Acta Scientiarum. Agronomy
ISSN: 1679-9275
eduem@uem.br
Universidade Estadual de Maringá
Brasil

Santos, Marli da Silva; de Lima, Jair José; Petkowicz, Carmen Lúcia de Oliveira; Candido, Lys Mary Bileski

Chemical characterization and evaluation of the antioxidant potential of gabiroba jam (Campomanesia xanthocarpa Berg)

Acta Scientiarum. Agronomy, vol. 35, núm. 1, enero-marzo, 2013, pp. 73-82
Universidade Estadual de Maringá
Maringá, Brasil

Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9275
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v35i1.14389

Chemical characterization and evaluation of the antioxidant potential of gabiroba jam (*Campomanesia xanthocarpa* Berg)

Marli da Silva Santos[1*], Jair José de Lima[2], Carmen Lúcia de Oliveira Petkowicz[3] and Lys Mary Bileski Candido[1,4]

*[1]Programa de Pós-graduação em Tecnologia de Alimentos, Departamento de Engenharia Química, Universidade Federal do Paraná, Rua Quinze de Novembro, 1299, 80060-000, Centro, Curitiba, Paraná, Brazil. [2]Departamento de Nutrição, Universidade Federal do Paraná, Curitiba, Paraná, Brazil. [3]Departamento de Bioquímica e Biologia Molecular, Universidade Federal do Paraná, Curitiba, Paraná, Brazil. [4]Departamento de Tecnologia de Alimentos, Universidade Tecnológica Federal do Paraná, Curitiba, Paraná, Brazil. *Author for correspondence. E-mail: marli.sisantos@bol.com.br*

ABSTRACT. Four formulations of gabiroba jam were processed, and their physicochemical and functional characteristics, rheological profile and jam acceptance were assessed. The physicochemical and chemical characteristics evaluated were water activity, titratable acidity, pH, reducing and non-reducing sugars, proteins, ashes, dietary fibers, color, and firmness. For functional analyses of the formulations, vitamin C, phenolic compounds and carotenoid contents were determined. The $ABTS^+$ and $DPPH^\bullet$ methods were employed to evaluate the antioxidant potential. Rheological analysis was performed in a HAAKE RS 75 Rheoestress rheometer with a plate/plate sensor. The flow curve behavior was adjusted using the Power Law and Herschel-Bulkley models. Sensory analyses were performed by 52 untrained testers using a 9-point structured hedonic scale. The content of total phenolic compounds in the jam was between 322.09 and 728.48 mg 100 g^{-1}. The variation of vitamin C content was 97.39 to 123.39 mg 100 g^{-1}. The samples also showed good retention of beta carotene. All samples showed a higher storage modulus (G') than loss (G") Thsensory evaluation revealed a satisfactory acceptance of the gabiroba jam formulations.

Keywords: gabiroba, jam, antioxidant activity, rheological profile.

Caracterização química e avaliação do potencial antioxidante do doce em massa de gabiroba (*Campomanesia xanthocarpa* Berg)

RESUMO. foram processar quatro formulações de doces em massa de gabiroba e avaliar às suas características físico-químicas, funcionais, perfil reológico e aceitabilidade dos doces. As características físico-químicas e físicas avaliadas foram: atividade de água, acidez titulável, pH, açúcares redutores e não redutores, proteínas, cinzas, fibra alimentar, cor, firmeza. Para avaliação funcional das formulações foram determinados os teores de vitamina C, compostos fenólicos, carotenóides. O potencial antioxidante foi determinado através dos métodos $ABTS^+$ e $DPPH^\bullet$. As análises reológicas foram realizadas em reômetro HAAKE RS 75 Rheoestress com o sensor placa-placa. O comportamento das curvas de fluxo foi ajustado pelos modelos de Lei da Potência e Herschel-Bulkley. A avaliação sensorial foi realizada por 52 provadores não treinados utilizando escala hedônica estruturada de nove pontos. Os doces apresentaram teores de compostos fenólicos totais entre 322,09 e 728,48 mg 100 g^{-1}. A variação do teor de vitamina C foi de 97,39 a 123,39 mg 100 g^{-1}. As amostras também apresentaram uma boa retenção de beta caroteno. Todas as amostras apresentaram módulo de armazenamento (G') superior ao módulo de perda (G"). O estudo de análise sensorial revelou uma aceitação satisfatória para formulações de doce em massa de gabiroba.

Palavras-chave: gabiroba, doce em massa, atividade antioxidante, perfil reológico.

Introduction

Campomanesia xanthocarpa Berg is a fruit-bearing tree belonging to the Myrtaceae family. Its fruits are not used frequently, except by local populations who consume them fresh. They are also a food source for wild animals. Data on crop production and usage of the fruit in human food, as well as its industrial applications, are incipient, even though the fruit shows potential as a nutritional source and as a raw material for the food industry. In Brazil, the plant *Campomanesia xanthocarpa* Berg, popularly known as the gabiroba tree, whose fruit is the gabiroba, guabiroba or guavirova, is present in the Southern region of the country as well as in Argentina, Paraguay and Uruguay (LORENZI, 2002). The gabiroba tree (*Campomanesia xanthocarpa* Berg) shows an extensive fruiting, mainly in natural environmental conservation areas. Regional native fruits, such as the gabiroba, are important not only for their technological potential but also because they can contribute to diversifying fruit production in a particular region. On the other hand, new product development is essential to ensure businesses survive, especially in the food industry. This is due to a need to launch new products to stand out in the consumer market, which is eager for new products and is increasingly disloyal to traditional products. These facts make the food market very competitive (WILLE et al., 2004).

Using the raw material of the gabiroba tree for processing may constitute an alternative source of income, especially for family agribusinesses, as it represents a new aroma and flavor option for the consumer market and contributes to the use of an underutilized natural resource.

Based on this situation and the fact that information on the industrial use of this fruit in the literature is scarce, the aim of this paper is to prepare four formulations of gabiroba jam, including one conventional sample and three reduced calorie formulations. Another aim is to analyze the physicochemical and functional characteristics, as well as the rheological profile of these products.

Material and methods

Samples - Physiologically developed fruits of gabiroba, *Campomanesia xanthocarpa* Berg, were collected from dispersed native plants in the Itaiacoca district, near the city of Ponta Grossa, Paraná State, located at 975 m of altitude and with the geographic coordinates 25° 05' 42" south latitude and 50° 09' 43" west longitude from the Greenwich meridian.

Jam processing - Fruits were properly selected according to color consistency, size and absence of injuries. The fruits were then sanitized and pulped in a horizontal pulping machine. Four formulations of gabiroba jam were prepared, including one conventional sample and three reduced calorie formulations. The following ingredients were used in the jam formulations: ripe gabiroba pulp, sucrose, sucralose® (a sweetener used for cooking), pectin texturizer from CPKelco®, xanthan gum, calcium chloride and citric acid.

After defining the formulations (Table 1) and mixing the ingredients, samples were submitted to steam cooking in a stainless steel pan to a soluble solid content of 75°Brix for the standard samples and the DF2 formulation and 50°Brix for the DF3 and DF4 jam formulations. The methodology used for the jam preparation was described by Jackix (1988).

Table 1. Gabiroba jam formulations.

Ingredients	DF1 Standard	DF2	DF3	DF4
Pulp (g)	1000	1000	1000	1000
Sucrose (%)	100	25	-	-
Sucralose (%)	-	5.0	5.0	4.0
Pectin - texturizer (%)	-	1.5	2.4	2.4
Xanthan gum (%)	-	-	2.4	3.6
Calcium chloride (%)	-	0.06	0.1	0.1
Citric acid (%)	-	0.5	0.5	0.5

The hot-fill packaging technique with glass jars and metal lids was utilized. The containers were cooled shortly after packaging and then refrigerated.

Physicochemical analyses - The following physicochemical parameters were evaluated. The pH was determined by means of a digital pH meter (300 M, Analyzer) previously calibrated with buffer solutions of pH 4.0 and 7.0. The total soluble solid content (°Brix) was determined by direct reading in a refractometer. The titratable acidity content was expressed in citric acid; the methodologies used for determination of such parameters are described by Brasil (2005). Moisture, ash, lipid and protein content were determined according to the AOAC (1997) method. The total and reducing sugars were determined by spectrophotometric analyses using the phenol-sulphuric method (DUBOIS et al., 1956) and the DNS method (3.5-dinitrosalicylic acid) (MILLER, 1959) at wavelength settings of 490 and 540 nm, respectively. The total dietary fiber content was determined according to the enzymatic gravimetric method (AOAC, 2000).

Determination of phytochemical compounds - Carotenoids were measured according to the Rodriguez-Amaya (2001) methodology. Vitamin C content was determined by the method proposed by Terada et al. (1979) and modified by Yazdinejad (2007) using dinitrophenylhydrazine (DNPH) and using ascorbic acid as a standard. The total phenolic compound content in the samples was calculated by means of UV-visible spectroscopy using the method described by Folin Ciocalteu (HORWITZ, 1980).

Evaluation of antioxidant potential - The antioxidant capacity in scavenging free radicals was evaluated using the DPPH (2.2-diphenyl –1– picryl-hydrazyl) method as described by Brand-Williams et al. (1995) as well as the ABTS radical formation method according to Re et al. (1999). The antioxidant activity results were expressed in Trolox Equivalent Antioxidant Capacity, or TEAC (μmol g^{-1} of sample). To determine the antioxidant capacity, two types of extract were performed, one of them using distilled water as solvent and the other using petroleum ether extract.

Obtaining the extracts - Two extracts were prepared: an aqueous extract and a hydroalcoholic extract. For the preparation of the aqueous extract of the gabiroba jam samples, a 25 g sample was weighed, and water was added in a 1:1 ratio (sample:water). The mixture was then homogenized for five minutes in a homogenizer (Marconi MA-102) on speed setting number four. The homogenized sample was then centrifuged at 18,000xg. Water was added to the precipitate for an additional 5-minute extraction followed by centrifugation. The procedure was repeated until either the solvent turned colorless or the residue turned whitish. The supernatants were collected, frozen and lyophilized to make up the aqueous extract. Lyophilized extract was stored at - 20°C until analysis. Hydroalcoholic extract was obtained using 92°GL ethanol from 25 g of sample in a 1:1 ratio (solvent:sample) followed by homogenization for five minutes using a homogenizer (Marconi MA-102) on speed setting number four. The sample was then filtered using a Buchner funnel. The material retained by the filter was added to alcohol one more time for an additional 5-minute extraction and later filtered. The procedure was repeated until either the solvent turned colorless or the residue turned whitish. The filtrate was concentrated on a rotary evaporator under reduced pressure to remove the ethanol, at 40°C, then lyophilized and kept frozen at - 20°C for further analysis.

Water activity - The water activity was measured at 25°C by means of a water activity meter (Decagon Aqualab CX- 2).

Color analysis - The color was determined using a colorimeter (Minolta CR300), CIE L*a*b* system (L*= lightness); a* (+) = redness; b*(+) = yellowness). Equipment calibration was conducted using a white ceramic plate and illuminant D65. Readings were taken directly at an average of three determinations considered to be a response to the color parameter (HUNTERLAB, 2011).

Firmness and adhesivity analysis - The firmness and adhesivity were determined in a TA-XT2i texturometer. Compression was performed at a 1 mm* s^{-1} speed, with a 10 mm penetration distance and approximately 1 cm^3 samples.

Rheological analyses - Rheometry was performed using a HAAKE RS 75 Rheoestress rheometer coupled with a Peltier temperature controller (TC81) with a water term circulator (DC5B) using the plate-plate PP-35ti sensor. The flow curve behavior for pulp and jam formulations was adjusted by the Power Law and Herschel-Bulkley models (ABU-JDAYIL et al., 2002; HOLDSWORTH, 1971).

Microbiological analyses - For microbiological evaluation, the following three analyses were performed: yeast and mold counting, coliforms at 45°C and *Salmonella* sp. research using the techniques outlined in the current legislation, RDC # 12 (BRASIL, 2001).

Sensory evaluation - An acceptance test of the gabiroba jam samples was carried out at the Sensory Analysis Laboratory of the Food Technology Department, Federal University of Paraná with the participation of 52 volunteer members of the university community from both sexes and of all ages. Volunteers were selected based on their interest and availability to take part in the tests. Samples were evaluated through tests of preference and intention to purchase in accordance with NBR 12806/1993 (ABNT, 1993). The testers assessed the samples using a 9-point structured hedonic scale, as follows: 1 – disliked very much; 2 – disliked quite a lot; 3 – fairly disliked; 4 – slightly disliked; 5 – neither liked nor disliked; 6 – slightly liked; 7 – fairly liked; 8 – liked quite a lot; 9 – liked very much. The samples were marked with random three digit numbers and served to testers in individual booths under white light. Plain mineral water and biscuit means cookie were provided for rinsing of the palate between sample evaluations.

For the sensory evaluation, the project was approved by the Ethics Committee on Research of the Health Sciences Sector/SCS at the Federal University of Paraná, and it is duly registered at SISNEP – National System of Ethics in Research – under no. CAAE-0014.0.091.000-10.

Results and discussion

The gabiroba is a round-shaped fruit with juicy, sweet-tasting pulp, and an average of 16% seeds. The skin is very thin and makes up 17% of the fruit, while the pulp makes up approximately 60% of the total fruit mass. The fruit also has a lingering calyx taking up, on average, 7% of the entire fruit.

The gabiroba fruit was found to have considerable amounts of vitamin C, carotenoids and total phenolic compounds (Table 2).

The gabiroba fruit had an increased moisture content (79.14 g%), which, according to Gemtchüjnicov (1976) and Legrand and Klein (1977), is one of the common characteristics of the fruits in the Myrtaceae family.

Table 3 shows the physicochemical composition of the jam prepared with gabiroba pulp.

The pH and titratable acidity values showed a significant difference ($p = 0.009$ and 0.004) among jam formulations. The natural acidity of the fruit is enough for preparation of conventional jam, which does not require the addition of an acidulate. The acidity values for the formulations were similar to the results found by Nachtigall et al. (2004) in the preparation of reduced calorie blackberry jelly (1.22 mg 100 g^{-1}), which also used sucralose and xanthan in the preparation, and for reduce calorie pineapple jelly observed by Granada (2005).

Table 2. The nutritional composition of ripe gabiroba fruits.

Evaluated Parameters	Average ± Standard Deviation
Moisture at 105 °C (g%)	79.14 ± 0.03
Ashes at 525 °C (g%)	0.68 ± 0.02
Lipids (g%)	1.31 ± 0.06
Total sugars (g%)	7.88 ± 0.60
Reducing sugars (g%)	6.77 ± 0.22
Total proteins (g%)	1.10 ± 0.04
Dietary fibers (g%)	9.88 ± 0.08
Vitamin C (mg 100g^{-1} AA)	313.21 ± 4.93
Total phenolic compounds (mg 100 g^{-1} GA)	131.90 ± 6.16
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

Note: GA = Gallic Acid; A.A = Ascorbic Acid.

Averages with the same letters in the same line do not differ according to the Tukey test at 5%. GA = equivalent in Gallic Acid mg 100 g^{-1} A.A = Ascorbic Acid mg 100 g^{-1}, Total carotenoids in beta-carotene (μg* g^{-1})

Adding pectin and maintaining part of the sucrose contributed to the increasing firmness in the DF2 formulation, but full substitution of sucrose by sucralose affected the firmness in DF3 and DF4 formulations. Regarding color, adding pectin, xanthan gum and replacing sucrose by sucralose reduced the a* values in the DF3 and DF4 formulations, which showed less hints of red and improved sample lightness (Table 3).

Water activity was lower for the jam containing sucrose, DF1 and DF2. A 23 to 32% retention of vitamin C content in the gabiroba jam formulations was observed, with the highest retention in the DF4 sample. The amount of pulp added to each formulation was used to calculate the vitamin C content retained in the jam. Jawaheer et al. (2003) observed a 37.5% retention of ascorbic acid in guava jam. The vitamin C loss is higher in conventionally prepared jam due to a higher processing time. In the case of jam without added sugar, the cooking time is lower, and the thermal treatments basic functions of the thermal treatment are to promote dissolution of ingredients in the mixture and to destroy microorganisms.

The average carotenoids retention was 25.72% in the DF1 and DF2 formulations and 30.14% in the DF3 and DF4 formulations with respect to the content of these substances in the pulp.

According to Toor and Savage (2006), a thermal treatment (temperature of approximately 80ºC) can increase the amount of free phenolic groups in the system by increasing the extraction of these compounds. This treatment may explain the higher phenolic compound retention in the reduced calorie jam formulations (DF3 and DF4) where the processing time was lower relative to the formulations prepared without added sugar (DF1 and DF2). The differences found in the chemical composition of gabiroba jam formulations are also due to the different amount of pulp in the formulation.

Figure 1 shows the results of the antioxidant capacity evaluation for the aqueous and hydroalcoholic extracts of the jam formulations prepared with gabiroba pulp. The results are expressed in TEAC (Trolox Equivalent Antioxidant Capacity) applying the DPPH (2.2-diphenyl –1–picryl-hydrazyl) radical scavenging method.

Table 3. The physicochemical composition of jam prepared with gabiroba pulp.

Evaluated Parameters	DF1	DF2	DF3	DF4
Water activity (aw)	$0.78{\pm}0.04^{b}$	$0.78{\pm}0.02^{b}$	$0.80{\pm}0.04^{a}$	$0.80{\pm}0.08^{a}$
Firmness (N)	$3.02{\pm}0.04^{a}$	$3.93{\pm}0.05^{a}$	$2.98{\pm}0.07^{b}$	$2.95{\pm}0.01^{b}$
Adhesivity (N.S^{-1})	$-1.15{\pm}0.02^{b}$	$-1.13{\pm}0.04^{b}$	$-1.28{\pm}0.03^{a}$	$-1.32{\pm}0.02^{a}$
a*	$8.56{\pm}0.18^{a}$	$8.78{\pm}0.21^{a}$	$6.67{\pm}0.34^{b}$	$6.54{\pm}0.28^{b}$
b*	$20.04{\pm}1.03^{a}$	$19.98{\pm}0.89^{a}$	$19.82{\pm}0.90^{a}$	$19.99{\pm}0.59^{a}$
L*	$40.96{\pm}0.28^{b}$	$41.02{\pm}0.37^{b}$	$42.47{\pm}0.76^{a}$	$42.45{\pm}0.81^{a}$
pH	$3.52{\pm}0.03^{a}$	$3.22{\pm}0.03^{b}$	$3.12{\pm}0.03^{c}$	$3.11{\pm}0.06^{c}$
Titratable acidity	$1.19{\pm}0.29^{b}$	$1.24{\pm}0.09^{a}$	$1.25{\pm}0.63^{a}$	$1.27{\pm}0.27^{a}$
Total Sugar (g%)	$58.07{\pm}0.13^{a}$	$32.54{\pm}0.21^{b}$	$10.09{\pm}0.33^{c}$	$9.59{\pm}0.48^{d}$
Reducing Sugar (g%)	$39.43{\pm}0.54^{a}$	$26.8{\pm}0.48^{b}$	$8.65{\pm}0.14^{c}$	$7.77{\pm}0.29^{c}$
Protein (g%)	$0.50{\pm}0.06^{a}$	$0.48{\pm}0.08^{a}$	$0.47{\pm}0.12^{a}$	$0.43{\pm}0.03^{b}$
Ashes (g%)	$1.12{\pm}0.11^{c,d}$	$1.22{\pm}0.14^{c}$	$1.42{\pm}0.09^{a,b}$	$1.55{\pm}0.26^{a}$
Lipids (g%)	$0.92{\pm}0.09^{a}$	$0.88{\pm}0.09^{a}$	$0.89{\pm}0.11^{a}$	$0.87{\pm}0.14^{a}$
Dietary Fibers (g%)	$8.03{\pm}0.18^{d}$	$10.9{\pm}0.12^{c}$	$11.83{\pm}0.08^{b}$	$13.69{\pm}0.29^{a}$
Vitamin C (A.A mg 100 g^{-1})	$97.39{\pm}4.88^{c}$	$97.43{\pm}5.18^{c}$	$113.37{\pm}3.88^{b}$	$123.66{\pm}6.31^{a}$
Phenolic Compounds (GA mg 100 g^{-1})	$32.21{\pm}2.29^{c}$	$33.2{\pm}2.14^{c}$	$68.95{\pm}3.20^{b}$	$72.85{\pm}4.15^{a}$
Total Carotenoids (Beta-carotene μg g^{-1})	$74.81{\pm}2.03^{c}$	$80.31{\pm}1.93^{b}$	$86.39{\pm}3.33^{a}$	$87.66{\pm}2.53^{a}$

Note: DF1: pulp and sucrose (1:1); DF2: pulp, sucrose, 5% sucralose and pectin; DF3: pulp, sucralose, pectin, xanthan gum, calcium chloride, citric acid; DF4: pulp, sucralose, pectin, xanthan gum, calcium chloride, citric acid.

The DF1 and DF2 formulations prepared by adding sucrose showed a lower antioxidant capacity (Figure 1), while the DF3 and DF4 formulations prepared without adding sucrose and with a lower cooking time showed higher antioxidant capacity and higher retention of bioactive compounds (Table 3). The same results were observed with the ABTS method, where DF3 and DF4 were the formulations showing higher antioxidant capacity. A product prepared using similar conditions for comparison purposes has not been found in the literature.

Figure 2 shows the results of the antioxidant capacity for the jam formulations using the ABTS method. The results are expressed in TEAC (µmol mL^{-1}) for aqueous and hydroalcoholic extracts.

All extracts showed significant antioxidant activity ($p \leq 0.05$), especially at higher concentrations (250 µg mL^{-1}).

It was also observed that the antioxidant capacity of the extracts is directly related to the bioactive compound content retained by the jam (Table 3).

According to Zheng and Wang (2001), it is difficult to compare and characterize the antioxidant activities of *in vitro* extracts due to the diversity and complexity of natural mixtures of different bioactive compounds present in the matrix. The antioxidant action in a food depends on several factors, perhaps the most important factors being the types of free radicals that are formed, where they are formed and how they are formed. The methodology used to analyze these factors and the ideal concentrations are also relevant factors (BIRCH et al., 2001).

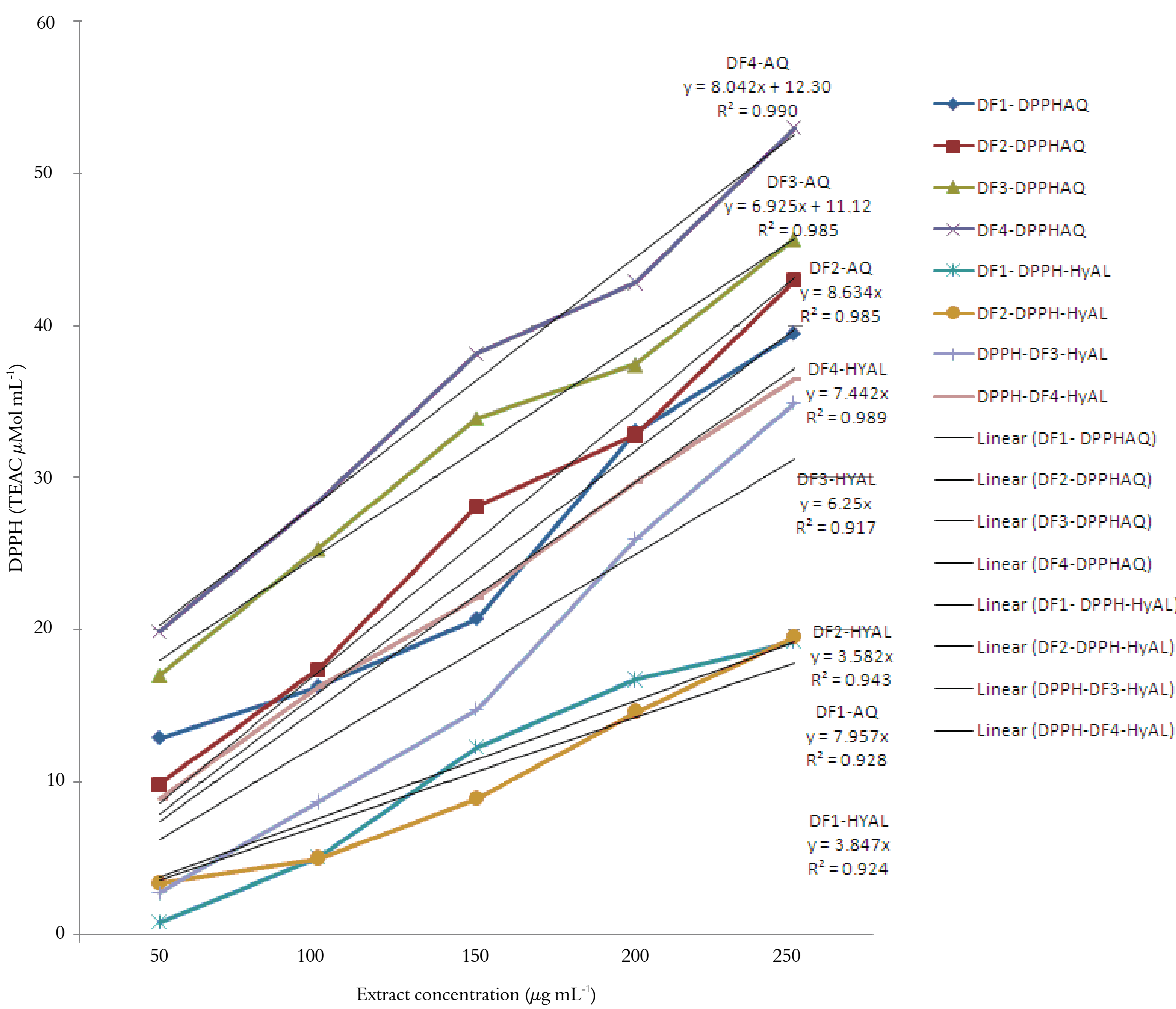

Figure 1. *In vitro* antioxidant potential for the gabiroba jam using the DPPH TEAC (µm mL^{-1}) method for aqueous and hydroalcoholic extracts. DF1: pulp and sucrose (1:1); DF2: pulp, sucrose, 5% sucralose and pectin; sample DF3: pulp, sucralose, pectin, xanthan gum, calcium chloride, citric acid; DF 4: pulp, sucralose, AQE= Aqueous Extract, EAE= Ethyl alcohol extract at 80% (v/v) alcohol and water.

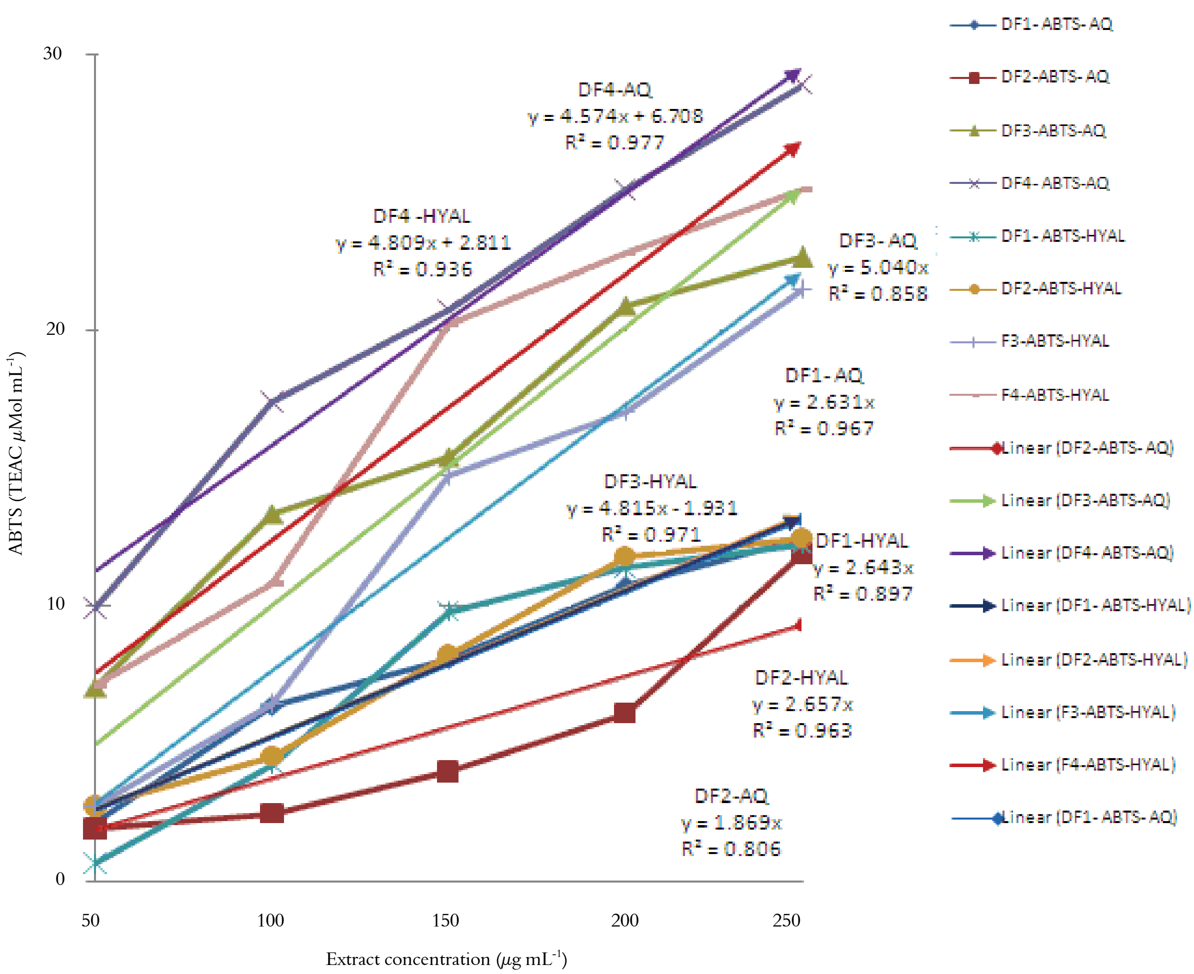

Figure 2. *In vitro* antioxidant potential for gabiroba jam using the ABTS TEAC (μm mL^{-1}) method for aqueous extract (AQ) and hydroalcoholic extract (HYAL).

According to the same author, the DPPH method is more efficient for polar fractions containing more phenolic compounds, which have more donating power than other compounds. This method does not identify pro-oxidant substances. However, the ABTS method identifies pro-oxidant substances, such as vitamin C (ZHENG; WANG, 2001).

The correlation analysis showed that the jam formulations have a positive ratio ($p \leq 0.05$) among the bioactive compounds and the antioxidant activity for both the ABTS and the DPPH methods (Table 4).

Phenolic compounds and carotenoids showed a significant correlation with antioxidant activity. According to Heim et al. (2002), phenolic compounds are responsible for most of the antioxidant activity in fruit-based foods. According to Hassimoto et al. (2005), the antioxidant activity of food cannot be associated with one compound but to the synergy between several substances with antioxidant action. This fact justifies the significant correlation of antioxidant capacity with the bioactive compounds analyzed in this study.

Knowledge of the rheological properties of these fruit products is extremely important for the food industry as they comprise a two-phase system made up of solid particles dispersed in an aqueous medium, which makes them unstable for optimization in industrial processes. Rheological properties also affect the development of new products, as there is a correlation between physical and sensory parameters (GUERRERO; ALZAMORA, 1997). The use of polysaccharides, either separately or associated as gelling agents, can benefit the rheological properties of jam without added sugar (RIBEIRO et al., 2004). Figure 3 shows the effects of shear stress (Pa) on shear rate (1 s^{-1}) for the jam formulations prepared with gabiroba pulp. A pseudoplastic behavior was observed.

Table 4. The correlation matrix between bioactive compounds and the methods used to evaluate the *in vitro* antioxidant potential of gabiroba jam formulations.

	AA	CF	BC	ABTS-EAE	ABTS-AQE	DPPH-EAE	DPPH-AQE
AA	1.00						
CF	0.97	1.00					
B C	0.90	0.93	1.00				
ABTS-EAE	0.57	0.79	0.85	1.00			
ABTS-AQE	0.65	0.94	0.93	0.93	1.00		
DPPH-EAE	0.75	0.89	0.82	0.88	0.99	1.00	
DPPH-AQE	0.63	0.87	0.98	0.98	0.98	0.99	1.00

Note: AQE= Aqueous Extract, EAE= Ethyl alcohol extract at 80% (v/v) alcohol and water. Phenolic Compounds (GA) =Gallic Acid; Carotenoids (BC) = beta carotene; flavonoids (QE) = Quercetin; Vitamin C (AA) = Ascorbic Acid.

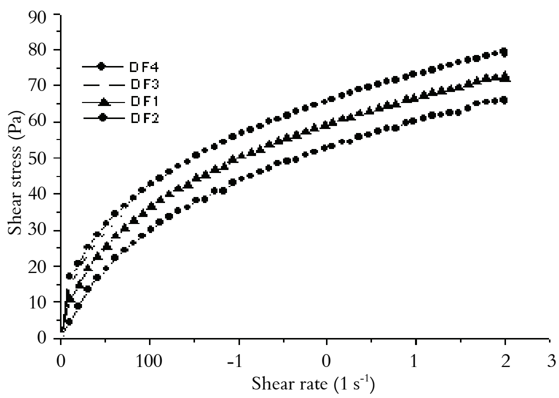

Figure 3. The effects of shear stress (Pa) on shear rate (s^{-1}) at room temperature (25°C) for gabiroba jam formulations

Several empirical and theoretical rheological models have been proposed in the literature, such as the Newton model, the Ostwald-de Waele or Power Law model and the Herschel-Bulkley model among others. The function of these models is to describe the mathematical relationships of the experimental values for shear stress and deformity rate, which are based on theoretical aspects related to fluid structure (BIRD et al., 2002). The Power Law model is one of the most extensively used models to describe the rheological behavior of natural fruit juices and fruit pulp juices (RAO; ANANTHESWARAN, 1982), which usually contain some type of polysaccharide that is responsible for the medium viscosity (BIRD et al., 2002). Table 5 shows the rheological constants based on the Power Law and Herschel-Bulkley models, which indicate that the increase in the consistency index, K (Pa s^n), was proportional to the addition of pectin and xanthan gum in the formulations.

Statistical parameters for both the Herschel-Bulkley and the Power Law models described the system with a high correlation coefficient (R^2 > 0.98). A chi-square test (χ^2) also showed low values, indicating a good adjustment for both models. A comparison of the models revealed that the Power Law model best describes the rheological behavior of the gabiroba jam as it showed a better linear correlation coefficient and a lower chi-square (χ^2) value than the Herschel-Bulkley model. According to the literature, gel strength in formulations containing pectin varies with concentration, pH, and calcium content. Good gel strength is usually obtained at pH 3.0 to 3.5, but excellent gels were obtained using a mixture of pectin and xanthan in the presence of calcium (EVAGELIOU et al., 2000). Nevertheless, high calcium concentrations have been reported to lead to a brittle gel with a tendency towards syneresis and, eventually, structure disintegration due to extensive crystallization (FISZMAN; DURÁN, 1989).

Table 5. Rheological constants based on the Power Law and Herschel-Bulkley parameters for the gabiroba jam formulations.

Power law or Ostwald - De Waele Model						
Formulations	Flow consistency index K (pas^n)	Flow Behavior Index (n)		χ^2	RSS	R^2
DF1	23.76	0.14		0.36	8.42	0.994
DF2	24.05	0.16		0.37	8.17	0.998
DF3	73.38	0.11		1.12	26.02	0.996
DF4	70.12	0.13		1.07	24.86	0.995
Herschel-Bulkley Model						
Formulations	Flow consistency index K (pas^n)	Flow Behavior Index (n)	Initial condition τ_0 (pa)	χ^2	RSS	R^2
DF1	23.94	0.39	2.336	1.38	5.91	0.983
DF2	23.95	0.41	2.314	1.36	5.90	0.986
DF3	39.04	0.43	3.496	3.12	9.62	0.994
DF4	38.16	0.43	3.487	3.10	9.41	0.989

Note: RSS (residual sum of squares), R^2 (correlation coefficient), χ^2 (chi-square).

A branched structure and high molecular weight provide xanthan gum with a high viscosity, even in low concentrations. The three-dimensional networks formed by xanthan gum chain associations provide efficient stability for suspensions and emulsions. Many of the rheological properties of polysaccharides are derived from a double-helix shape adopted in solution (TAKO; NAKAMURA, 1984). Generally, pH has little effect on the viscosity of xanthan gum solutions. In the pH ranges found in food processes, the high and uniform viscosity of xanthan is maintained for long periods of time at pH 2 - 12, with some reduction in viscosity at extreme pH values. Xanthan gum has a low energy intake (0.5 kcal g^{-1}) and, as a bonding agent, it improves texture, increases soluble solids content and promotes stability by avoiding syneresis of products without added sugar (FISZMAN; DURÁN, 1989).

The temperature and substitution of sucrose for sucralose significantly affected the texture of the jam prepared with gabiroba pulp, as shown in Figures 4 and 5.

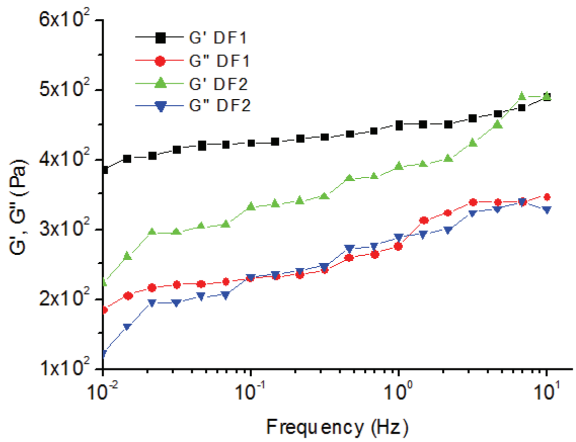

Figure 4. The effects of frequency (Hz) on storage modulus (G') and loss (G") for gabiroba jam DF1 and DF2 formulations .

Among the formulations prepared with sucralose and pulp only, DF4 had a stronger gel because it contains a higher content of xanthan gum (3.6%) than DF3.

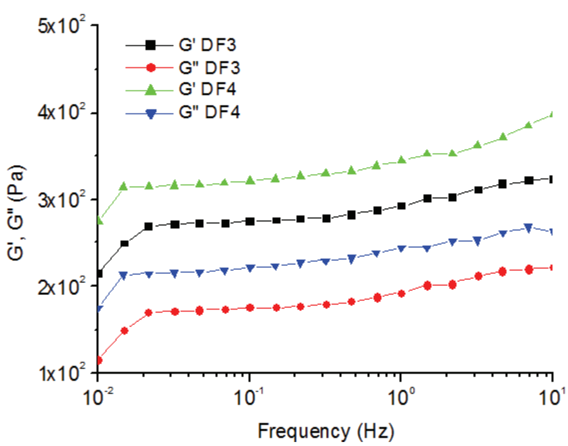

Figure 5. The effects of frequency (Hz) on storage modulus (G') and loss (G") for gabiroba jam DF3 and DF4 formulations.

The main characteristic exhibited by xanthan gum is its capacity to change the rheological behavior of solutions. This property is mainly related to the substance's chemical composition, molecular arrangement and average molar mass. The biopolymer solution concentration has a direct effect on viscosity (GARCÍA-OCHOA et al., 2000).

The microbiological characteristics observed for the gabiroba jam after three months of refrigerated storage are shown in Table 6.

The jam maintained its microbiological quality during storage and was well within the requirements set forth by ANVISA in Brazil (the Brazilian National Health Surveillance Agency) (BRASIL, 2001).

Sensory evaluation was applied for the development and improvement of products, quality control and studies on process storage (PÉREZ; GERMANI, 2007). Figure 6 shows the average scores for the sensory evaluations. The DF1 formulation was the most accepted by testers, receiving the largest number of indications for the responses 'liked quite a lot' and 'liked very much'. The DF3 formulation was the least accepted, receiving the largest number of responses 'disliked very much'. According to Teixeira et al. (1987), for a product to be considered acceptable in terms of its sensory properties, it needs to have a minimum 70% level of approval. Thus, only DF1 and DF2 formulations were acceptable, as DF3 and DF4 received an average 60% level of approval, with the highest number of responses being between 'slightly liked' and 'fairly liked'.

Table 6. The microbiological characteristics of the gabiroba jam formulations.

Microorganisms	Time (days)	DF1	DF2	DF3	DF4	Standard*
	CFU g^{-1}					
Molds and yeasts	0	< 10	< 10	< 10	< 10	10^4
	90	< 10	< 10	< 10	10^2	10^4
Coliforms at 45°C	0	< 10	< 10	< 10	< 10	10^2
	90	< 10	< 10	< 10	< 10	10^2
Salmonella	0	ABS	ABS	ABS	ABS	ABS 25 g^{-1}
	90	ABS	ABS	ABS	ABS	ABS 25 g

*RDC # 12 from January 2nd, 2001 from Ministry of Health; CFU g^{-1} – Colony Forming Units; ABS – Absence in 25 g of product.

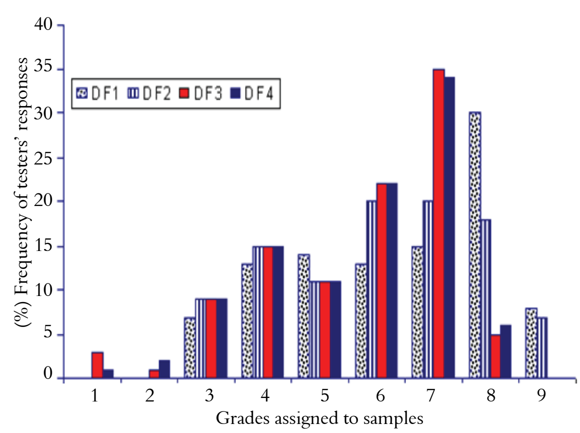

Figure 6. A histogram of the results of the gabiroba jam sensory analysis with respect to the frequency of hedonic values assigned to the overall impression of samples.

In general, the samples showed acceptance levels varying from 'slightly liked', 'liked quite a lot' and, in some answers, 'liked very much'.

Regarding the intention to purchase, 23% of testers said they would not buy the product, 45% said they would buy the product and 32% said they would most likely buy the product.

Conclusion

The jam had considerable nutritional value, with high levels of vitamin C, phenolic compounds, carotenoids and antioxidant activity. Therefore, it is a good food alternative, and its consumption should be encouraged to add value to the fruit as well as to its cultivation. Interest in alternative sources of raw material at accessible costs, coupled with growing interest in functional foods that have antioxidant properties, justifies greater efforts in studying the market potential of regional native fruits, such as the gabiroba. The gabiroba fruits were adequate for making jam in both conventional and reduced calorie formulations.

References

ABNT-Associação Brasileira de Normas Técnicas. **NBR 12806**: análise sensorial de alimentos e bebidas – terminologia. Rio de Janeiro: ABNT, 1993.

ABU-JDAYIL, B.; AL-MALAH, K.; ASOUD, H. Rheological characterization of milled sesame (tehineh). **Food Hydrocolloids**, v. 16, n. 6, p. 55-56, 2002.

AOAC-Association of Official Analytical Chemists. **Official methods of analysis of the association of official analytical chemists**. 16th ed. Washington, D.C.: AOAC, 1997.

AOAC-Association of Official Analytical Chemists. **Official methods of analysis of the association of official analytical chemists**. 12th ed. Washington, D.C.: AOAC, 2000.

BIRCH, A. E.; FENNER, G. P.; WATKINS, R.; BOYD, L. C. Antioxidant proprieties of evening primrose seed extracts, **Journal of Agricultural and Food Chemistry**, v. 49, n. 11, p. 4502-4507, 2001.

BIRD, R. B.; STEWART, W. E.; LIGHTFOOT, E. N. **Transport phenomena**. 2nd ed. New York: John Wiley and Sons, 2002.

BRAND-WILLIAMS W.; CUVELIER, M. E.; BERSET, C. Use of a free radical method to evaluate antioxidant activity. **Lebensmittel-Wissenschaft und Technologie**, v. 28, n. 1, p. 25-30, 1995.

BRASIL. ANVISA-Agência Nacional de Vigilância Sanitária. Ministério da Saúde. Resolução da diretoria colegiada da secretaria de vigilância sanitária n. 12. **Diário Oficial da União**, Brasília: Ministério da Saúde, 2001.

BRASIL. ANVISA-Agência Nacional de Vigilância Sanitária. Ministério da Saúde. Métodos Físico-Químicos para Análise de Alimentos. **Diário Oficial da União**. Brasília: Ministério da Saúde, 2005.

DUBOIS, M.; GILLES, K. A.; HAMILTON, J. K.; REBERS, P. A.; SMITH, F. Colorimetric method for determination of sugars and related substances. **Analitical Chemistry**, v. 28, n. 3, p. 350-356, 1956.

EVAGELIOU, V.; RICHARDSON, R. K.; MORRIS, E. R. Effect of pH, sugar, type and thermal annealing on high-methoxy pectin gels. **Carbohydrate Polymers**, v. 42, n. 3, p. 245-259, 2000.

FISZMAN, S. M.; DURÁN, L. Mechanical properties of kappa carrageenan-locust bean gum mixed gels with added sucrose. **Food Hydrocolloids**, v. 35, n. 12, p. 209-216, 1989.

GARCÍA-OCHOA,?Xanthan gum proportion of 1:4 (v/v) for recovery and properties. **Biotechnology Advances**, v. 18, n. 7, p. 549-579, 2000.

GEMTCHÜJNICOV, I. D. **Manual de taxonomia vegetal**: plantas de interesse econômico, agrícola, ornamentais e medicinais. São Paulo: Ceres, 1976.

GRANADA, G. G. Caracterização física, química, microbiológica e sensorial de geléias light de abacaxi. **Ciência e Tecnologia de Alimentos**, v. 25, n. 4, p. 629-635, 2005.

GUERRERO, S. N.; ALZAMORA, S. M. Effect of pH, temperature and glucose ... I. Banana purée. **Journal of Food Engineering**, v. 33, p. 239-256, 1997.

HERTOG, M. G. L.; HOLLMAN, P. C. H.; VAN DER PUTTE, B. Content of potentially anticarcinogenic flavonoids of tea infusions, wines and fruit juices. **Journal of Agricultural and Food Chemistry**, v. 41, n. 2, p. 1242-1246, 1993.

HASSIMOTTO, N. M.; GENOVESE, M. I.; LAJOLO, F. M. dietary fruits, vegetables, and commercial frozen fruit pulps. **Journal of. Agricultural and Food Chemistry**, v. 53, n. 8, p. 2928-2935, 2005.

HEIM, K. E.; TAGLIAFERRO, A. R.; BOBILYA, D. J. Flavonoid antioxidants: chemistry, metabolism and structure-activity relationships. **Journal of Nutritional Biochemistry**, v. 25, n. 13, p. 572-584, 2002.

HOLDSWORTH, S. D. Applicability of rheological models to the interpretation of fluid food products. **Journal of Texture Studies**, v. 2, n. 4, p. 393-418, 1971.

HORWITZ, W. **Official methods of analysis of the association of official analytical chemists**. 13th ed. Gaithersburg: AOAC, 1980.

HUNTERLAB. **Applications note: CIE L* a* b* color scale**, v. 8, n. 7. p. 1-15, 1996. Available from: <http://www.elfiz2.kee.hu/cie/newcie/nc/DS014-43.pdf>. Access on: Jun. 14, 2011.

JACKIX, M. H. **Doces, geléias e frutas em calda**. (Teórico e Prático). Campinas: Editora Ícone, 1988.

JAWAHEER, B.; GOBURDHUN, D.; RUGGOO, G. Effect of processing and storage of guava into jam and juice on the ascorbic acid content. **Plants Foods for Human Nutrition, Dordrecht**, v. 58, n. 3, p. 1-12, 2003.

LEGRAND, C. D.; KLEIN, R. M. Mirtáceas: campomanesia. In: REIZ, P. R. (Ed.). **Flora ilustrada catarinense**. Itajaí: Herbário Barbosa Rodrigues, 1977. p. 573-623.

LORENZI, H. **Árvores brasileiras**: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. 4. ed. Nova Odessa: Instituto Plantarum, 2002

MILLER, G. L. Use of dinitrosalicylic acid reagent for determination of reducing sugar. **Analytical Chemistry**, v. 31, n. 3, p. 426- 428, 1959.

NACHTIGALL, A. M.; SOUZA, E. L.; MALGARIN, M. B.; ZAMBIAZI, R. C. Geléias light de amora-preta. **Boletim do Centro de Pesquisa e Processamento de Alimentos**, v. 22, n. 1, p. 337-357, 2004.

PÉREZ, P. M. P.; GERMANI, R. Elaboração de biscoitos tipo salgado, com alto teor de fibra alimentar, utilizando farinha de berinjela. **Ciência e Tecnologia de Alimentos**, v. 27, n. 5, p. 186-192, 2007.

RAO, M. A.; ANANTHESWARAN, R. C. Rheology of fluids in food processing. **Food Technology**, v. 36, n. 2, p. 116-126, 1982.

RE, R.; PELLEGRINI, N.; PROTEGGENTE, A.; PANNALA, A.; YANG, M.; RICEEVANS, C. Antioxidant activity applying an improved ABTS radical cation decolonization assay. **Free Radical Biology and Medicine**, v. 26, n. 9-10, p. 1231-1237, 1999.

RIBEIRO, K. O.; RODRIGUES, M. I.; SABADINI, E.; CUNHA, R. L. Mechanical properties of acid sodium caseinate-k-carrageen and gels: effect of co-solute addition. **Food Hydrocolloids**, v. 18, n. 3, p. 71-79, 2004.

RODRIGUEZ-AMAYA, D. B. **A guide to carotenoids analysis in foods**. Washington, D.C.: ILSI, 2001.

TAKO, M.; NAKAMURA, S. Rheological properties of deacetylated xanthan in aqueous media. **Agricultural and Biological Chemistry**, v. 48, n. 12, p. 2987-2993, 1984.

TEIXEIRA, E; MEINERT, E; BARBETTA, P. A. **Análise sensorial dos alimentos**. Florianópolis: UFSC, 1987.

TERADA, M.; WATANABE, Y.; KUNITOMA, M.; HAYASHI, E. Differential rapid analyses ascorbic acid and ascorbic acid 2-sulfate by dinitrophenilhydrazine method. **Annals of Biochemistry**, v. 4, n. 2, p. 604-608, 1979.

TOOR, R. K.; SAVAGE, G. P. Effect of semi-drying on the antioxidant components of tomatoes. **Food Chemistry**, v. 94, n. 1, p. 90-97, 2006.

WILLE, G. M. F. C.; MACEDO, F. R.; STERTZ, C. S.; MASSON, M. L.; CELLUPI, N.; LIMA, M. J. Desenvolvimento de tecnologia para a fabricação de doce em massa com araçá-pêra (Psidium acutangulum D.C.) para o pequeno produtor. **Ciência e Agrotecnologia**, v. 28, n. 6, p. 1360-1366, 2004.

YAZDINEJAD, M. N. Indirect determination of ascorbic acid (vitamin C) by spectrophotometric method. **International Journal of Food Science and Technology**, v. 42, n. 1, p. 1402-1407, 2007.

ZHENG, W.; WANG, S. Y. Antioxidant activity and phenolics compounds in selected herbs. **Journal of Agricultural and Food Chemistry**, v. 49, n. 11, p. 5165-5170, 2001.

Received on August 5, 2011.
Accepted on February 16, 2012.