Evaluation of the Technological Potential of Gabiroba [*Campomanesia xanthocarpa Berg*] Fruit

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Abstract

Native fruits are receiving special attention from food researchers all around the world. The *Campomanesia xanthocarpa* Berg [*gabirobeira*] is a species native to Brazil, being part of family Myrtaceae. The *gabirobeira* produces a fruit named *gabiroba*, whose pulp presents a nice acidic-sweet taste. This work was aimed at evaluating the *gabiroba* technological potential for use as a raw material for the food industry. The gabiroba pulp was evaluated for its physical-chemical features. In addition, the pectin that was extracted from the pulp was evaluated for its rheological features. The pulp bioactive compounds content, namely vitamin C, flavonoids, phenolics and carotenoids, was measured during 180 days of freezer storage. The pulp antioxidant capacity was measured by means of the DPPH and ABTS methods. The rheological measurements were performed through the use of a Haake RS 75 rheometer. The generated flow curves were fitted by means of the Power Law and Herschel-Bulkley models. Results show that the gabiroba contains remarkable contents of iron, phosphorus, zinc, manganese, total phenolics [131.90 mg/100 g, expressed as galic acid], vitamin C [312.21 mg/100 g] and total carotenoids [290.84 µg/g]. About 42% of the carotenoids corresponded to beta-carotene. During pulp storage, it was observed a decrease of 10.00% in total phenolics content, 5.35% in flavonoids and 23.52% in the vitamin C. There was a positive and significant correlation between antioxidant capacity and bioactive compounds content, suggesting that such capacity might be influenced in a synergic way by the detected bioactive compounds. The *gabiroba* pulp pectin presented a shear-thinning behavior, being the data best fitted by the Herschel-Bulkley model. The viscoelastic measurements showed that the dynamic moduli are frequency independent. Concluding, *gabiroba* showed a remarkable potential to be used as a raw material in the food industry due to its rheological, functional [phytochemicals], sensory and nutritional [vitamins and mineral salts] features. Despite their large fructification, in addition to nutritional and attractive sensory characteristics, these fruits are not collected, being lost in the fields. In this work, the fruit pulp without seed [1500 g] was crushed in ethanol/water at a ratio of 1:4 [v/v], refluxed for 15 minutes at boiling temperature. The residue obtained was subjected to sequential extractions. The extractions were optimized using a factorial design 2^2, with the concentration of citric acid [0.5 and 5%] and temperature [50 and 100ºC] as variables. The polysaccharides were characterized according to their chemical composition and rheological profile. The high concentrations of uronic acids, arabinose and galactose, detected in all fractions, indicate that they consist of pectin. The results showed that the extraction method was efficient for fractionation of pectin from different areas of the cell wall. The polysaccharides extracted from the fruit pulp of gabiroba showed a pseudoplastic behavior. All the fractions were resistant to temperature variations. When these gels are heated up and cooled down, they adopt their original structure.

Introduction

The gabiroba is a native fruit which belong to the Myrtaceae family, presenting high acceptability due to its sensory features. Native fruits have been receiving much attention lately, not only due to their technological potential, but also due to the fact that they can be used to diversify the fruit production of a selected region [1]. Even though gabiroba presents a high potential to be used by food industries, data on its cultivation production and usability features are scarce. The gabirobeira can be naturally found in the Southern region of Brazil, Argentina, Paraguay and Uruguay [2].

The gabiroba is a fruit with sweet juicy pulp and rounded in shape, showing an average 16% of seed. The rind of the fruit is a thin film which comprises 17% and pulp corresponds about 60% of the total mass of the fruit. The fruit also has a persistent calyx that takes on average 7% of the total fruit. The constitution of the percentage fractions of the fruit is sketched in figure 1 and is shown to the actual size of the fruit in two dimensions.

The ethylene production influences the process of fruit ripening, affecting a large number of physiological changes occurring during fruit ripening [3].

On the first day post-harvest, gabiroba had a lower ethylene production close to zero, and the greater production of ethylene (1.95 µL of ethylene.kg^{-1}.h^{-1}) was observed on the fifth day after harvest. Similar results were observed for fruits of guava, red and yellow which showed

peak ethylene production only after 130 and 170 hours, between about five and seven days of storage at 20°C [4].

The increase in ethylene production was associated with changes in pigmentation, the decrease in the levels of acidity and the increase in soluble solids, suggesting that ethylene production contributed to these changes.

The elucidation of the operation and interaction between different components of these processes is aimed at increasing knowledge about the factors that could manipulate, control or interfere, allowing modifications that allow extending the shelf life of these fruits [5].

Nutritional Composition of Gabiroba Fruits [*Campomanesia xanthocarpa berg*] Fruits

The ripe gabiroba presented remarkable levels of vitamin C, carotenoids and phenolics compounds. From a nutritional perspective, gabiroba can be considered as a good source of vitamin C, since the consumption of two fruits (25.04 g) fulfill the reference daily intake (RDI, 45 mg) of an adult. The deficiency of vitamin A is a public health
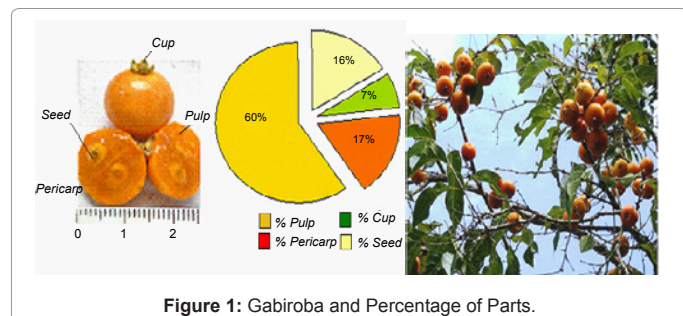

Figure 1: Gabiroba and Percentage of Parts.

Parameter	Mean ± Standard Deviation
Moisture at 105°C	79.14 ± 0.03
Ashes at 525°C	0.68 ± 0.02
Lipids (g%)	1.31 ± 0.06
Total sugars (g%)	7.88 ± 0.60
Reducing sugars (g%)	6.77 ± 0.22
Glucose (g%)	3.11 ± 0.26
Fructose (g%)	3.67 ± 0.39
Sucrose (g%)	1.11 ± 0.25
Total proteins (g%)	1.10 ± 0.04
Dietary fiber (g%)	9.88 ± 0.08
Vitamin C (mg.100g^{-1} AA)	313.21 ± 4.93
Total phenolic compounds (mg.100g^{-1} GA)	131.90 ± 6.16
Total flavonoids (mg.100g^{-1} QE)	67.97 ± 3.62
beta-Carotene (µg.g^{-1})	123.47 ± 2.35
alfa-Carotene(µg.g^{-1})	55.61 ± 1.45
Lycopene (µg.g^{-1})	0.91 ± 0.07
beta-cryptoxanthin (µg.g^{-1})	93.09 ± 2.91
Lutein (µg.g^{-1})	14.92 ± 0.24
Violaxanthin (µg.g^{-1})	2.84 ± 0.09
Phosphorus	46.43 ± 0.78
Potassium	3.88 ± 0.07
Sodium	0.39 ± 0.01
Calcium	50.26 ± 0.96
Magnesium	43.01 ± 0.90
Iron	6.05 ± 0.05
Manganese	0.57 ± 0.03
Zinc	2.77 ± 0.02

Table 1: Nutritional composition of ripe gabiroba fruits.

STORAGE TIME (DAYS)	ABTS$^+$		DPPH•	
	Ethereal extract	Hydro alcoholic extract	Ethereal extract	Hydro alcoholic extract
30	79.54 ± 2.45[b]	109.9 ± 4.12[a]	53.25 ± 0.87[d]	70.67 ± 0.96[c]
60	76.17 ± 3.14[a]	76.82 ± 1.34[a]	49.56 ± 0.79[d]	68.23 ± 0.34[c]
90	55.38 ± 2.56[c]	75.78 ± 1.09[a]	32.56 ± 0.26[d]	62.35 ± 0.12[b]
120	45.32 ± 2.34[c]	75.34 ± 0.98[a]	22.45 ± 0.07[d]	55.08 ± 0.23[b]
150	33.38 ± 0.45[c]	69.14 ± 0.76[a]	14.56 ± 0.32[d]	52.45 ± 0.45[b]
180	19.13 ± 0.23[c]	66.89 ± 0.85[a]	7.70 ± 0.09[d]	49.8 ± 0.56[b]
EC$_{50}$	128.04[B]	44.63[C]	216.29[A]	43.58[C]

Table 2: Trolox-Equivalent Antioxidant Capacity (TEAC) for the Gabiroba Extract as Measured by using the Dpph• and the Abts$^+$ Methods (µMol Trolox. g^{-1} of fruit pulp).

Power Law					
Temperature	K (Pa.s^n)		n	R^2	X^2	RSS
20°C	0.621		0.364	0.976	0.281	1.396
40°C	0.506		0.372	0.987	0.056	0.134
50°C	0.453		0.397	0.995	0.022	0.029
60°C	0.462		0.403	0.996	0.019	0.018
Herschel-Bulkley					
Temperature	τ(Pa)	K(Pa.s^n)	n	R^2	X^2	RSS
20°C	1.871	0.116	0.626	0.993	0.025	1.031
40°C	1.351	0.098	0.631	0.997	0.007	0.016
50°C	1.392	0.101	0.673	0.998	0.008	0.015
60°C	1.229	0.089	0.735	0.998	0.009	0.016

Table 3: Rheological features of the gabiroba pulp and statistical features for the fit of the power law and the herschel-bulkley models to the data.

problem in developing countries, including some Brazilian regions [6]. The gabiroba presented a vitamin A content of 20.61µg.g^{-1} (expressed as retinol). Therefore, 30 g of fruits are enough to fulfill the RDI (600 µg) of an adult [7]. In addition, the gabiroba presented a caratenoid content of 290.84 µg.g-1, from which 42% corresponds to beta-carotene. When compared to other fruits, the gabiroba presents remarkable contents of iron, being superior to that of bananas (0.4 mg.100 g^{-1}) and apples (0.1 mg.100 g^{-1}) [8]. Therefore, the gabiroba can be considered a good source of iron (6.05 ± 0.05 mg, 43.21% of the RDI) and zinc (2.77 ± 0.02 mg, 39,57% of the RDI), as shown in table 1.

In order to determine which solvent provides the highest antioxidant capacity of bioactive compounds, it is necessary perform the extraction with solvents of different polarity. In this study, it was observed that the hydro alcoholic gabiroba pulp extract presented the highest TEAC values and the lowest EC$_{50}$ values. A low EC$_{50}$ value reflects a high *in vitro* antioxidant capacity of a selected compound, since the concentration necessary to inhibit the radical oxidation in 50% is low. On the other hand, the ethereal extract presented low values of TEAC and high values of EC$_{50}$, as shown in table 2. It was observed that, during storage, the antioxidant capacity of the gabiroba pulp changed significantly on 5% confidence level.

The obtained results reflect the different solvent polarities, being ethanol more polar than the petroleum ether for methods studied. Such result can be explained by the fact that the phenolics compounds are polar, presenting high affinity for polar solvents like ethanol. On the other hand, the petroleum ether extracts more easily the lipophilic compounds, like carotenoids.

Rheological Measurements the Gabiroba Pulp

Rheological measurements are an analytical tool that provides a proper profile of one food structural features. In fruit pulps, several
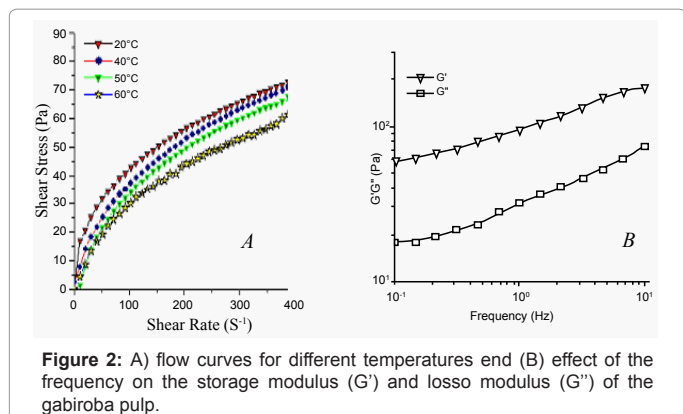
Figure 2: A) flow curves for different temperatures end (B) effect of the frequency on the storage modulus (G') and losso modulus (G'') of the gabiroba pulp.

Fractions	Yield (%)[1]	degree of esterification DE[2]	Levels of total Sugars (%)	Levels of Proteins (%)
F - H$_2$O	8,5^a	62.7^a	86.2^a	5.73^d
F1	5,9^b	53.6^b	84.3^b	5.6^d
F2	3,2^c	52.9^c	74.4^e	5.8^d
F3	3,1^d	51.2^d	75.4^d	7.3^b
F4	2,1^e	50.5^d	78.2^c	6.3^c
F - NaOH 2 mol.L^{-1}	2,1^e	47.7^e	78.8^c	7.5^a

NOTE: [1]Yield of fractions with respect to the residue insoluble in alcohol. [2]DE: Degree of esterification determined by FT-IR, Extraction conditions: F H$_2$O (water extracted with 26°C/60 min), F1 (extracted with citric acid 0.5%/ 50° C/60min) and F2 (extracted with citric acid 0.5%/ 100 °C / 60min), F3 (extracted with citric acid 5% / 50°C/60min) and F4 (extracted with 5%citric acid / 100°C / 60 min). F-NaOH (extracted with a solution of sodium hydroxide 2 mol L^{-1}/26 °C / 60 min) Means with same letters in the same column are not significantly different (Tukey p<0.05)

Table 4: Yield of fractions, Degree of Esterification (DE), determination of total sugar and protein fractions of the pulp of polysaccharide gabiroba in different conditions.

Fractions	Monosaccharide Neutral							
	ÁCIDS URONIC	Rha	Fuc	Ara	Xyl	Man	Gal	Glc
%								
F - H$_2$O	16.91^e	0.82^e	nd	74.99^a	2,94^e	0.81^d	16.83^d	3.62^d
F1	22.47^a	3.07^b	nd	50.15^d	4,34^c	2.39^a	27.37^a	12.7^a
F2	17.09^d	1.13^d	0.2^c	71.62^b	2,63^e	0.61^e	20.99^d	2.81^d
F3	17.79^{c,d}	2.16^c	0.37^b	61.66^d	5,13^b	1.16^c	22.31^b	7.22^c
F4	18.35^c	2.16^c	nd	66.71^c	3,19^d	1.11^c	22.93^d	3.89^d
Fração NaOH 2 mol.L^{-1}	20.73^b	3.64^a	1.41^a	58.54^e	6,77^a	1.64^b	19.53^c	8.48^b

NOTE $^{-1}$: determined by GLC,% extraction conditions F H$_2$O (water 26°C/60 min) F1 (citric acid 0.5%/50 ° C/60 min) and F2 (0.5% citric acid / 100 °C/60 min), F3(citric acid 5%/50°C/60min) and F4 (5% citric acid/100°C/60 min). F-NaOH (sodium hydroxide solution 2 mol L^{-1} / 26°C/60 min) Means with same letters in the same column are not significantly different (Tukey p<0.05). Nd: not detected.

Table 5: Monosaccharide composition of the fractions of polysaccharides pulp gabiroba.

factors contribute to the observed rheological behavior, such as temperature, soluble solids content and particle size [9]. With regard to the time-independent behavior of the gabiroba pulp, figure 2 shows the variation of the shear stress as a function of the shear rate for different temperatures (20, 40, 50 and 60°C). It was observed a non-Newtonian behavior, since the relation between shear rate and shear stress is not linear. In addition, the shear stress decreases with increasing shear rate, which denotes a shear-thinning behavior. Such behavior can be explained by a structural change in the pulp when the shear rate increases, namely the alignment of the biopolymers with increasing

rotational speeds [10]. The low concentration in the disperse phase turns the continuous phase to determine he fluid features [11].

Table 3 shows the rheological features of the gabiroba pulp at different temperatures as fitted by the studied mathematical models.

Table 4 shows that the flow behavior index (n) is minor than one, which denotes a shear-thinning behavior for the gabiroba pulp. The increase in temperature led to a decrease in the values of yield shear stress and in the flow consistency index. A slight increase in the flow behavior index with increasing temperatures was also observed. When comparing the fits provided by the two models used, it can be concluded that the Herschel-Bulkley model provides a better fit than the Power Law model, as denoted by a higher determination coefficient (R^2), a lower chi-square (X^2) and a lower value of Residual Sum of Squares (RSS). Therefore, the Herschel-Bulkley model is proper for describing the gabiroba pulp rheological behavior.

With regard to the viscoelastic measurements, an initial stress sweep (0 to 100Pa) was performed in order to find the linear viscoelastic region. On a second stage, a frequency sweep was performed at a stress of 10Pa. Figure 3 shows the mechanical spectrum for the gabiroba pulp at 25°C. It was observed that the storage modulus (G') and the loss modulus (G'') are frequency independent.

The hydro alcoholic extract of gabiroba pulp presented the highest values of TEAC and the lowest values of EC$_{50}$, which denotes a higher antioxidant capacity when compared to the ethereal extract. It was observed a slight tendency of increase in the flow behavior index (n) with increasing temperature. The gabiroba pulp presents a shear-thinning behavior with the presence of a yield stress. The mechanical
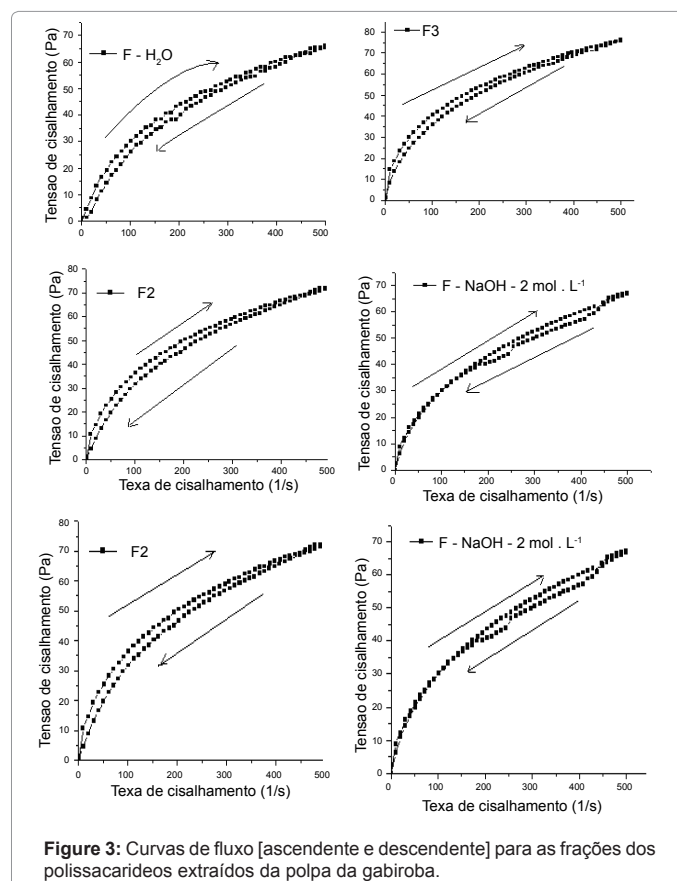

Figure 3: Curvas de fluxo [ascendente e descendente] para as frações dos polissacarideos extraídos da polpa da gabiroba.

spectrum of the gabiroba pulp shows that the module is frequency independent. Taking into account the Phytochemicals found in the gabiroba fruit, this fruit can be considered a native fruit with proper functional features and a great potential for use by the food industry.

Chemical Characterizations of Polysaccharides Extracted from the Pulp of Gabiroba

Pectins

Pectins are complex polysaccharide found in primary cell wall and intercellular layers of vegetables; these are associated with structural polysaccharides, contributing to adhesion between cells and the mechanical resistance of the cell wall. Structurally pectins are composed of a linear main chain of wetlands repeated D-galacturonic acid linked by bonds α (1 → 4), where part of these units may present esterified as methyl ester. The linear chains are interspersed with units of (1 → 2)-α - L-rhamnose, which serve as points of links to the side chains composed of neutral sugars, mainly D-galactose, L-arabinose, L-rhamnose. The pectins are subdivided into two groups, one with a high degree of methoxylation which have more than 50% of its esterified carboxyl groups and one with low degree of esterification those with less than 50% of its carboxyl groups esterified. The high degree of pectin methoxylation gelled in the presence of high concentrations of soluble solids, generally exceeding 55% and pH values from 2.0 to 3.5 [12]. This gel is stabilized by hydrophobic interactions between the methyl ester groups and formation of hydrogen bonds. The addition of soluble solids decreases the activity and availability of free water to solvate polysaccharides, approached them and facilitating the occurrence of hydrophobic interactions between the methyl ester groups [13]. The low degree of pectin methoxylation form gels in the presence of calcium and other divalent ions. The gelation is due to formation of intermolecular junction zones between regions of different homo-galacturonic chains, according to the egg box model. Pectins are polysaccharides widely used industrially, especially in food products, which are added in small quantities.

Extraction of polysaccharides from the pulp of gabiroba

The pulp of ripe fruit (1500 g), seeded, was added water/ethanol 1:4 (v/v), crushed in blender, subjected to heating under reflux for 15 minutes at boiling temperature for inactivation of endogenous enzymes, followed cooling in an ice bath and filtration to obtain the synthetic Alcohol Insoluble Residue (AIR), starting material for extraction of polysaccharides. The AIR was subjected to centrifugation four times (15400xg for 20 min) and dehydrated in the vacuum oven (Brand-Q819V Quimis) to constant weight. The insoluble residue [AIR] was first subjected to extraction with distilled water for 60 minutes at room temperature (26 ± 2°C). Then the material was filtered through filter synthetic (polyester). The retained fraction was used for acid extraction. The extraction time was 60 minutes in all experiments, with the variable concentration of citric acid [0.5% and 5%] and temperature (50°C and 100°C), resulting in four fractions. After the final extraction with citric acid the insoluble residue was subjected to an alkaline extraction using a solution of sodium hydroxide, 2 mol L^{-1} at room temperature (26 ± 2°C) for 60 minutes.

The extractions were performed using a mechanical shaker Fisaton brand model 713. After each extraction, the dispersions were centrifuged at 15400xg for 20 minutes, separating the residue used for subsequent extractions. The polysaccharides were precipitated from the supernatant by adding two volumes of 95% ethanol and kept under refrigeration for 24 hours to precipitate the polysaccharides. After

filtration of polyester, the precipitated material was dehydrated in the vacuum oven (Q819V-Brand Quimis) to constant weight, resulting in the respective fraction. The yield of extraction was calculated in relation to Alcohol Insoluble Residue (AIR).

Chemical characterization of polysaccharides extracted from the pulp gabiroba

The determination of protein content of the polysaccharide fractions was conducted by Hartree [14], using solutions of Bovine Serum Albumin (BSA) as standard, at concentrations of 20-80μg.mL^{-1}. Readings were made at 660 nm. All tests were performed in triplicate. The absorbance was measured in a spectrophotometer Shimadzu UV-VIS multispecies 1501. To determine the monosaccharide composition, the polysaccharides were hydrolyzed with trifluoroacetic acid 2 mol L^{-1} in tightly sealed tube at 100°C in an oven Fanem, Orion controller with A-HT for five hours [15]. The remaining acid was removed by evaporation of the hydrolyzed. The monosaccharides resulting from total acid hydrolysis were reduced with sodium borohydride (NaBH$_4$) for two hours to promote the reduction of carboxylic groups of the monosaccharide and train alditóis. The excess of the reducing agent was decomposed and removed by adding sodium cations of cation exchange resin in acid form (Lewatit®). The solution was filtered through cotton and after this step the material was evaporated to dryness with nitrogen flow, followed by three consecutive washes of methanol to remove the remaining boron by co-distillation in the form of trimethyl borate. The resulting alditóis were acetylated by adding pyridine, which acts as a catalyst and acetic anhydride at a ratio of 1:1 (v/v) for about 16h hydrolysis tube tightly closed in 27°C temperature [16].

The alditóis acetates were extracted with 1 mL of chloroform. The residual pyridine was complexed with an aqueous solution of copper sulphate (CuSO$_4$) to 5% [w/v], thus being separated from the chloroform phase and eliminated by successive washes interspersed with distilled water and CuSO$_4$.

The chloroform phase containing the acetates alditóis was collected and after drying with nitrogen flow, the sample was resolubilized in acetone for analysis by Gas-Liquid Chromatography (GLC). Analyses by GLC were performed in a gas chromatograph Hewlett Packard model 5890 Series II with Flame Ionization Detector [FID] and injector temperature of 250°C, capillary column DB-210 (30m×0.25 mm internal diameter), with film thickness of 0.25 mM to 220°C, and nitrogen as carrier gas flow of 2.0 mL min^{-1}. The degree of esterification of pectin was determined by infrared spectroscopy (FT-IR-Fourier-transform infrared) spectrophotometer Bomem MB -100. The spectra were collected in transmittance mode in the range of wave numbers 4000-400cm^{-1} at a resolution of 4 cm^{-1}, 32scans, using powdered solid samples. We prepared tablets of potassium bromide 90: 10 (w/w) KBr /sample. As white, KBr pellet was used for correction of absorption of CO$_2$ and air mixture prior to analysis. The areas of peaks corresponding to carboxylic groups esterified and not esterified were obtained using the software. The degree of esterification was calculated by the equation: area COO-R/(area COO-R+area COO–H)×100, with calculation of the areas of bands around 1741 and 1635cm^{-1}, corresponding to the uronic acids esterified and free, respectively. Weighing of polysaccharides and KBr was used Radwag an analytical balance, accurate to 0.0001 g. The table 4 presents the results for income, Degree of Esterification (DE), levels of total sugars and proteins of the polysaccharide fractions obtained from the pulp gabiroba.

Yields of polysaccharide fractions obtained from the pulp gabiroba ranged from 2.1 to 8.5%. These results were similar to those obtained

for pectin of *Psidium cattleianum Sabine* pulp fruit [17], but lower than those found for pectin extracted from apple pomace flour [18].

The F4 fraction, obtained in more severe conditions (5% citric acid /100°C/60 min), had lower income and lower degree of esterification compared to other fractions obtained from the pulp gabiroba. The total sugar content of the polysaccharide fractions was between 74.4% and 86.2%, similar to values the levels found for polysaccharides extracted from fruits of Cambridge shire [19]. The physico-chemical properties of polysaccharides are determined by monosaccharide composition and content of uronic acids [20]. The highest proportion of uronic acid was detected in a fraction extracted with citric acid 0.5%/ 50°C/60 min in less drastic conditions (Table 5).

The rhamnose is a monosaccharide that is at points of branching of the side chains, which according to table 5 contain mainly arabinose and galactose in higher proportions. After determining the monosaccharide composition, the polysaccharides extracted from the pulp gabiroba were evaluated for their rheological behavior under different conditions in the concentration of 30 g.L^{-1}.

Analysis rheology of polysaccharides extracted from the pulp of gabiroba

Rheometry was performed in HAAKE rheometer RS 75 Rheoestress coupled to a Peltier temperature controller (TC81) with water termocirculador DC5B3. The gels of polysaccharides were analyzed using a cone-plate sensor C-60 2 Ti. Initially it was determined the inertia of the machine with the sensor to be used to discount the values of the centrifugal and centripetal forces generated during the experiments. This procedure was repeated at each change of sensor.

During the analysis, the temperature was maintained at 20 ± 1°C. Prior to the rheological analysis to determine the viscoelastic behavior of the samples was performed in a scanning voltage to a frequency of 10 Hz, to verify the linear viscoelastic range and selection of the voltage that would be employed in the analysis of scan frequency and temperature ramps, to preserve the structure of the viscoelastic sample.

The frequency sweeps were conducted in pre selected voltage, increasing the oscillatory frequency with time, in the range 0.1-10 Hz. The samples were also analyzed against temperature variations with a fixed frequency of 1 Hz. To prevent evaporation of the solvent was applied a layer of mineral oil around the plate analysis.

Preparation of gels of polysaccharides extracted from the pulp to the gabiroba Rheometry: To obtain the gels used in rheometry powdered polysaccharides and sugar were dissolved in a solution of sodium chloride 0.1 mol L^{-1} with stirring for about 24 hours at room temperature (28 ± 2°C). After dissolution, the pH of the suspension was adjusted to 4.0 and added calcium chloride in the relationship (2(Ca +2/)(COO-)) forth ratio R = 0.58 followed by heating to 80°C under stirring for 10 minutes [21]. The gel was kept refrigerated until the time of analysis.

Most practical applications of polysaccharides involves its ability to alter the physical properties of food, is to confer high viscosity solutions or create inter molecular cohesive networks. The gel formation is a very important process, because the structure of the gel influences the processing and the texture of a variety of products, this being one of the factors that have attracted great interest in the rheological properties of polysaccharides over the years [22].

Most of the fluid presents a rheological behavior that ranks among the liquid and solid: they are called viscoelastic. Thus, the viscosity

and elasticity are two possible answers to the stress they are subjected. The behavior of solid (relaxation) or liquid (flow) will depend on the characteristics related to the natural relaxation time and the duration of the experiment [23].

The flow curves obtained for the polysaccharide fractions of pulp gabiroba can be seen in figure 3, where it appears that all the fractions showed a pseudoplastic behavior. To determine the linear viscoelastic range, the pulp gabiroba underwent a scan voltage in the range 1 to 10 Pa and then selected the tension of 1 Pa, for the sweep frequency. After scanning voltage according to the linear viscoelastic range, the polysaccharide fractions were tested for frequency scanning.

The results of analysis of the oscillatory dynamics of polysaccharide fractions showed storage modulus (G') higher than the loss modulus (G") over the entire range examined (Figure 4).

The fraction (F-H$_2$O) extracted at room temperature (26°C) showed a predominance of solid character (G'> G") throughout the frequency range analyzed. The fractions F1 and F2 showed a predominance of solid character (G'> G") in the conditions studied. It is observed that the storage modulus (G') and loss (G") showed little dependence on the frequency range analyzed. This behavior reflects the existence of a three-dimensional network [24].

The F1 fraction had values of G ' higher than those obtained for fraction F2, as well as a greater difference between the storage modulus (G') and loss (G "). These features allow us to conclude that the fraction F1 forms a stronger gel than the F2 fraction under the conditions tested. As the fraction F2 was obtained under more drastic extraction, it is possible that they have promoted depolymerization of polysaccharides, which could hinder the formation of the network. The oscillatory dynamic test results for samples F3 and F4 obtained at higher temperature (100°C) showed that these fractions also showed the storage modulus (G') higher than the loss modulus (G") across the range frequency analysis. Again, the fraction obtained under
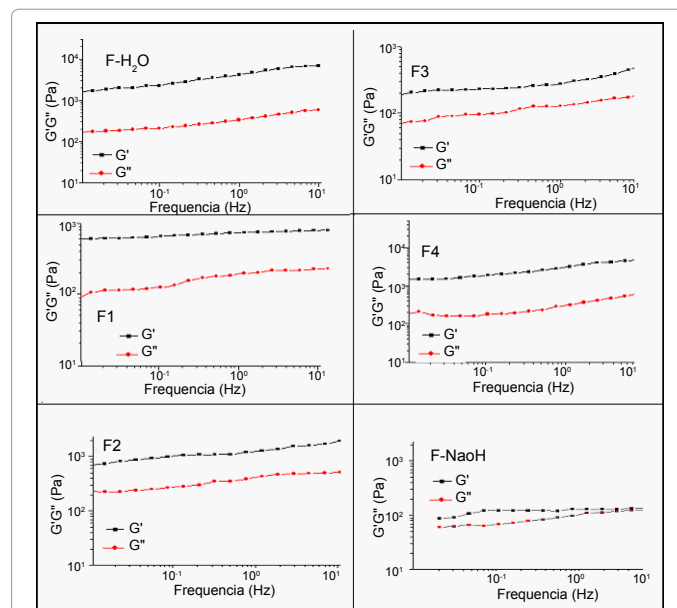

Figure 4: Effect of frequency (HZ) on storage modulus [G'] and loss [G"] of polysaccharide fractions extracted from the pulp of the fruit of gabiroba: F1, F2 in the presence of calcium and sucrose R=0.58 / 20%, and F3 F4 in the presence and sucrose de calcium R=0.58 / 20%. The fractions F-H$_2$OF and NaOH in presence of sucrose70%.
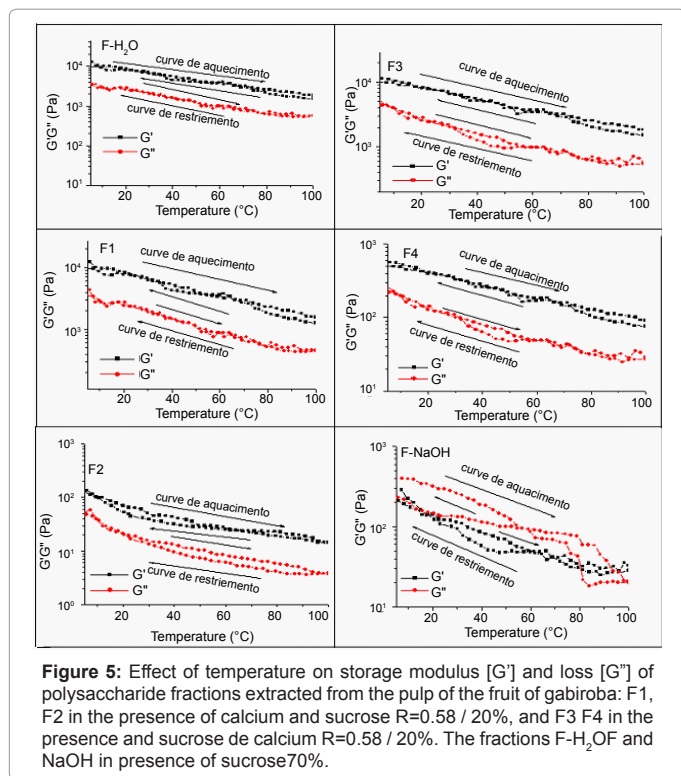
Figure 5: Effect of temperature on storage modulus [G'] and loss [G"] of polysaccharide fractions extracted from the pulp of the fruit of gabiroba: F1, F2 in the presence of calcium and sucrose R=0.58 / 20%, and F3 F4 in the presence and sucrose de calcium R=0.58 / 20%. The fractions F-H_2OF and NaOH in presence of sucrose70%.

POWER LAW				HERSCHEL-BULCKEY				
Fractions	K (mPa.s/n)	n	R2	X2	τ0(mPa/n)	K (mPa.s/n)	n	R2	X2
F - H_2O	50.25	0.71	0.997	0.1	50.34	33.54	0.81	0.998	0.02
F1	44.89	0.69	0.995	0.04	47.37	29.15	0.8	0.998	0.01
F2	30.74	0.71	0.993	0.08	60.81	27.22	0.79	0.997	0.03
F3	29.97	0.72	0.996	0.05	65.01	24.35	0.8	0.995	0.01
F4	28.62	0.71	0.994	0.06	46.98	22.13	0.82	0.996	0.01
F4-NaOH	16.45	0.71	0.993	0.03	38.77	19.89	0.81	0.995	0.02

Table 6: Rheological parameters for the model power law and herschel-bulckey.

more drastic extraction (F4) had lower values of G' and a smaller difference between the modules of the fraction F3 extracted with 5% citric acid at 100°C and F-NaOH extracted with solution of the sodium hydroxide 2 mol L^{-1}, which were the more drastic conditions. These results corroborate the hypothesis that temperature, and solvent type and the highest concentrations of solvent can promote degradation of polysaccharides.

The drastic conditions of extraction of polysaccharides leads to depolymerization and deseterification therefore polygalacturonic chain fragmentation occurs, affecting the gelation of pectin [25]. All factions have formed gels but with different characteristics. The fractions that showed the lowest powers were gelling fractions F4. The polysaccharide fractions of pulp gabiroba were also evaluated against in temperature (Figure 5).

The heating and subsequent cooling caused marked changes only in the texture of the gels of the last fraction extracted with sodium hydroxide. Aside from this fraction all other fractions showed characteristic good resistance against temperature changes. When subjected to cycles of heating and subsequent cooling these gels return to their original structure. The *Herschell-Bulkley* model was what

provided the best fit parameters for polysaccharides studied, with the lowest values for X^2 in all fractions (Table 6).

No significant change was observed between the trend of the curve rising shear rate from 0 to 500 s^{-1} and the downward trend of the curve for shear rate 500 to 0 s^{-1}.

We can observe that the values of the behavior index (n), which were lower one [1] for all samples investigated, showing that the pectin extracted from the pulp gabiroba presents pseudoplastic behavior. Many factories affect the rheological properties of pectin, as well as the gel strength formed. However, the main role is played by molecules of pectin, so that your chain length and chemical nature of the connection areas have a strong influence on these characteristics. Under equal conditions, the gel strength increases with increasing molecular weight of pectin used and any treatment those depolymerize the chains of pectin gels reflected in weakest. Decrease justifying the consistency of the gels the fractions obtained in harsh conditions

Conclusion

The hydroalcoholic extract of gabiroba pulp presented the highest values of TEAC and the lowest values of EC_{50}, which denotes a higher antioxidant capacity when compared to the ethereal extract. It was observed a slight tendency of increase in the flow behavior index (n) with increasing temperature. The gabiroba pulp presents a shear-thinning behavior with the presence of a yield stress. The mechanical spectrum of the gabiroba pulp shows that the moduli are frequency independent. Taking into account the phytochemicals found in the gabiroba fruit, this fruit can be considered a native fruit with proper functional features and a great potential for use by the food industry.

The fractions of pectin isolated from pulp gabiroba had to consist mainly of uronic acid, arabinose, galactose and rhamnose in different proportions. The extraction conditions interfere with the monosaccharide composition, degree of esterification and gelling power of the polysaccharide a concentration of pectin 30 g. L presented pseudoplastic behavior. All fractions isolated pectin gels formed. All fractions of pectin extracted from gabiroba, even those obtained in more drastic conditions, showed characteristic resistance to variations in temperature. When subjected to cycles of heating and subsequent cooling, these gels return to their original structure.

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