

## Rheological behavior of cupuaçu and taperebá juice with added inulin

### ABSTRACT

**Pedro Henrique Campelo**

[pedrocampelo@ufam.edu.br](mailto:pedrocampelo@ufam.edu.br)

Faculdade de Ciências Agrárias,  
Universidade Federal do Amazonas,  
Manaus, Brasil.

**Eyde Cristianne Saraiva Bonatto**

[bonatto@gmail.com](mailto:bonatto@gmail.com)

Faculdade de Ciências Agrárias,  
Universidade Federal do Amazonas,  
Manaus, Brasil.

**Samara Claudia Picanço Batista**

[samarabatista@gmail.com](mailto:samarabatista@gmail.com)

Departamento de Engenharia Agrícola e  
Solos, Universidade Federal do Amazonas,  
Manaus, Amazonas.

**Romuald Euloge Yomkil**

[romualdyk@hotmail.fr](mailto:romualdyk@hotmail.fr)

Faculdade de Ciências Agrárias,  
Universidade Federal do Amazonas,  
Manaus, Brasil.

Rheological behavior of liquid foods is an important physicochemical characteristic for processing in the food industry. This work has the objective to evaluate the rheological behavior of *cupuaçu* and *taperebá* juice with added inulin. Analyzes of centesimal composition, soluble solids, pH and titratable acidity of pulp and juice were performed plus rheology of inulin-added juices at temperatures of 5, 25 and 45 °C. The rheological data were adjusted for the power law model. The centesimal composition confirmed the physicochemical characteristics of fruit pulps, with acceptable quality parameters and recommended by current legislation. It was observed that temperature and solids addition (inulin) influenced the rheological behavior of *cupuaçu* and *taperebá* juice, with viscosity reduction with increasing temperature; and increase in viscosity with the addition of inulin. The power law adjusted the flow curve data, evidencing the pseudo-plastic behavior of fruit juices. The rheological behavior of juices is an important tool in the food industry as it helps in the dimensioning of transmission lines and unit operations equipment, such as pasteurizers.

**KEYWORDS:** *Theobroma grandiflorum*; *Spondias mombin* L.; juice rheology; inulin; prebiotic.

## INTRODUCTION

Among the native tropical fruits of the Amazon, cupuaçu (*Theobroma grandiflorum*) is one that meets the best conditions for industrial use. It is a fruit originating in the South and Southeast of the Amazon and is appreciated for its acidic and intensely aromatic pulp (BUENO et al., 2002). The taperebá (*Spondias mombin* L.) is a fruitful species originating in tropical America, common in the Amazon region, where it occurs in the wild state. Fruit pulp presents high economic potential and growing demand in the North and Northeast regions of Brazil (SOUZA, 2000).

Inulin is a prebiotic formed from fructose units with a degree of polymerization (DP) ranging from 10 to 60 extracted from chicory roots. Inulin is widely used in functional foods around the world because of its properties related to improved health and technological possibilities. Prebiotics, such as inulin, are at the forefront of the emerging trend toward functional foods (CAMPELO-FELIX et al., 2017; SOUZA; MENEZES; CUNHA, 2009). Prebiotics are nondigestible nutritional ingredients that beneficially affect the host by selectively stimulating the growth and activity of one or more species of beneficial intestinal bacteria, improving the health of its host (SOUZA; MENEZES; CUNHA, 2009).

The consumption habits of industrialized fruit juices have been increasing all over the world, due to several aspects such as the search for health, concern with the consumption of healthy foods, practicality offered by the products, substitution of carbonated beverages for the consumption and nutritive value (LIMA et al., 2008). The behavior of industrial materials became of interest in physics, mechanics, mathematics and even colloid chemistry. Rheology aims to study the deformation and flow of materials. It is the study of the way in which materials respond to tension or deformation. During processing, the fruit juices show variations in their concentrations and temperatures. These are subjected to unitary operations such as pumping, evaporation, drying and spraying. For a correct dimensioning, operation and control of the process, the knowledge of the rheological parameters is of fundamental importance (CABRAL; QUEIROZ; FIGUEIREDO, 2002).

From the above, the objective is to evaluate the rheological behavior of cupuaçu and taperebá juice with added inulin. Centesimal composition, soluble solids, pH and titratable acidity of pulps and juices were performed; rheology of added inulin juices at temperatures of 5, 25 and 45°C.

## MATERIALS AND METHODS

### MATERIALS

Cupuaçu and taperebá pulps were donated by Nutrisucos (Manaus, Amazonas, Brazil). Inulin (IN) Frutafit® DP = 2-60 (Sensus Ingredients, Netherland) were donated by Metachem (Itupeva, São Paulo, Brazil). Upon receipt, the samples were kept at -18° C until the analyzes. The laminated packaging used in our study had: PET 15 µ – ethylene polytereftalate (polyester); OPA 15 µ – bi-oriented polyamide (nylon) and CPP 70 µ – (or PP Cast) co-extruded cast polypropylene. Therefore, they are resistant to temperatures up to 121 °C for 45 min, at pH 3.5, and under vacuum conditions.

### PHYSICAL-CHEMICAL CHARACTERIZATION OF THE RAW MATERIAL: CENTESIMAL COMPOSITION

Cupuaçu and taperebá pulps were characterized in terms of moisture, ash, protein, lipids, carbohydrate and fiber (AOAC, 2016).

## SOLUBLE SOLIDS

The fruit pulps were homogenized and 1 to 2 drops transferred to the refractometer prism, neglecting any large particles. When the temperature of the sample and the temperature of the apparatus were equal and the reading was performed on the °Brix scale.

## pH

Fruit pulp pH was measured using a peagameter. The equipment was calibrated with buffer solutions, and pH values were measured by inserting the electrode directly into the sample at 25°C.

## TITRATABLE ACIDITY

To determine the titratable acidity, 20 mL of the homogenized sample was pipetted into an Erlenmeyer flask, diluted with approximately 100 mL of water, and received 0.3 mL of phenolphthalein solution. Flask contents were titrated with 0.1 M sodium hydroxide solution under constant stirring until pink staining persisted for 30 seconds (ADOLFO LUTZ, 2008).

## PRODUCTION OF JUICES

The juices were elaborated using the following ingredients: citric acid, commercial sucrose, water and inulin. Four formulations were developed: two standards (without the addition of inulin), and two with prebiotic concentrations of 1.5%, which are presented in Table 1. The nectars were mixed in an Ultraturrax homogenizer (T25, IKA, USA) for 5 min, speed 7000 rpm.

**Table 1** - Formulation of Amazon fruit nectars

Assay	TI	T	CI	C
Water	68.9	69.8	72	73
Cupuaçu pulp	19.2	19.5		
Taperebá pulp			15	15.2
Sugar	10.3	10.6	11.3	11.6
Citric acid	0.1	0.1	0.2	0.2
Inulin	1.5	-	1.5	-

NOTE: Taperebá (T), cupuaçu (C) and inulin (I).

## RHEOLOGICAL MEASUREMENTS

The rheological measurements were performed on a rotational viscometer (LV model, Brookfield, USA) at temperatures of 4°C, 25°C and 45°C, connected to a computerized Rheocalc data acquisition system to record the apparent viscosity ( $\eta_{ap}$ ), shear stress ( $\sigma$ ) and shear rate ( $\dot{\gamma}$ ) were obtained using WinGathero software. We used: a SC4-18 Spindle, which allows deformation rate reading ( $\dot{\gamma}$ ) in the range of 0 to 10 s<sup>-1</sup>, and the accessory for small sample quantity (20 ml), DIN

adapter including temperature and approximate refrigeration, storage and pasteurization respectively. With the experimental data of shear stress, viscosity and deformation rate obtained in the viscometer, adjustments were made with the Ostwald-De-Waele rheological models (Power Law). The analysis of the model adjustments to the experimental results was done through the statistical parameters coefficient of determination ( $R^2$ ) and sum of squares of residues (SSR). Therefore, the model that best fits is that with high  $R^2$  values and low SSR values.

#### PHYSICOCHEMICAL PROPERTIES OF JUICE: SOLUBLE SOLIDS, pH AND TITRATABLE ACIDITY

Soluble solids, pH and titratable acidify analyzes were performed according to the methodologies previously described.

#### VITAMIN C

Approximately 10 mL of each juice sample were transferred to a 300 mL Erlenmeyer flask. 1 mL of the potassium iodide solution (10% w / w) and 1 mL of the starch solution (1% w / w) were added. The solutions were titrated with potassium iodide solution (0.02M) to blue coloration (ADOLFO LUTZ, 2008).

### RESULTS AND DISCUSSION

#### CENTESIMAL COMPOSITION OF FRUITS PULP

Climatic factors, soil type, genetic variability and season of the year can interfere the centesimal composition of fruits (MATOS, 2007). The moisture content corroborated with other studies (CANUTO et al., 2010), with values of 89.2% (cupuaçu) and 93.8% (taperebá). In studies with taperebá values of 0.62, 1.06 and 13.9% (TIBURSKI et al., 2011) for lipids, proteins and total carbohydrates, respectively, were obtained corroborating those of this present work. Canuto et al., (2010) observed lipid values of 0.2 and 0.3% for taperebá and cupuaçu, respectively. The content of this compound can vary between different regions of the country, depending on factors such as temperature, light intensity and moisture content (CANUTO et al., 2010).

pH and total titratable acidity (TTA) are two methods used to measure fruit acidity, which reveal, respectively, the percentage of organic acid and the concentration of hydrogen ion. Generally, to indicate the acid taste parameter, total titratable acidity is the most viable method, measured in predominant organic acids (CHITARRA; CHITARRA, 1990). The pH values (Table 2) found are in agreement with other studies (MORZELLE et al., 2009; CANUTO et al., 2010; CARVALHO et al., 2011) which reported a pH less than 4.0 for industrialized fruit nectar. pH values can directly interfere with the color of the product and consequently its acceptance by the consumer. In addition, pH regulates microbial growth, which may be related to the useful life of the juice.

Other studies obtained TTA values for cupuaçu of 1.0% (BUENO et al., 2002) and 2.27%(COSTA et al., 2003); and for taperebá of 1.86% (MATTIETTO; LOPES; MENEZES, 2010) and 1.20 – 1.93% (CARVALHO et al., 2011). Fruits with high acidity generally have low sugar content. High levels of acidity may present low acceptance for in natura consumption but it is a good characteristic for industry

because it avoids the use of organic acids to produce by-products such as jellies and sweets (MATOS, 2007).

**Table 2** – Centesimal composition and physicochemical properties of fruits pulp

Parameter	Cupuaçu pulp	Taperebá pulp
Ash (%)	0.14 ± 0.0b	0.76 ± 0.1 a
Moisture content (%)	89.92 ± 1.2 b	91.92 ± 0.1 a
Protein (%)	0.65 ± 0.1 a	0.61 ± 0.0 a
Fat (%)	0.17 ± 0.1 b	0.30 ± 0.0 a
Carbohydrate (%)	9.12 ± 0.1 a	6.41 ± 0.2 b
Fiber (%)	6.12 ± 0.5 a	4.18 ± 0.8 b
Soluble solids (%)	10.00 ± 0.0 a	10 ± 0.0a
pH	3.30 ± 0.0 a	3.05 ± 0.0 b
Titrateable acidity (%)	2.27 ± 0.0 a	1.79 ± 0.0 b

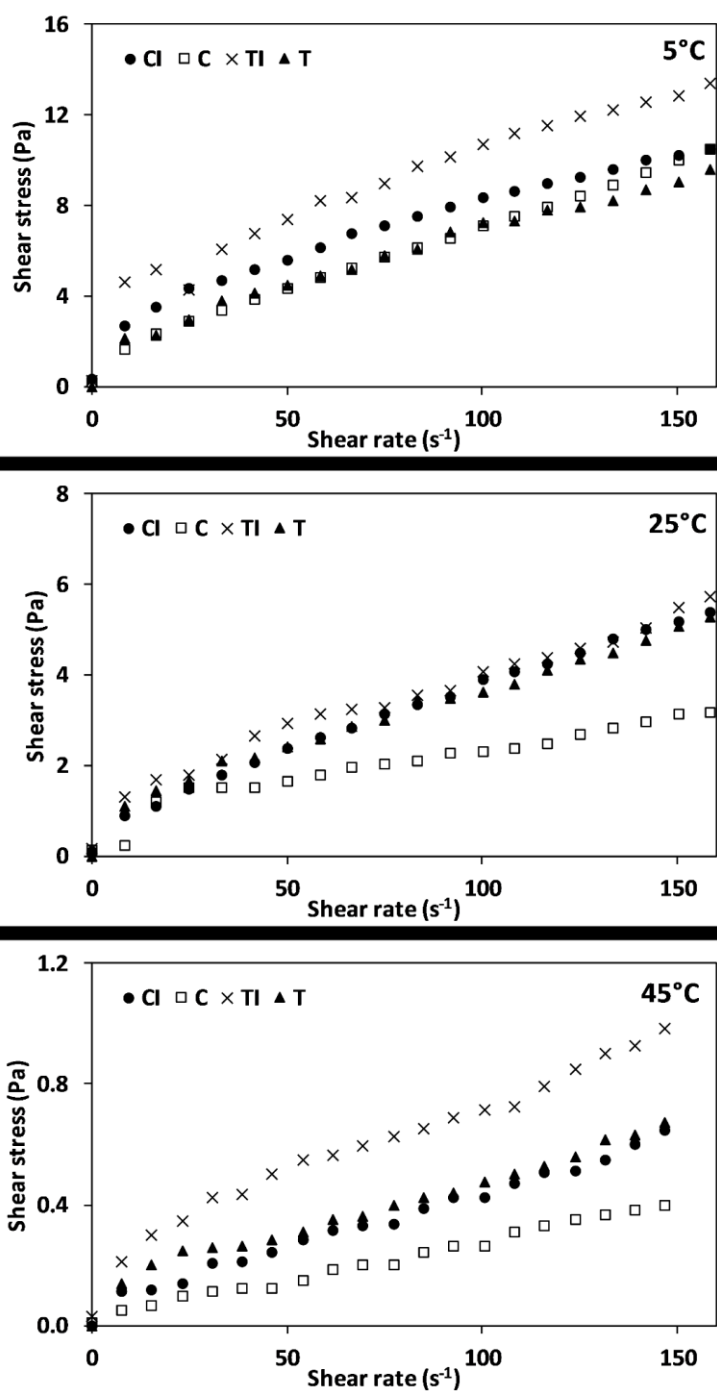
NOTE: Values represent the means ± standard deviation; n=3. Same letters in the same column did not present significant difference ( $p > 0.05$ ) by t-student test.

Total soluble solids content correlates with sugars and organic acids, a characteristic of interest for products sold in natura, since the consumer market prefers sweet fruits (CANUTO et al., 2010). The total soluble solids content of 10° Brix for both fruits was presented for other studies with cupuaçu (FERREIRA; GUIMARÃES; MAIA, 2008) and taperebá (MATTIETTO; LOPES; MENEZES, 2010). Others authors (CANUTO et al., 2010) observed lower values than those of the present study. The content of total soluble solids tends to increase with the degree of maturation of the fruit, because with maturation the starch is hydrolyzed and the complex sugars are transformed into simple sugars and as a consequence acidity reduces. In fruit production, climatic conditions, mainly precipitation and high temperatures, are factors that influence the formation of soluble solids (MATOS, 2007; FERREIRA; GUIMARÃES; MAIA, 2008).

### RHEOLOGICAL BEHAVIOR

Figure 1 shows the rheological behavior from the flow curves of cupuaçu and tapereba juice with added inulin. A gradual increase is observed in the shear stress in line with the increase of the deformation rate, an effect that towards stability under high deformation rates. This non-linear flow curve behavior is typical of pseudoplastic fluids (PELEGRINE; VIDAL; GASPARETTO, 2000). Fruit juices tend to present non-linear flow curve behavior due to the presence of pectin, facilitating the formation of gels and increasing the viscosity of the medium (TIZIANI; VODOVOTZ, 2005).

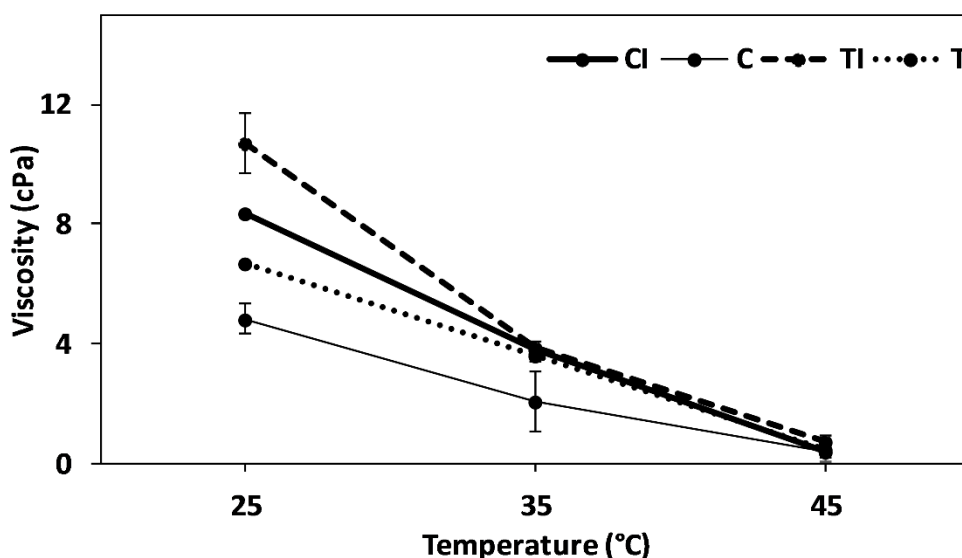
When the influence of temperature is analyzed, the results show that the increase in temperature causes a reduction of the viscosity value in all treatments. Temperature is one of the factors that most affects the viscosity of fruit pulps, since most of them are in the form of solids dispersed in liquid medium. An increase in temperature causes the viscosity of the fluid phase to decrease, increasing the movement of the suspended particles, thereby reducing the viscosity of the pulp (PELEGRINE; VIDAL; GASPARETTO, 2000; KUMORO; RETNOWATI; BUDIYATI, 2011). Other authors also observed the same behavior when studying flow curves at different temperatures for cherry (JUSZCZAK; FORTUNA, 2004), tomato (TIZIANI; VODOVOTZ, 2005) and mango juices (DAK; VERMA; JAAFFREY, 2007).



**Figure 1** – Flow behavior properties of cupuaçu and taperebá juice with inulin.

When the addition of solids was compared, it was seen that the juices with inulin presented higher viscosity in relation to the juice without prebiotics. This behavior was noted by other authors who studied Cherry (JUSZCZAK; FORTUNA, 2004) and Nori (KUMORO; RETNOWATI; BUDIYATI, 2011) juices with different concentrations of solids. The increase in viscosity with increasing solids is related to the increase of hydrogen bonds and the distortion of the liquid velocity pattern due to the increase of molecules in the solute (KUMORO; RETNOWATI; BUDIYATI, 2011).

Corroborating the flow curves, cupuaçu juices had lower viscosity values (Figure 2) when compared to tapereba juices. This behavior is similar to non-Newtonian fluids with high viscosity values at low shear rates, with decrease and stabilization at high rates. The increase in temperature reduced the apparent viscosity values of the juices. This behavior was similar to that studied for other studies with cupuaçu juice (CABRAL; QUEIROZ; FIGUEIREDO, 2002).



**Figure 2** – Viscosity apparent curves at  $100 \text{ s}^{-1}$  to cupuaçu and taperebá juice with inulin.

Table 3 shows the values of the power law model parameters for fruit juices. All treatments presented a good fit to the Power Law model, with  $R^2$  values close to 1. All treatments presented values of  $n < 1$ , evidencing the non-Newtonian behavior (SILVA; GUIMARÃES; GASPARETTO, 2005). In all treatments, the consistency index ( $k$ ) reduced with increasing temperature, corroborating with studies on rheology of mango, acerola (SILVA; GUIMARÃES; GASPARETTO, 2005) and cherry (VANDRESEN *et al.*, 2009). In this case the increase of the temperature promotes the decrease of the viscosity in the liquid phase due to the increase of the mobility of the particles in suspension (VIDAL *et al.*, 2006).

The increase in solids concentration increased  $K$  values. The concentration of soluble solids and insoluble solids has a strong non-linear effect on the viscosity of fluid foods (JUSZCZAK; FORTUNA, 2004). The flow index ( $n$ ) increased with the addition of inulin and may be related to the increase of the solids content in the nectars, increasing the pseudoplastic character (OLIVEIRA; ROSSI; BARROS, 2011). Similar behavior was observed in rheology studies of pear juice (AUGUSTO *et al.*, 2011) with different solids content.

According to colloidal molecular theory, the non-Newtonian behavior is due to the friction between the dispersed particles and the dispersant liquid molecules themselves, and also due to the interparticle electrostatic forces (OLIVEIRA *et al.*, 2009). These factors are responsible for the increase in flow resistance. The pseudoplastic systems, despite the homogeneous appearance, actually have dispersed particles with irregular shapes, such as filaments and planar plates (OLIVEIRA; ROSSI; BARROS, 2011).

**Table 3** – Rheological parameter for Power Law model

Temperature (°C)	Parameter	CI	C	TI	T
5	K	0.808	0.251	1.168	0.416
	N	0.505	0.729	0.478	0.613
	R <sup>2</sup>	0.998	0.997	0.991	0.997
	SSR	1,369	0,249	2,036	4,601
25	K	0.216	0.146	0.302	0.219
	N	0.71	0.523	0.567	0.618
	R <sup>2</sup>	0.999	0.981	0.991	0.994
	SSR	0,477	0,101	1,016	2,074
45	K	0.012	0.004	0.058	0.026
	N	0.776	0.901	0.545	0.624
	R <sup>2</sup>	0.993	0.994	0.992	0.986
	SSR	0,008	0,022	0,049	0,020

NOTE: k is consistency index (Pa.sn); n is flow behavior index; R<sup>2</sup> is Pearson’s correlation index; SSR is sum of squares of residues. Taperebá (T), cupuaçu (C) and inulin (I).

### PHYSICOCHEMICAL PROPERTIES OF CUPUAÇU AND TAPEREBÁ NECTARS

The pH values (Table 4) found are in accordance with the studies of Morzelle *et al.* (2009) and Carvalho *et al.* (2011), which reported pH lower than 4.0 for industrialized fruit nectar. For the industrial processing of nectar the high titratable acidity content is important, since it reduces the need for addition of acidifiers and provides food security, hindering the development of yeasts (LIMA *et al.*, 2002). The parameters titratable acidity and total soluble solids in all studied nectars remained in accordance with the identity and quality standards for tropical juices (BRASIL, 2003), which establish minimum values of 0.20% titratable acidity in citric acid and 11° Brix for soluble solids. Other authors (SANTOS *et al.*, 2010) observed pH values between 3.40 - 3.77 and titratable acidity 0.37 - 1.37% for cupuaçu juices. The results of ascorbic acid in the nectars analyzed were very expressive for taperebá and cupuaçu without inulin, since the increase of solids content may interfere with the vitamin C content reduction.

**Table 1** - Physicochemical properties of cupuaçu and taperebá nectars with inulin

Parameters	CI	C	TI	T
Soluble solids	9.00 ± 0.1	13.00 ± 0.2	12.00 ± 0.4	11.00 ± 0.8
pH	3.09 ± 0.1	3.25 ± 0.1	2.98 ± 0.2	2.95 ± 0.1
Titratable acidity	0.83 ± 0.2	0.65 ± 0.2	0.67 ± 0.2	0.64 ± 0.2
Vitamin C	5.50 ± 0.1	11.00 ± 0.1	2.20 ± 0.3	10.27 ± 0.1

### CONCLUSIONS

The centesimal composition confirmed the physicochemical characteristics of fruit pulps, with acceptable quality parameters and recommended by current



legislation. Temperature and inulin influenced the rheological behavior of cupuaçu and taperebá juice, with a viscosity reduction according to increasing temperature; and an increase in viscosity with the addition of inulin. The power law adjusted the flow curve data, evidencing the pseudo-plastic behavior of fruit juices. The rheological behavior of juices is an important tool in the food industry as it helps in the dimensioning of transmission lines and unit operations equipment, such as pasteurizers. It is suggested that the rheological behavior of different concentrations of inulin be studied, evaluating the influence on the flow characteristics of Amazonian juices.

## Comportamento reológico do suco de cupuaçu e taperebá com adição de inulina

### RESUMO

O comportamento reológico de alimentos líquidos é uma característica físico-química importante para processamento na indústria de alimentos. Este trabalho tem como objetivo avaliar o comportamento reológico do suco de cupuaçu e taperebá com adição de inulina. Foram realizadas análises da composição centesimal, sólidos solúveis, pH e acidez titulável da polpa e suco, além da reologia dos sucos adicionados de inulina nas temperaturas de 5, 25 e 45 ° C. Os dados reológicos foram ajustados para o modelo da lei de potência. A composição centesimal confirmou as características físico-químicas das polpas de frutas, com parâmetros de qualidade aceitáveis e recomendados pela legislação vigente. Observou-se que a adição de temperatura e sólidos (inulina) influenciou o comportamento reológico do suco de cupuaçu e taperebá, com redução da viscosidade com o aumento da temperatura; e aumento da viscosidade com a adição de inulina. A lei de potência ajustou os dados da curva de fluxo, evidenciando o comportamento pseudo-plástico dos sucos de frutas. O comportamento reológico dos sucos é uma ferramenta importante na indústria de alimentos, pois auxilia no dimensionamento de linhas de transmissão e equipamentos de operações unitárias, como pasteurizadores.

**PALAVRAS-CHAVE:** *Theobroma grandiflorum*; *Spondias mombin* L.; Reologia de sucos; inulina; prebióticos

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**Correspondência:**

Pedro Henrique Campelo

Faculdade de Ciências Agrárias, Universidade Federal do Amazonas, Manaus, Brasil.

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