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PHYSICAL-CHEMICAL CHARACTERIZATION AND TECHNOLOGICAL AND THERMAL PROPERTIES OF TAMARIND (*TAMARINDUS INDICA* L.) FROM THE CERRADO OF GOIÁS, BRAZIL

Karen Carvalho Ferreira[1*], Márcio Caliari[1], Juliana Aparecida Correia Bento[1], Marília Cândido Fideles[1], Manoel Soares Soares Júnior[1]

[1] Departament of Agronomy, University Federal of Goiás, Campus Samambaia, Goiânia/Nova Veneza Highway, Km 0, 74690-900, Goiânia, Goiás, Brazil.
**karencarvalho1@hotmail.com*

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ABSTRACT

Brazil is a country with different biomes and the Cerrado is known for its rich resources and flora. Among the fruits in the Cerrado, we can highlight the tamarindeiro, whose fruit, tamarind, exhibit excellent nutritional quality. Tamarind is enough explored on the continent of origin (Africa), however surveys involving all utilities of the plant are still insignificant. So, the objective of the work was to characterize shells, pulp and tamarind seeds of the Cerrado, Goiás, as to physico-chemical, technological and thermal properties. The collected fruits obtained average proportions of 22,2 ± 1,1% shells, 44,0 ± 2,4% pulp and 14,4 ± 1,6% seeds, and approximately 20% fibers. It presented high carbohydrate content and low water activity for the three portions and lower values of ash, lipids and proteins. The shell and seed flours presented high content of total dietary fiber and fruit pulp presented acid pH (3,02 ± 0,01) and high titratable acidity (29,82 ± 0,24). The seed flour had a water absorption and solubility index greater than the shell flour, and lower oil absorption index. The tamarindo pulp presented 4 peaks in your thermogram, being the first relative to the gelatinization of starch, 2 and 3 peaks suggested the formation of carbohydrate-lipid complexes and protein denaturation and 4 peak the glass transition. Tamarind shell and seed flour showed similar behavior to pulp after 115 °C, with 2 endothermic peaks. Concluded that the integral tamarind fruit has specific physico-chemical, nutritional, thermal and technological characteristics and suitable for use in the food industry.

1.Introduction

Brazil is a country of great dimensions and with a variety of biomes, of which the Cerrado is included. Considered the second largest Brazilian biome, the Cerrado occupies areas in the states of Goiás, Minas Gerais, Maranhão, Tocantins, Mato Grosso, Mato Grosso do Sul, and portions in other states, and stands out as one of the richest savannahs in the world, one of the Brazilian *hotspots*. In addition, it presents a lesser known vegetable heterogeneity, which includes numerous exotic fruit species with peculiar sensorial characteristics (Morzelle *et al*., 2015, Carneiro *et al*., 2014).

Among the fruit species of the Cerrado of Goiás, the tamarind (*Tamarindus indica* L.) is found in dispersed plantations without great agroindustrial interest. The tamarind tree is a multifunctional tropical fruit tree grown mainly for its fruits, but all its parts, such as bark, seeds, leaves may offer some benefit because they present nutritional and therapeutic properties

(Rao, Kumar and Ramana, 2015, Sulieman *et al.*, 2015). Tamarind is characterized by a unique sweet acid taste due to the combination of high levels of tartaric acid and sugars. The fruit has excellent nutritional quality with high levels of carbohydrates, proteins and mineral elements (Adeola and Aworh, 2012, Pereira *et al.,* 2011).

In general, fruits and vegetables are sources of macro, micronutrients and dietary fiber, besides being important natural sources of phytochemical compounds (Yahia, 2010). The consumption of raw fruits and also of its by-products brings numerous health benefits, contributes to the development of new foods and, consequently, to the recovery of waste from agro-industrial processes, with greater industrial, economic and environmental impacts (Silva *et al.*, 2014).

In the countries of origin, on the African continent, tamarind is widely exploited and valued as a source of sustainable subsistence of cultural, dietary and economic importance. However, the impact of the research involving all utilities of the plant has been insignificant (Adeola and Aworh, 2012). Studies of the properties of fruits and their parts are important for the knowledge of the nutritional value, to add value and quality to the derived products (Paz *et al.*, 2015). The production of food from exotic or lesser known fruits and, consequently, their trade and consumption have increased due of their attractive sensory properties and nutritional and therapeutic values (Bicas *et al.*, 2011).

Brazil being a country with great potential and diversified production of fruit, and yet there are several species of these little explored and/or known beyond their regions of origin, which have excellent sensory and nutritional characteristics, the objective of this work was to characterize the tamarind fruit of the Cerrado of Goiás in its pulp, bark and seeds.

2. Material and methods

2.1. Raw material collection and sample preparation

The fruits were collected in Rio Verde (latitude 18º01’09,8”S, longitude 50º40’17,7”W) and Ceres cities (latitude 15º18’23,7”S, longitude 49º36’02,6”W), Goiás state, Brasil, in maturation stage suitable for consumption in the months of August and September 2017, and transported to the Agroindustrial Waste Utilization Laboratory, School of Agronomy of the Federal University of Goiás, in plastic bags at room temperature. The fruits were then selected for the presence of insects and breakdowns and separated manually in shells, pulp and seeds, weighing in a semi-analytical balance and calculating the proportions in percentages of whole fruit. The shells and seeds were sanitized in sodium hypochlorite solution 200 ppm, dried in an air circulation oven at 40 °C for 16 hours, then crushed in an industrial blender (Vitalex, LQI-02, Catanduva, Brazil), and ground in a cyclone rotor mill (Tecnal, TE65I/2, Piracicaba, Brazil). The tamarind shell and tamarind seed flour were conditioned in bags of high density polyethylene (HDPE) and stored in a freezer at –18 °C until the analysis. The tamarind pulps were kept in natura, conditioned and stored under the same conditions as flours until the analysis.

2.2. Proximal composition and total energy value

Moisture, ash, protein, lipids and total dietary fiber were determined according to the methods of the Association of Official Analytical Chemistry (2010). Moisture was determined by oven drying with air circulation at 105 ºC until constant weight, ash by weighing after muffle incineration at 550 ºC, the nitrogen content by the Kjeldahl method, considering 5,75 as a conversion factor for the calculation of crude protein of vegetable origin, the total lipid content by hot extraction using petroleum ether by the Soxlet method. The dietary fiber was obtained by enzyme-gravimetric method and the total carbohydrate content by difference. All analyzes performed in triplicate. The total energy was estimated considering the conversion factors of 4 kcal g^{-1} for protein and carbohydrate, and 9 kcal g^{-1} for lipids (Merrill and Watt, 1973).

2.3. Physical and chemical characterization

The pH measurement was determined using a potentiometer (Tecnal, TEC-51, Piracicaba, Brazil), with electrode insertion directly into 5 g of diluted sample in 100 mL of water. The total titratable acidity was determined by titration with NaOH 0,1 N. The determination of the water activity (a_w) was obtained in digital AquaLab (Series 3 TE, Pullman, Washington, USA), of 25 ºC. Soluble solids content (SS) was determined using a digital refractometer. All according to the AOAC (2010). The instrumental color parameters (L*, a* and b*) were determined in a colorimeter (Bankinh Meter Minolta, BC-10, Ramsey, USA), in which the coordinate L* expresses the degree of luminosity of the color, a* the degree of variation between red and green and b* the degree of variation between blue and yellow. The values a* and b* were used to calculate the coordinate C* (chroma = $(a^{2*}+b^{2*})^{1/2}$) and hue angle (H = tang $^{-1}$(b*/a*)) (Machado *et al.*, 1997). The determination of reducing and total sugar was performed by the 3,5-dinitrosalicylic acid method, according to Miller (1959), with absorbance reading at 540 nm in the spectrophotometer (Ultrospec, 2.000 UV/Visível, Cambridge, Inglaterra), in aqueous extracts with concentration of 0,2 mg mL^{-1}.

2.4. Absorption and solubility in water and oil absorption of tamarind shell an seed flours

The water solubility index (WSI) of the flours was determined according to Anderson *et al.* (1969). Samples of 2 g were weighed into centrifuge tubes, added with 30 mL of distilled water at 25 °C and shaken on a mechanical stirrer for complete homogenization of the samples. The tubes were placed in a water bath for 30 min at 28 °C with shaking and centrifuged for 10 min at 5300 rpm (2500 G) (Best Etetronics, TG-WS, Xangai, China). A 10 mL aliquot of the supernatant was removed and placed in previously tared petri dishes, which remained in an air circulation oven for 2 hours at 105 °C. The plates were weighed and the ISA value was expressed in g of precipitate per g of dry matter. The water absorption index (WAI) of flours equals the weight precipitate in the tube after removal of the supernatant. The result was expressed in g precipitated per g of dry matter.

The oil absorption index (OAI) of the flours was determined according to the methodology described by Castilho, Fontanari and Batistuti (2010). 2 g of sample was weighed into centrifuge tubes, 10 ml of soybean oil was added and homogenized for 2 min on mechanical stirrer. Samples were left standing for 15 minutes at 25 ± 3 °C, and then centrifuged at 8.000 rpm/10 minutes. The volume of the supernatant was measured in graduated cylinder and the OAI was expressed in ml of absorbed oil per gram of sample.

2.5. Thermal properties

The thermal properties of the samples were determined by Differential Scanning Calorimetry (DSC), with calorimeter (TA Instruments, Q20 DCS, New Castle, EUA), based on the methodology described by Weber, Collares-Queiroz and Chang (2009). Samples of 2 mg (b.s) were weighed in aluminum sample port, suitable for DSC equipment. Distilled water (6μL) was added and maintained for 12h at 25 °C to standardize the water distribution. The samples were subjected to a heating cycle of 35 – 160 °C the velocity of 10 ° C min^{-1}, and subsequent cooling at the same speed, in order to determine the initial, peak and final temperature, and the enthalpy change (ΔH) during heating and cooling, according to the manufacturer's manual.

2.6. Statistical analysis

Statistical analysis (Statsoft, Statistica 7.0, Tusla, USA) was performed using statistical analysis of variance (ANOVA) and Tukey's test at 5% of statistical significance.

3. Results and discussions

3.1. Proportions and proximal composition of fruits

The collected tamarind fruits had average proportions of 22,2 ± 1,1%, 44,0 ± 2,4% e 14,4 ± 1,6% for shell, pulp and seeds, respectively, in relation to the whole fruit. About 20% of the fruit is the fibers that involve pulp and seeds. The proportions found differ from the averages reported by Pereira *et al*. (2011) and Favet, Frikart and Potin (2011) which indicated values of approximately 30% of pulp, 30% of shell and fibers and 40% of seeds, as the average of the proportions of tamarinds. The average number of seeds per fruit was 3 seeds, which explains the lower proportion of seeds in relation to the other parts of the fruit. The proportion of pulp was higher than that suggested by Pereira *et al.* (2011), which can be considered an advantage for fruits of this region, because a higher proportion of pulp in relation to residual fractions are preferred by the industries, as they guarantee a higher processing yield according by Rebouças, Gentil and Ferreira (2008).

The proximal composition and the total energy value are presented in Table 1. The tamarind pulp presented low moisture content when compared to other fruits few explored as Cerrado jatobá (*Hymenaea stigonocarpa* Mart.) (83,12±0,03 g 100 g^{-1}) (Batista *et al.*, 2011) and cajarana (*Spondias lutea* L) (96,1±0,2 g 100 g^{-1}) (Canuto *et al.*, 2010). Evaluating tamarinds from different regions of Nigeria, Adeola and Aworh (2012) found moisture contents in the pulp varying from 16,8 at 36,2 g 100 g^{-1}, inferring that these variations may occur due to climatic differences and cultivars. Costa *et al.* (2015) found high moisture content (74±2 g 100 g^{-1}) in tamarind fruits of the northeast region of Brazil, confirming the variation. Moisture content found in the seed flours of this study is similar to those reported by Mohamed, Mohamed and Ahmed (2015) that found value of 11,21 g 100 g-1 in samples of tamarind seeds. The tamarind shell flour presented the lowest moisture content in relation to the other parts of the fruit, being even smaller than other non-edible fruit shell flours such as passion fruit shell (Cazarin *et al*., 2014) and banana peel (Gonçalves *et al*., 2016). Queiroz *et al*. (2015) evaluated peeling and lychee seed flour finding moisture values of 6,10 and 8,7 g 100 g-1, respectively, being of the larger shells and smaller seeds than the flours of the present study.

The three fractions of the analyzed fruit presented significant difference for verified parameters of ash, lipids, proteins and carbohydrates (Table 1). The values of lipids and proteins were higher in the seed flour, followed by pulp and shell flour. The fact that seeds are better sources of protein when compared to other parts of the fruit can be explained by the storage of their proteins in the concentrated form, since the seeds are nutrient reserve organs (Costa *et al*., 2015). The presence of lipids is always higher in oilseeds and seeds than in fruits and other vegetables, which have low amounts of this nutrient (Rocha *et al*., 2008), fact observed in this study. Khairunnuur *et al*. (2009) studied pulp and tamarind seeds in Malaysia and found ash content of 3,30 and 2,15 g 100 g^{-1}, proteins 2,4 and 13,35 g 100 g^{-1} and lipids 0,14 and 2,90 g 100 g^{-1}, respectively, which are close to the values obtained in this study.

Table 1. Mean and standard deviation of the proximal composition, (g 100 g^{-1}), total and reducing sugars (g 100 g^{-1}) and total energetic value (kcal 100 g^{-1}) of the “in natura” pulp, tamarind shell flour and tamarind seed flour.

Proximal Composition	Tamarind (*Tamarindus indica* L.)		
	Pulp	Shell flour	Seeds flour
Moisture	31,22 ± 0,009a	5,96 ± 0,001c	10,20 ± 0,002b
Ash	2,96 ± 0,004b	3,76 ± 0,000a	2,22 ± 0,002c

Lipids	0,99 ± 0,00b	0,54 ± 0,000c	1,77 ± 0,001^{a}
Protein	4,12 ± 0,153b	3,22 ± 0,141c	14,56 ± 0,35^{a}
Carbohydrates	60,71c	86,62a	71,25b
Total food fiber	5,19c	70,33a	53,89b
Total sugars	23,84 ± 0,50a	10,22 ± 0,82c	12,66 ± 1,59b
Reducing sugars	0,25 ± 0,03c	5,60 ± 0,07b	8,21 ± 0,09^{a}
Total energetic value	268,23c	364,22a	359,17b

* Means followed by the same letter, in the same line, did not differ significantly among themselves by the Tukey test, at 5% probability.

The integral fruit presented as a good source of carbohydrates, however with different compositions between the fractions (Table 1). The pulp presented higher total soluble sugars, and the shell and seed flours, higher fiber content. The seed flour had the highest concentration of reducing sugars. In the tamarind pulp, the total dietary fiber content was within the value suggested by USDA – United States Department of Agriculture (2009) of 5,1 g 100 g^{-1}. Tamarind shell and seed flours presented high fiber contents when compared to other flours of fruit residues such as lychee shell and seeds flour (*Litchi chinensis Sonn*) with 19,88 and 4,75 g 100 g^{-1}, respectively (Queiroz *et al*., 2015), and the banana caturras peel flour (*Musa avendish* Lamb.) with total fibers 10,03 g 100 g^{-1} (Santos *et al*., 2015). The inclusion of these flours in products can guarantee a greater functionality to these foods because the presence of fiber in the diet helps in regularization of the intestinal transit, giving greater protection to the colonocytes and improving digestion according by Araújo and Menezes (2010).

The total energy value presented by the tamarind fractions reveals a high energy fruit offering 13,4 %, 18,2 % and 17,9 % of kcal in a 2000 kcal/day diet for pulp, shell and seeds, respectively.

3.2. Physical-chemical characteristics

Regarding the chemical characteristics evaluated (Table 2), the pulp, shell and tamarind seeds fractions showed significant differences by Tukey test at 5% probability.

The pH found in the tamarind pulp was relatively lower than the pH of 3,40 found by Sulieman *et al*. (2015) in tamarind in the eastern part of Sudan, and higher than that Santos *et al*. (2016) of 2,75 in a study with frozen tamarind pulps. Low pH values can guarantee the preservation of fruit pulp without the need for thermal treatment, avoiding nutritional losses and yeast growth (Brasil *et al*., 2016). The presence of organic acids, important components in the formation of various fruit properties, can also contribute to pH variation (Santos *et al*., 2016). Tartaric, malic and citric acids are the main chemical compounds related to tamarind aroma and taste, according to Palomares (2009), being tartaric acid a strong acid, resistant to oxidative respiration, not decreasing with maturation (Pereira *et al*., 2011; Rizzon and Sganzerla, 2007). The tamarind can be considered a non-climacteric fruit, that is, the respiratory pattern decreases after harvesting, being necessary that the fruit stays in the plant until it is in an optimum state of maturity, which would guarantee more sweet fruits (Chitarra and Chitarra, 2005).

The titratable acidity (TA) presented by the pulp was much higher than in the shell and seed flour, a fact explained by Pereira *et al*. (2011) due to the large amount of organic acids present in this fruit (12 to 30% dry matter). Tartaric acid is the main acid present in tamarind pulp and its presence is uncommon in fruits (Hamacek *et al*., 2013). Thus, TA of the tamarind pulp was expressed in grams of tartaric acid per 100 g of pulp. Tamarinds from the State of Goiás were similar in terms of TA observed by Sulieman *et al*. (2015) in tamarinds from Sudan (28,60 g tartaric acid 100g^{-1}).

In the literature, the value of soluble solids (SS) for the tamarind pulp presents great variation. The values found in this study (Table 2) corroborate those verified by Lima *et al*. (2015) of 7,25 °Brix and by Santos *et al*. (2016) of 7,70 to 12,58 °Brix, analyzing frozen tamarind pulps. However, they were much lower than the values verified by Sulieman *et al*. (2015) of 39,9 to 46,6 °Brix and by Canuto *et al*. (2010) of 24 °Brix. Factors such as climate, irrigation during cultivation and addition of water during the pulp manufacturing process may influence the soluble solids content, which would explain the lack of uniformity between the values presented in different studies (Santos *et al*., 2016).

The SS/TA ratio is related to the quality of the fruit in terms of maturity and taste, evidencing the balance between sugars and organic acids (Chitarra and Chitarra, 2005). The tamarind pulp showed this reduced relationship, influenced by the high acidity, and it was possible that the fruit was harvested before the optimum ripening stage, which justifies the low soluble solids content.

Shell and tamarind seeds flours showed low water activity (Table 2), and below 0,60 the majority of pathogenic microorganisms do not develop (Forsythe, 2013). The a_w is a relevant factor in the quality of a food because it influences the speed of reactions, oxidation of lipids, microbial growth, degradation of compounds such as chlorophyll, anthocyanins, besides interfering directly in the perishability of a food (Damodaran, Parkin and Fennema, 2010).

The tamarind fruit, in all its parts, presented reddish-yellow coloration (Figure 1) indicated by the angle value Hue obtained (H between 60-70) (Table 3).

Table 2. Mean and standard deviation of the chemical characteristics of the “in natura” pulp, tamarind shell flour and tamarind seed flour.

Characteristics	Tamarind (*Tamarindus indica* L.)		
	Pulp	Shell flour	Seeds flour
pH	3,02 ± 0,01c	4,19 ± 0,02b	5,81 ± 0,03a
SS (°Brix)	7,0 ± 0,1a	0,1 ± 0,1c	1,0 ± 0,1b
AT (g tartaric acid 100 g^{-1})	29,82 ± 0,24a	6,53 ± 0,23b	4,26 ± 0,12c
SS/AT ratio	0,23 ± 0,001a	0,02 ± 0,001b	0,23 ± 0,006a
a_w	0,615 ± 0,01a	0,319 ± 0,001c	0,415 ± 0,002b

* Means followed by the same letter, in the same line, did not differ significantly among themselves by the Tukey test, at 5% probability.

Table 3. Mean and standard deviation of the color coordinates L*, a*, b*, C* and Hue angle of the “in natura” pulp, tamarind shell flour and tamarind seed flour.

Tamarind	Color coordinates				
	L*	a*	b*	C*	H
Pulpa	37,54 ± 0,35c	2,56 ± 0,44c	9,26 ± 0,52c	9,60c	74,56a
Shell flour	54,24 ± 1,04b	11,35 ± 0,3a	24,22 ± 0,58a	26,75a	64,88c
Seeds flour	64,14 ± 2,07a	7,13 ± 0,39b	16,12 ± 0,37b	17,63b	66,13b

* Means followed by the same letter, in the same column, did not differ significantly from each other by the Tukey test, at 5% probability. a* and b* represent the coordinates of chromaticity (C*). The color coordinates were converted to a color angle, H = $\tan^{-1b/a}$ indicating the Hue (H) angle of the sample (0º or 360º = red, 90º = yellow, 180º = green, 270º = blue).

Figure 1. Portions of tamarind (*Tamarindus indica* L.): (A) Pulp, (B) Flours of the shell, (C) Flours of the seeds.

With respect to the chroma (C*), the results indicate that the pulp presents a more opaque coloration, in relation to the other portions. The pulp is characterized as the darkest part, and the seeds the clearest, according to the values of L* found, where values closer to zero approximate black. Canuto *et al*. (2010) found in their studies values L* (33,8 ± 0,5) and H (63,1 ± 0,2) in tamarind pulp, close to the present study, describing the same reddish-yellow coloration.

3.3. Absorption and solubility in water and oil absorption of tamarind shell on seed flours

The water absorption (WAI) and oil (OAI) and water solubility (WSI) indices of the tamarind bark and seed meal at 28 °C were evaluated and their results are expressed in Table 4. The flour of tamarind seeds presented higher WAI than the flour of the shells. Increasing the concentration of fiber and protein in flours can raise the rate of water absorption. WAI is a property that is related to the availability of hydrophilic groups in binding to the water molecules, the gel-forming capacity of the starch molecules and the hygroscopic properties of the fibers, which also makes it possible to absorb water (Santillán-Moreno *et al*., 2011, Filli and Nkama, 2007). Seed flour, even with a lower fiber value than the shell flour, has a protein concentration of 4,5 times higher. Santana, Oliveira Filho and Egea (2017) found in their studies 1,15 g g^{-1} WAI for wheat flour and 4,85 g g^{-1} for passion fruit flour, that is, tamarind shell and seed flours have a greater ability to absorb water than wheat flour, the main raw material in baked goods. This property is important in foods that require hydration and moisture retention as meat products, cakes, breads and other baking products improving yield and texture (Porte *et al*., 2011).

Water solubility index (WSI) was lower in tamarind shell flour when compared to seed flour. The solubility of the flours is related to the amount of water soluble molecules, which can be verified by comparing the water solubility values with the total soluble solids contents of the samples (Ferreira *et al*., 2015). Santana, Oliveira Filho and Egea (2017) presented WAI values of 15,33 g g^{-1} for flaxseed flour and 10,0 g g^{-1} for passion fruit flour, values higher than those found in this study. Flours with high WAI values can be used in foods that require lower temperatures to be prepared as instant and liquid foods or as ingredients for the formulation of soups, desserts and sauces (Santana, Oliveira Filho and Egea, 2017).

The OAI found in the flour of tamarind shells was higher than in the seed flour, however, both presented values higher than the value found by Tril *et al*. (2014) for tamarind powder extract (1,35 g g^{-1}). The ability to absorb oil from a flour may be related to the presence and amount of exposed hydrophobic groups of proteins and their interaction with the hydrophobic chains of fat (Santana, Oliveira

Filho and Egea, 2017). This is an important parameter of quality because it improves the palatability of the food, in addition to also influencing the emulsifying capacity of a product (Goldmeyer *et al*., 2014). High oil absorption index determine whether the flour can be used in meat products such as sausages and bologna or emulsified products such as cakes, mayonnaise or sauces (Porte *et al*., 2011).

Table 4. Mean and standard deviation of the water absorption index (WAI), water solubility (WSI) and oil absorption (OAI) of tamarind shell flour and tamarind seed flour.

Index	Tamarind (*Tamarindus indica* L.)	
	Shell flour	Seed flour
WAI (g g^{-1})	2,43 ± 0,06	4,17 ± 0,04
WSI (g g^{-1})	5,19 ± 0,06	8,19 ± 0,27
OAI (mL g^{-1})	2,06 ± 0,03	1,90 ± 0,02

3.4. Thermal properties

Figures 2, 3 and 4 illustrate the DSC graphical analyzes of lyophilized pulp, tamarind shell and tamarind seeds flours, respectively. The thermogram of the pulp (Figure 2), which presented 4 endothermic peaks, was divided into two parts, the first one being from 35 to 105 °C and the second part from 105 to 155 °C for better visualization of the peaks. The first peak (Figure 2A) relates to gelatinization of the starch present in the pulp. The initial gelatinization temperature (To) of the tamarind pulp was 69,98 °C ± 1,55, to peak (Tp) was 78,66 °C ± 0,02 and end (Te) 86,61 °C ± 0,57. The gelatinization temperature range was 16,63 °C with gelatinization enthalpy (ΔH) to 3,27 ± 0,27 J g^{-1}. When the available water is restricted, as in the case of lyophilizates, the gelatinization can be delayed at higher temperatures due to the melting of the remaining amylopectin crystals (Moreira, Chenlo and Arufe, 2015).

The 2 peak (101,19 °C) (Figure 2A) and 3 peak (118,51 °C) (Figure 2B) suggest endothermic peaks related to protein denaturation and the formation of amylose-lipid complexes, according to Santiago-Ramos *et al*., (2018) and Sánchez-Arteaga *et al*. (2015). The tamarind pulp presents a more complex chemical composition (protein, amylose / amylopectin ratio, minerals, etc.), thus indicating a more complex thermal profile than those reported for isolated starch systems. The presence of two peaks in bands close to temperature may be due to different chemical compounds present (Sánchez-Arteaga *et al*., 2015). Evaluating the thermal properties of bean flour of different varieties, Sánchez-Arteaga *et al*. (2015) found the second endothermic peak between 85 and 105 °C, associated with the presence of heat-resistant proteins. The same peak was observed by Moreira, Chenlo and Arufe (2015) with transition varying between 94,6 and 122,2 °C for flours of chestnut and corn starch.

The peak number 4 (Figura 2B) suggests the glass transition peak (Tg) of the tamarind pulp which presented a range of Tg, *onset*: 138,61°C to *endset*: 147,55°C, and peak 138,85 °C. The Tg evaluates the temperature at which the sample exits from an amorphous equilibrium state to a rubbery or gummy state, inferring thermal treatments lower than Tg temperature in the processing of possible products based on lyophilized tamarind pulp. Tg can be used as an indicator of physico-chemical changes in long periods of storage (Alpizar-Reyes *et al*., 2017).

The tamarind shell and seed flours (Figures 3 e 4) presented similar thermograms after 115 °C, with two endothermic peaks and similar behavior to the lyophilized pulp after this temperature, which suggests the same evaluation of the peaks, that is, the peak between 115 and 120 °C corresponds to the formation of carbohydrate-lipid complexes and/or denaturation of proteins and the peak formed approximately at 135 °C corresponding to the glass transition of the sample. A small peak in the tamarind shell flour thermogram (Figure 3) is also observed at 86,69 °C for gelatinization.

The endothermic peak of the glass transition to tamarind shell flour had an energy of 18,52 J g^{-1} and Tg of 135,93 °C. In the tamarind seed flour thermogram (Figure 4), is possible check the first peak with To 119,80 °C, Tp 119, 94 °C and Te 120,15 °C. Tg was observed at 137,92 °C with transition energy of 23,65 J g^{-1}.

The melting temperature of the carbohydrate-lipid complexes is generally high because they have high thermal stability, so the longer the chain length of the complex the greater the physical stability (Kawai *et al*., 2012). During the thermal sweep of samples of chestnut flour, Ahmed and Al-Attar (2015) detected transitions at various temperatures (104-106 °C, 114-120 °C e 135-142 °C), associating these transitions to the processes of amylose-lipid complex disorders.

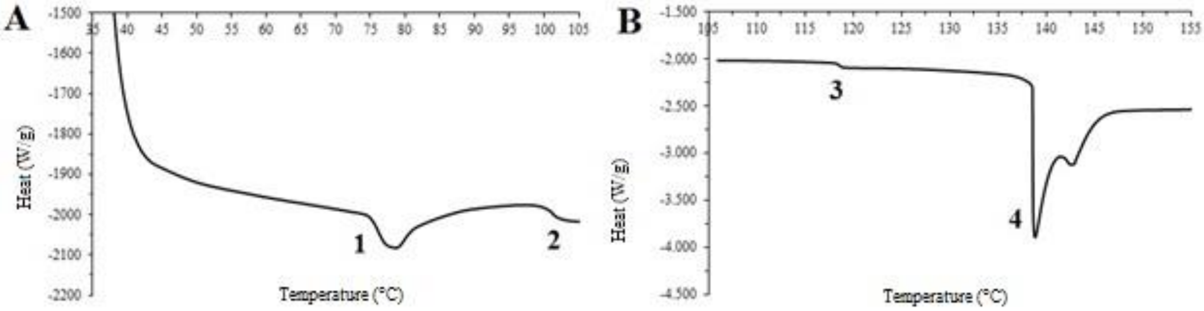

Figure 2. DSC of the freeze-dried tamarind pulp. (A) DSC in the temperature range of 35 to 105 ° C, (B) DSC in the temperature range of 105 to 155 ° C.

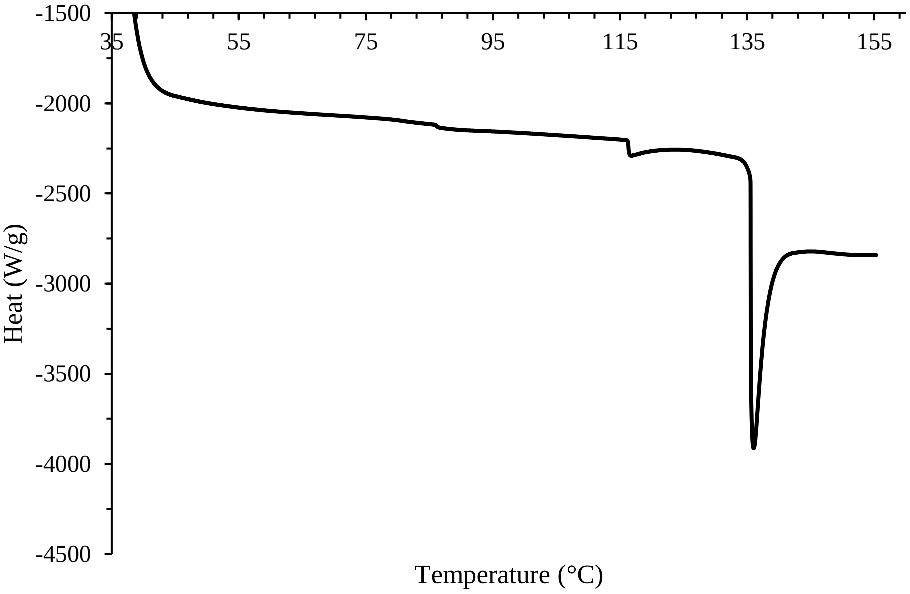

Figure 3. DSC of Tamarind shell flour.

4. Conclusion

The tamarind fruit presents excellent physical-chemical and nutritional qualities in all its portions. Flours derived from tamarind shells and seeds are rich in fiber and have technological properties suitable for the food industry, such as instant products such as soups, and even on products that do not require high temperatures. The thermal properties of the tamarind portions suggest a more detailed investigation because they are complex systems.

5. References

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