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Is the bioaccessibility of minerals affected by the processing steps of juçara fruit (*Euterpe edulis* Mart.)?

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ABSTRACT

The objective of this study was to verify if the processing steps of juçara fruit (*Euterpe edulis* Martius) affect mineral bioaccessibility using *in vitro* gastrointestinal digestion (IVG) followed by inductively coupled plasma optical emission spectrometry (ICP OES) analysis. The processing of the juçara fruit affected the content of calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn), and their bioaccessibility. It was observed an increase in the content of all minerals after the pulp extraction and reduction in bioaccessibility. It was possible to determine the bioaccessibility with the use of the IVG method and ICP OES. The bioaccessibility of Mg, Fe, Mn, and Cu decreased in the last processing step (pulp extraction), with the exception of Ca and Zn that could not be determined.

1. Introduction

The biodiversity richness of the Atlantic Forest makes this biome a hotspot (Tabarelli, Pinto, Silva, Hirota, & Bedê, 2005). However, this richness contrasts with the socioeconomic reality of the Ribeira Valley, Brazil, where is observed low Human Development Index (HDI) and the high rates of infant mortality and illiteracy (Romão, 2006). The population of the Ribeira Valley is composed mainly of quilombola (Afro-Brazilian people), caiçaras (people native to the coast) and indigenous communities. The income of these populations derives from the sustainable management of natural resources from the Atlantic Forest, such as fishing, mining, tourism, and agricultural activities (Nunes et al., 2016). Miguel and Bom (1974) reported that the inhabitants of this region have an inadequate dietary pattern, with deficiency of almost all nutrients, mainly of calcium (Ca), vitamins A, B_{12} and C, due to the low consumption of staple foods and nutrients such as milk and dairy products, fruit, vegetables, and meat.

An alternative to improve the food security of Ribeira Valley populations is the consumption of local foods derived from species native from the Atlantic Forest, such as juçara (*Euterpe edulis* Mart.), also known as the jiçara, ripeira or palmiteiro (Henderson & Galeano, 1996). Juçara was extensively exploited in the 50 and 60 decades due to its excellent palm heart quality, which led the juçara palm to be considered an endangered species (Silva-Matos, Frecklenton, & Watkinson, 1999). Currently, the pulp of the fruit produced by this palm, which is very similar to açaí (*Euterpe oleracea* Mart.), has been consumed due to its nutritional composition, and to make up the traditional Ribeira Valley population feeding, besides serving as a source of income for these families (Schulz et al., 2017).

The juçara pulp contains many essential micronutrients for the homeostasis of the human organism, such as potassium (K), iron (Fe), zinc (Zn), phosphorus (P), copper (Cu), calcium (Ca), and magnesium (Mg). Also it has the macronutrients: carbohydrates, proteins and lipids, the last two in greater quantity when compared to the açaí pulp, making the consumption of this food an extremely healthy and energetic option (Schulz et al, 2015, 2017). Despite the nutritional richness of juçara pulp, it is necessary to evaluate the bioavailability of the nutrients, since the presence of them in the food or its ingestion does not guarantee its utilization. Several factors interfere like chemical form of the nutrient, presence of binding agents, besides homeostatic regulating absorption mechanisms in the case of the micronutrients (Cozzolino, 2012). It is also indispensable to know the bioaccessibility of the nutrients present, fraction of a certain nutrient that is released from its alimentary matrix during the digestion and available for

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absorption, since this is a factor that also directly interferes in the bioavailability (Cilla, Bosch, Barberá, & Alegría, 2016).

Bioavailability and bioaccessibility is specially affected by food processing which can affect positively or negatively the nutrients content (Cilla et al., 2016). In order to obtain the juçara pulp, the fruit are submitted to several unit operations that can cause the quantitative reduction of nutrients; similar to what was observed by Krishnan, Dharmaraj, and Malleshi (2012), who reported reductions in mineral content in processed finger millet. On the other hand, processing can increase mineral content as reported by Briones-Labarca, Venegas-Cubillos, Ortiz-Portilla, Chacana-Ojeda, and Maureira (2011) in 'Granny Smith' apples and Gabaza et al. (2017) in millet. In this regard, it is important to verify the effect of the processing of juçara fruit on its micronutrients bioaccessibility.

The objective of this study was to verify if the processing of the juçara fruit affects the bioaccessibility of the minerals calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn), and the specific objectives were: *i.* verify the effect of processing steps on the content of minerals present in the mesocarp and pulp of juçara fruit, and *ii.* determine the *in vitro* bioaccessibility of the micronutrients by the gastrointestinal digestion (IVG) method followed by inductively coupled plasma optical emission spectrometry (ICP OES) analysis.

2. Material and methods

2.1. Plant material

Juçara (*Euterpe edulis* Mart.) fruit were harvested in five different locations: batches 1 and 2 were obtained from a cooperative of the Institute of Permaculture and Ecovillage of the Atlantic Forest (IPEMA), whose property was located in the rural area of the Serra do Mar in Ubatuba-SP (23°26′02″ South, 45°04′16″ West, altitude of 3 m). Batches 3 and 4 were collected in Jaboticabal-SP (21°15′17″ S, 48°19′20″ W, and 605 m altitude), at the São Paulo State University (UNESP), Faculty of Agrarian and Veterinary Sciences (FCAV), Jaboticabal Campus, and, batch 5 was obtained at the Araraquara Nautical Club located in Américo Brasiliense-SP (21°47′40″ S, 48°10′32″ W and altitude 664 m).

2.2. Processing and samples collection

The mesocarp and juçara pulp from the batches 1 and 2 were processed in a family agroindustry of Ubatuba-SP, and batches 3, 4 and 5, were processed in the Laboratory of Plant Production of FCAV-UNESP, according to the practices adopted by IPEMA. The fruit and pulp mesocarp samples were obtained in the following processing steps: *i.* at the time of harvest (fresh ripe fruit), *ii.* after selection and washing with potable water, *iii.* after immersion in hot water at ~100 °C for 2 min (soaking), and *iv.* after the pulp extraction using vertical pulping equipment. Subsequently the samples were frozen and stored at −20 °C until further laboratory analysis.

2.3. Quality analysis of the mesocarp and juçara pulp

Moisture content. The moisture content was determined using the method described by AOAC. (1997), which consisted of drying 10 g of the sample in an oven at 105 °C for 24 h. The results were expressed as percentage (%).

Hydrogenionic potential (pH). The pH was determined using a phmeter (Thermo Scientific, Orion 3 Star model) with the introduction of the electrode directly into the mesocarp and/or in the juçara pulp (AOAC., 1997).

Soluble solids content (*SSC*). SSC was determined using a digital refractometer (Alpha, Atago Co, Ltd, Japan), and expressed as percentage (%) (AOAC., 1997).

Titratable acidity (*TA*). The samples were titrated with 0.1 M sodium hydroxide solution to the equivalence point (pH 8.1) with the magnetic stirrer. TA was expressed as mg.100 g^{-1}, according to AOAC. (1997).

2.4. Minerals determination

2.4.1. Nitroperchloric digestion

Approximately 0.5 g of the mesocarp and/or the dehydrated pulp was weighed and 8 mL of a solution containing nitric/perchloric acids 2:1 (v/v) was added. Samples were digested at 100 °C for 2 h, filtered using ash-free paper filters (Unifil, Germany) into a 50 mL volumetric flask with the volume completed using Milli–Q® water, according to the methodology described by Sarruge and Haag (1974).

2.4.2. In vitro digestion

The bioaccessibility of micronutrients was assessed as described by Garret, Failla, and Sarama (1999) and Oomen et al. (2003). The fresh samples, without drying, were crushed and digested in three digestive solutions: basal saline (saliva), gastric juice and duodenal. Briefly, the *in vitro* digestion procedure consisted of weighing 3 g of sample of mesocarp and/or processed pulp of juçara which were placed in 50 mL Erlenmeyer containing 10 mL of the basal saline solution (150 $mmol.L^{-1}$) which consisted of NaCl (w/v), 5 $mmol.L^{-1}$ of KCl (w/v) and 6 $mmol.L^{-1}$ of $CaCl_2$ (w/v). To this solution was added 2 mL of Sigma-Aldrich α-amylase (0.075 g mL^{-1} - 3000 units; 20 $units.mg^{-1}$), the pH adjusted to 6.5 + 0.1 with 0.1 M $NaHCO_3$. The Erlenmeyers were then placed in a water bath with circular orbital motion at 95 rpm at 37 °C for 10 min. After this time the pH was adjusted to 2.5 + 0.1 with 0.1 M HCl and 2 mL of Sigma-Aldrich pepsin (0.04 g mL^{-1}; > 400 $units.mg^{-1}$) was added. Then the Erlenmeyers were placed in a water bath with circular orbital motion at 95 rpm at 37 °C for 1 h. After gastric digestion, the pH was adjusted to 6.5 ± 0.1 with 1.0 M $NaHCO_3$ and 10 mL of the solution containing the Sigma-Aldrich pancreatin (0.0006 g mL^{-1}; 8 × USP) and Sigma-Aldrich lipase (0.0036 g mL^{-1}; 30–90 $units.mg^{-1}$). Then the Erlenmeyers were placed in a water bath with circular orbital motion at 95 rpm at 37 °C for 2 h. After duodenal digestion, samples were placed in an ice bath and centrifuged (Beckman centrifuge, model Avanti J-25, Coulter, USA) at 20,000 × g for 20 min at 4 °C, to separate the supernatant (digestive fluid) from the solid phase. After centrifugation the digestive fluids were filtered on ash-free paper filter (Unifil, Germany) and stored at −20 °C until further analysis by inductively coupled plasma optical emission spectrometer (ICP OES). The entire digestive procedure was done in duplicate for each type of processing sample.

2.5. Quantification of chemical elements

The quantification of the chemical elements calcium (Ca), copper (Cu), Iron (Fe), manganese (Mn), magnesium (Mg), and zinc (Zn) present in the nitroperchloric and *in vitro* extracts (IVG) was performed by inductively coupled plasma optical emission spectrometry (ICP OES) with a radial viewing plasma configuration using a PerkinElmer Optima 8000 spectrometer (PerkinElmer, Waltham USA.) operating at 1400 W. The instrumental parameters can be observed in Table 1. To minimize the influence of salts and proteins which were added to simulate IVG digestion, all samples were diluted 100 times (v/v) using high purity deionized water (18.2 MΩ cm^{-1}) obtained by Milli-Q® water purification system (Millipore, Bedford, USA). The samples were introduced using Scott (Ryton®) cyclonic double pass spray chamber and an alumina (2 mm d.i.) injector was used. The Scott chamber was cleaned up with HNO_3 5% for 60 s every 10 readings. A multi-element standard solution (Merck, Darmstadt, Germany) containing all elements was used to plot the analytical curves of each element.

2.6. Determination of bioaccessibility

After determination of the micronutrient content in the samples

Table 1
Instrumental parameters used in the inductively coupled plasma optical emission spectrometer (ICP OES).

Model and Spectrometer brand	PerkinElmer Optima 8000
Plasma power (W)	1400
Plasma gas flow (L/min)	10
Auxiliary gas flow (L/min)	0.2
Nebulization flow (L/min)	0.7
Optics Purge (nitrogen) (mL/min)	5
Injector	Alumina (2 mm d.i.)
Nebulization chamber	Scott (Ryton®); ciclonic
Plasma orientation in relation to the optical path	Radial View
Signal processing	Area under the peak
Integration time	Automatic
Sample introduction rate (mL/min)	1.5
Replicates	2
Monitored spectral lines	calcium (Ca), 317.933 nm; copper (Cu) 327.393 nm iron (Fe), 238,204 nm; magnesium (Mg), 285.213 nm; manganese (Mn), 257.610 nm; zinc (Zn), 206.200 nm.

submitted to nitroperchloric and *in vitro* digestion, the bioaccessibility was calculated using the formula described by Pereira et al. (2016):

Bioaccessibility (%) = (Y / X) x 100, where:

Y = mineral content determined after simulated *in vitro* digestion.Z = total mineral content in the sample after nitroperchloric digestion.

2.7. Statistical analysis

A completely randomized design (CRD) in a factorial 5 × 4 arrangement was used, where the origins constituted the firth factor (Ubatuba I - batch 1, Ubatuba II - batch 2, Jaboticabal I - batch 3, Jaboticabal II - batch 4 and Américo Brasiliense - batch 5) and the processing steps the second (fresh fruit, fruit after washing, fruit after soaking in water, and freshly processed pulp). The data was subjected to analysis of variance (ANOVA) using the PROC MIXED procedure of SAS. (1999). The averages were compared by the Tukey's test ($p < .05$).

3. Results

3.1. Quality of juçara mesocarp and pulp

The quality parameters of the mesocarp and juçara pulp from the different origins and processing steps can be observed in Table 2.

Regarding the fruit origin, it was observed significant interactions between origin and processing steps ($p < .05$) for all quality parameters (Table 2). The moisture content of the mesocarp and juçara pulp ranged from 65.8% to 74.2%, and the fruit from Ubatuba (batch 2) presented the highest moisture contents, the lowest content was observed from Jaboticabal (68.2% % - batch 3 and 65.8% batch 4) (Table 2). Dry matter (DM) content was lower in Ubatuba fruit (25.7% - batch 2) and higher in Jaboticabal fruit, 31.7% and 34.1% for batches 3 and 4, respectively (Table 2). Soluble solids contents (SSC) ranged from 7.0% to 9.7%, with the mesocarp and pulp of juçara from Américo Brasiliense (batch 5) presenting the lowest SSC (7.0%), and also the lowest pH values (4.63), Table 2. Regarding the titratable acidity, a significant difference was observed between the samples from Ubatuba (batch 2) in relation to those from Jaboticabal (batch 3), that is, 0.37 mg.100 g^{-1} and 0.24 mg.100 g^{-1}, respectively (Table 2). These differences were reflected in the SSC/TA (ratio), with the Jaboticabal samples (batch 3) presenting the highest values in relation to Ubatuba (batch 1) and Américo Brasiliense (batch 5), Table 2.

Regarding the processing steps, except for the pH, significant differences ($p < .05$) were observed for all parameters evaluated (Table 2). In relation to moisture, an increase in the moisture content of the samples at the different processing steps was observed, which means the mesocarp of the newly harvested fruit had a content of 61.8% and this increased to 88.7% in the pulp (Table 2). On the other hand, the fresh fruit presented the highest DM (38.16%) and pulp (11.28%) contents, Table 2. In relation to the other quality parameters, a decrease was observed in the contents of SSC, AT and ratio in the mesocarp samples of freshly harvested fruit and freshly processed pulp (Table 2).

3.2. Minerals determination

3.2.1. Macroelements content

It was observed a significant interaction between origin and processing steps ($p < .05$) regarding total Ca and Mg content (Table 3). The total Ca content did not present significant differences according to fruit origin, and Ca contents varied from 622.8 to 1235.1 mg.100 g^{-1} (Table 3). On the other hand, total Mg content varied according to fruit origin, with higher Mg contents observed in the batches from Ubatuba, 721.0 and 710.3 mg.100 g^{-1}, batches 1 and 2, respectively. Regarding the other origin regions, Mg content ranged from 331.0, 403.1, and 470.6 mg.100 g^{-1} for fruit from Jaboticabal (batches 3 and 4) and Américo Brasiliense (batch 5), respectively (Table 3).

The Ca contents after *in vitro* digestion were higher than those obtained with nitroperchloric digestion and a significant interaction between origin and processing steps ($p < .05$) was observed (Table 3). Unlike total Ca content, significant differences were observed for fruit origin, with the fruit of Jaboticabal (batch 3) being richer in this mineral (879.8 mg.100 g^{-1}) than the batch 4 (519.9 mg.100 g^{-1}) obtained in the same locality (Table 3). On the other hand, the content of Mg obtained after the *in vitro* digestion was lower than those obtained with nitroperchloric acid and the fruit of Ubatuba (batch 2) continued to be richer in Mg (116.8 mg.100 g^{-1}) than the other batches (66.8–93.2 mg.100 g^{-1}), Table 3.

In relation to processing, it was observed that the total Ca content in the newly processed pulp (1731.1 mg.100 g^{-1}) was approximately five times higher than the average total content found in the fruit mesocarp (343.8 mg.100 g^{-1}), Fig. 1A. The same was observed for the total Mg content, where the content of this mineral was three times higher in the pulp (1348.3 mg.100 g^{-1}) than in the mesocarp of the fruit in the other stages of processing (253.5 mg 0.100 g^{-1}), Fig. 2A. In relation to *in vitro* digestion, the Ca and Mg contents also showed significant differences in the last processing step, however with lower increases that were of the order of three times for Ca (490.8 and 1410.0 mg.100 g^{-1}) and twice for Mg (75.4 and 146.7 mg.100 g^{-1}), Figs. 1B and 2B.

3.2.2. Microelements content

It was observed significant interactions between origin and processing steps ($p < .05$) regarding total Mn, Cu, and Zn (Table 3). For Fe, only the processing step affected the total content of this mineral (Table 3). In general, the fruit from Ubatuba (batches 1 and 2) had higher total contents of Mn, Cu, and Zn than those harvested in the other localities, with maximum values of 28.3, 13.3, and 13.8 mg.100 g^{-1} for Mn, Cu and Zn, respectively (Table 3). Only the total Fe content did not vary according to the origin of the fruit, ranging from 28.4 to 127.1 mg.100 g^{-1} (Table 3).

With the exception of Zn, whose contents after *in vitro* digestion were higher than those obtained with nitroperchloric digestion (Table 3), the other microelements presented levels much lower than the totals after IVG (Table 3). In relation to Mn, fruit from Jaboticabal (batch 3) presented the highest contents (2.8 mg.100 g^{-1}) in relation to the other localities (Table 3). For Cu, the fruit from Ubatuba (batch 2) were the richest in this element (0.62 mg.100 g^{-1}) and those from

Table 2
Physicochemical results found in the mesocarp and juçara pulp (*Euterpe edulis* Martius).

Different sources	Moisture (%)	Dry Matter (%)	SSC (%)	pH	TA (mg.100g^{-1})	*Ratio*
Origin (O)						
Ubatuba I	70.99^{b}	29.01^{c}	8.9^{ab}	4.97^{a}	0.37^{a}	24.17^{bc}
Ubatuba II	74.21^{a}	25.79^{d}	8.8^{abc}	5.02^{a}	0.33^{ab}	26.51^{abc}
Jaboticabal I	68.26^{dc}	31.74^{ab}	7.4^{bc}	5.11^{a}	0.24^{b}	30.17^{a}
Jaboticabal II	65.88^{d}	34.12^{a}	9.7^{a}	5.03^{a}	0.32^{ab}	29.37^{ab}
Américo Brasiliense	69.60^{bc}	30.40^{bc}	7.0^{c}	4.63^{b}	0.30^{ab}	23.22^{c}
Treatment (T)						
Fresh fruit	61.84^{c}	38.16^{a}	10.17^{ab}	4.96	0.36^{a}	28.59^{a}
After washing	63.88^{bc}	36.12^{ab}	8.53^{b}	5.01	0.32^{a}	27.15^{a}
After soaking	64.72^{b}	35.28^{b}	10.27^{a}	4.80	0.35^{a}	29.58^{a}
Freshly processed pulp	88.72^{a}	11.28^{c}	4.48^{c}	5.04	0.21^{b}	21.44^{b}
Interaction						
O x T	0.0400	0.0400	0.0001	0.0001	0.0001	0.0008
CV	2.40	5.54	14.40	4.43	19.59	13.64

[a,b] Averages following to the same letters in the same column do not differ statically between them by Tukey's Test ($p > .05$). CV = coefficient of variation.

Table 3
Macro and microelements (mg.100 g^{-1}) of the mesocarp and pulp of the juçara fruit (*Euterpe edulis* Martius.).

Different sources	Calcium (Ca)		Magnesium (Mg)		Manganese (Mn)		Cupper (Cu)		Zinc (Zn)		Iron (Fe)	
	Total	*in vitro*	Total	*in vitro*	Total	*in vitro*	Total	*in vitro*	Total	*in vitro*	Total	*in vitro*
Origin (O)												
Ubatuba I	622.8	726.4^{ab}	721.0^{a}	97.97^{ab}	28.30^{ab}	1.27^{b}	10.47^{ab}	0.54 ^{ab}	13.85^{a}	10.22 ^{ab}	127.12^{a}	1.09^{ab}
Ubatuba II	588.2	746.9^{ab}	710.3^{a}	116.8^{a}	26.7^{b}	1.44^{b}	1.39^{a}	0.62^{a}	13.44^{a}	15.41^{a}	112.92	1.73^{a}
Jaboticabal I	420.0	879.8^{a}	331.0^{b}	93.2^{ab}	43.0^{a}	2.84^{a}	6.41^{b}	0.41 ^{ab}	5.48 ^{b}	9.42 ^{ab}	28.48	0.91^{ab}
Jaboticabal II	586.8	519.9^{b}	403.1^{b}	79.4^{ab}	8.6^{c}	0.38^{b}	5.70^{b}	0.30^{bc}	7.84 ^{b}	9.45 ^{ab}	90.95	0.99^{ab}
Américo Brasiliense	1235.1	723.0^{ab}	470.6^{ab}	66. 8^{b}	30.1^{ab}	0.72^{b}	4.57^{b}	0.13^{c}	7.52 ^{b}	6.74 ^{b}	126.58	0.51^{b}
Treatment (T)												
Fresh Fruit	327.8^{b}	490.8^{b}	244.5^{b}	75.48^{b}	14.47	0.95^{a}	3.62^{b}	0.22^{b}	5.12^{b}	5.86 ^{b}	25.22^{b}	0.40^{b}
After washing	344.1^{b}	499.8^{b}	246.2^{b}	70.63^{b}	17.71	1.33	4.02^{b}	0.30^{b}	5.03^{b}	6.34 ^{b}	33.32^{b}	0.42^{b}
After soaking	359.4^{b}	476.1^{b}	269. 7^{b}	70.86^{b}	18.12	1.37	4.61^{b}	0.25^{b}	5.10^{b}	7.46 ^{b}	75.87^{b}	0.72^{b}
Freshly processed pulp	1731.1a	1410.0a	1348.3a	46.75^{a}	59.08	1.68	20.19^{a}	0.83^{a}	23.27^{a}	21.33^{a}	254.42^{a}	2.65^{a}
Interaction												
O x T	0.0001	0.0020	0.0001	0.0038	0.0001	0.0001	0.0033	NS	0.0001	0.0001	0.2540	0.0002
CV	77.24	24.98	36.77	34.18	37.69	57.29	54.90	40.77	35.99	49.92	72.61	56.85

[a,b] Averages following to the same letters in the same column do not differ statically between them by Tukey's Test ($p > .05$). CV = coefficient of variation.

Américo Brasiliense (batch 5) the poorest (0.13 mg.100 g^{-1}) (Table 3). For Zn, fruit from Ubatuba (batch 2) had higher levels (15.4 mg.100 g^{-1}) than those from Américo Brasiliense (batch 5–6.7 mg.100 g^{-1}), Table 3. The same occurred for Fe, with values of 1.73 and 0.51 mg.100 g^{-1} were observed for batches 2 and 5, respectively (Table 3).

Regarding processing, significant differences were observed for all microelements mainly in the last unitary operation, pulp extraction. Total Mn levels increased from 14.7 to 59.1 mg.100 g^{-1} (4 times), Cu concentrations increased from 3.6 to 20.2 mg.100 g^{-1} (5.6 times), Zn from 5.1 to 23.3 mg.100 g^{-1} (4.5 times) and Fe from 25.2 to 254.4 mg.100 g^{-1} (10 times), Table 3. The same happened after *in vitro* digestion for all microelements (Figs. 3–6).

3.3. Bioaccessibility

3.3.1. Macroelements

As the Ca content after *in vitro* digestion was higher than the total Ca content determined in the mesocarp and juçara pulp, it was not possible to calculate the bioaccessibility of this macroelement. However, it was possible to determine the bioaccessibility of Mg, and a significant interaction between origin and processing steps ($p < .05$) was observed. In the last processing step, pulp extraction, it was observed a general reduction in the bioaccessibility (Fig. 7A). In the mesocarp of fresh fruit, after washing and soaking, the bioaccessibility of Mg was 30.8%, 28.6%, 26.2%, respectively, and of only 10.8% in freshly processed pulp (Fig. 7A).

3.3.2. Microelements

It was observed significant interactions between origin and processing steps ($p < .05$) regarding the bioaccessibility of Mn and Fe (Fig. 7B and D). However, for Cu the only significant difference was related to fruit origin (Fig. 7C). The bioaccessibility of the microelements ranged from 0.94% to 7.56% (Fig. 7), and it was affected by fruit origin and the different processing steps. The Fe was the micromineral that presented the lowest bioaccessibility, that means values varying from 1.58% to 1.04% (Fig. 7D).

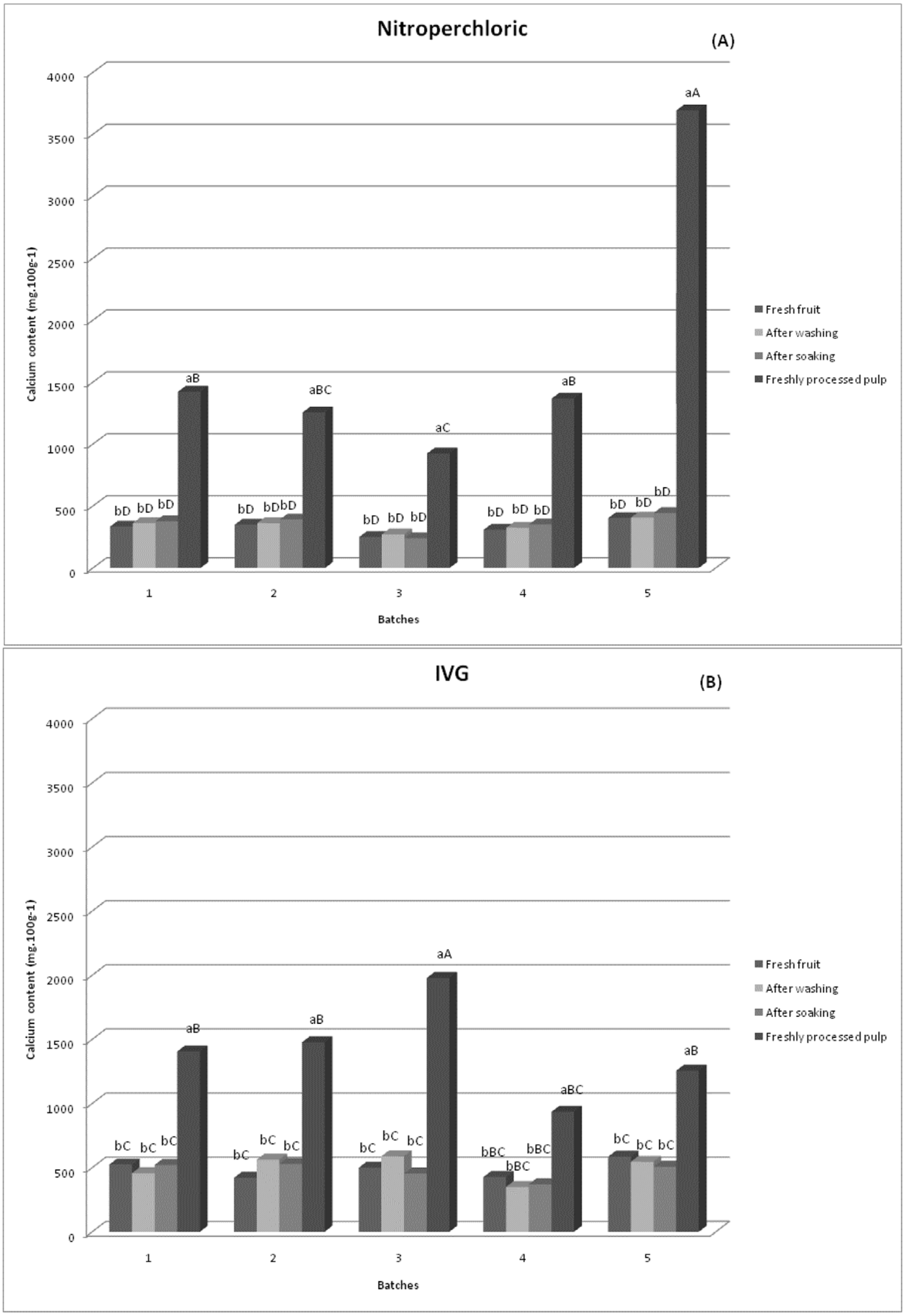

Fig. 1. Total (A) and *in vitro* (B) calcium (Ca) content in the mesocarp and juçara (*Euterpe edulis* Mart.) pulp from different origins (batches) and processing stages. Values with the same lowercase letters, within origins, and with the same upper case letter, between treatments, are not statistically different by Tukey's test ($p > .05$).

4. Discussion

4.1. Quality of the mesocarp and juçara pulp

The differences observed in relation to the quality parameters of the mesocarp and pulp of juçara as a function of the origin of the samples may be related to the inherent differences between the batches. However, the values of the evaluated parameters are in agreement with what is usually reported for this fruit (Ribeiro, Mendes, & Pereira, 2011; Barros, Costa, Ribeiro, Mendes, Pereira, & 2015). According to Peirs, Tirry, Verlinden, Darius, and Nicolaï (2002), variability due to plant age, yield, age of reproductive buds, position and lighting, as well as, variations between orchards (soil characteristics, nutrition and climate), fruit age and seasonal variability, might have affected the chemical composition of the fruit from the different batches. In addition, differences in fruit maturity stages may also have contributed to the observed variations. The fruit of juçara are very similar to açaí and the ripening of these fruit in the same bunch is quite heterogeneous (Andrade, 2001). More mature fruit remain on bunches, dry up, and remain adhered to them, which may be related to the observed differences in moisture content and DM.

In relation to processing, since fruit contact with water occurs during the processing, mainly in the unitary operation of fruit soaking, which is carried out in order to facilitate the extraction of the pulp,

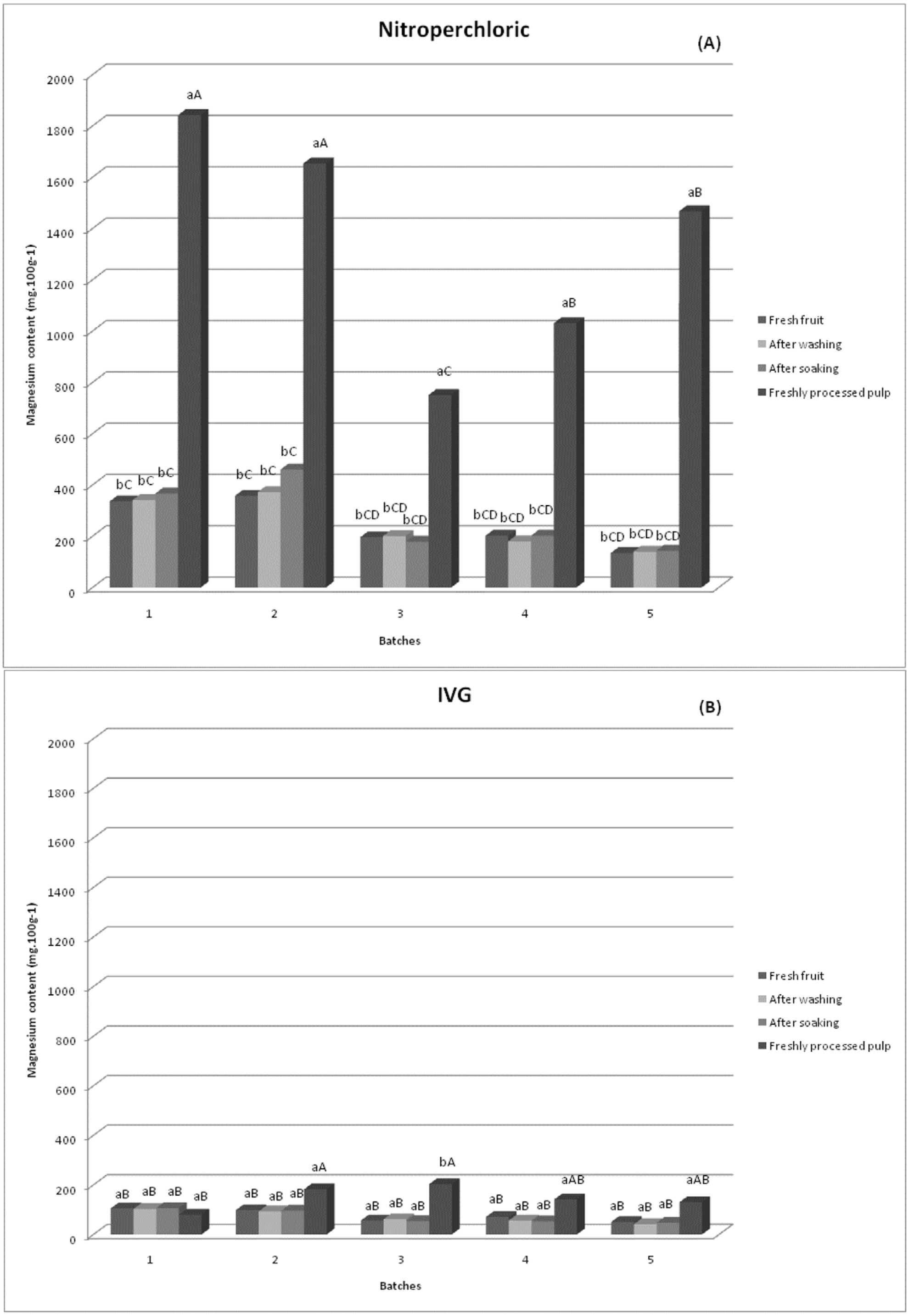

Fig. 2. Total (A) and *in vitro* (B) magnesium (Mg) content in the mesocarp and juçara (*Euterpe edulis* Mart.) pulp from different origins (batches) and processing stages. Values with the same lower-case letters, within origins, and with the same upper case letter, between treatments, are not statistically different by Tukey's test ($p > .05$).

there is water incorporation in the mesocarp and, consequently, increase in moisture content and decrease of DM content. Likewise, for the other quality parameters, reductions in their levels were also observed. In this way, the different stages of processing affected the quality parameters of juçara pulp, generally promoting a reduction in the content of these parameters.

4.2. Minerals determination

4.2.1. Macroelements content

The total Ca and Mg contents observed in the mesocarp of the fruit of all batches were higher than those reported by Silva, Barreto, & Serôdio (2004), that is, 430 and 150 mg.100 g^{-1}, respectively. On the other hand, Schulz et al. (2015) reported levels similar to those presented in Table 3, that means values of 349 mg.100 g^{-1} for Ca and 166 mg.100 g^{-1} for Mg. Again, these differences may be related to the origin of the fruit, since the mineral composition of the fruit reflects the concentration found in the soils and also its maturation stage (Schulz et al., 2017). The Ca concentrations were also higher than those reported by Silva, Barreto, Serôdio (2004) and Garbin, Helm, Pimentel, and Dalzoto (2015) after *in vitro* digestion, but the Mg levels were within the range presented by these authors. It is worth mentioning that Ca contents *in vitro* were higher than those of total Ca, which did not make it possible to calculate the bioaccessibility of this macroelement.

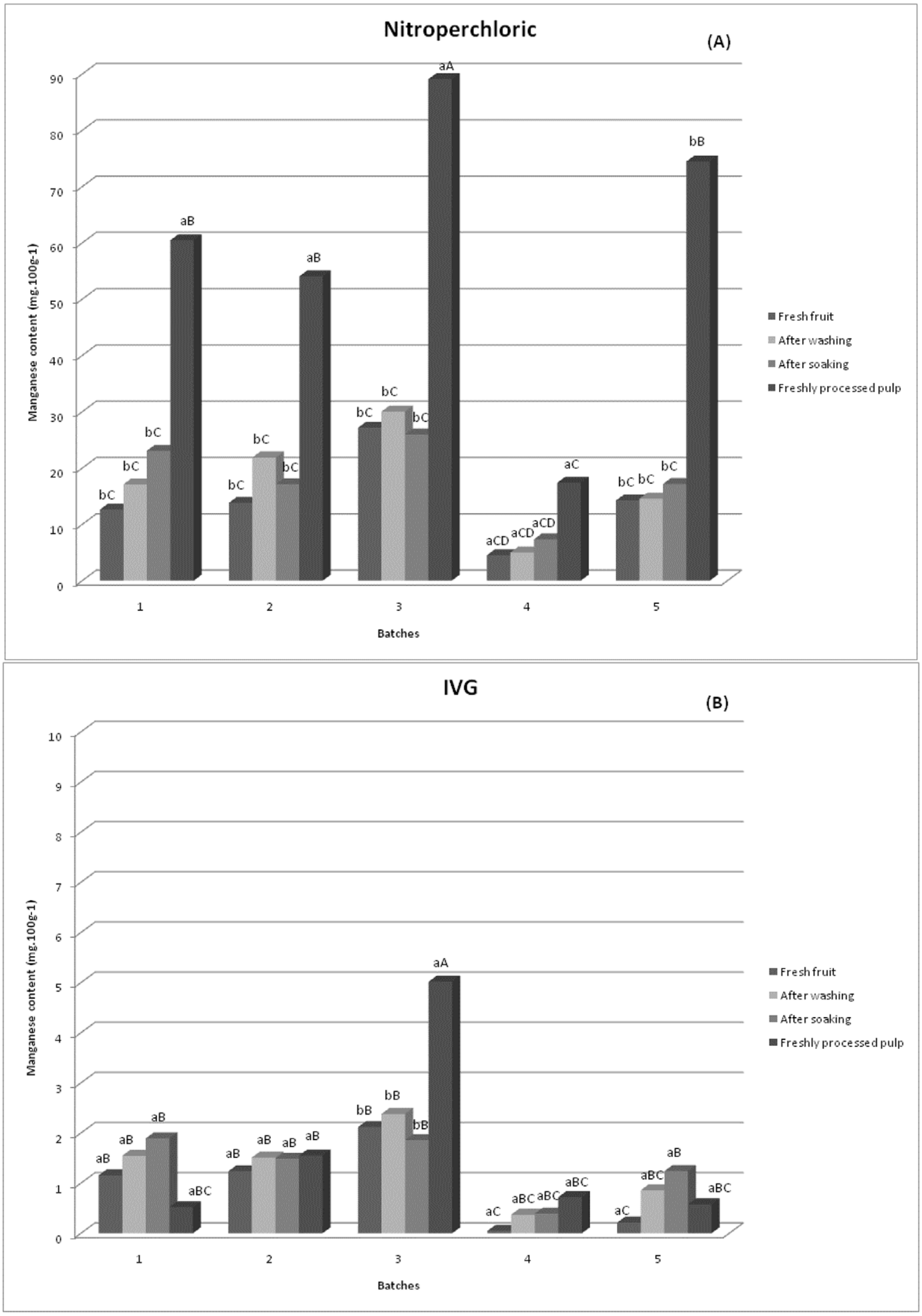

Fig. 3. Total (A) and *in vitro* (B) manganese (Mn) content in the mesocarp and juçara (*Euterpe edulis* Mart.) pulp from different origins (batches) and processing stages. Values with the same lowercase letters, within origins, and with the same upper case letter, between treatments, are not statistically different by Tukey's test ($p > .05$).

Possibly the *in vitro* digestion might result in microelements to be released from the food matrix, but the total mineral content (nitroperchloric digestion) must always be higher than the IVG.

It was observed that during processing the total and *in vitro* contents of Ca and Mg increased significantly after the pulp extraction step (Figs. 1 and 2). In general, an increase of approximately six times in the total content of these macroelements after pulp extraction was observed. This increase may be related to the friction that occurs between the seeds of juçara during pulp extraction, occurring the migration of Ca and Mg from the seeds to the pulp, because the seeds are richer in these macroelements in relation to the pulp (Garbin, 2011). On the other hand, Krishnan et al. (2012), reported decreases in Ca in finger millet subjected to decortications, popping and malting. In this way, the fruit processing method can influence the micronutrient contents.

4.2.2. Microelements content

The total contents of the microelements were similar to those observed by Silva, Barreto, & Serôdio (2004), who reported values of 4.3, 1.4, 1.2, and 55.9 mg.100 g^{-1} of Mn, Cu, Zn and Fe, respectively. When comparing to the contents of these microelements found in açaizeiro fruit, the fruit of juçara are richer in minerals, which demonstrate their nutritional importance, especially for the poor population of the Ribeira Valley. In relation to the rare earths content, there are great differences between the pulp of açaí and juçara, with açaí pulp richer in samarium (Sm), thorium (Th), lanthanum (La), cerium (Ce), and neodymium (Nd) than the juçara pulp (Santos, Nardini, Cunha, Barbosa Jr. & Teixeira,

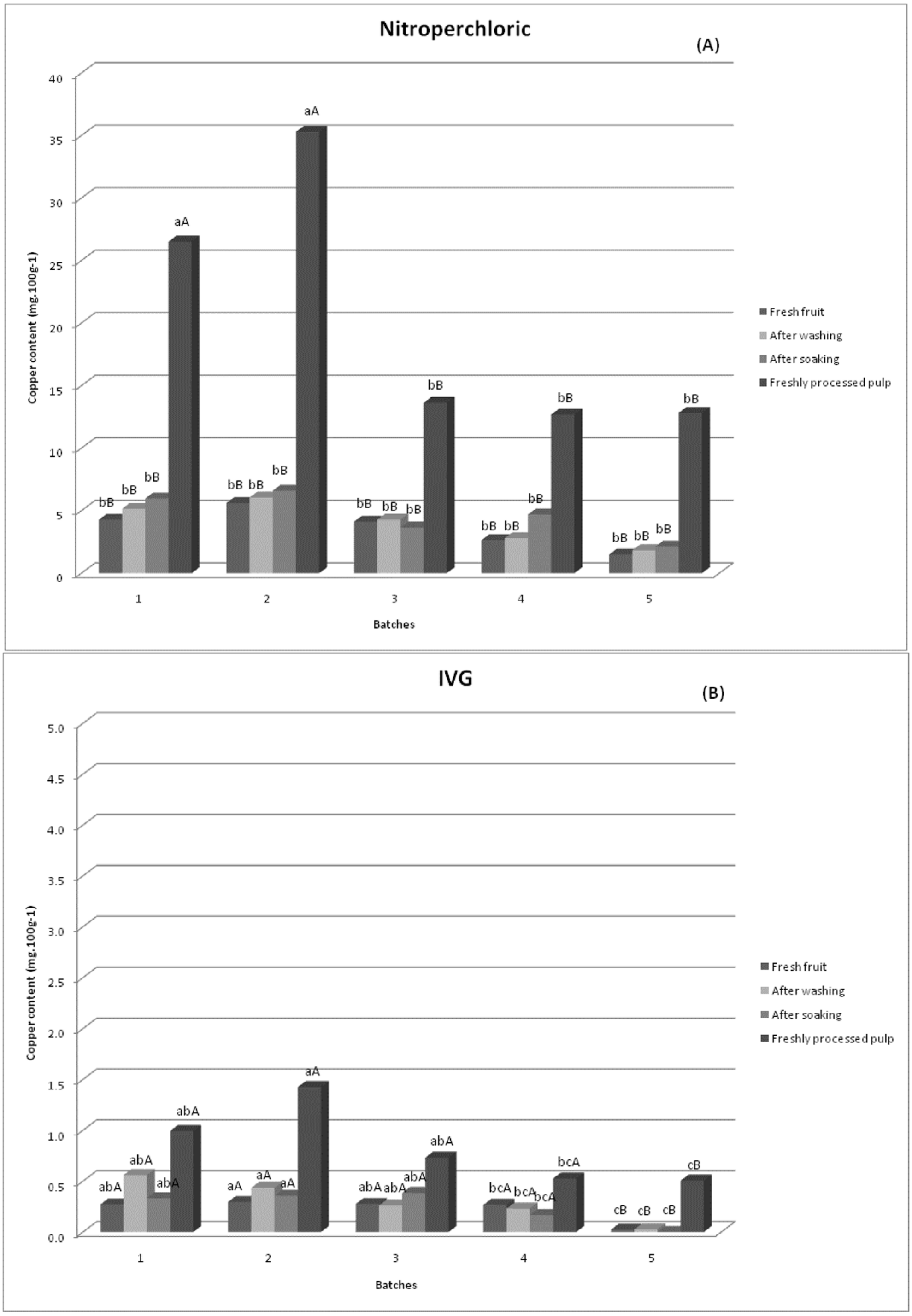

Fig. 4. Total (A) and *in vitro* (B) copper (Cu) content in the mesocarp and juçara (*Euterpe edulis* Mart.) pulp from different origins (batches) and processing stages. Values with the same lowercase letters, within origins, and with the same upper case letter, between treatments, are not statistically different by Tukey's test ($p > .05$).

2014).

Regarding *in vitro* digestion, the contents of the microminerals of all batches were much lower than those found in the nitroperchloric (total) digestion, with the exception of Zn whose contents were higher, making it impossible to calculate the bioaccessibility.

Similar to what was observed for the macroelements, the total and *in vitro* contents of Mn, Cu, Zn and Fe increased in freshly processed pulp (Table 3). In relation to total Mn, a significant increase was observed in the last stage of processing (59.08 mg.100 g^{-1}), pulp extraction, with results much higher than those reported by Troian, Corbellini, and Bufalo (2014) and Garbin et al. (2015), that is, 0.31 mg.100 g^{-1} and 0.26 mg.100 g^{-1}, respectively. Cu content was also higher in the freshly processed pulp in both nitroperchloric digestion (20.19 mg.100 g^{-1}) and *in vitro* digestion (0.83 mg.100 g^{-1}), but after IVG the content of Cu was similar to that reported by Garbin (2011), that is, 0.68 mg.100 g^{-1}. The Zn contents were higher in the last processing step (pulp extraction) for both digestions, but almost twice as high as what was found by Silva, Barreto, & Serôdio (2004), 12.2 mg.100 g^{-1} in juçara pulp. Finally, the Fe content was also higher in freshly processed pulp, but there was a large difference between total contents (254.42 mg.100 g^{-1}) and *in vitro* 2.65 mg.100 g^{-1}, both diverging from result found by Ribeiro et al. (2011) which was 46.6 mg.100 g^{-1} of pulp.

The explanation for the significant increase of the micronutrient content in the newly processed juçara pulp may be related to the contamination of the pulp with chemical elements coming from the friction

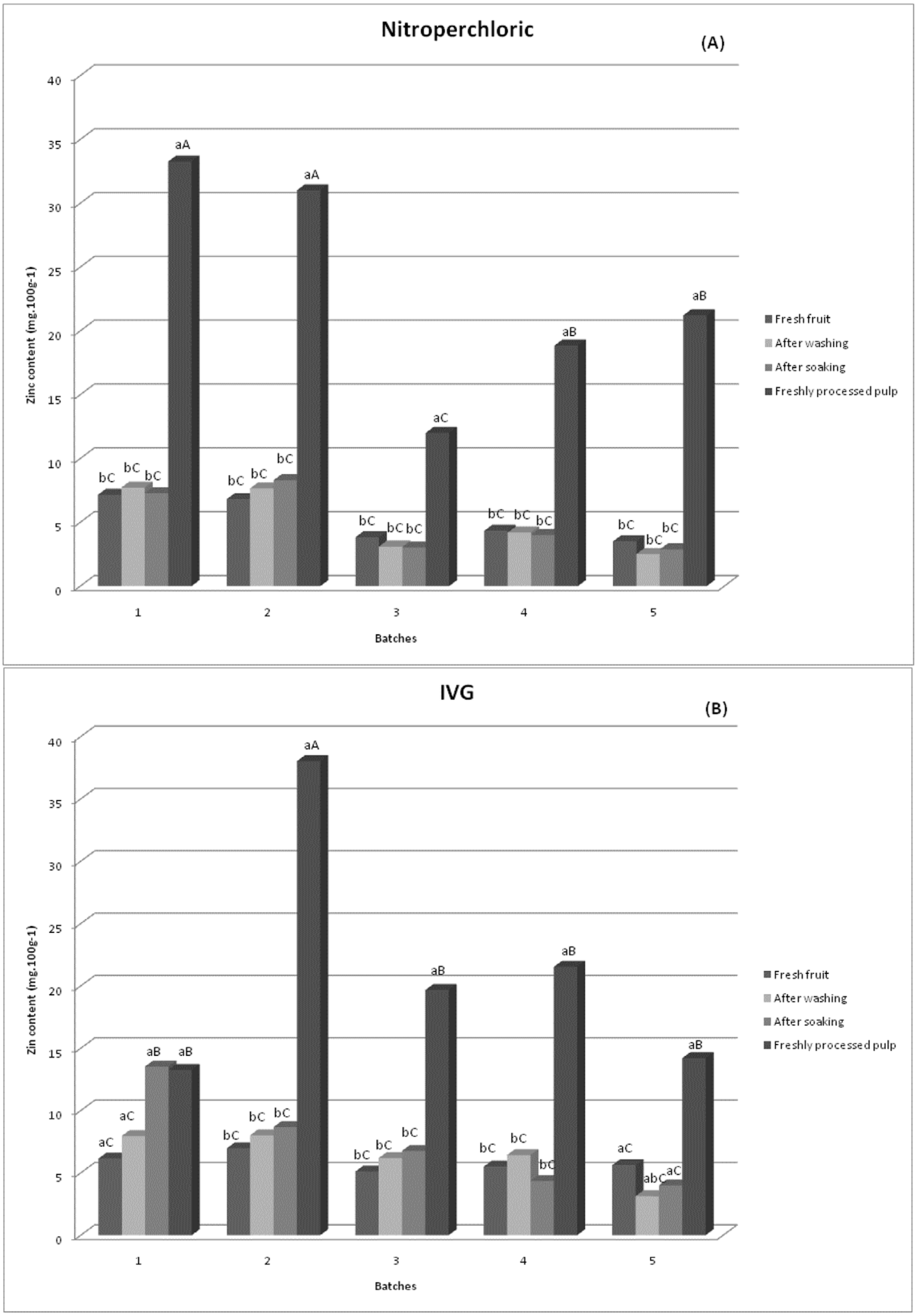

Fig. 5. Total (A) and *in vitro* (B) zinc (Zn) content in the mesocarp and juçara (*Euterpe edulis* Mart.) pulp from different origins (batches) and processing stages. Values with the same lowercase letters, within origins, and with the same upper case letter, between treatments, are not statistically different by Tukey's test ($p > .05$).

that occurs between the seeds of juçara during the pulp extraction with the metallic parts of the machine as the stainless steel used in the equipment is an iron-chromium-nickel metallic alloy which might also contains Cu, Mn, P, S, silicon (Si), carbon (C), and other minerals (McGuire, 2008). The increase in mineral contents during processing is common and has been observed in other foods such as shrimps, crabs and oysters (Pedrosa & Cozzolino, 2001) and some types of beans (Cardenas, Leonel, & Costa, 2008). In some cases contamination may have implications for consumers' health, as reported by Carneiro, Evangelista, and Barbosa (2013) who observed lead (Pb) contamination during the production of cassava (*Manihot esculenta* L.) flour due to contact with the metal sheet used to dry out the flour.

4.3. Bioaccessibility

4.3.1. Macroelements

The Mg was the micronutrient that presented the highest bioaccessibility in comparison to the other minerals. However, a significant difference was observed for the last processing step, with the bioaccessibility decreasing from 30.87% to 9.88% (Fig. 7A). These results were lower than what Schulz et al. (2017) reported, that means a Mg bioaccessibility of 32.2–55.5% in juçara pulp obtained with ripe fruit. Possibly, with the processing, there was a greater interaction between the compounds present in the pulp of juçara, such as: fibers, polyphenols and phytates, with the micronutrients leading to the formation of insoluble complexes, which may have negatively affected the

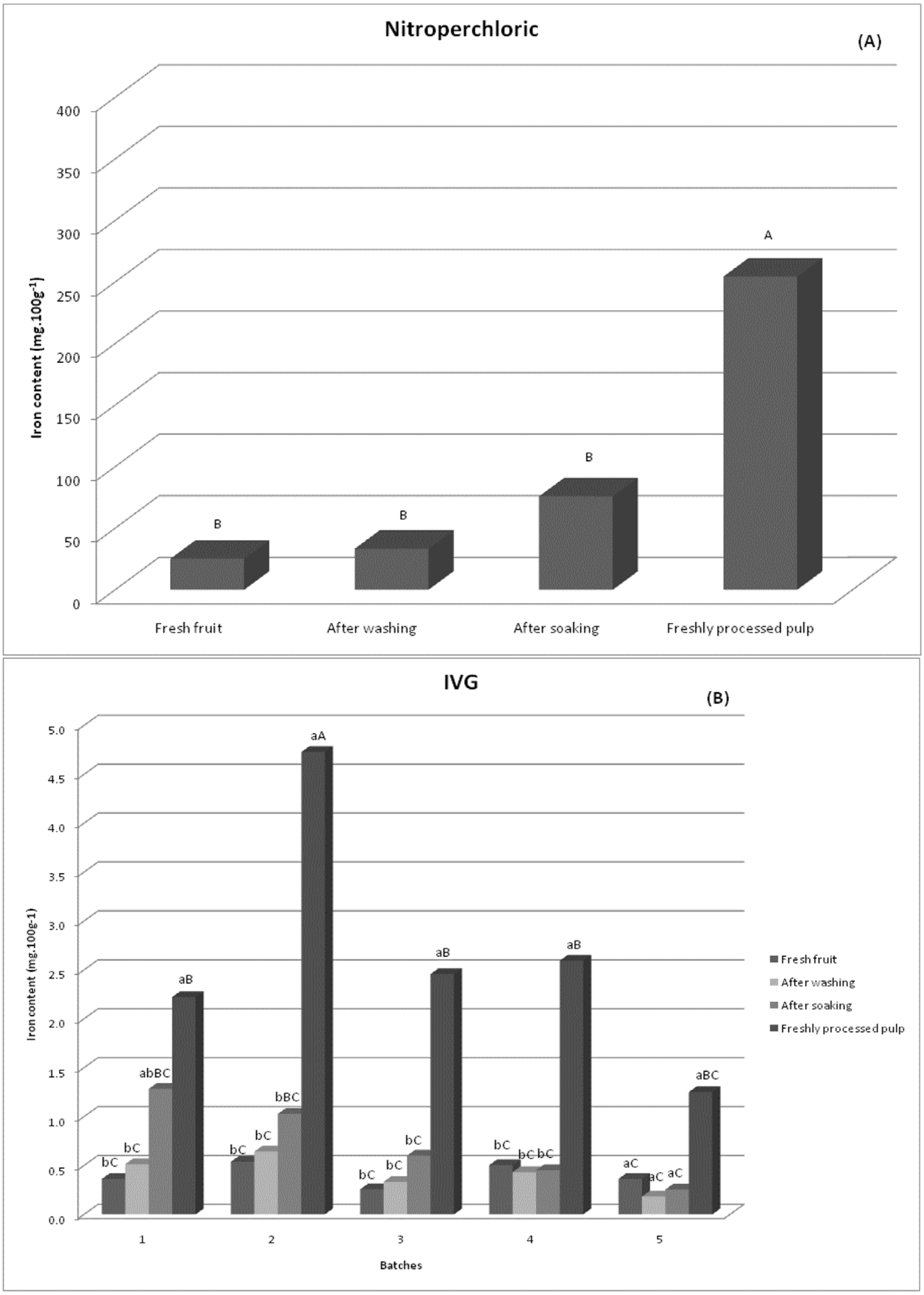

Fig. 6. Total (A) and *in vitro* (B) iron (Fe) content in the mesocarp and juçara (*Euterpe edulis* Mart.) pulp from different origins (batches) and processing stages. Values with the same lowercase letters, within origins, and with the same upper case letter, between treatments, are not statistically different by Tukey's test ($p > .05$).

bioaccessibility of the same (Sandberg, 2002).

4.3.2. Microelements

The average bioaccessibility of the microelements varied from 5.90% for Mn, 5.76% for Cu, and only 1.20% for Fe (Fig. 7). In general all microelement have a significant reduction in bioaccessibility the last processing step. These results also were lower than what Schulz et al. (2017) reported, that means a Mg bioaccessibility of 22.5% in immature juçara fruit and 35.1% in mature fruit. These authors also reported that Cu bioaccessibility increased as fruit matures, from 25.4% in immature fruit to 55.6% in mature fruit, both results were much higher than those observed in Fig. 7C, that is, 6.0%, 7.0%; 7.46%; 5.42%, and 4.11% for the different batches. A possible explanation for the low bioaccessibility of Cu is the presence of Zn in high amounts in freshly processed pulp, since the excess of Zn impairs the absorption of Cu (Melo, 2015). In relation to Fe, Schulz et al. (2017) only were able to determine the bioaccessibility of this microelement in the third maturity stage, which was related to the increase of the protein content allowing a greater bioaccessibility of this mineral. Likewise, the presence of fibers in the juçara pulp (Troian et al., 2014) may have contributed to the low Fe bioaccessibility. In fruit such as blackberries, raspberries, blueberries, and strawberries the Fe bioaccessibility was of only 9%, and the authors associated that to presence of insoluble compounds, such as phytates and fibers present in fruit (Pereira et al., 2016), what can be the case of juçara pulp.

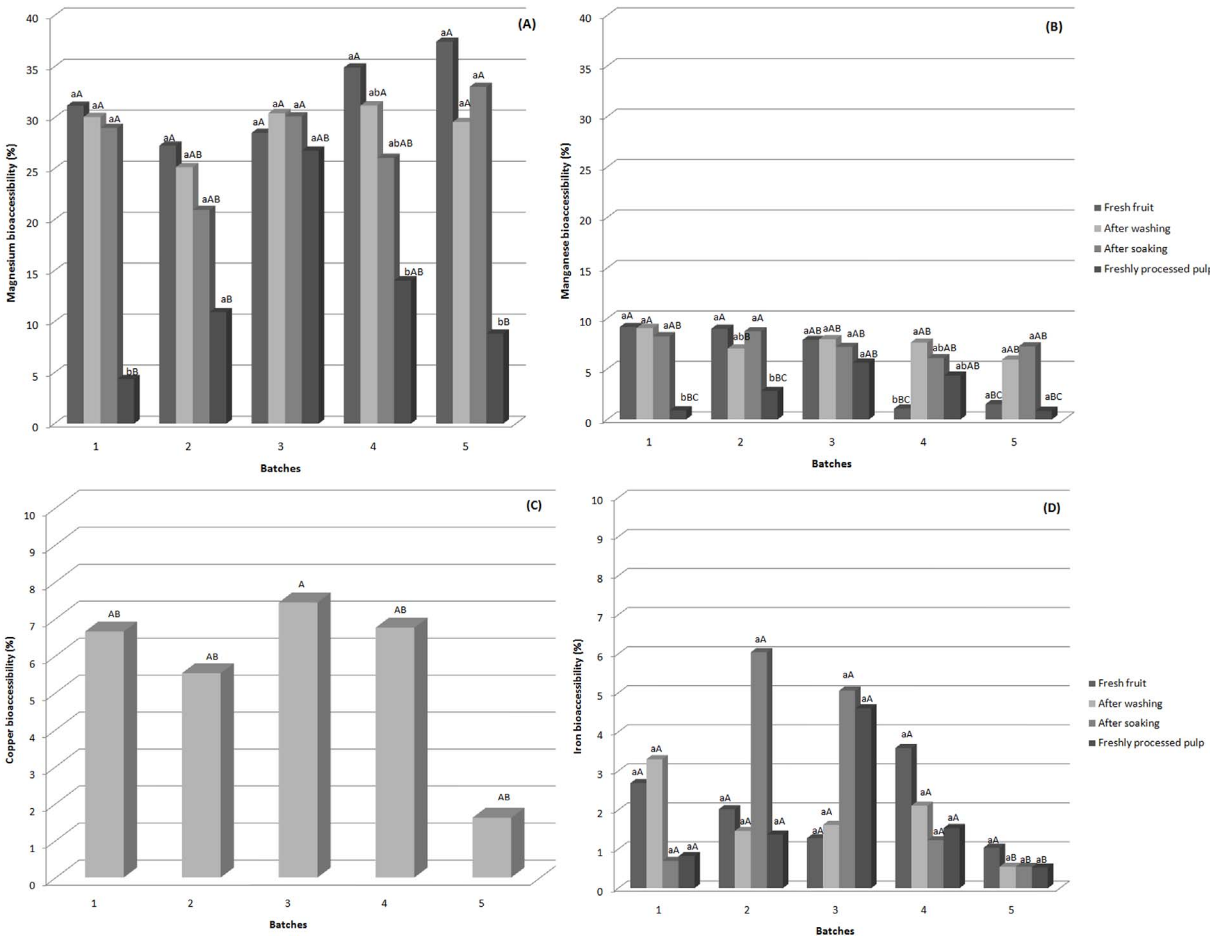

Fig. 7. (A) Magnesium (Mg), (B) manganese (Mn), (C) copper (Cu), and (D) iron (Fe) bioaccessibility (%) in the mesocarp and juçara (*Euterpe edulis* Mart.) pulp from different origins (batches) and processing stages. Values with the same lowercase letters, within origins, and with the same upper case letter, between treatments, are not statistically different by Tukey's test ($p > .05$).

5. Conclusions

The last processing step of juçara fruit, pulp extraction, affects the content of macro and microelements by increasing the contents of all chemical elements (Ca, Mg, Cu, Fe, Mn, and Zn) and reducing the bioaccessibility of Mg, Fe, Mn, and Cu.

All chemical elements (Ca, Mg, Cu, Fe, Mn, and Zn) were assessed via ICP OES, but Ca and Zn bioaccessibility could not be determined possibly due to contamination and/or the sensitivity of ICP OES.

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