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Relationship between the chemical components of taro rhizome mucilage and its emulsifying property

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ABSTRACT

The objective of this study was to determine the chemical composition of taro mucilage (TM) and explain its emulsification properties using different commercial emulsifiers and gums as benchmarks. The following analyses were performed: moisture, ether extract, protein, fiber, ash, sugar fraction, starch content, infrared spectroscopy and determination of monosaccharides and amino acids using HPLC. The analyses showed that TM has a high carbohydrate content and small protein fraction, similar to commercial gums. Commercial emulsifiers have a high content of lipids compared to TM. Therefore, it can be concluded that the emulsifying power of the studied mucilage is primarily caused by the protein content along with weakly polar amino acids, which occur in gums. The methyl group (—CH_3), which was observed in the infrared spectrum, and the lipid content may also contribute to the emulsifying activity by providing a hydrophobic moiety.

1. Introduction

Taro (*Colocasia esculenta*) is a plant from the humid tropical regions of Asia (India, Bangladesh and Myanmar) and belongs to the family *Araceae*. It is characterized by large dark green leaves, heart-shaped leaf blades and green or purplish petioles, which are long and positioned in the middle of the leaf. The height of the plant can vary from 30 to 180 cm depending on the cultivar (Brazil Ministry of Agriculture & Livestock & Food Supply, 2010). Its stem is modified into a starchy rhizome and forms the edible part of the plant. Its roots are abundant and fasciculated (Santos & Puiatti, 2002).

The rhizome from the taro plant can contain significant levels of mucilage, averaging between 6.84 g per 100 g (Tavares et al., 2011) and approximately 10 g per 100 g (Nip, 1980), depending on the extraction method. This mucilage has a viscous appearance and light color.

According to Njintang et al. (2014), the amount of carbohydrates in the mucilage of six different varieties of taro varies between 46 and 69 g per 100 g, suggesting that carbohydrates are the major component of this product. In the same study, the protein content was relatively high, ranging from 30 to 50 g per 100 g.

The literature states that the mucilage from this vegetable has emulsification and/or stabilization properties (Lin & Huang, 1993; Tavares et al., 2011), but the components that contribute to such stabilization remain unknown.

Emulsifiers are products that contain amphiphilic molecules: these molecules have a water-soluble polar component (hydrophilic) and a non-polar water insoluble component (lipophilic or hydrophobic), and are commonly used in the food industry. In baking, for example, emulsifiers can provide several benefits, ranging from easy dough manipulation to an increase in the volume and shelf life of the final product (Kokelaar, Garritsen, & Prins, 1995; Ribotta, Pérez, Léon, & Añón, 2004).

The main types of synthetic commercial emulsifiers are monoglycerides, propylene glycol monoesters, lactylate esters, acetylated monoglycerides and ethoxylated esters. Certain emulsifiers, such as lecithin and arabic, guar, xanthan, locust bean and carrageenan gums, have a natural origin.

Foods with natural ingredients and additives are currently preferred due to concerns about maintaining healthy lifestyles. Thus, the discovery, research and use of natural additives are very important. In addition to being a natural product, taro rhizome mucilage is easy to extract, has a large yield and is inexpensive to produce compared with some synthetic additives. Studying the chemical

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components of this mucilage is important, in order to better understand its activity as an emulsifier, and to identify the specific chemical molecule responsible for its emulsifying activity.

The objective of this study was to determine the chemical composition of the mucilage from the taro rhizome and to explain its emulsification properties via comparisons with different commercial emulsifiers and gums.

2. Materials and methods

2.1. Extraction of taro mucilage

Rhizomes were harvested ten months after planting and purchased at commercial establishments. Approximately 10 kg of rhizome was washed in running water, peeled and washed again in running water. Rhizome portions weighing 300 g were ground in an industrial blender for five minutes, and all portions were subsequently pooled and homogenized.

The mucilage was extracted manually from the triturated taro by filtration in a polyester mesh (40 cm × 40 cm), as proposed by Tavares et al. (2011).

The filtered mucilage was lyophilized for approximately 72 h to obtain lyophilized taro mucilage (TM) for further chemical analysis.

The emulsifiers used for comparison were calcium stearoyl-2-lactylate (CSL), sodium stearoyl-2-lactylate (SSL), diacetyl tartaric acid esters of mono-and di-glycerides (DATEM), lecithin, monoglycerides, arabic, carrageenan, guar, xanthan and locust bean gums, which were provided by different companies.

2.1.1. Extracted mucilage yield

The taro rhizomes were weighed, peeled and crushed. The taro mucilage was extracted and lyophilized, and the material was then reweighed to determine the TM yield.

2.2. Analyses

2.2.1. Proximate composition

The following analysis of the proximate composition (moisture, ether extract, crude protein, ash, crude fiber and sugar fraction) was performed for the TM and commercial gums. The emulsifiers (CSL, SSL, DATEM, lecithin and monoglycerides) were only subjected to ether extract analysis.

1. Moisture analysis according to AOAC method No. 925.09 (2000), to obtain the constant weight.
2. Ether extract analysis according to AOAC method No. 925.38 (2000).
3. Crude protein analysis according to the micro-Kjeldahl method – AOAC No. 920.87 (2000).
4. Ash analysis according to the AOAC gravimetric method (2000) No. 923.03, and calcined at 550 °C with the sample remaining inside the muffle furnace (Fornitec model 1926, Brazil).
5. Crude fiber analysis according to Van de Kamer and Van Ginkel (1952).
6. Sugar fraction (non-nitrogenized extract) analysis, which was determined as the remaining fraction according to Eq. (1) and AOAC (2000).

$$\text{Sugar fraction} = 100 - (\text{ether extract} + \text{protein} + \text{crude fiber} + \text{ash}) \quad (1)$$

2.2.2. Starch content

Starch was extracted by acid hydrolysis according to the AOAC technique (1990) and identified using the Somogyi method as modified by Nelson (1944). The resulting starch content is expressed as g per 100 g of dry matter. This analysis was only performed on TM because starch is not a component of the other products.

2.2.3. Determination of monosaccharides

Determination of monosaccharides was performed on the TM and commercial gums, and 8 benchmarks were used: fucose, arabinose, rhamnose, galactose, glucose, mannose, xylose and fructose. For carbohydrate hydrolysis, 0.8 mL of 72% sulfuric acid was added to a previously homogenized sample, which had rested for 1 h. A total of 5.0 mL of ultrapure water was added, and the flask was subjected to vacuum and ultrasound treatment for 5 min. The sample was then heated to 90 °C for 4 h in a block digester and then cooled and transferred to a 100 mL. The pH was adjusted to between 7.0 and 11.5. The sample was then transferred to a volumetric flask and topped up with ultrapure water.

High-performance liquid chromatography (HPLC) was used for the quantitative determination of monosaccharides. The HPLC consisted of an ICS-3000 SP pump (Dionex Brand) and AS Model autosampler (Dionex Brand) operating with a Model ICS-3000 ED amperometric electrochemical detector (IntAmp) (Dionex Brand). A CarboPac™ PA 1, 4 × 250 mm was used at a temperature of 22 °C. The mobile phase was ultrapure water at a flow rate of 0.7 mL min^{-1} and injection volume of 25 μL. A NaOH solution (200 mmol L^{-1}) and flow of 0.3 mL min^{-1} were used for the post-column. Under these conditions, the retention times of the monosaccharides fucose, arabinose, rhamnose, galactose, glucose, mannose, fructose and xylose were approximately 8.19, 20.73, 22.96, 27.27, 33.67, 47.17, 52.52 and 41.04 min, respectively.

The quantification of monosaccharides was performed by comparing the peak areas of the samples to a standard calibration curve.

2.2.4. Determination of amino acids

To identify the amino acids present in the TM and commercial gums, 10 mL of 6 mol L^{-1} hydrochloric acid was added to the previously homogenized sample, which was then placed in an oven at 110 °C for 24 h. After removal from the oven, the sample was cooled and filtered, and the filtrate was washed with ultrapure water and subsequently evaporated almost to dryness. A pH 2.2 citrate buffer was then added to the sample, and the pH was checked and adjusted to between 2.2 and 2.5. A 1.00 mL aliquot of the sample was extracted using a disposable syringe, filtered in a filter unit and placed in the autosampler for subsequent injection into the amino acid analyzer (chromatography–HPLC).

The mobile phases used to measure amino acids were labeled A, B and C.

Mobile phase A was prepared by dissolving 39.2 g of sodium citrate dihydrate in ultrapure water and then adding 140 mL of 99.5% ethanol and 33.3 mL of 60% perchloric acid. The pH was adjusted to 3.22, and the volume was brought up to 2 L with ultrapure water.

Mobile phase B was prepared by dissolving 117.6 g of sodium citrate dihydrate in ultrapure water and then adding 24.8 g of boric acid (0.2 mol L^{-1}) and 60 mL of NaOH (4.0 mol L^{-1}). The pH was adjusted to 10, and the volume was brought up to 2 L with ultrapure water.

Mobile phase C consisted of, 0.2 mol L^{-1} NaOH.

A Shimadzu Prominence HPLC operating with a fluorescence detector was used for the quantitative determination of amino acids. A Shim-pack Amino-Na (Shimadzu Brand) column was used. Amino acids were quantified using the mobile phases A, B and C described above, in a gradient, with an injection volume of 10 μL. The wavelength of the detector was set at 350 nm for excitation and 450 nm for emission.

For post-column reaction derivatization, sodium hypochlorite, orthophthaldehyde (OPA) and 2-mercaptoethanol were used, with the latter two used for the formation of a stable fluorescent compound.

The quantification of amino acids was performed by comparing the peak areas of the samples to a standard calibration curve (Prates, 2002).

2.2.5. Infrared spectroscopy (FTIR)

The TM and commercial gums were analyzed using Fourier transform infrared spectroscopy (FTIR) on a Digilab Excalibur device, series FTS 3000 (United States), with a DTGS detector, spectral range of 4000–400 cm^{-1} and resolution of 4 cm^{-1}. The transmission of the samples in 7 mm diameter KBr pellets was measured.

2.3. Statistical analysis

To compare the ether extract content between the TM and commercial emulsifiers, a mean test (Scott-Knott) was used with a 5% significance level using the Sisvar program (Ferreira, 1999).

Principal component analysis (PCA) was used with autoscaling to compare the characteristics of the TM and the five commercial gums using the software Chemoface version 1.4 (Nunes, 2012).

3. Results and discussion

3.1. Lyophilized taro mucilage (TM) yield

The TM yield in relation to its rhizome content was 9.63 g per 100 g, or 9.63%.

In an earlier work by Tavares et al. (2011), the yield of this mucilage was 6.84 g per 100 g, which is lower than the value found in the present study. This difference may be related to the physiological stage of the rhizome, which may affect its chemical composition and mucilage yield. The value found was shown to be consistent because taro rhizome has an average moisture content of 73.21 g per 100 g.

3.2. Ether extract content of commercial emulsifiers and TM

The percentage and standard deviation for the ether extract content of the commercial emulsifiers CSL (calcium stearoyl-2-lactylate), SSL (sodium stearoyl-2 lactylate), monoglycerides, lecithin, DATEM (diacetyl tartaric acid ester of mono- and di-glycerides) and of TM (full field values) were 48.02 ± 0.05, 73.33 ± 0.65, 96.16 ± 0.32, 90.54 ± 0.88, 89.01 ± 0.92 and 0.44 ± 0.02, respectively. A Scott-Knott test at 5% probability of these means indicated that all of the values were different from each other, with a coefficient of variation of 0.90%.

A high amount of ether extract was detected in the commercial emulsifiers, indicating that this chemical component was responsible for the emulsifying power. However, the TM had a low ether extract content; thus, the ether extract was not the component most responsible for the emulsifying activity of TM, and further study of its chemical composition was justified.

The chemical component that provides emulsifying power to TM may be related to the presence of carbohydrates (which contribute to the hydrophilic component), and the presence of a protein fraction (which provides the hydrophobic component because of nonpolar radical amino acids) These components are similar to those in the commercial gums that have been used as emulsifiers, stabilizers (emulsion stabilizers) and suspending agents since ancient times (Simão, 1985).

3.3. Proximate composition

Table 1 shows the values for the proximate composition of TM and arabic (GA), carrageenan (CG), locust bean (LBG), guar (GG) and xanthan (XG) gums.

All of the products analyzed had a high sugar fraction and protein fractions between 1.45 and 6.34 g per 100 g.

Both the TM and five gums studied had a percentage of ether extract lower than 1.00.

The moisture content of GA quantitatively differed from the other components. Even when the TM was lyophilized, it had a moisture percentage that may have been acquired during storage, prior to analysis and/or caused by incomplete lyophilization.

The GA was the only product with a high crude fiber content. The GA, CG and XG gums were high in ash.

In a study by Tavares et al. (2011), the moisture, ether extract, protein, ash and sugar fraction values of TM were 8.68, 0.70, 9.66, 5.33 and 65.18 g per 100 g, respectively. Large discrepancies were found in the sugar and protein content, which can be explained by the maturation stage of the plant, which is one of the factors that decisively influences the characteristics of horticultural products. In yam/taro rhizomes, the maximum dry matter content can be achieved for products that are close to physiological maturity, whereas the maximum protein content occurs well before the maturity stage. The greatest accumulation of starch usually occurs six months after planting, and there may be a reduction at the eighth month (Brillouet, Treche, & Sealy, 1981; Ketiku & Oyenuga, 1973). In addition, the conversion of organic acids into sugars may occur as the rhizome matures. It can therefore be stated that the chemical composition of TM varies according to the physiological stage of the rhizomes.

When the chemical composition of the gums was compared to values in the literature, the largest discrepancy was found in the ash content of the GA, CG, XG and GG gums. For the first three gums, the value was much higher than usually found: 1.20, 15.0,

Table 1
Mean values for the moisture, ether extract, crude protein, crude fiber, ash and sugar fractions in g per 100 g of taro mucilage and of arabic, carrageenan, locust bean, guar and xanthan gums.

Mucilage and gums	M	EE*	CP*	CF*	A*	SF*
	g per 100 g					
TM	8.47 ± 0.09	0.48 ± 0.02	3.18 ± 0.09	0.35 ± 0.09	4.05 ± 0.11	91.94 ± 0.17
GA	16.06 ± 0.13	0.52 ± 0.13	1.45 ± 0.35	28.03 ± 0.17	20.26 ± 0.25	49.74 ± 0.70
CG	6.52 ± 0.49	0.20 ± 0.02	4.79 ± 0.07	0.61 ± 0.16	25.45 ± 0.06	68.95 ± 0.09
LBG	7.99 ± 0.18	0.99 ± 0.09	6.15 ± 0.30	2.43 ± 0.12	1.05 ± 0.05	89.38 ± 0.28
GG	7.71 ± 0.11	0.41 ± 0.06	4.39 ± 0.08	0.60 ± 0.28	0.79 ± 0.02	93.81 ± 0.22
XG	7.70 ± 0.02	0.20 ± 0.02	6.34 ± 0.10	0.49 ± 0.13	10.55 ± 0.03	82.42 ± 0.14

The results reported are the means of triplicate samples ± SD. TM = lyophilized taro mucilage; GA = gum arabic; CG = carrageenan gum; LBG = locust bean gum; GG = guar gum; XG = xanthan gum; M = moisture; EE = ether extract; CP = crude protein; CF = crude fiber; A = ash; SF = sugar fraction.
* Dry basis.

and 0.86 g per 100 g, respectively (CARRAGENAS, 2012; Cui & Mazza, 1996). For GG, the value was lower than the value found by Cui and Mazza (1996): 11.90 g per 100 g. These results show that the gums studied are not in their purest form, and in some cases, this can change their function as additives.

The chemical composition suggests that the emulsifying power of the gums and TM can occur due to the presence of carbohydrates (hydrophilic part) together with the small protein fraction, because of its conformation and the presence of amino acids with hydrophobic radicals. The lipid fraction may help in emulsification, however its content is low, and the gums usually do not contain lipids.

3.4. Starch and monosaccharides

Starch is not present in the official description of the five commercial gums used in the study. TM may have a higher starch content because the taro rhizome is rich in starch. Therefore, it is important to determine the starch content of TM to account for the emulsifying power of the mucilage.

A value of 47.10 g per 100 g for starch was found in the TM. This value is lower than the value found by Tavares et al. (2011): 59.45 g per 100 g. This difference can be explained by the physiological stage of the rhizome.

Fig. 1 shows the chromatograms of the monosaccharides in the TM and commercial gums, and Table 2 shows their values in g per 100 g.

The following monosaccharides were found in TM in descending order: glucose, fructose, galactose, mannose, fucose, arabinose, rhamnose and xylose. The glucose percentage was high because starch was not removed during mucilage extraction. As previously noted, TM has 47.10 g per 100 g starch. According to Njintang et al. (2014), the main monosaccharides present in the mucilage of six different varieties of taro are galactose, mannose and arabinose. A data simulation that disregarded all of the TM starch as if the mucilage had been fully purified was performed in the present study; this simulation indicated that the main monosaccharides would be fructose (48.45%), galactose (26.97%), mannose (9.31%), fucose (7.88%) and arabinose (5.49%). In this case, there would be a higher concentration of arabinogalactan-protein (AGP), which could be responsible for the emulsifying power because according to Jiang and Ramsden (1999), TM has between 93.2% and 98.2% AGP.

In all of the studied gums, monosaccharides that are not commonly expected were found. In the case of GA, fructose, fucose and mannose were present. For LBG, mannose and galactose residues were prominent as expected, but others were present, such as fructose, glucose, xylose and rhamnose. There were high levels

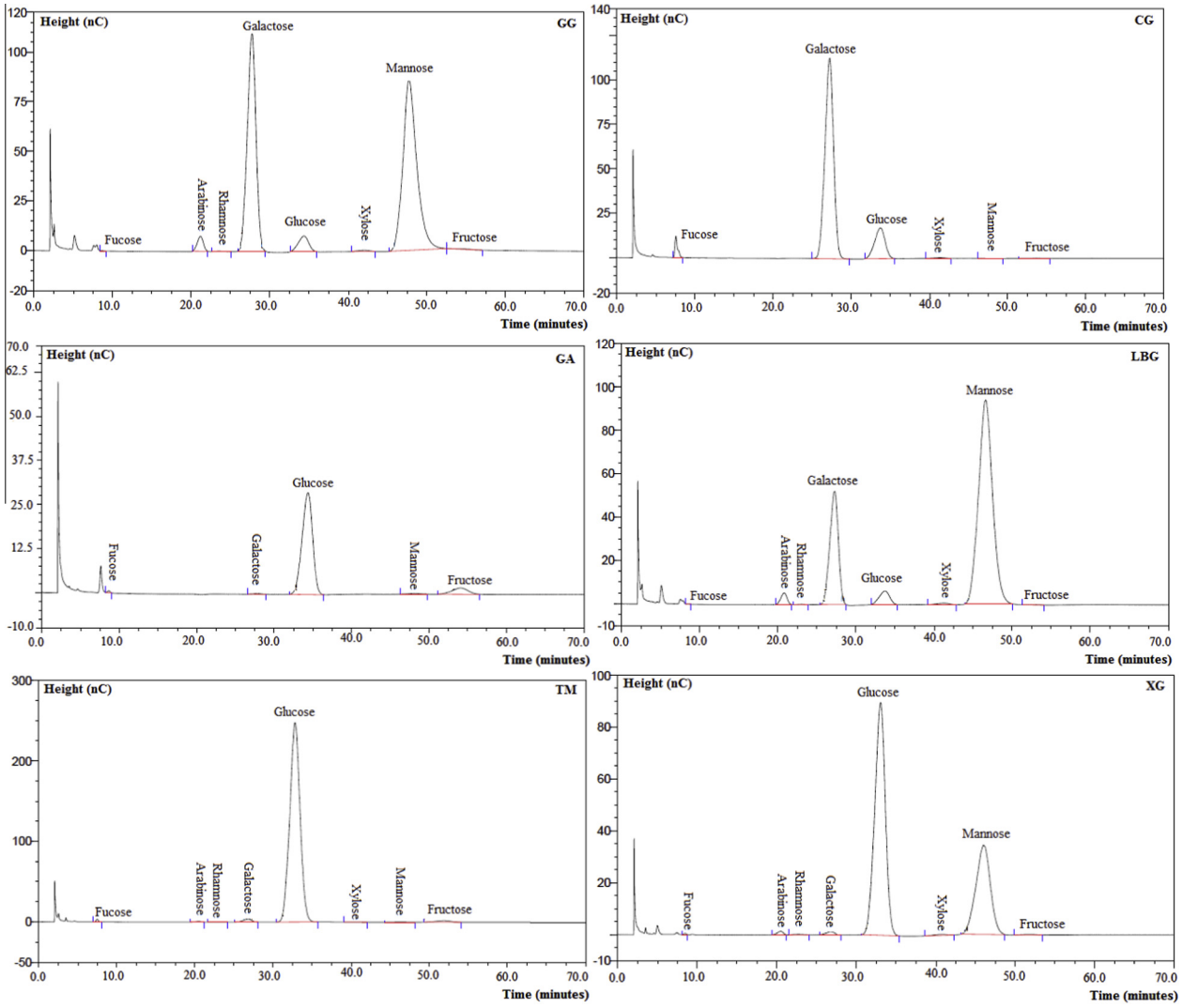

Fig. 1. Chromatograms of monosaccharides from taro mucilage (TM) and carrageenan (CG), arabic (GA), locust bean (LBG), xanthan (XG) and guar (GG) gums.

Table 2
Values in g per 100 g for the main monosaccharides and amino acids present in taro mucilage and in arabic, carrageenan, locust bean, guar and xanthan gums.

	TM	GA	CG	LBG	GG	XG
Monosaccharides			*g per 100 g*			
Fructose	1.63	1.56	0.13	0.07	0.19	0.19
Fucose	0.26	0.05	1.03	*	0.03	0.04
Arabinose	0.18	**	**	0.97	1.29	0.23
Galactose	0.90	0.05	29.04	12.10	24.25	0.25
Glucose	76.46	8.47	5.16	1.91	2.24	27.77
Xylose	0.02	**	0.10	0.26	0.19	0.12
Rhamnose	0.04	**	**	0.06	0.07	0.11
Mannose	0.31	0.21	0.07	84.13	70.69	30.83
Amino acids			*g per 100 g* ***			
Lysine	23.27	4.02	6.22	13.06	13.00	14.66
Tryptophan	20.93	13.63	9.81	19.16	19.18	25.69
Threonine	6.72	5.37	6.37	4.77	5.58	5.18
Serine	5.85	6.83	15.00	10.33	6.54	4.94
Proline	0.00	0.00	1.68	0.34	0.19	0.11
Glycine	2.75	2.01	6.13	2.83	5.72	2.70
Alanine	4.91	6.43	4.73	4.00	4.02	5.90
Cysteine	9.50	14.12	7.38	6.88	7.31	5.20
Valine	0.00	7.01	1.76	0.00	0.00	0.00
Isoleucine	8.80	14.83	5.38	6.43	6.98	7.86
Leucine	7.97	7.19	11.63	6.13	5.90	8.02
Phenylalanine	6.16	4.53	6.39	4.79	4.31	4.29
Tyrosine	0.00	4.79	5.65	0.00	4.98	5.29
Histidine	3.14	9.24	3.36	6.12	2.75	2.76
Glutamine	0.00	0.00	8.51	15.16	13.54	7.40
Asparagine	0.00	0.00	0.00	0.00	0.00	0.00
Arginine	0.00	0.00	0.00	0.00	0.00	0.00

TM = lyophilized taro mucilage; GA = gum arabic; CG = carrageenan gum; LBG = locust bean gum; GG = guar gum; XG = xanthan gum.
* Below analytical quantification limit of 100.00 mg per kg.
** Below analytical detection limit of 50.00 mg per kg.
*** Results expressed in % of each amino acid relative to the total amino acid content in the sample.

of galactose in CG because it is the major monosaccharide, but fructose, fucose, glucose and other sugars were also found.

The presence of other monosaccharides that are not characteristic of GA, CG, LBG, GG and XG may result from contamination during the processing of the gum, which indicates that the commercial gums were not completely pure.

3.5. Amino acids

Table 3 shows the mean retention times (RT_m) and the peak area of each amino acid found in the TM and five commercial gums. Table 2 shows their respective values per 100 g. Alanine, isoleucine, leucine, phenylalanine, proline, tryptophan and valine are weak-polar amino acids.

In the present study, the main amino acids in TM were lysine, tryptophan, cysteine, isoleucine and leucine. According to Njintang et al. (2014), the major amino acids present in the mucilage of six different varieties of taro were aspartic acid, asparagine, glutamine, glutamic acid, glycine, leucine and serine. The discrepancy may be related to differences among the taro rhizome varieties and environmental issues during cultivation and at the maturity stage. The presence of leucine, isoleucine and tryptophan found in the present study could contribute to the emulsifying power of TM, because radicals of these amino acids are partially or entirely hydrophobic.

For GA, XG, LBG and GG, the presence of certain amino acids contradicted the literature results. Anderson, Howlett, and McNab (1985) performed a careful comparison of amino acids in samples of commercial GA and noted that there was variability among them. Such variations are expected because GA is a complex natural product that is subject to seasonal and geographical variations.

In the case of XG, the amino acid valine was not found, and arginine was not found in the LBG and GG gums. According to the literature, these amino acids should be present (Anderson, Howlett, & McNab, 1986; Anderson et al., 1985; Kök, 2007).

In CG, the amino acids found with the highest concentrations were serine, tryptophan, glutamine, leucine and cysteine. However, data on the predominant amino acids in this commercial gum were not found in the literature.

The difference found in the presence of certain amino acids compared with that reported in the literature may result from the large variability in the quality of existing brands. This may affect their functional and chemical properties and may therefore change the amount and type of amino acids found.

3.6. FTIR

Fig. 2 shows the Fourier transform infrared spectra (FTIR) for the taro mucilage and five gums.

A wide band between 3500 and 3100 cm^{-1} can be observed in all of the spectra, which corresponds to the axial deformation of hydroxyl groups with intermolecular hydrogen bonding in alcohol, which is commonly found in polysaccharide groups and confirms the presence of carbohydrates in all of the samples (Mothé &

Table 3
Mean retention time (RT_m) and peak areas for all amino acids found in taro rhizome mucilage (TM) and arabic (GA), guar (GG), carrageenan (CG), locust bean (LBG) and xanthan (XG) gums.

Amino acid	RT_m (min)	Peak area					
		GG	CG	GA	LBG	TM	XG
Lysine	5.85	629616.7	974495.0	109067.8	716449.9	813872.1	631532.6
Tryptophan	7.19	689191.2	3217467.9	116106.5	797765.6	538717.9	834404.6
Threonine	7.69	948497.4	4356887.9	135834.9	922125.8	809693.0	736881.6
Serine	8.25	1325515.2	12,908,775	209716.0	2736243.1	726690.1	753405.6
Proline	9.53	119441.9	826461.0	0.00	145434.5	0.00	106923.3
Glycine	12.19	3566049.1	13229060.0	258929.8	1936344.8	1134415.1	1380341.8
Alanine	13.09	602290.4	3810778.9	111804.8	755854.5	490589.0	940038.0
Cysteine	17.10	651983.2	4343033.3	131508.1	771097.5	580898.1	76709.9
Valine	19.61	0.00	578051.7	151484.5	0.00	0.00	0.00
Isoleucine	21.91	447786.7	2728284.9	60716.1	527387.6	340813.6	450755.1
Leucine	22.80	508432.2	4599328.9	81765.7	646164.6	503067.3	661514.5
Tyrosine	24.59	207889.8	1000430.2	17410.9	0.00	0.00	192183.1
Phenylalanine	26.04	340198.8	2424630.6	2554.3	484222.6	366332.3	279531.2
Histidine	27.69	426985.6	1795048.4	499841.7	1116285.8	357051.0	379263.5
Glutamine	31.52	150334.1	279709.6	0.00	183561.9	0.00	89422.4

TM = lyophilized taro mucilage; GA = gum arabic; CG = carrageenan gum; LBG = locust bean gum; GG = guar gum; XG = xanthan gum; RT_m = mean retention time; min = minutes.

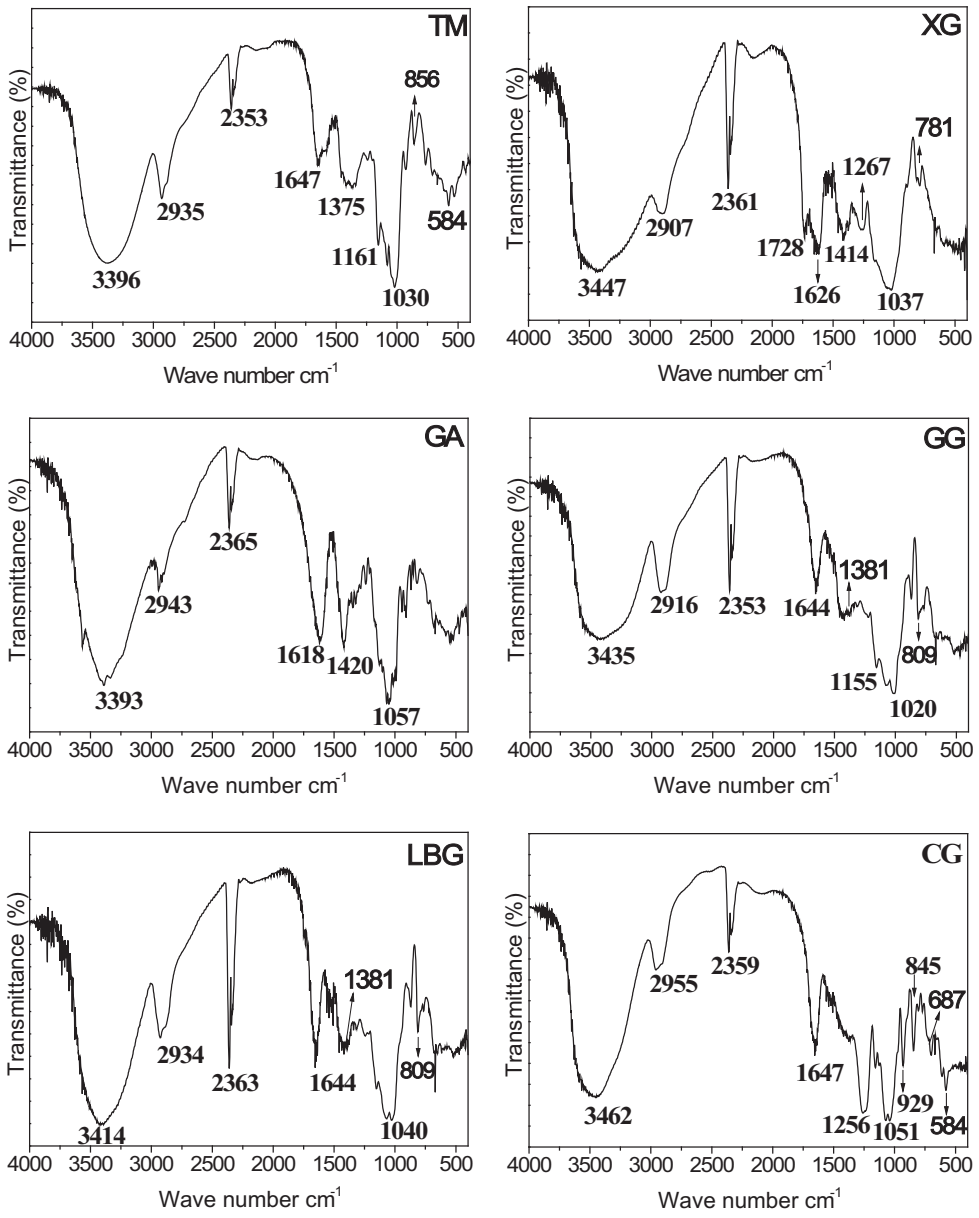

Fig. 2. FTIR spectra of taro mucilage and xanthan (XG), arabic (GA), guar (GG), locust bean (LBG) and carrageenan (CG) gums.

Correia, 2002). This band may also represent the N—H bonds in the proteins.

The bands at 2907, 2935, 2943, 2916, 2934 and 2955 cm^{-1} are assigned to the axial deformation of the CH bond, which is found in the region between 3000 and 2840 cm^{-1} (Mothé & Correia, 2002).

The band between 1700 and 1600 cm^{-1} is known as the amide I band and is mainly due to the C=O stretching of the peptide groups, revealing the presence of a protein in TM and in the commercial gums studied (Osiro, Coleta-Filho, Machado, & Colnago, 2000). Lin and Huang (1993) observed a band at 1650 cm^{-1}, supporting the presence of proteins in unpurified taro gum.

In the LBG, GG and TM samples, bands near 1380 cm^{-1} were found for the first two samples, and a 1375 cm^{-1} band was found for the latter sample. These bands indicate the presence of a methyl group ($—CH_3$) (Silverstein, Webster, & Kiemle, 2006), which can provide a hydrophobic moiety to these samples, and thus facilitates their emulsifying activity.

The XG spectra showed a characteristic band of the axial deformation of the carbonyl (C=O) in esters, carboxylic acids, aldehydes and ketones that lies between 1730 and 1710 cm^{-1} (Faria et al., 2011). This same gum had a band between 1320 and 1210 cm^{-1}, which is characteristic of the C—O stretching of carboxylic acids (Silverstein et al., 2006).

In the XG and GA spectra, there was a band between 1440 and 1395 cm^{-1}, which is characteristic of an angular deformation of the C—O—H of carboxylic acid (Silverstein et al., 2006).

The band between 1200 and 1000 cm^{-1} in TM (1161 cm^{-1}), which is similar to that reported by Lin and Huang (1993), may result from alcohol C—OH groups, especially in structures such as carbohydrates. As expected, a band in this region was found in all gums.

For TM, Tavares et al. (2011) found bands between 3400 and 3300, 2950 and 2800, 1680 and 1630, and 900 and 1300 cm^{-1}; these bands are similar to the bands found in the present study and indicate that TM contains carbohydrates.

CG had a band between 1260 and 1210 cm^{-1}, which differs from TM and other gums, indicating the presence of a sulfate ester group that is characteristic of this gum.

Charles, Huang, and Chang (2008) state that absorption at 800 cm^{-1} in crude and purified manioc mucilage samples is due to mannose, which can also be observed in the GG and LBG spectra at 809 cm^{-1}. The monosaccharide analysis in this study shows that these gums have high concentrations of these sugars, with 70.69 g per 100 g and 84.13 g per 100 g, respectively.

3.7. Chemometric comparison between the characterization of TM and commercial gums

The results from the characterization of TM and five commercial gums were subjected to principal component analysis (PCA), to compare the characteristics of TM with those of the commercial gums.

A visual representation of the first three principal components, which explain 85.55% of the total variability among the samples (Fig. 3), showed that only GG and LBG were similar based on the analyses performed.

The graph showing the scores revealed that for the analyses conducted, the chemical composition of TM is not close to that of any of the commercial gums. This result may be explained by the high glucose content compared with that of the other samples. The high glucose content can be explained by the high amount of starch detected. The compounds that distinguish TM from the other gums are not responsible for all or part of its emulsifying power. In this case, the compounds are the proteins with hydrophobic amino acids and the remainder are carbohydrates with their polar components.

GG and LBG are similar according to the analyses performed; this similarity most likely occurs because of the similar contents of monosaccharides, such as mannose, arabinose and rhamnose. The GG and LBG gums are galactomannans and have high mannose and galactose content. In LBG, in general, there are four mannose units per unit of galactose.

The chemical compositions of XG, CG and GA are not similar to each other or to the other samples studied because of the tryptophan and tyrosine outliers for XG, and the high levels of fucose and proline for CG. Finally, it can be observed that the values of crude fiber, moisture, and the amino acids isoleucine and valine of GA are quite different compared with those of the other gums.

Even if TM is not similar to any of the commercial gums according to the PCA, it can be inferred that its emulsifying power is a result of the presence of protein, either just as a residue or as a complex with carbohydrates, and also to the possible presence of the methyl group observed in the infrared spectrum.

3.8. Hypotheses about the emulsifying power of TM and the commercial gums

The polysaccharides that are most commonly used in foods as emulsifiers are gum arabic, modified celluloses, starches and some galactomannans (Dickinson, 2003; Garti & Reichman, 1993). The interfacial activity and emulsifying power of these hydrocolloids have their origin in the following: the hydrophobic nature of the chemical groups attached to the polysaccharide (in the case of modified starch and cellulose), the presence of protein linked covalently or physically to the polysaccharide (such as gum arabic) or simply contamination by weak-polar proteins/peptides in the sample, such as in the case of galactomannans (guar and locust bean gum, for example).

According to some studies, gum arabic consists of three major components, namely, arabinogalactan (AG), arabinogalactan-protein (AGP) and glycoprotein (GP) (Randall, Phillips, & Williams, 1989; Renard, Lavenant-Gourgeon, Ralet, & Sanchez, 2006). AGP has a protein fraction attached to the carbohydrate blocks and may be responsible for the emulsifying power because of the weak-polar amino acids usually present in this complex.

Jiang and Ramsden (1999) investigated the mucilage of twelve varieties of taro and found that they all had a large percentage of AGP (93.2–98.2%). This fact suggests that AGP (a glycoprotein) is responsible for the emulsifying power in taro rhizome mucilage, as it is in gum arabic. In the present study, a reasonable amount of weak-polar amino acids were found, which may have contributed to the emulsification.

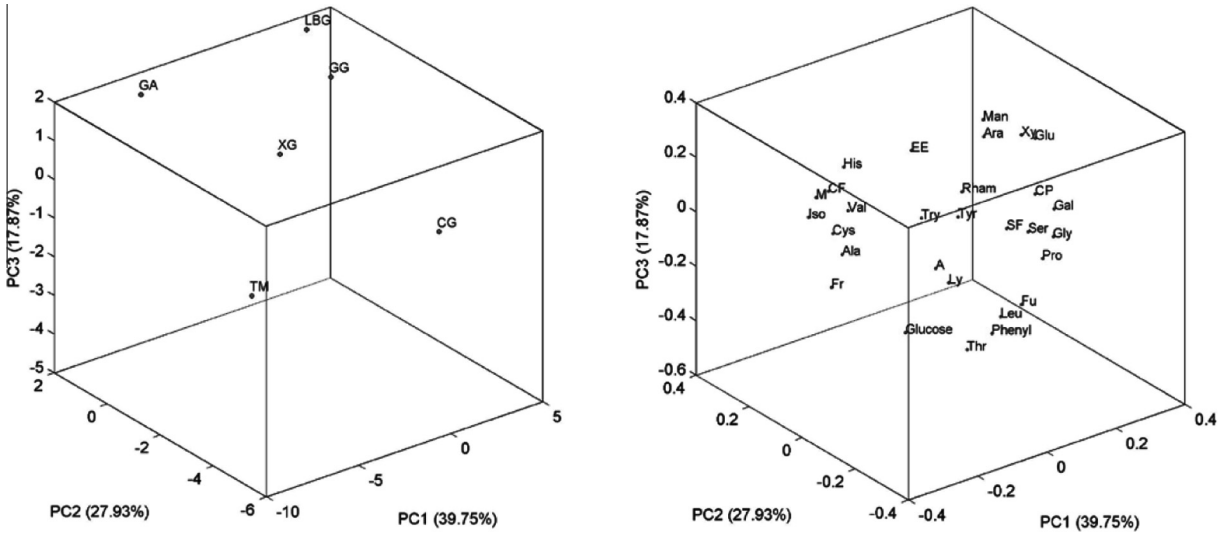

Fig. 3. Graph of principal component analysis (PCA) scores of TM and the five commercial gums and graph of the PCA weights with the following abbreviations: TM = lyophilized taro mucilage; GA = gum arabic; CG = carrageenan gum; LBG = locust bean gum; GG = guar gum, XG = xanthan gum, M = moisture; EE = ether extract; CP = crude protein; CF = crude fiber; A = ash; SF = sugar fraction; Fr = fructose; Fu = fucose; Ara = arabinose; Gal = galactose; Glucose = glucose; Xy = xylose; Rham = rhamnose; Man = mannose; Ly = lysine; Try = tryptophan; Thr = threonine; Ser = serine; Pro = proline; Gly = glycine; Ala = alanine; Cys = cysteine; Val = valine; Iso = isoleucine; Leu = leucine; Phenyl = phenylalanine; Tyr = tyrosine; His = histidine; and Glu = glutamine.

A hypothesis proposed by Yadav, Igartuburu, Yan, and Nothnagel (2007) is that gum arabic contains traces of lipids, and these lipids may be linked to AGP as a glycosylphosphatidylinositol (GPI) link, which may contribute to the emulsifying activity of the gum. It can thus be inferred that the amount of 0.48 g per 100 g of ether extract found in TM may, perhaps, contribute to its emulsifying power; however, further analyses are required to better understand these lipids and confirm this effect.

An interesting discovery in the TM was the presence of a band at 1375 cm^{-1} in the FTIR spectrum; this band is characteristic of the methyl group (—CH_3) that, depending on quantity, can also contribute to the emulsifying power of this mucilage.

4. Conclusions

In the experimental conditions under which this study was conducted, the results show that TM has a high sugar fraction and is largely composed of starch, which leads to the large glucose content after acid hydrolysis. Moreover, TM also has a protein fraction. The compound that provides the emulsifying power of TM is not the same as that in commercial emulsifiers (CSL, SSL, monoglycerides, lecithin and DATEM) because, unlike TM, the commercial emulsifiers have a high ether extract content. The emulsifying power of the mucilage studied mainly results from the protein content, with the presence of weak-polar amino acids, especially leucine, isoleucine and tryptophan. The presence of the methyl group, which was observed in the infrared spectra, and the presence of low amounts of lipids may also contribute to the emulsifying power by providing a hydrophobic moiety. The hydrophilic portion of this emulsifier mainly consists of hydroxyl-containing carbohydrates.

The PCA revealed that the composition of TM is not close to that of any commercial gum. However, this difference is not caused by the protein compound that can provide, fully or in part, the emulsifying activity of all these products; instead, the difference is caused by the high glucose content.

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