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Impact of spouted bed drying on bioactive compounds, antimicrobial and antioxidant activities of commercial frozen pulp of camu-camu (*Myrciaria dubia* Mc. Vaugh)

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ABSTRACT

Camu-camu (*Myrciaria dubia* Mc. Vaugh) has promising perspectives for agro industrial purposes mainly due to the functional potential. This works deals with the impact of spouted bed drying on bioactive compounds, antioxidant and antimicrobial activities, having the fresh and freeze-dried fruit pulp as references. Commercial camu-camu pulp was spouted bed dried at selected temperatures with different maltodextrin concentrations (carrier agent). The fruit powders were compared in relation to color, in vitro antioxidant capacity, total phenolics, ascorbic acid and proanthocyanidin contents. The spouted bed drying of the pulp led to significant losses, in the order ascorbic acid (45–64%) > total phenolics (33–42%) > proanthocyanidins (16–18%), and freeze-drying better preserved antioxidant capacity (74 to 87%) compared to spouted bed drying (29 to 78%). Freeze-dried powder was classified as active, and spouted bed powders as partially active, against *S. aureus*. Despite of losses caused by drying, camu-camu powders still represent excellent sources of bioactive compounds with great potential for use as new bioactive ingredients.

1. Introduction

Camu-camu (*Myrciaria dubia* Mc. Vaugh) is an Amazonian fruit with high vitamin C and polyphenol contents, such as flavonoids and ellagitannins, besides strong in vitro and in vivo antioxidant capacity (Akter, Oh, Eun, & Ahmed, 2011; Gonçalves, Lajolo, & Genovese, 2010; Inoue, Komoda, Uchida, & Node, 2008). This fruit is mainly found at the Brazilian Northern Region and is consumed locally, but it has promising perspectives for agro industrial purposes. Nowadays, the production of camu-camu derivatives, such as frozen pulp, extract and juice, is small (around 20 tons/years; average cost of 4 to 10 dollars per kilograms, INPA, 2011) and mostly destined to Japan, United States of America and the European Union. However, the Brazilian internal market remains unexplored, in part because the rest of the country has little access to the fruit, as well as little knowledge about the fruit properties.

Camu-camu, in particular, is highly perishable, which makes the transportation chain more complex and expensive. Dehydration is one of the most important technological processes applied to fruits. Besides extending food shelf life, it is also an interesting way to concentrate bioactives naturally present in food (Bennett et al., 2011; Vinson, Zubik, Bose, Samman, & Proch, 2005). Due to its versatility and many practical applications, dried fruits are widely consumed all over the world. The spouted bed drier is considered as a very flexible drying technique, which has the advantage of its lower cost and also the possibility of using lower temperatures when compared to conventional spray driers (Bezerra, Amante, de Oliveira, Rodrigues, & da Silva, 2013).

Despite its many advantages, the drying process itself can print relevant impact on the bioactive compounds and other food components. Temperature and adjuvant concentration are among the many relevant production parameters which can be assessed in order to evaluate the drying impact on food. On the other hand, freeze drying is a cost drying technique which is known by its little effect on food components. Its low impact is justified by the fact that food remains at a temperature below the freezing-point during the process of sublimation, which tends to better preserve food quality. Despite that, the expensive equipment, high energy costs and long drying times are disadvantages which disable this technique to be applied as a routine basis procedure (Ratti, 2001). However, it can be considered as a drying control process in order to compare and evaluate the possible drying impact on food products.

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Therefore, the aim of this work was to evaluate the impact of spouted bed drying on selected bioactive compounds and antioxidant and antimicrobial properties of camu-camu fruit pulp, comparing to freeze dried and fresh samples. Besides this, the bioactive value of camu-camu dried products is also assessed and discussed. Overall, this article approaches the development of functional ingredients derived from camu-camu fruit, in order to generate potential new fruit ingredients to be added in other food systems.

2. Materials and methods

2.1. Materials

Frozen commercial pulp of camu-camu (*M. dubia* Mc. Vaugh) was purchased from Cupuama do Amazonas Com. Ind. Exp. Ltda. (Manaus, AM, Brazil).

2.2. Physicochemical characterization

The defrosted pulp was evaluated in regard to its moisture content and titrable acidity (TA) according to AOAC (2005). Total sugars (TS) were determined using the method of Dubois, Giles, Hamilton, Rebers, and Smith (1956), pH with potentiometer (Hanna pH21) and soluble solids (SS, °Brix) with refractometer (Reichert r^2mini).

2.3. Spouted bed drying

The drying process was performed in a stainless steel spouted bed dryer of laboratory size with high density polyethylene (HDPE) inert particles. The angle of the conical base is 60°, 13 cm high and has 3 cm diameter inlet orifice. The cylindrical column is 72 cm high and has a diameter of 18 cm. Drying was performed with a 2.5 kg of inert material, 1.8 m/s speed at different temperatures (60, 80, 95 and 110 °C) and different concentrations (0%, 3% and 6%) of maltodextrin MOR-REX® 1910 ($9 \leq DE \leq 12$) (Corn Products, Brazil).

2.4. Freeze-drying

Two kilograms of frozen pulp was lyophilized in a Pironi 501 freeze-drier (Thermo Electron Corporation, New York, USA) at −80 °C and 100 mTorr for 120 h.

2.5. Color measurement

The color (L*, a*, and b* values) of camu-camu powders was measured using a reflectance spectrophotometer (Color Quest XE, HunterLab, Fairfax, VA, USA), calibrated by the use of a standard white tile (top of the scale)/light trap (bottom of the scale) included with the instrument. C* (chroma) and h* (hue angle) were calculated by using values of a* and b* coordinates according to the following equations: $C^* = (a^{*2} + b^{*2})^{1/2}$ and $h^* = \tan^{-1}(b^* / a^*)$.

2.6. Ascorbic acid content

Ascorbic acid was extracted with meta-phosphoric acid (3% w/v) and analyzed by reversed-phase HPLC in a HP Agilent 1100 series (Hewlett-Packard, Palo Alto, CA, USA) with autosampler and quaternary pump coupled to a diode array detector as previously reported (Genovese et al., 2008). The column used was a 3.9 × 300 mm column 10 μm, 125 Å, Waters, μBondapak™ C18 and elution (flow rate of 0.8 mL/min) was performed in isocratic condition with 2 mmol/L potassium chloride buffer (pH 2.5), monitored at 245 nm. Total ascorbic acid was estimated after reduction of dehydroascorbic acid (DHA) with 10 mM dithiotreitol. Results were expressed as mg ascorbic acid equivalents (AAE)/g sample in dry weight (DW).

2.7. Sample extraction for total proanthocyanidin and antioxidant capacity assays

The powders obtained (1 g) were extracted 3 times in a solvent mixture (100 mL the first time, 50 mL the next two times) comprising methanol/water (70:30, v/v) using a Brinkmann homogenizer (Polytron-Kinematica GmbH, Kriens-Luzern), at moderate speed for 1 min, while cooled in ice. The homogenate was filtered under reduced pressure through filter paper (Whatman No. 1) and it was stored at −18 °C until analysis. All extractions were done in duplicate, and the subsequent assays were run in triplicate.

2.7.1. Folin–Ciocalteu reducing capacity

The analysis was performed according to Singleton, Orthofer, Lamuela-Raventós, and Lester (1999) with some modifications. A 0.25 mL aliquot of the extract obtained above was mixed with 0.25 mL of the Folin–Ciocalteu reagent and 2 mL of distillated water. After 3 min at room temperature, 0.25 mL of a saturated sodium carbonate (Na_2CO_3) solution was added and the mixture was placed at 37 °C in a water bath for 30 min. The absorbance was measured at 750 nm using a Microplate Spectrophotometer (Benchmark Plus, Biorad, Hercules, CA, USA). Gallic acid was used as the reference standard, and the results were expressed as mg gallic acid equivalents (GAE)/g DW.

2.7.2. Total phenolics

Total phenolics (GAE/g) were calculated subtracting the value of Folin–Ciocalteu reducing capacity due to ascorbic acid, using a standard curve.

2.7.3. FRAP ferric reducing power

The analysis was performed according to Benzie and Strain (1996). The absorbance was measured at 593 nm using a Microplate Spectrophotometer (Benchmark Plus, Biorad, Hercules, CA, USA), using an aqueous solution of Trolox (0.25 mg/mL), at different concentrations (0.1; 0.2; 0.4; 0.6 and 0.8 mM), as control. The ferric reducing power was expressed as mmols Trolox equivalents/g DW.

2.7.4. DPPH• scavenging activity

DPPH• (2,2-diphenyl-1-picrylhydrazyl radical) scavenging activity was assessed according to Brand-Williams, Cuvelier, and Berset (1995), with some modifications. Briefly, a 50 μL aliquot of the extract previously diluted and 250 μL of a methanolic solution of DPPH• (0.5 mM) were shaken and after 25 min at 25 °C the absorbance was measured at 517 nm using the Microplate Spectrophotometer (Benchmark Plus, Biorad, Hercules, CA, USA), using a methanolic solution of Trolox, at different concentrations (20, 40, 60, 80 and 100 μM), as control. The DPPH• scavenging activity was expressed as μmol Trolox equivalents/g DW.

2.7.5. Total proanthocyanidin content

It was determined according to Porter, Hrstich, and Chan (1985) using a reagent comprising 154 mg of $FeSO_4 \cdot 7\ H_2O$ per liter of n-butanol:hydrochloric acid (3:2) was prepared. A total of 250 μL of each sample extract and 2.5 mL of the described reagent were incubated at 90 °C for 15 min. The blank consisted of 2.5 mL of the reagent and 250 μL of methanol:acetic acid (99.5:0.5). The absorbance was measured at 540 nm using a model U1100 UV/Visible spectrophotometer (Hitachi, Japan). The results were expressed as mg of quebracho tannin/g DW.

2.8. Antimicrobial activity and determination of Minimum Inhibitory Concentration (MIC)

The extracts were tested for activity against *Staphylococcus aureus* ATCC 29213, *Escherichia coli* ATCC 8739, *Enterobacter aerogenes* ATCC

13048, *Listeria monocytogenes* ATCC 7644, *Salmonella typhimurium* ATCC 14028 and *Salmonella enteritidis* ATCC 13076, according to CLSI (CLSI, 2009). The cultures were grown in Tryptic Soy Agar (Oxoid, Basingstoke, UK) for 18–24 h at 35 °C, and the colonies were suspended in sterile saline solution (0.85%) to reach a turbidity correspondent to 0.5 of the McFarland scale (10^8 UFC mL^{-1}). The suspensions (0.1 mL) were applied to the surface of Muller–Hinton agar plates (Oxoid, Basingstoke, UK) and wells of 13 mm diameter were perforated using the proper perforator. The wells were filled with 100 μL of the extracts, and the plates were incubated at 37 °C for 24 h, when the diameters of the inhibition zones were measured using a caliper rule. Results were evaluated according to the following scale: <16 mm, inactive; 17–19 mm, partially active; 20–25 mm, active; >25 mm, very active.

For determination of the MIC, the microdilution method was used (CLSI, 2010). Except for the first row, the wells of sterile 96-well microplates were filled with 50 μL of Muller–Hinton broth (Oxoid, Basingstoke, UK). The wells of the first row of were filled with 100 μL of the extracts, homogenized, and then 50 μL was serially transferred to the subsequent wells The microplates were incubated at 37 °C for 24 h and the MIC, correspondent to the lowest concentration that inhibited the visible growth of the microorganism after 24 h. Ampicillin was used as a positive control. The tests were carried out in duplicate.

2.9. Statistical analysis

All analyses were run in triplicate and results were expressed as mean ± standard deviation (SD). For statistical analysis, the Statistic software package version 11.0 (StatSoft, Inc., Tulsa, OK) was employed. Differences between means were first analyzed by ANOVA test and then Tukey test ($p < 0.05$). Data were subjected to Pearson correlations.

3. Results and discussion

3.1. Camu-camu pulp

The physicochemical characterization of camu-camu pulp is presented in Table 1. According to the results, camu-camu pulp can be considered too acidic and non-sweet. Compared to sweet orange (*Citrus sinensis*) and açaí (*Euterpe oleraceae* Mart.), camu-camu pulp showed lower pH and higher acidity (Barros, Ferreira, & Genovese, 2012; Tonon, Brabet, & Hubinger, 2008). The low pH and high acidity observed for camu-camu fruit are similar to those for lemon. Jabuticaba, also a Brazilian native fruit which belongs to the same genus of camu-camu (*Myrciaria cauliflora* Berg) has higher pH (around 3.5), titrable acidity (about 0.98 g acid citric/100 g) and SS (around 14.5 °Brix) (Lima, Duarte Corrêa, Carvalho Alves, Patto Abreu, & Dantas-Barros, 2008). Camu-camu acidity and low sugar content are factors that discourage its use in natura, and also justify the search for derived products with higher sensory acceptance potential.

Table 1
Physicochemical characterization of camu-camu frozen pulp.

Components	Mean ± SD
Moisture (%)	92.9 ± 0.1
Total sugars (g glucose/100 g)	1.54 ± 0.01
pH	2.62 ± 0.01
Soluble solids (°Brix)	6.97 ± 0.46
Titrable acidity (g acid citric/100 g)	1.44 ± 0.02

3.2. Color of camu-camu powder

Table 2 shows the effect of the spouted bed drying process over the color of camu-camu powder. Overall, the spouted bed dried powders had lower values of lightness (L*), compared to the lyophilized powder. For samples with higher concentration of maltodextrin (6%), the differences in lightness are not so evident ($p < 0.05$). The camu-camu pulp contains soluble solids and sugars (Table 1), which can cause a stickiness problem during drying (Fang & Bhandari, 2012). The product particles clumping together adversely affect the free-flowing of the fruit material into the drier, which can lead to overheating and browning. Maltodextrin favors flowability and could justify the observed behavior.

There were wide variation of C* and h* values independent of the increase in temperature or maltodextrin concentration. Similar observations were made by Tonon et al. (2008) for C* values when investigating açai juice powder produced by spray drying.

3.3. Total phenolics, ascorbic acid and proanthocyanidins content

Total phenolics, ascorbic acid and proanthocyanidins contents of camu-camu fresh and dried pulps are presented in Table 3. In order to assess the process impact, results are expressed in dry weight (DW). Camu-camu is known as having the highest ascorbic acid and total phenolics contents among tropical and exotic fruits (Abe, Lajolo, & Genovese, 2012; Akter et al., 2011; Genovese, Da Silva Pinto, De Souza Schmidt Gonçalves, & Lajolo, 2008; Reynertson, Yang, Jiang, Basile, & Kennelly, 2008; Rufino et al., 2010). However, drying of the pulp led to significant losses, in the order ascorbic acid > total phenolics > proanthocyanidins. Although these were more extensive for spouted bed, freeze drying also caused losses of around 18% to both ascorbic acid and total phenolics.

Vitamin C is known for the thermolability and a decrease of 45 to 64% was observed for camu-camu during spouted bed drying, more intense the higher the temperature, although this temperature-dependence was not observed at 60 and 80 °C in the presence of maltodextrin. In spite of that, as camu-camu has the highest vitamin C content among comestible fruits, including acerola (Akter et al., 2011), the powders presented still significant concentrations, of 3 to 8% (Table 3).

Total phenolics and proanthocyanidin losses were of 33–42 and 15.5–18.4%, respectively, and not statistically affected by the increase of drying temperature, probably due to the proportional decrease in the drying time. Similar behavior was observed by Vega-Gálvez et al. (2012) when studying apple slices dried by hot air process at 40,

Table 2
Color measurement of camu-camu powder produced by spouted bed drying in different temperatures (60, 80, 95 and 110 °C) and maltodextrin addition (0, 3 and 6%).

Maltodextrin concentration		Color parameters[b]		
		L*	C*	h*
0%	Fresh pulp	0.36 ± 0.04^{g}	0.89 ± 0.20^{g}	0.61 ± 0.06^{g}
	Freeze dried	60.45 ± 2.78^{ab}	26.04 ± 0.87^{d}	1.18 ± 0.04^{ab}
	60 °C	40.84 ± 1.62^{e}	24.55 ± 1.02^{e}	0.84 ± 0.00^{f}
	80 °C	46.40 ± 0.42^{d}	24.53 ± 0.27^{e}	1.02 ± 0.01^{e}
	95 °C	37.80 ± 0.18^{ef}	21.79 ± 0.16^{f}	1.06 ± 0.00^{cde}
	110 °C	36.60 ± 0.35^{f}	21.26 ± 0.19^{f}	1.06 ± 0.00^{de}
3%	60 °C	54.33 ± 0.05^{c}	26.83 ± 0.06^{cd}	0.87 ± 0.00^{f}
	80 °C	58.66 ± 0.13^{ab}	27.66 ± 0.11^{c}	1.09 ± 0.00^{cde}
	95 °C	54.42 ± 0.66^{c}	29.72 ± 0.45^{b}	1.14 ± 0.00^{abc}
	110 °C	47.30 ± 0.15^{d}	27.26 ± 0.41^{c}	1.13 ± 0.00^{bcd}
6%	80 °C	57.52 ± 0.01^{bc}	26.92 ± 0.02^{cd}	1.08 ± 0.00^{cde}
	95 °C	61.40 ± 0.57^{a}	28.00 ± 0.05^{c}	1.20 ± 0.01^{ab}
	110 °C	59.87 ± 0.23^{ab}	31.97 ± 0.10^{a}	1.21 ± 0.00^{a}

Values are expressed as means ± SD (n = 3). a,b,c,d. means in the same column followed by different superscripts are significantly different ($p < 0.05$). [b]L*, lightness (+100 = white, −100 = black); C*, chroma (color intensity); h*, angle hue.

Table 3
Total phenolics, ascorbic acid and proanthocyanidin contents of camu-camu powder produced by spouted bed drying in different temperatures (60, 80, 95 and 110 °C) and maltodextrin addition (0, 3 and 6%).

Maltodextrin concentration		Ascorbic acid (AAE mg/g DW)	Total phenolics (GAE mg/g DW)	Proanthocyanidins (QTE mg/g DW)
0%	Fresh pulp	150.3 ± 0.2^{a}	81.6 ± 6.5^{a}	72.2 ± 2.0^{a}
	Freeze dried	123.0 ± 0.1^{b}	67.1 ± 6.4^{ab}	71.9 ± 2.2^{a}
	60 °C	82.7 ± 4.2^{c}	54.7 ± 3.9^{bc}	61.0 ± 3.9^{b}
	80 °C	74.7 ± 2.0^{d}	46.9 ± 1.0^{cde}	58.9 ± 1.8^{b}
	95 °C	65.2 ± 5.0^{e}	54.3 ± 5.8^{bc}	59.8 ± 1.1^{b}
	110 °C	54.2 ± 1.0^{gh}	51.8 ± 1.0^{bcd}	59.5 ± 2.5^{b}
3%	60 °C	66.1 ± 2.0^{e}	39.4 ± 1.0^{cde}	49.9 ± 1.1^{c}
	80 °C	63.9 ± 3.3^{e}	45.0 ± 3.2^{cde}	48.1 ± 1.3^{cd}
	95 °C	55.7 ± 1.5^{gh}	39.5 ± 0.8^{cde}	49.0 ± 0.4^{c}
	110 °C	46.7 ± 1.0^{i}	34.5 ± 0.8^{de}	44.6 ± 1.5^{de}
6%	60 °C	60.0 ± 3.5^{f}	32.2 ± 3.3^{e}	40.8 ± 3.0^{ef}
	80 °C	57.0 ± 2.2^{fg}	32.2 ± 2.0^{e}	40.3 ± 0.5^{f}
	95 °C	53.4 ± 1.0^{h}	34.4 ± 0.8^{de}	42.5 ± 0.9^{ef}
	110 °C	29.8 ± 1.5^{j}	36.2 ± 0.2^{de}	41.2 ± 1.0^{ef}

Values are expressed as means ± SD (n = 3). a,b,c,d. means in the same column followed by different superscripts are significantly different ($p < 0.05$).

60 and 80 °C. They reported higher total phenolics content at 40 and no statistical difference between their levels at 60 and 80 °C.

When maltodextrin was used in spouted bed drying, total phenolics losses were of 22–40 (3% MD) and 18–27% (6%MD) and, in this way, in a similar range to that observed without carrier, taking into account the dilution effect.

Proanthocyanidins were not affected by freeze drying. Also, there was a gradual preservation of the proanthocyanidin contents with addition of maltodextrin, of about 88–98% and 100%, when 3% and 6% MD were added, respectively.

Proanthocyanidins are a large class of polyphenols varying in size from monomer to polymers of 20 or more units. Fruits normally present a range of proanthocyanidins of varying molecular size. The effects of spouted bed drying could be related to an increase in polymerization degree and consequent loss of extractability.

Although freeze-drying is considered one of the main techniques to preserve phytochemicals, a negative effect on carotenoid, ascorbic acid, and total phenolic concentrations was previously reported. The decrease of β-carotene was 14% and 11% in lyophilized red and yellow tomatoes, respectively, and lycopene decreased by 47% in red tomatoes (Georgé et al., 2011). Similarly, Chang, Lin, Chang, and Liu (2006) found that the lycopene content of freeze-dried tomatoes was reduced by 33% and 48% in two different varieties, and also reported an 8–10% loss of ascorbic acid in lyophilized red tomatoes. In yellow tomatoes, the amount of total polyphenols decreased by 30% after freeze-drying (Georgé et al., 2011). In concordance with that, significant reductions in lycopene, β-carotene, and ascorbic acid contents were reported after lyophilization of grapefruits (Vanamala et al., 2005).

The observed decreases could be due either to degradation during freeze-drying, and/or to a lower extractability in lyophilized compared to fresh material. The increase in sample porosity caused by freeze-drying increases phytochemical exposition to oxygen, and thus can have a detrimental effect on their stability.

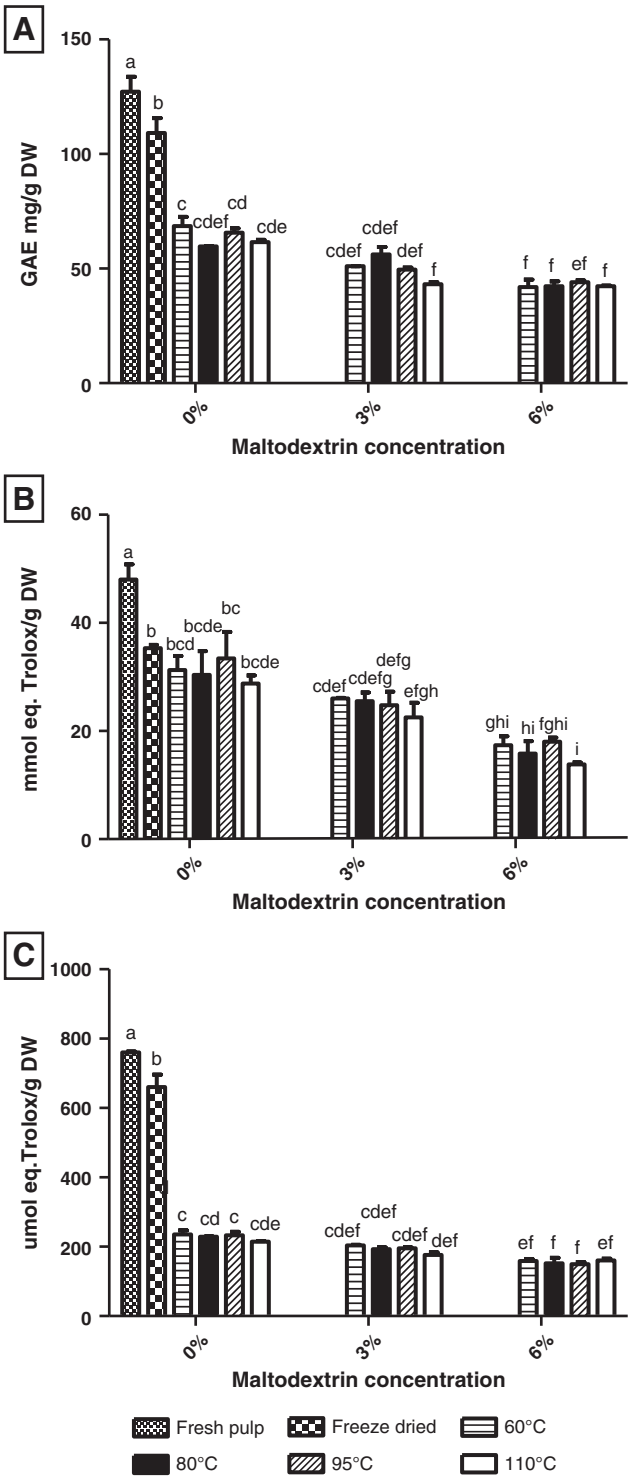

Fig. 1. Effect of spouted bed drying of camu-camu pulp in (A) Folin–Ciocalteu reducing capacity; (B) Ferric reducing antioxidant power; (C) DPPH• scavenging capacity.

3.4. Antioxidant capacity

The antioxidant capacity of camu-camu powders was measured by three methods: Folin–Ciocalteu reducing capacity (Fig. 1A), FRAP ferric reducing power (Fig. 1B) and DPPH scavenging activity (Fig. 1C). Gonçalves et al. (2010) compared the antioxidant activity of several Brazilian tropical fruits and camu-camu showed the highest activity, which was around 10 times higher than that for tucumã and uxi. Antioxidant activity is directly proportional to total phenolic and ascorbic acid contents (Genovese et al., 2008), and, consequently, it was affected by drying processes.

Lyophilization was shown to cause a slight decrease in FC and DPPH (13–14%) and a 26% reduction in FRAP (Fig. 1). Spouted bed drying resulted in temperature-independent decreases in antioxidant capacity. Folin–Ciocalteu reducing (46–67%) and DPPH scavenging capacities (61–71%) reductions were greater than those for the FRAP (22%–46%). This behavior could be explained by differences in

losses of ascorbic acid, proanthocyanidins and total phenolics among the processes (Table 3).

A good correlation between Folin–Ciocalteu reducing and DPPH scavenging capacities was found. The same occurred for Folin–Ciocalteu and FRAP ($r = 0.97$ and $r = 0.90$, respectively, at $p < 0.05$). The lower correlation between FRAP and AA values ($r = 0.74$) suggests that the losses of ascorbic acid during drying affected more significantly the Folin–Ciocalteu reducing and DPPH scavenging capacities ($r = 0.99$). DPPH capacity ($r = 0.94$) was also more significantly affected by TP reduction than FRAP ($r = 0.87$). Similar coefficient values were observed by Correia, Borges, Medeiros, and Genovese (2012) for acerola, jambolan, pitanga and caja-umbu residue powders. Chirinos, Galarza, Betalleluz-Pallardel, Pedreschi, and Campos (2010) and Myoda et al. (2010) also found a linear relationship between TP and DPPH for camu-camu pulp, and for both seed and peel, respectively. Although Luximon-Ramma, Bahorun, and Crozier (2003) found a poor correlation between AA and FRAP, this could be explained by the much lower vitamin C levels in the fruits analyzed by the authors.

3.5. Antimicrobial activity

Among the tested microorganisms, only *S. aureus* ATCC 29213 was inhibited by the crude extracts of camu-camu powders (Table 4). The extracts of freeze dried powder and spouted bed powders were classified as active and partially active, respectively. Similar results were found by Myoda et al. (2010) with methanolic extracts of seed and peel of camu-camu against *S. aureus* at 5 mg/mL. Other extracts such as those obtained from pericarp of *P. granatum* also presented activity against *S. aureus* (Pradeep, Manojbabu, & Palaniswamy, 2008).

The MIC value for freeze-dried and spouted bed powders obtained at 60 °C without carrier was 0.08 $mg \cdot mL^{-1}$. The MIC values were much higher for powders obtained at higher temperatures and with maltodextrin, ranging between 0.16 $mg \cdot mL^{-1}$ and 0.31 $mg \cdot mL^{-1}$ (Table 4). The higher the maltodextrin concentration and inlet drying temperature, the lower the inhibition. In this way, the extract of camu-camu powder produced at 6% MD and from 80 to 100 °C was less effective than the extract produced at 3% MD in the same temperature conditions. Despite loss of inhibitory activity caused by drying, these extracts were more active against *S. aureus* than ampicillin (MIC 0.26 $mg \cdot mL^{-1}$).

Phenolic constituents of fruits such as pomegranate were shown to possess significant antimicrobial activity (Pradeep et al., 2008). In this way, the reduction in phenolics concentration caused by drying of camu-camu pulp may have been responsible for the partial loss of inhibitory activity. Kil et al. (2009) suggested that the antimicrobial activity of sorghum may be due to the presence of tannic acid. Saraiva et al. (2012) observed that extract from *Caesalpinia pyramidalis* Tull containing quercetin, catechin, ellagic acid, flavonoids, proanthocyanidins and gallic acid, also presented antistaphylococcal activity. Besides, pure compounds such as flavone, quercetin, naringenin, morin and kaempferol were shown to inhibit *S. aureus* (Rauha et al., 2000). Camu-camu fruit presents high contents of ellagic acid, tannins, cyanidin, quercetin, catechin, kaempferol and rutin (Akter et al., 2011; Chirinos et al., 2010; Gonçalves et al., 2010; Reynertson et al., 2008). Therefore, the detected antimicrobial activity in the extracts was expected.

Table 4
Antimicrobial activity and minimum inhibitory concentration (MIC) of extracts of camu-camu powders produced by spouted bed drying in different temperatures (60, 80, 95 and 110 °C) and maltodextrin addition (0, 3 and 6%) against *S. aureus* strains.

Maltodextrin concentration		Inhibition (mm)	MIC of extracts ($mg \cdot mL^{-1}$)
0%	Freeze dried	25 ± 1^{a}	0.08^{a}
	60 °C	19 ± 1^{b}	0.08^{a}
	80 °C	ne	ne
	95 °C	ne	ne
	110 °C	19 ± 1^{bc}	0.16^{b}
3%	60 °C	18 ± 1^{bcd}	0.16^{b}
	80 °C	18 ± 1^{bcd}	0.16^{b}
	95 °C	19 ± 1^{bc}	0.16^{b}
	110 °C	ne	ne
6%	60 °C	ne	ne
	80 °C	17 ± 1^{d}	0.31^{d}
	95 °C	17 ± 1^{d}	0.31^{d}
	110 °C	18 ± 1^{cd}	0.31^{d}
	Ampicillin	ne	0.26^{c}

Values are expressed as means ± SD ($n = 3$). a,b,c,d. means in the same column followed by different superscripts are significantly different ($p < 0.05$). ne = not evaluated.

4. Conclusions

Drying of camu-camu pulp causes a decrease of in vitro antioxidant capacity, mainly associated to ascorbic acid and polyphenol degradation. The decrease is more intense for spouted bed drying compared to freeze-drying. Use of maltodextrin may protect the bioactive contents, mainly proanthocyanidins. Despite the observed losses caused by the drying process, camu-camu powders still retain high levels of phenolics, ascorbic acid, proanthocyanidins, antioxidant and antimicrobial activity. Therefore, they represent good sources as antioxidants and antimicrobials and may find several applications in functional food development.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.foodres.2013.07.025.

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