PHYSICAL AND CHEMICAL ANALYSIS IN CRUDE TARO MUCILAGE OBTAINED BY SIMPLE EXTRACTION TECHNIQUE

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ABSTRACT: The crude taro mucilage (CM) is considered a product that contains the presence of starch and other carbohydrates. The use of this mucilage, especially as an emulsifier, is interesting for the bakery industry. The objective of this study was to understand the chemical and physical characteristics of CM in order to justify its emulsifying action, and find other potential applications in the food industry. In the first stage of the work, the raw material (taro rhizome) used for the extraction of mucilage was chemically characterized (moisture, ether extract, crude protein, crude fiber, ashes, and glicidic fraction). The CM was extracted through a simple method and without the use of chemical reagents, using rhizome crushed, filtration on a polyester mesh and lyophilized. Proximate composition, starch, minerals, monosaccharides, amino acids, infrared spectrum, X-ray diffractometry, and thermal property analyses were conducted in the mucilage. The CM has thermal stability up to approximately 200 °C, and it has semi-crystalline structure. The mucilage studied contains arabinogalactan polysaccharide, which can be linked to the protein fraction according to infrared analysis, forming the arabinogalactan-protein macromolecule responsible for the emulsifying property. The starch found is the main cause for its thickening action. Moreover, the CM can be considered a mineral-enriching flour in food products due to the increase of ashes by the mucilage extraction process and the high content of iron micromineral.

KEYWORDS: COLOCASIA ESCULENTA, MINERALS; MONOSACCHARIDES; NATURAL EMULSIFIER; TARO RHIZOME.

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1. INTRODUCTION

The taro (*Colocasia esculenta*) originates from humid tropical regions in Asia, and it is part of the Araceae family. Its rhizome has a high carbohydrate content, with starch as the main component, formed by small granules (Singla et al., 2020; Wanga, Reddy, & Xu, 2018, Andrade, Barbosa, & Pereira, 2017). The taro has a significant amount of mucilage, a light colored and viscous hydrocolloid (Andrade, Nunes, & Pereira, 2015).

The taro rhizome mucilage can be used in the food industry as an emulsifier, thickener, stabilizer, and partial replacement of hydrogenated fat in baking (Contado et al., 2009; Tavares et al., 2011; Nagata, Andrade, & Pereira, 2014). Its use is interesting because it is a natural product.

The purified taro mucilage, that is, extracted cold (4 °C) and precipitated with ethanol, is formed, mainly, by non-starchy carbohydrates and proteins with the presence of AGP glycoprotein (arabinogalactan-protein) responsible for its emulsifying action, with carbohydrates responsible for the hydrophilic part, and non-polar and weakly polar amino acids contributing to the hydrophobic fraction (Andrade et al., 2015; Andrade, Silva, Nunes, & Pereira, 2020).

It is interesting to study simpler and more cost-effective ways of extracting taro mucilage that can be used in food industries, adding value to the taro rhizome. The simplest way to extract mucilage from this rhizome is to grind the taro with water in a blender and filter it in polyester fabric (Contado et al., 2009; Tavares et al., 2011; Nagata et al., 2014; Andrade et al., 2015; Miamoto, Pereira, & Bertolucci, 2018; Andrade et al., 2020). The drying method can be in an oven with forced air circulation, vacuum oven or lyophilization. The product obtained is called crude taro mucilage (CM) due to the presence of impurities, mainly starch. The CM is also formed by non-starchy carbohydrates, proteins, and ashes in addition to other compounds such as lipids in smaller proportions (Andrade et al., 2015).

Most of the works carried out with taro mucilage do not study its crystalline structure or its profile of minerals and other impurities. Therefore, there is a lack of information regarding the properties of the mucilage and its emulsifying action.

The objective of this study was to understand the chemical and physical characteristics of CM to justify its emulsifying action and find other potential uses in the food industry. The CM was extracted through a simple method and without the use of chemical reagents.

2. MATERIAL AND METHODS

The study was divided into two phases. The first one chemically characterized the taro rhizomes used for extracting the mucilage. The second phase extracted the crude taro mucilage (CM) with a simple method and without the use of chemical reagents, and characterized it, chemically and physically, to justify its properties.

2.1 FIRST PHASE - PROXIMATE COMPOSITION OF TARO RHIZOMES

Taro rhizomes were purchased at a retailer of horticultural products in the city of Lavras, in the state of Minas Gerais, Brazil. These rhizomes were washed and peeled for subsequently completing the proximate composition. The following chemical analyzes were conducted with results published in dry matter:

1. Moisture was determined using the gravimetric method and the use of heat. The material was submitted to heating in an oven at 105 °C in order to lose weigh. This process was carried out until constant weight was reached as in accordance to the AOAC methodology (2000).
2. Ether extract was determined following the Soxhlet method, using sulfuric ether as organic solvent (AOAC, 2000);

3. Crude protein was obtained by determining the percentage of total nitrogen in the sample following the Kjeldahl method (AOAC, 2000). The result was multiplied by the factor 6.25;
4. Ashes were determined according to the AOAC gravimetric method No. 923.03 (2000) with calcination at 550 ºC, and with the sample remaining inside the FORNITEC muffle oven, model 1926, Brazil;
5. Crude fiber was determined by the gravimetric method of Kamer and Ginkel (1952);
6. The method used to determine the glicidic fraction was the difference calculation according to AOAC (2000).

2.2 SECOND PHASE - CM EXTRACTION AND ITS CHEMICAL AND PHYSICAL CHARACTERIZATION

The rhizomes were washed in running water, peeled, and, once more, washed in water. 300 g portions of the vegetable were crushed at high speed in an industrial blender (Lucre, Catanduva, Brazil) for five minutes, and, at the end, all portions were homogenized.

Mucilage of the crushed taro was manually extracted by filtration on a polyester mesh (40 cm x 40 cm), as mentioned by Contado et al. (2009). Later, it was lyophilized for approximately 75 hours in the Liobras device (L101), and, next, macerated, homogenized, and kept in a desiccator until the analyzes were performed.

2.2.1 DETERMINATION OF CHEMICAL COMPONENTS

The proximate composition was performed as mentioned in item 2.1 with the exception of the moisture content that was measured by a rapid method, using an infrared moisture analyzer (MOC-120H, Shimadzu, Brazil). Approximately 10 g of the taro mucilage sample was used, which remained subject to infrared rays for a period of time. The equipment itself calculated the moisture content.

The starch content was identified according to the Somogy-Nelson method (1944), by washing (ethanol) for sugar removal, autoclaving, neutralization, deproteinization, and determination by spectrophotometer (Varian Indústria e Comércio Ltda., Inc., modelo Cary 50, Brasil) reading using a 510 nm wavelength.

The minerals calcium, magnesium, manganese, copper, zinc, and iron were determined by atomic absorption spectrometry; phosphorus, sulfur and boron, by spectrophotometry, and potassium, by flame photometry, according to the techniques described by Malavolta, Vitti and Oliveira (1997). The result was expressed in g 100 g^{-1} of dry matter for macrominerals and in mg kg^{-1} for microminerals.

For the determination of monosaccharides, eight standards were used, which were fucose, arabinose, rhamnose, galactose, glucose, mannose, xylose, and fructose. For the hydrolysis of carbohydrates, 0.8 mL of 72% sulfuric acid solution was used in the previously homogenized sample that remained at rest for one hour. 5.0 mL of ultrapure water was added, and the flask was subjected to vacuum and ultrasound for 5 minutes. The sample was heated to 90 °C for four hours in the digester block. It was cooled and transferred with ultrapure water to a 100 mL beaker. The pH was adjusted between 7.0 and 11.5. It was transferred to a volumetric flask and completed with ultrapure water to 100 mL.

For the quantitative determination of monosaccharides, the high-performance liquid chromatograph (HPLC), composed of a pump Model ICS-3000SP (Dionex brand); automatic injector Model AS (Dionex brand) operating with amperometric electrochemical detector Model ICS-3000 ED (IntAmp) (Dionex brand), was used. The column used was CarboPac TM PA 1, 4 x 250 mm, at 22 °C. For the quantification of monosaccharides, the mobile phase used was ultrapure water, with a flow rate of 0.7 mL min^{-1} and an injection volume of 25 µL. The NaOH solution (0.2 mol L^{-1}) and flow

of 0.3 mL min^{-1} were used for post-column. The quantification of monosaccharides was performed by comparing the peak area of the samples with the standard calibration curve (Andrade et al., 2015).

The determination of amino acid contents was conducted by HPLC. The samples underwent previous hydrolysis with hydrochloric acid 6.0 mol L^{-1} and 3% phenol (mass by volume). Subsequently, the tubes were conditioned to thermal reaction for 24 hours, at 110 °C. According to Hagen, Frost, and Augustin (1989), with the addition of phenyl isothiocyanate, the derivatization of amino acids separated in the reverse phase occurred, using LUNA C18 column (100 Å, 5µm 250 x 4.6 mm; cod. 00G-4252-EQ) and quantified by UV detector at 254 nm. Quantification was performed by multilevel internal calibration, using α-aminobutyric acid as the internal standard, as described by White, Hart, and Fry (1986). The tryptophan amino acid was determined according to the methodology proposed by Lucas and Sotelo (1980).

2.2.2 ANALYSIS OF ATR-FTIR, THERMAL, AND X-RAY DIFFRACTION

The ATR-FTIR spectrum was collected using a spectrometer (IRAffinity-1), equipped with an attenuated total reflectance (ATR) accessory with ZnSe (zinc selenide) crystal. The spectrum was acquired with 64 scans and a resolution of 4 cm^{-1}, in the range from 4,400 cm^{-1} to 600 cm^{-1}.

The thermogravimetric and differential thermal analyzes (TGA and DTA) were performed in a thermogravimetric analyzer (model DTG - 60H Shimadzu Corp., Sartorius AG Germany), in the range from 30 °C to 600 °C, with a sweep of 10 °C min^{-1} in N_2 (nitrogen gas) atmosphere with a flow of 50 mL min^{-1}.

The CM was analyzed by X-ray diffraction, powder method, using a PANalytical device, model Xpert Pro., with angular variation from 4° to 70º 2θ, CoKα radiation and scanning speed of 5º min^{-1}.

2.3 STATISTICAL ANALYSIS

To calculate the proximate composition and the starch content, three random replicates were taken, and the results obtained were reported as means ± standard deviation.

3. RESULTS AND DISCUSSION

3.1 FIRST PHASE - PROXIMATE COMPOSITION OF TARO RHIZOMES

Table 1 shows the values of chemical components (moisture, ether extract, crude protein, crude fiber, ashes, and glicidic fraction) found in taro rhizomes, the raw material used for CM extraction.

TABLE 1 AVERAGE VALUES ± STANDARD DEVIATION OF THE CHEMICAL COMPONENTS FROM THE TARO RHIZOME IN G 100 G^{-1}

Chemical components	Content (g 100 g^{-1})
Moisture	73.21 ± 0.09
Ether extract *	0.56 ± 0.04
Crude protein*	3.11 ± 0.00
Crude fiber*	2.57 ± 0.23
Ashes*	3.48 ± 0.04
Glicidic fraction*	90.28 ± 0.22

*Dry matter results.

The results show that taro rhizome has high moisture content, presenting high carbohydrate (90.28 ± 0.22) and low lipid levels. Due to the high moisture content, the rhizome storage time is shorter than other vegetables with lower moisture, such as legumes and cereals.

Aboubakar, Njintang, and Nbofung (2008) studied the taro rhizome flour of six different varieties and obtained in g 100 g^{-1} the following value ranges for lipids (0.3 to 1.17), proteins (2.9 to 4,9), ashes (1.3 to 5.5), and carbohydrates (90.5 to 95.5). All values found in this study are consistent with the aforementioned study, showing that taro rhizome is a good source of energy, having primarily starch as the main representative of carbohydrates, as shown in the study of Zárate and Vieira (2004). The crude fiber content (2.57 ± 0.23), that is, the presence of lignin and cellulose, which are compounds that are not digestible by the human digestive system, is low when compared to the carbohydrate content.

In this case, for the extraction of taro mucilage, the most important values are carbohydrate and proteins, which are responsible for the emulsifying action in the mucilage. As seen in Table 1, the rhizome analyzed shows satisfactory amounts of the aforementioned macromolecules, which suggests emulsifying capacity.

3.2 SECOND PHASE - CHEMICAL AND PHYSICAL CHARACTERIZATION OF CRUDE TARO MUCILAGE (CM)

According to the study of Andrade et al. (2020), the taro mucilage extracted cold (4 °C) and precipitated with ethanol showed high activity and stability emulsion. As seen in the study, this high emulsifying action is mainly due to the absence of starch and the presence of glycoprotein AGP in the mucilage.

However, in the study mentioned above, it was observed that the mucilage extracted at room temperature and with filtration in polyester mesh showed considerable emulsifying action, as it can be seen in Table 2, even with the presence of starch in its composition, which is considered an impurity in the mucilage. Thus, it is interesting to study, chemically and physically the product obtained by this simple extraction technique to better understand the origin of its emulsifying action, and, in this way, add value to the taro culture. In addition, this extraction technique does not use chemical reagents, thus not generating waste that must be treated and disposed properly so as not to pollute the environment.

In this study, the aforementioned simple technique as mucilage extracted at room temperature is called crude taro mucilage (CM) due to the presence of impurities in its composition. The same CM extracted for analysis in the study by Andrade et al. (2020) was used in the present work for characterization.

3.2.1 PROXIMATE COMPOSITION AND STARCH CONTENT

Table 2 shows the chemical components (moisture, ether extract, crude protein, crude fiber, ashes, glicidic fraction and starch) and the emulsifying properties of CM.

TABLE 2 AVERAGE VALUES ± STANDARD DEVIATION OF THE CHEMICAL COMPONENTS AND EMULSIFYING PROPERTIES OF CRUDE TARO MUCILAGE IN G 100 G^{-1}**

Chemical components	Content (g 100 g^{-1})
Moisture	7.17 ± 0.06
Ether extract *	0.62 ± 0.09
Crude protein*	8.49 ± 0.12
Crude fiber*	0.00 ± 0.00
Ashes*	6.26 ± 0.05
Glicidic fraction *	84.63 ± 0.21
Starch*	63.42 ± 3.37
Emulsifying properties**	Content (g 100 g^{-1})
Emulsifying activity**	71.07 ± 0.36
Emulsifying capacity**	67.86 ± 3.57

*Dry matter results. ** Extracted from the work of Andrade et al. (2020). The sample used in the present study is the same used by Andrade et al. (2020).

According to Table 2, it can be seen that mucilage is composed mainly of glicidic fraction (84.63 ± 0.21), proteins and ashes, and the glycidic fraction is formed mainly by starch (63.42 ± 3.37). The starch is considered an impurity in the mucilage. However, even with its presence, there is a considerable emulsifying action of the mucilage, as described in Table 2. This is probably due to the presence of proteins and non-starchy carbohydrates. Non-starchy carbohydrates are responsible for the hydrophilic part and proteins with amino acids non-polar or weakly polar radicals contributing to the hydrophobic fraction (Andrade et al., 2015; Andrade et al., 2020), thus characterizing an emulsifier.

The presence of starch in the mucilage can be an advantage when the mucilage is added as a partial fat substitute in food products, as described in the work by Nagata et al. (2014). According to Nagata et al. (2014), the optimal levels of lyophilized taro mucilage and hydrogenated vegetable fat in the sliced bread formulation were 0.73 g 100 g^{-1} and 1.58 g 100 g^{-1}, respectively. The resulting bread was found to have good sensory, physical, and nutritional qualities; excellent values for specific volume and texture; and reduced vegetable fat and caloric content. Thus, adding an optimal concentration of lyophilized taro mucilage to sliced bread formulations is not only technically viable but also improves the characteristics of the bread. The taro starch, for having small granules, can be a great fat substitute (Andrade et al., 2017), justifying the good results of the work by Nagata et al. (2014), since the mucilage used in this work contained starch.

Comparing taro rhizome ashes values (Table 1) and CM (Table 2), it is possible to observe a higher value in CM, that is, this inorganic fraction was concentrated when the mucilage was extracted. Thus, taro mucilage is an alternative to be used as enriching flour in other products, such as, for example, in bakery.

The ether extract content in CM is less than 1.0 g 100g^{-1}, a low value, as occurs in taro rhizome (Table 1) and in the crude mucilage extracted by Andrade et al. (2015) and Miamoto et al. (2018). There is no presence of crude fiber, that is, lignin and cellulose. Therefore, it is possible to state that the emulsifying action is not obtained by these two chemical components.

Thus, in order to better understand the properties of CM, it is interesting to know the minerals, monosaccharides, and amino acids present to justify its emulsifying action and other possible uses in the food industry.

3.2.2 MINERAL CONTENT

Table 3 shows prominent macro and micro minerals present in the mucilage, that is, the CM inorganic fraction.

TABLE 3 PROMINENT MACRO (G 100 G^{-1}) AND MICRO (MG KG^{-1}) MINERALS PRESENT IN CRUDE TARO MUCILAGE (CM)

Macrominerals	Content (g 100 g^{-1})
Phosphorus (P)	0.33
Potassium (K)	4.31
Calcium (Ca)	0.02
Magnesium (Mg)	0.13
Sulfur (S)	0.16
Microminerals	Content (mg kg^{-1})
Boron (B)	4.1
Copper (Cu)	6.4
Manganese (Mn)	26,9
Zinc (Zn)	44.7
Iron (Fe)	47.3

The mineral content is considered an important attribute of food quality because the food that contains considerable mineral values is considered “proper” food (Miamoto et al., 2018). Macromineral potassium stood out for CM, similar to the studies by Tavares et al. (2011) and Nagata et al. (2014). For microminerals, the highlights were manganese, zinc, and iron. In the study by Miamoto et al. (2018) the prominent micromineral in the mucilage was iron.

Baking products with added flours with reasonable iron content are significant since they reduce the incidence of anemia in children and pregnant women (Miamoto et al., 2018), and CM is a good option for this need. The interesting part about using CM as mineral enriching flour in relation to taro rhizome flour is the fact that ashes content increased approximately 80% from rhizome to CM, as already observed in Tables 1 and 2, thus concentrating the minerals.

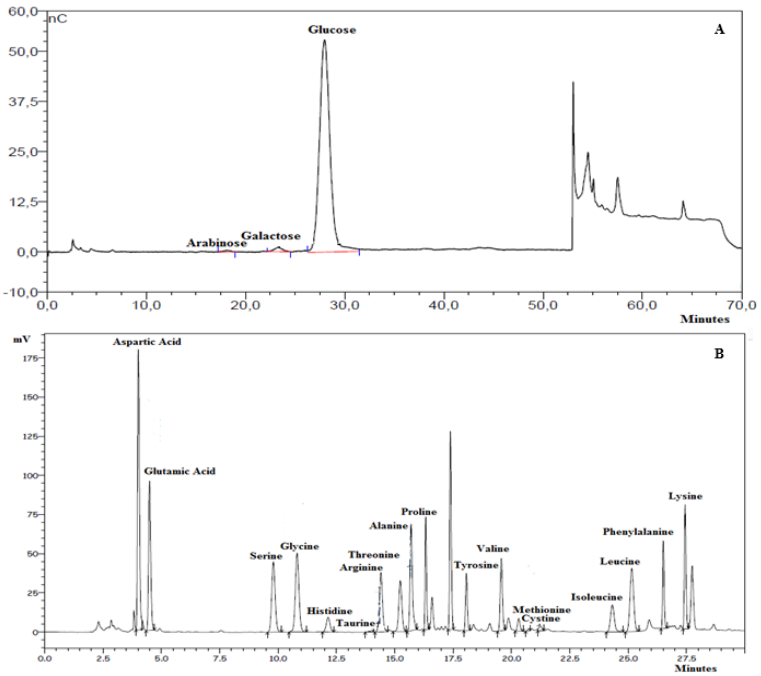
3.2.3 MONOSACCHARIDE CONTENT

Table 4 shows the contents of monosaccharides in the CM of this study and of the purified mucilage extracted in the study by Andrade et al. (2020) for comparison. Figure 1A shows the chromatogram generated for the CM sugar analysis.

TABLE 4 CONTENT OF MONOSACCHARIDES IN THE CM OF THIS STUDY AND IN THE PURE MUCILAGE EXTRACTED COLD IN THE STUDY BY ANDRADE ET AL. (2020) FOR COMPARISON

Monosaccharides	Crude taro mucilage (CM)	Pure mucilage extracted by Andrade et al. (2020)
	(g 100 g^{-1})	
Arabinose	0.66	16.68
Galactose	1.46	72.38
Glucose	97.88	10.94
Fucose	0.00	0.00
Xylose	0.00	0.00
Mannose	0.00	0.00
Fructose	0.00	0.00
Rhamnose	0.00	0.00

FIGURE 1 CHROMATOGRAMS GENERATED FROM CM MONOSACCHARIDE (A) AND AMINO ACID (B) ANALYZES.



Knowing the monosaccharides is important to know what types of sugars provide the hydrophilic part of the emulsifying action of CM. As seen in Table 4, there was the presence of arabinose, galactose, and glucose in the two mucilages. The high glucose content in CM is due to the high starch content (63.42 g $100g^{-1}$), as seen in Table 2. This fact also occurred in the study

of Andrade et al. (2015) with taro mucilage, and Ma et al. (2017) with yam mucilage (*Dioscorea opposita*), extracted similarly to this study.

Although there was no starch in the purified mucilage, the presence of glucose (10.94 g 100 g^{-1}) was observed. This was probably due to the presence of glucose residues in the structure of AGP (protein-arabinogalactan) (Andrade et al., 2020). Thus, it is believed that, in the CM, the glucose found comes from starch and, also, from residues of the AGP molecule.

It was observed, in the study by Andrade et al. (2020), that, in the purified mucilage, there was a higher content of arabinose and galactose, consequently showing the possible presence of AGP, responsible for the emulsifying action. In CM, the content of these monosaccharides was lower due to the presence of starch, but this did not prevent the presence of arabinogalactan, which probably may be associated with proteins, forming AGP.

3.2.4 AMINO ACID PROFILE

Table 5 contains the amino acids profile in the CM, and, as a reference, the pure mucilage amino acid content, extracted and analyzed by Andrade et al. (2020). Figure 1B also shows the chromatogram of the CM amino acid analysis.

TABLE 5 CONTENT OF AMINO ACIDS IN THE CRUDE TARO MUCILAGE (CM) OF THIS STUDY AND IN THE PURE MUCILAGE EXTRACTED COLD IN THE STUDY OF ANDRADE ET AL. (2020) FOR COMPARISON

Amino Acids	Crude taro mucilage (CM)	Pure mucilage extracted by Andrade et al. (2020)
	(g 100 g^{-1})	
Alanine	0.43	2.20
Isoleucine	0.28	1.39
Leucine	0.62	4.28
Phenylalanine	0.46	2.66
Proline	0.34	2.01
Tryptophan	0.15	0.80
Valine	0.40	2.63
Methionine	0.10	0.46
Aspartic acid	1.54	7.26
Glutamic acid	0.97	4.87
Serine	0.54	2.87
Glycine	0.45	2.75
Histidine	0.24	1.29
Taurine	0.01	0.00
Arginine	0.73	3.50
Threonine	0.40	2.23
Tyrosine	0.38	2.52
Cystine	0.16	1.31
Lysine	0.36	2.48

Understanding the predominant amino acids in mucilage is important as they are responsible for the emulsifying power thus providing the hydrophobic part since the hydrophilic part is represented by carbohydrates (Andrade et al., 2020).

The prominent amino acids in the two mucilages were aspartic and glutamic acid, arginine, leucine, serine, glycine, phenylalanine, alanine, valine, threonine, tyrosine, lysine, and proline. Leucine, phenylalanine, proline, and valine are non-polar amino acids. Other non-polar or weakly polar amino acids are also present in lower contents such as isoleucine, methionine, and tryptophan. According to the authors Tan et al. (2012) and Manhivi, Venter, Amonsou, and Kudanga (2018), appreciable amounts of proline, serine, alanine, and threonine in the mucilages suggest the presence of AGP. As observed in Table 5, the CM showed significant amounts of these amino acids, which indicates the presence of AGP, as already predicted in the analysis of monosaccharides.

The prominent amino acids found in the taro flour extracted by Panyoo et al. (2014) were aspartic and glutamic acids, alanine, glycine, lysine, and leucine, similar to this study. This fact shows that the protein composition of taro flour may be strongly associated with mucilage.

According to the study of Dickinson (2003), it can be said that, in most cases, the emulsifying capacity of some carbohydrate polymers can be attributed mainly to the presence of protein, either as a contaminant or as a covalent binding agent (or physically associated), thus having a protein-polysaccharide complex. Therefore, it can be inferred that the presence of protein is responsible, totally or partially, for the emulsifying power of CM. That reinforces the importance of carbohydrates and proteins with non-polar amino acids in the mucilage, as seen in this study.

3.2.5 INFRARED ANALYSIS WITH ATTENUATED TOTAL REFLECTANCE

FIGURE 2 A SHOWS THE ATR-FTIR SPECTRUM OF CRUDE TARO MUCILAGE.

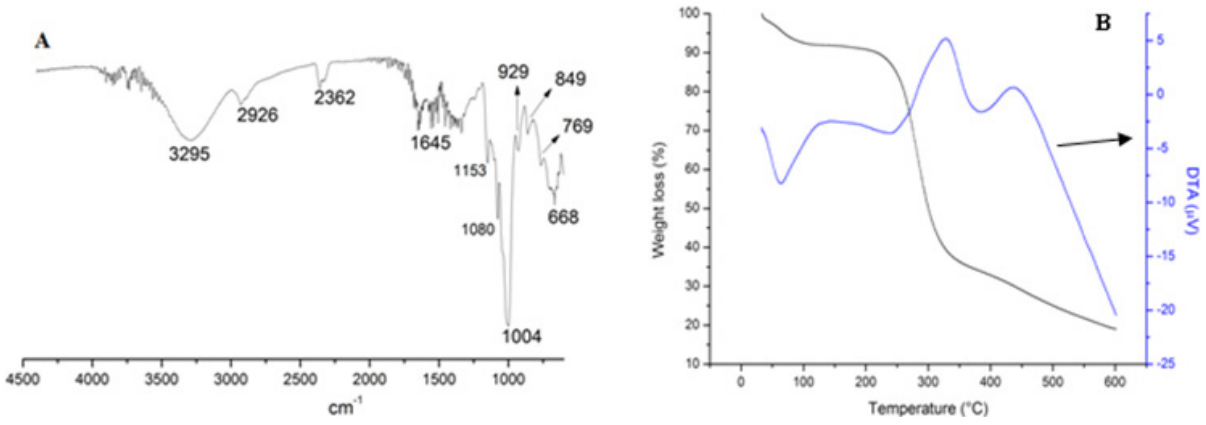


Figure 2 ATR-FTIR Spectrum (A) and TGA and DTA curves for crude taro mucilage (B).

The band at 3,295 cm^{-1} corresponding to hydroxyl groups (-OH) in alcohol intermolecular hydrogen bonds, commonly found in polysaccharides, confirms the presence of carbohydrates in the CM (Tavares et al., 2011; Andrade et al., 2015; Ma et al., 2017; Ma et al., 2018; Manhivi et al., 2018; Andrade et al., 2020). This band may also be related to the N-H bonds of proteins, as observed by the proximate composition (Andrade et al., 2015).

The band at 2,926 cm^{-1} is attributed to the axial strain of the C-H connection (Ma et al., 2017). At 2,362 cm^{-1}, the band is identified as attributed to the CO_2 (carbon dioxide) absorbed from the environment.

There are three bands between 1,200 and 1,000 cm^{-1} that are analogous to those observed by Lin and Huang (1993), which may result from the C-OH groups of alcohol, mainly from structures such as carbohydrate. Ma et al. (2017) showed bands close to 1,080 cm^{-1} and 1,153 cm^{-1} on Chinese Yam mucilage that indicate vibration from C-O-C stretch of the pyranose ring. Thus, the infrared

spectrum proves the structure of a polysaccharide with C-O-C bond, characteristic of carbohydrates, between 1,200 cm^{-1} and 900 cm^{-1}, confirming the bond between the polymer-forming monomers, as observed by Dalonso et al. (2009). For Zhou, Sun, Bucheli, Huang, and Wang (2009), who studied the AGP glycoprotein extracted from Green Tea, the region from 1,200 cm^{-1} to 800 cm^{-1} is determined as the fingerprint region of this macromolecule.

The region between 1,750 cm^{-1} and 1,500 cm^{-1}, attributed to the C=O stretch of nucleic acids amide I and amide II of proteins, is present in the CM (Santos et al., 2012), confirming the existence of protein, as present in the AGP spectra extracted from Green Tea (Zhou et al., 2009). There may be presence of AGP in the mucilage extracted in this study according to the ATR-FTIR spectrum.

The ATR-FTIR analysis lead to the conclusion that CM has polysaccharides with associated proteins. The C-O, O-H, and C=O groups confirm the nature of carbohydrates in the mucilage, in addition to N-H protein bonds, similar to the study of Manhivi et al. (2018) with the mucilage of *Colocasia esculenta* and *Opuntia* spp., showing the presence of glycoprotein, which is responsible for the mucilage emulsifying action. The ATR-FTIR analysis corroborates and proves all the statements made in the proximate composition, monosaccharides, and amino acids analyzes.

3.2.6 THERMAL ANALYSIS

The thermogravimetric analysis is a simple and accurate method for studying the decomposition pattern and thermal stability of polymers (Singh & Bothara, 2014). The TGA (thermogravimetric analysis) and DTA (differential thermal analysis) curves of CM can be seen in Figure 2B.

For Tavares et al. (2011), physical and chemical characteristics, in addition to the thermal characteristics of taro mucilage, are directly involved with their functional properties. In Figure 2B, a first loss is observed up to approximately 105 °C with an average mass loss of approximately 8.0%, which may represent the elimination of water and volatile compounds (Tavares et al., 2011). The initial mass loss is consistent with the moisture content shown in Table 2. The DTA curve shows an endothermic peak for this first loss, which may represent water volatilization.

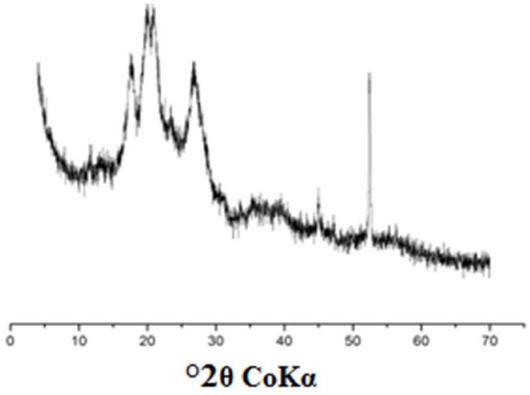
The second mass loss for CM varied from 210 °C to 340 °C with a mass loss close to 53%. This second mass elimination shows the depolymerization of the extracted hydrocolloid, with endothermic and exothermic peaks, that is, for the depolymerization and disorganization of the compound's structure, there was energy absorption and release depending on the decomposition stage. For Sarkar et al. (2014), the greatest mass losses for taro mucilage are observed in the range between 230 °C and 310 °C, which corresponds to the mucilage structural decomposition, similar to this study. Therefore, the thermal stability of CM studied is up to approximately 200 °C. Temperatures above 200 °C can affect the properties of the mucilage such as its emulsifying action.

Subsequently, the material loses mass up to 600 °C, with a final mass of 19% with exothermic and endothermic peaks. This final mass value was lower than the one found by Mijinyawa Durga and Mishra (2018), which was 24.13%. This difference may be related to the maturation stage of the taro rhizome used, which has an altered composition based on the harvest period.

3.2.7 X-RAY DIFFRACTOMETRY (XRD)

The CM X-ray diffractogram is shown in Figure 3. The XRD provides information on the structure of the material where the diffractogram may present an amorphous, semi-crystalline, or crystalline profile.

FIGURE 3 X-RAY DIFFRACTOGRAM OF CRUDE TARO MUCILAGE.



In the range of 4° < 2θ < 70° the assessed mucilage presents characteristic patterns of semi-crystalline state, similar to the study by Mijinyawa et al. (2018) who extracted the mucilage in a similar way to the CM. The semi-crystallinity in the CM is explained by its high starch content (63.42 g 100 g^{-1}).

Starch is a reserve polysaccharide for vegetables, and it is stored in the form of granules, which have a certain degree of molecular organization, providing them a partially crystalline or semi-crystalline nature, with degrees of crystallinity ranging from 20% to 45% (Young, 1984).

Mishra, Yadav, Pal, and Singh (2006) obtained the X-ray diffractogram for fenugreek mucilage where they observed a semi-crystalline structure, similar to this study. In another study, mucilage extracted from seeds of *Diospyros melonoxylon Roxb*. presented a totally amorphous structure (Singh & Bothara, 2014). For Ma et al. (2020), *Dioscorea opposita* (chinese yam) mucilaginous polysaccharides have an amorphous structure according to its X-ray diffractogram probably because the extraction of this mucilage eliminated all the starch initially present in the yam tubers. Yam tubers have chemical characteristics similar to taro rhizomes.

The results presented and found in the literature for XRD show that the mucilage structure can be semi-crystalline or amorphous, depending on the plant source and its extraction method.

3.3 EXPLANATION OF THE CM EMULSIFYING CAPACITY AND ITS POTENTIAL APPLICATIONS

As already confirmed by other studies, the emulsifying action of taro mucilage is due to the presence of the AGP glycoprotein, with carbohydrates responsible for the hydrophilic part and the protein with non-polar amino acids for the hydrophobic part (Andrade et al., 2015; Andrade et al., 2020). The AGP molecule was detected by ATR-FTIR while the arabinogalactans and non-polar amino acids by HPLC.

The difference between the CM and the purified mucilage of the study by Andrade et al. (2020) is that, in the first, there is the presence of starch, which reduces its emulsifying action; however this impurity does not totally disable this property. Nevertheless, the presence of starch in the mucilage may favor the partial replacement of fats by mucilage in bakery products due to the small taro starch granules (Nagata et al., 2014; Andrade et al., 2017).

Therefore, amidst the presence of water and oil, which do not mix, the non-starchy carbohydrate of CM would be in the water fraction (hydrophilic portion) and the protein with its non-polar amino acids in the oil fraction (hydrophobic portion), forming an emulsion (Andrade et al., 2020). The starch impurity could remain in the water part, but forming a suspension since it is not completely soluble in water at room temperature. If the CM is added to food that will be submitted to

high temperatures, the starch will gelatinize and increase the thickness of the final product. Hence, we have mucilage with emulsifying action and thickening agent.

According to the mineral analysis, CM can be added to foods, such as breads, to increase mineral content, such as iron, bringing health benefits and showing a fourth property of this mucilage in addition to emulsifier, thickener, and fat substitute.

4. CONCLUSIONS

This study concludes that CM has a high content of carbohydrates that are formed by arabinogalactans and starch. CM presents emulsifying action due to the presence of arabinogalactans and non-polar amino acids. The CM also present a thickening property due to the presence of starch. Moreover, mucilage is a mineral-enriching agent when added as flour in food products. CM has thermal stability up to approximately 200 °C, and it has semi-crystalline structure.

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