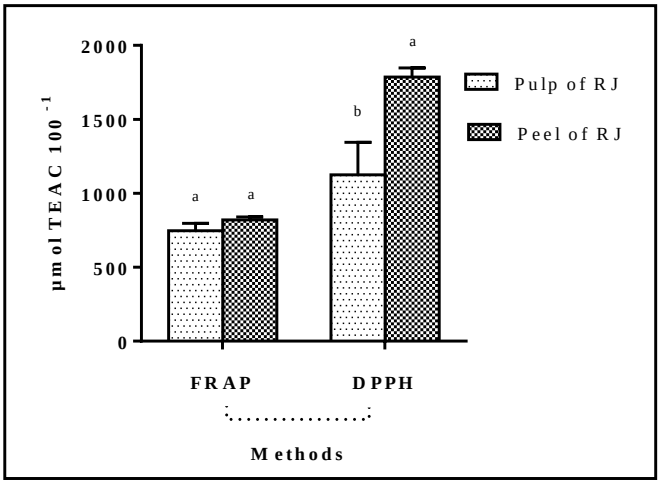
In this way, RJ is an interesting fruit that can contribute to the daily intake of minerals, since it is often consumed *in nature*, a factor considered a differential in the absorption of nutrients. Furthermore, since minerals are within the food matrix of fruits, the absorption of these nutrients is often favored, making it interesting to investigate the bioavailability of nutrients from RJ.

3.2 Antioxidant activity and phenolic compounds

3.2.1 Antioxidant activity

Before checking the bioavailability of RJ nutrients, it is interesting to determine the content of total phenolic compounds and their antioxidant potential. In this way, RJ is a good source of natural antioxidants, mainly in the peel (Figure 1). Fractions displayed statistical differences only for the DPPH test ($p < 0.05$).

Figure 1 Antioxidant activities by both DPPH and FRAP assays of pulp and peel of lyophilized Red Jambo.



Different letters denote significant differences between samples (Student's t-test, $p < 0.05$). RJ: Red Jambo. Source: Authors.

We found a possible protective effect by the DPPH assay, especially in the peel. Antioxidant activity in food is directly related to the chemical structure of the phenolic compounds that the fruit presents due to synergistic or antagonistic interactions. Additionally, phenolic compounds capture different oxidative radicals or sources using single or multiple mechanisms, depending on the system used for evaluation, or using the components of the food matrix (Hidalgo et al., 2010). As a result, the differences observed in the two antioxidant trials may be related to the antioxidant evaluation method, which is based on different principles (Silva et al., 2016).

It is worth noting that our values for the concentration of the phenolic compound using the DPPH method were higher than those found in the RJ of Pernambuco (Nunes et al., 2016). As for the FRAP method, the results were similar to those reported for the specie from São Paulo (Batista et al., 2016). In summary, the results show that both pulp and peel have relatively high antioxidant and free radical scavenging activity, and the peel has the highest protective activity.

3.2.2 Phenolic compounds

In our other study (Gibbert et al., 2021) we had identified an expressive content of total phenolic compounds in the edible fraction of RJ (202.30 GAE $100g^{-1}$) and now we confirm that most of this content is found in the peel (269 mg GAE

$100g^{-1}$) of this fruit. That can be attributed to the accumulation of phenolic compounds in the fruit epidermis, acting as a protection against ultraviolet radiation as well as a defense mechanism to certain pathogens and predators (Denardin et al., 2015).

Fruits can present very different amounts of phenolic compounds; however, fruits frequently consumed by the Brazilian population present similar amounts: apple (321 mg $100g^{-1}$), pear (271 mg $100g^{-1}$), strawberry (131 mg $100g^{-1}$), and kiwi (274 mg $100g^{-1}$) (Faria et al., 2008). Therefore, by comparing RJ with other fruits, especially the most consumed by the aforementioned population, it is possible to emphasize that the amount of total phenolic compounds present in this fruit is relatively similar, which makes this specie quite attractive for consumption.

Due to this high amount of total phenolic compounds found in this fruit, we decided to determine the profile of these compounds. We emphasize here that our analysis did not detect the profile of anthocyanins, compounds already reported in this fruit (Batista et al., 2017; Nunes et al., 2016). However, in return, we have identified several other compounds (fourteen) that are also important (Table 4).

Table 4 - Content of phenolic compounds in the pulp and peel of lyophilized Red Jambo.

Phenolic Compounds	**Pulp (mg 100 g^{-1})**	**Peel (mg 100 g^{-1})**
Ferulic acid	52.12±0.1[a]	19.83±0.1[b]
Caffeic acid	42.19±0.1[a]	39.66±0.1[b]
Myrcetin	35.99±1.75[b]	45.86±0.1[a]
Vanillic acid	24.82±0.1[a]	24.79±0.1[a]
Catechin	19.86±0.1[b]	29.75±0.1[a]
Kaempferol	14.89±0.1[a]	12.39±0.1[b]
Rutin	7.45±0.1[b]	13.39±0.1[a]
Synaptic Acid	7.45±0.1[a]	7.44±0.1[a]
Syringic acid	4.96±0.1[a]	4.96±0.1[a]
Quercetin	4.96±0.1[a]	4.96±0.1[a]
Ac4 Hydroxybenzoic	4.96±0.1[a]	4.96±0.1[a]
Salicylic acid	ND	13.63±0.1
p-Coumaric acid	2.48±0.1[b]	4.96±0.1[a]
TransCinnamic acid	ND	39.66±0.1

Different letters in the same line represent statistically significant differences in the content of the phenolic compound of pulp and peel (Student's t-test, $p < 0.05$). ND: Not Detected. Source: Authors.

The compounds found in greater quantities in our study were: ferulic acid, caffeic acid, and myricetin. Ferulic acid is present in several known fruits, such as apple, orange, and pineapple. The consumption of 250 mg/day of ferulic acid has

beneficial effects (Reidah, 2013), and thus, 100 grams of RJ reaches 21% (pulp) and 8% (peel) of the daily recommendation. The pulp values of ferulic acid are almost 3 times higher than the peel, which makes us consider interesting the development of some product that uses this fraction, both in the nutraceutical area and in the development of cosmetics, since this acid acts inhibiting the formation of thymine dimers in the DNA of skin cells exposed to UV radiation, a result of the carcinogenic process (Delpino-Rius et al., 2015).

Another acid that deserves attention in this study is caffeic acid, which is a potent antioxidant, even more, when combined with other acids, such as ferulic (Magnani et al., 2013). One of the main sources of caffeic acid is coffee, one liter of this drink (200 mL) contains about 250 mg of the acid (Riobó & Gonzalez, 2008), and so, 100 g of RJ edible fractions reaching almost 17% of that amount present in coffee.

The chlorogenic acids found in this study are also relevant since the fruits with the highest amounts of chlorogenic acids are blueberry, kiwi, cherry, apple, and plum, with quantities ranging from 500 mg to 2 g of acid per kg of fresh fruit (Reidah, 2013). Concerning RJ, if the values of the four main components of chlorogenic acids (caffeic, ferulic, synaptic, and p-cumaric acids) were transformed into fresh fruit, it would present about 1 g per kg of chlorogenic acid. So, according to our results, this specie can be inserted into the list of fruits with good amounts of chlorogenic acids.

A study carried out with the same specie also in Brazil found p-coumaric acid (0.99 mg 100 g^{-1}) in the fruit; however, it did not analyze the acid bioaccessibility (Batista, et al., 2016; Batista et al., 2017). In that study, anthocyanin was the main compound found (representing more than 75 % of the total quantity determined), which makes our findings unique.

Another compound identified that also is a potent antioxidant is myricetin, and we highlight mainly the content found in peel (45.86 mg 100 g^{-1}). Myricetin is a flavonoid that can be found in various fruits, especially those that have a red color. It is difficult to estimate the amount of daily intake of flavonoids, but until then it has been assumed that the intake of 2-4 mg per day already has beneficial effects (Taheri et al., 2020). Thinking about this logic, RJ has great content with this flavonoid. Thus, we conclude that promising phenolic compounds were found in the fruit studied, such as ferulic acid, caffeic, and myricetin. However, although the fruit contains several compounds, it is important to evaluate their bioaccessibility, since the intake of such compounds does not result necessarily in their absorption.

3.3 Bioaccessibility of phenolic compounds

As shown in Table 5, phenolic compounds contend varied throughout the gastrointestinal digestion in vitro. For this analysis, the RJ edible fraction was used (71% of the pulp and the peel to 29%), since the fruit is usually consumed as a whole and since the benefits derived from the mixture of phenolic compounds present in the whole fruit have already been reported (Gibbert et al., 2021). Two compounds, p-coumaric (88.8 % of bioaccessibility) and trans-cinnamic acid (46.48 % of bioaccessibility) were particularly promising. Until then, only the bioaccessibility of anthocyanins from this fruit peel was verified, obtaining a total of 15 % of intestinal absorption (Peixoto et al., 2016). This shows that there are other compounds present in the fruit that have good absorption.

Table 5 - Phenolic profile in a lyophilized edible fraction of RJ after in vitro gastrointestinal digestion.

Phenolic Compounds	Gastric phase	Intestinal phase	Bioaccessibility (%)
p-Coumaric acid	3.59 ± 0.001	3.19 ± 0.012	88.8
Trans-Cinnamic acid	0.71 ± 0.001	0.33 ± 0.001	46.48
Syringic acid	4.96 ± 0.001	0.55 ± 0.003	11.11
Quercetin	4.96 ± 0.001	0.55 ± 0.001	11.11
Caffeic acid	41.46 ± 0.001	4.07 ± 0.027	9.82
Synaptic Acid	7.44 ± 0.001	0.66 ± 0.005	8.87
Ferulic acid	42.75 ± 0.001	2.86 ± 0.001	6.69
Myrcetin	39.20 ± 0.001	2.97 ± 0.005	7.58
Ac4 Hydroxybenzoic	4.96 ± 0.001	0.33 ± 0.005	6.67
Vanillic acid	24.80 ± 0.001	1.32 ± 0.001	5.32
Kaempferol	14.16 ± 0.001	0.44 ± 0.005	3.11
Catechin	22.72 ± 0.001	ND	ND
Rutin	8.88 ± 0.001	ND	ND
Salicylic acid	4.31 ± 0.001	ND	ND

Values expressed in mg 100 g $^{-1}$ dry matter. ND: not detected. Source: Authors.

The number of phenolic compounds released after digestion (Table 5) was lower than their initial concentrations (Table 4). For this, we highlight that the variations in phenolic compound contents were expected since they are very unstable and susceptible to oxidation reactions during their production or until the fruit is stored. Throughout the gastrointestinal digestion simulation, the compounds undergo an acidic environment with several changes of pH, which may compromise their final content (Olennikov et al., 2015).

However, even the bioaccessibility of some compounds has decreased, we need to highlight the high bioaccessibility found in this p-coumaric acid fruit (88.8%). This acid is also a potent antioxidant and has faster and more effective absorption of ferulic and caffeic acid since it is absorbed quickly in the free form by the gastrointestinal tract. Two fruits that have good amounts of p-cumaric acid are the grape (3.8 mg 100 $^{g-1}$) and the strawberry (4.9 mg 100 g^{-1}) (Pei et al., 2015), and therefore, RJ is a good source of p-cumaric acid, mainly its shell (4.96 mg 100 g^{-1}). Thus, we can suggest that one of the main factors responsible for these fruit being a natural antioxidant is due to p-coumaric acid.

It is important to note too that other nutrients present in fruits may also interfere in the bioaccessibility of phenolic compounds, such as carbohydrates. There is evidence that carbohydrates interact directly with these compounds and may impair their absorption (Rodriguez-Roque et al., 2013; Palafox-Carlos, Lafay et al., 2006; Lafay & Gil-Izquierdo, 2008). Thus, carbohydrates may have interfered in the bioaccessibility of some bioactive compounds in RJ, since it contains large amounts of carbohydrates, mainly dietary fibers (Gibbert et al., 2021).

Until now, the studies that address dietary fibers interference in the absorption of bioactive compounds in the organism present three main mechanisms: bioactive compounds - not easily released from fruit and vegetable matrices; dietary fiber - traps bioactive compounds during digestion in the upper intestine; and some compounds that may be linked to

polysaccharides and, therefore, require absorption of enzymatic hydrolysis, which is restricted by the action of food fiber matrices (Rodriguez-Roque et al., 2013; Palafox-Carlos, Ayala-Zavala & González-Aguilar, 2011). The two main interrelated effects of dietary fiber interference in the absorption of bioactive compounds relate to the physical-chemical form of the fiber and the influence it has on digestive viscosity (Lafay & Gil-Izquierdo, 2008).

Consequently, the bioaccessible compounds we found demonstrate that the complexity of the food matrix that comprises them can affect their degree of digestibility and, therefore, their bioaccessibility. However, despite some factors interference in the absorption of bioactive compounds from RJ, the components that were found bioaccessible make this fruit very interesting regarding the amount that remains present even after ingestion and absorption in the body.

4. Conclusion

Red jambo proved to be a fruit with several nutritional components, mainly carbohydrates (sugars) and minerals that can contribute to the mineral content of the RDA, mainly of adults. Also, the contents of bioactive compounds and the antioxidant potential of the fruit are relatively high in the pulp and peel fractions. The peel presented great potential for antioxidant activity, as we could relate it to the amount of phenolic compounds found in this fraction. Our main highlight in this study was the evaluation for the first time of the bioavailability of the compounds present in the fruit, and we find that p-coumaric and trans-cinnamic acids are present the most bioaccessibility in this specie.

In general, we conclude that Red jambo is of interest both for its *in natura* consumption, as well as for the development of products in the food and pharmaceutical industry, since it has shown beneficial effects on health. Also, this fruit is an important source of some compounds and may become a focus of future studies regarding the potential for technological processes and the evaluation of *ex* and *in vivo* effects.

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