Effect of temperature on dynamic and steady-state shear rheological properties of siriguela (Spondias purpurea L.) pulp

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1. Introduction

*Spondias purpurea* L. is a native fruit of Central America, dispersed in Mexico, Guatemala and the Caribbean, and in some countries of South America, mainly in the northeast region of Brazil (Sampaio et al., 2008; Augusto et al., 2000). The species belongs to the family Anacardiaceae, the same as mango (*Mangifera indica*), cashew apple (*Anacardium occidentale*) (Sampaio et al., 2008), cajá (*Spondias mombin* L.) and umbu (*Spondias tuberosa* Arruda Camara) (Bicas et al., 2011).

It is a small red fruit, with a pleasant aroma and taste which is consumed in natura or as juice and other products such as jams and different candies. The *S. purpurea* L. is called by different names, which are function of the geographic region, such as red mombin, siriguela, seriguela, ciriguela, jocote, jocote de corona, ciruela, ciruela Mexicana, jobillo, spanish plum and hog plum (Bicas et al., 2011; Furtado et al., 2010; Ceva-Antunes et al., 2006; Parada et al., 2006; Martins et al., 2003; Augusto et al., 2000).

The consumer demand for native and exotic products is growing, in special for food products, creating the need for better understanding of its processing and properties. Moreover, Furtado et al. (2010) and Ceva-Antunes et al. (2006) observed that the native fruit commercialization plays an important role in social and employment perspectives in development countries like in Brazil.

The rheological characterization of food is important for unit operations design, process optimization and high quality products assurance (Ibarz and Barbosa-Cánovas, 2003; Rao, 1999). Although the rheological characterization of exotic fruits is being studied for various authors, there is no work in literature related to the rheological characterization of *S. purpurea* L. pulp, even though it is essential for processing design.

The present work has evaluated and modeled the rheological properties of siriguela (*S. purpurea* L.) pulp as function of temperature.

2. Material and methods

A pasteurized frozen commercial siriguela (*S. purpurea* L.) pulp was used in order to guarantee the standardization and repeatability. After washing, the fruits are pulped, pasteurized, packaged in small plastic bags and then frozen. Further information related to siriguela fruits and pulp can be obtained in the works of Sampaio et al. (2008) and Martins et al. (2003).

Samples were thawed and carefully homogenized before the rheological measurements were taken. Its soluble solids content was determined by using a refractometer (digital refractometer *r*² mini, Reichert Analytical Inst., Japan), after filtering the samples in cotton, being 10.9 ± 0.1°Brix (mean of three replicates ± standard deviation). The sample total solid content was measured using the pulp moisture, determined by an infra-red moisture analyzer (IV2002, Gehaka, Brazil). The sample total solid content was 15.8 ± 0.4% (mean of three replicates ± standard deviation).
2.1. Rheology procedures

Rheological measurements were carried out with a controlled stress ($\sigma$) rheometer (AR2000ex, TA Instruments, USA), using a grooved plate–plate geometry (40 mm of diameter). The gap dimension (1.0 mm) was determined by using a gap-independency procedure, as described by Tonon et al. (2009).

The rheological properties were evaluated from 0 to 80 °C, and temperature was controlled by a Peltier system in each procedure. Geometry material thermal expansion was considered in order to guarantee the appropriated gap dimension. Moreover, at the temperatures of 60 and 80 °C, a solvent trap was used in order to minimize water vaporization from the product (it was observed that it was not necessary in temperatures below 60 °C).

The rheological evaluation was carried out with new samples, i.e., with non-mechanical history. Thus, samples were placed in the rheometer and kept at rest for 5 min before shearing.

The experiments were carried out in three replicates, and the regressions were done for each replicate. The parameters of each model were obtained by non-linear regression using the software CurveExpert Professional v.1.0.1 using a significant probability level of 95%.

2.1.1. Steady-state shear properties

The steady-state shear experiments were carried out in the shear rate ($\dot{\gamma}$) range of 0.01–100 s⁻¹. After rest, samples were submitted to shearing at 300 s⁻¹ for 5 min to avoid any thixotropy (data not shown). Then, a logarithmic decreasing stepped protocol (100–0.01 s⁻¹) was used in order to guarantee the steady-state condition. The products flow behavior was modeled using the Herschel–Bulkley’s model (Eq. (1)). Herschel–Bulkley’s model comprises Newton, Bingham and Ostwald-de-Waele (power law) models. It is commonly used to describe the rheological properties of food products.

$$\dot{\gamma} = \frac{\sigma - \sigma_0}{k}$$

(1)

2.1.2. Viscoelastic properties

Oscillatory stress sweeps between 0.01 and 10 Pa were performed at a frequency of 1 Hz to determine the products’ linear viscoelastic range. Then, frequency sweep measurements were carried out at 1.0 Pa, a shear stress value within the linear viscoelastic range. The oscillatory frequency ($\omega$) was then varied from 0.01 to 100 Hz. The storage modulus ($G'$), loss modulus ($G''$) and complex viscosity ($\eta^*$) were thus obtained, as function of frequency ($\omega$).

The storage ($G'$) and loss ($G''$) modules were modeled as a power function of oscillatory frequency ($\omega$) (Eqs. (2) and (3)), as commonly used for describing the viscoelastic behavior of food and dispersions (Rao, 1999):

$$G' = k' \cdot \omega^n$$

(2)

$$G'' = k'' \cdot \omega^n$$

(3)

2.2. Applicability of the Cox–Merz rule

The Cox–Merz rule states that the apparent viscosity ($\eta_a = \sigma/\dot{\gamma}$) at a specific shear rate ($\dot{\gamma}$) is equal to the complex viscosity ($\eta^*$) at a specific oscillatory frequency ($\omega$), when $\dot{\gamma} = \omega$ (Eq. (4); Rao, 2005). When this rule is valid, the rheological food properties can be determined by either oscillatory or steady-state shear experiments, which are useful due to limitations in each kind of experiment (Gunasekaran and Ak, 2000).

Thus, the obtained results from the steady-state shear and viscoelastic analysis were used for the evaluation of the Cox–Merz rule applicability:

$$\eta_a(\dot{\gamma}) = \eta(\omega)|_{\dot{\gamma}=\omega}$$

(4)

3. Results and discussions

3.1. Steady-state shear properties

Fig. 1 shows the flow curves ($\sigma$ versus $\dot{\gamma}$) of siriguela (S. purpurea L.) pulp at 0, 20, 40, 60, and 80 °C. As expected, the S. purpurea pulp showed a shear-thinning behavior ($n < 1$) with a representative yield stress ($\sigma_0$).

The yield stress is the minimum shear stress required to initiate product flow, being related to the material’s internal structure which must be broken (Genovese and Rao, 2005; Tabiolo-Munizaga and Barbosa-Cánovas, 2005). At stress below the yield stress, the material deforms elastically, behaving like an elastic solid; above the yield stress, it starts flowing, behaving like a viscous liquid (Bayod et al., 2007). The presence of a yield stress is a typical characteristic of multiphase materials (Sun and Gunasekaran, 2009), as fruit pulps and juices, which are formed by a dispersion of insoluble components (materials of cellular walls) in a water solution (serum, containing sugars, minerals, proteins, and soluble polysaccharides).

Table 1 shows the values of the Herschel–Bulkley model parameters for S. purpurea pulp in the evaluated temperature range. The $R^2$ values were always higher than 0.98. The obtained values of yield stress ($\sigma_0$), flow behavior index ($n$), and consistency coefficient ($k$) are close to those described in the literature for fruit products (Table 2; 20–30 °C).
Values for the parameters of Herschel–Bulkley model the S. purpurea L. pulp (mean of three replicates ± standard deviation; R² higher than 0.98 in each regression).

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>σ₀ (Pa)</th>
<th>k (Pa·sⁿ)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11.24 ± 0.53</td>
<td>21.54 ± 0.95</td>
<td>0.25 ± 0.01</td>
</tr>
<tr>
<td>20</td>
<td>13.26 ± 0.15</td>
<td>15.22 ± 0.20</td>
<td>0.30 ± 0.00</td>
</tr>
<tr>
<td>40</td>
<td>12.56 ± 0.25</td>
<td>11.22 ± 0.13</td>
<td>0.34 ± 0.01</td>
</tr>
<tr>
<td>60</td>
<td>1.50 ± 0.04</td>
<td>3.01 ± 0.07</td>
<td>0.44 ± 0.00</td>
</tr>
<tr>
<td>80</td>
<td>1.37 ± 0.12</td>
<td>1.71 ± 0.19</td>
<td>0.48 ± 0.01</td>
</tr>
</tbody>
</table>

The S. purpurea pulp is characterized by a high consistency, which can be observed by the magnitudes of σ₀ (13.3 Pa) and k (15.2 Pa·sⁿ) at 20 °C. As can be seen in Table 2, it is closed to the values reported for other fruit pulps as peach (σ₀ = 25.3 Pa; k = 11.3 Pa·sⁿ), umbu (σ₀ = 8.1 Pa; k = 37.7 Pa·sⁿ) and mango (σ₀ = 6.2 Pa; k = 11.3 Pa·sⁿ).

As expected, the increase in temperature reduces the yield stress (σ₀) and consistency coefficient (k), increasing the flow behavior index (n). Although the temperature reduces the shear-thinning behavior (i.e., increasing in n), the pulp shear-thinning behavior is still representative even at 80 °C (n₀ = 0.48).

The most used approach to modeling the temperature influence on the rheological properties of food is to consider its effect on the viscosity or apparent viscosity. However, the most important approach for the evaluation of non-Newtonian fluids is modeling each Herschel–Bulkley model’s parameter separately. Thus, the Herschel–Bulkley parameters were modeled as function of temperature.

The effect of temperature on the consistency coefficient (k) are generally modeled using the Arrhenius Equation (Eq. (5)), where each parameter A is modeled by a pre-exponential factor – A₀, and the activation energy – Eₐ; R is the constant of the ideal gases, and Tₚ is the absolute temperature:

$$ A = A₀ \cdot \exp \left( \frac{Eₐ}{R \cdot Tₚ} \right) $$  

The consistency coefficient (k, Fig. 2) could be well modeled by the Arrhenius Equation (Eq. (6); R² = 0.91). Although being in the same order of magnitude, the siriguela (S. purpurea) pulp activation energy value (Eₐ = 17509.2 J mol⁻¹) was higher than those described for other fruit products as tomato derivates (Table 3). Thus, the S. purpurea pulp internal structure is less affected by temperature than those products. Even though, its activation energy (Eₐ) value is close to those described in the literature for fruit products (Table 3), such as tomato paste, jabuticaba pulp and Juniperus drupacea fruit juice.

Massa et al. (2010) observed that the Brownian motion increased with the temperature, resulting in a less developed structure at higher temperatures, which explains the lower consistency coefficient values:

$$ k = 20.92 \cdot \exp \left( \frac{17509.2}{R \cdot Tₚ} \right) $$  

The flow behavior index (n) is generally assumed to be relatively constant with temperature (Rao, 1999). However, as can be seen in Fig. 2, the flow behavior index showed a rising trend in relation to temperature, which could be well modeled by a linear function (Eq. (7); R² = 0.97):

$$ n = 0.241 + 0.03 \cdot Tₚ $$

The yield stress (σ₀) modeling is not often carried out in literature works, as it behavior is the less pronounced. In some products it tends to remain constant (as, for example, in 21 °Brix peach puree between 5 and 55 °C; Massa et al., 2010), while in others it shows a monotonous falling behavior (as, for example, in butia pulp between 10 and 60 °C; Haminiuk et al., 2006). In some products, however, it shows a non-identifiable behavior (as, for example, in potato puree between 25 and 65 °C; Canet et al., 2005). In fact, it is important to observe that the property behavior in relation to temperature is function not only of the product itself, but also of the studied temperature range.

Although having a falling behavior with temperature increasing, the yield stress (σ₀) could not be modeled by the Arrhenius Equation. This behavior is different than those observed in tomato juice (Augusto et al., in press-a), where the yield stress was modeled using the Arrhenius Equation (the other works listed in Table 2 have not modeled each Herschel–Bulkley model’s parameter separately).

As can be observed in Fig. 2, the yield stress has shown a falling sigmoidal trend in relation to temperature, in contrast with the continuous decrease of the exponential function (Arrhenius Equa-
tion). Until 40 °C, the yield stress shows quasi-constant values (11–13 Pa) followed by a great decrease in temperatures between 40 and 60 °C. Then, it tends to stay back in a constant value (1–2 Pa). This trend could be well modeled by a power sigmoidal function (Eq. (8); $R^2 = 0.98$), and shows that an important transformation is carried out in siriguela (S. purpurea) pulp between 40 and 60 °C, as the yield stress value changes are more important in this temperature range when compared to temperatures below 40 °C and above 60 °C. The viscoelastic analysis corroborates this observation (Fig. 3).

Bhattacharya (1999) had studied the mango pulp yield stress in temperatures of 5, 30, 55 and 80 °C, observing a great fall in yield stress value between 55 and 80 °C:

$$\sigma_0 = \frac{12.36}{1 + (0.018 \cdot T_{c})^{20.77}}$$  

3.2. Viscoelastic properties

Fig. 3 shows the mechanical spectra of S. purpurea L. pulp at 0 and 80 °C. The siriguela (S. purpurea L.) pulp storage modulus values ($G'$) were always higher than those of the loss modulus ($G''$), which indicates that the pulp has dominant elastic properties over the viscous ones. Thus, the product can be classified as a weak gel (Rao, 1999). Similar behavior has been reported for other food products such as peach puree (Massa et al., 2010), acai pulp (Tonon et al., 2009), jabuticaba pulp (Sato and Cunha, 2009), umbu pulp (Pereira et al., 2008), baby foods (Ahmed and Ramaswamy, 2006), potato puree (Alvarez et al., 2004), tomato juice (Augusto et al., in press-b) and concentrates (Bayod et al., 2008; Valencia et al., 2002; Yoo and Rao, 1996).

As expected, the values of $G'$ and $G''$ had shown a rising tendency with the oscillatory frequency, the opposite behavior of the complex viscosity ($\gamma$). Thus, it was possible to model the storage and loss modules as a power function of the oscillatory frequency (Eqs. (2) and (3)). Table 4 shows the values for the power law model (Eqs. (2) and (3)) as a function of temperature. The $R^2$ values were always higher than 0.93 in each replicate. The ob-

<table>
<thead>
<tr>
<th>Product</th>
<th>$E_a$ (kJ mol$^{-1}$)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. purpurea L. pulp</td>
<td>17509.2</td>
<td>Present work</td>
</tr>
<tr>
<td>Tomato juice</td>
<td>7353.3</td>
<td>Augusto et al. (in press-a)</td>
</tr>
<tr>
<td>Tomato paste</td>
<td>8600–13000</td>
<td>Dak et al. (2008)</td>
</tr>
<tr>
<td>Reconstituted tomato</td>
<td>7360–3630</td>
<td>Barbana and El-Omri (in press)</td>
</tr>
<tr>
<td>concentrates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jaboticaba pulp</td>
<td>13000</td>
<td>Sato and Cunha (2007)</td>
</tr>
<tr>
<td>Juniperus drupacea fruit</td>
<td>60380–78230</td>
<td>Akbulut et al. (2008)</td>
</tr>
</tbody>
</table>

Table 4

Values for the power law model for storage ($G'$) and loss ($G''$) modules of S. purpurea L. pulp as a function of oscillatory frequency ($\omega$) (1 Pa, mean of three replicates ± standard deviation; $R^2$ higher than 0.93 in each regression).

<table>
<thead>
<tr>
<th>$T$ (°C)</th>
<th>$k'$ (Pa s$^{n'}$)</th>
<th>$n'$</th>
<th>$k''$ (Pa s$^{n''}$)</th>
<th>$n''$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>303.0 ± 6.2</td>
<td>0.16 ± 0.01</td>
<td>74.4 ± 1.5</td>
<td>0.28 ± 0.01</td>
</tr>
<tr>
<td>20</td>
<td>286.3 ± 4.3</td>
<td>0.14 ± 0.01</td>
<td>66.4 ± 0.8</td>
<td>0.27 ± 0.00</td>
</tr>
<tr>
<td>40</td>
<td>294.7 ± 15.2</td>
<td>0.15 ± 0.01</td>
<td>71.3 ± 4.4</td>
<td>0.23 ± 0.01</td>
</tr>
<tr>
<td>60</td>
<td>92.7 ± 6.4</td>
<td>0.16 ± 0.02</td>
<td>23.3 ± 1.6</td>
<td>0.28 ± 0.01</td>
</tr>
<tr>
<td>80</td>
<td>37.1 ± 2.8</td>
<td>0.14 ± 0.01</td>
<td>11.7 ± 0.6</td>
<td>0.30 ± 0.02</td>
</tr>
</tbody>
</table>
Ahmed and Ramaswamy (2006) have evaluated the viscoelastic behavior of vegetable based baby food. The values of \( k' \) and \( k'' \) ranged from 131.0–13500 Pa s\(^n\) to 19.7–1750 Pa s\(^n\), respectively (20–25 °C). The values of \( n' \) and \( n'' \) were in the range from 0.06–0.14 to 0.16–0.22, respectively.

The viscoelastic behavior of tomato products (concentrates and ketchups; 24–27% of total solids, 22–27°Brix) have been evaluated by Bayod et al. (2008) and Yoo and Rao (1996). The values of \( k' \) and \( k'' \) ranged from 1660–16982 Pa s\(^n\) to 106.6–3802 Pa s\(^n\), respectively (20–25 °C). The values of \( n' \) and \( n'' \) were in the range from 0.12–0.25 to 0.10–0.33, respectively.

Augusto et al. (2011) studied the effect of fiber addition on the rheological properties of peach juice (10–12.5% fiber; 0–40 °C). The values of \( k' \) and \( k'' \) ranged from 263.9–1567.1 Pa s\(^n\) to 59.8–616.6 Pa s\(^n\), respectively. The values of \( n' \) and \( n'' \) were in the range from 0.14–0.28 to 0.24–0.54, respectively.

The values of \( n' \) were always higher than \( n'' \) (Table 4), which demonstrate that the viscous behavior of \( S. \) purpurea pulp becomes more important in high frequencies. Moreover, the viscous behavior becomes more important in high temperatures, as can be seen by the convergence of \( k' \) and \( k'' \) (Table 4, Fig. 4).

When the parameters of the power law model for storage \( (G') \) and loss \( (G'') \) moduli (Eqs. (2) and (3)) were evaluated in relation to the temperature, a different behavior was observed. The values of \( n' \) and \( n'' \) have shown to be relatively constant with temperature, as expected for the flow behavior index \( (n; \) Rao, 1999\). It can be clearly seen in Fig. 4, where the mean values for the \( n' \) and \( n'' \) are, respectively, 0.15 and 0.27.

The \( k' \) and \( k'' \) values, though, have shown a sigmoidal decay behavior with temperature, as observed for the yield stress \( (\sigma_0) \). As can be seen in Fig. 4, both \( k' \) and \( k'' \) showed almost constant values in the temperature range between 0 and 40 °C. It indicates that the \( S. \) purpurea pulp viscoelastic properties are low dependent of temperature at this range, reflecting low internal structure changes. In fact it is the same behavior observed for the yield stress \( (\sigma_0, \) Fig. 2). Once more, it is observed that the most important changes in the \( k' \) and \( k'' \) values are carried out between 40 and 60 °C, corroborating the yield stress \( (\sigma_0) \) discussion. This behavior could be well modeled by a power sigmoidal function (Eqs. (9) and (10); \( R^2 > 0.97 \)). It is interesting to observe that, even for \( k' \) and \( k'' \), the parameters related to the sigmoidal shape are quite the same (the proportional and power parameters in temperature). It demonstrates that the decrease in the magnitudes of \( G' \) and \( G'' \) in relation to temperature follows the same trend:

\[
k' = \frac{299.8}{1 + (0.018 \cdot T_C)^{0.32}}
\]

\[
k'' = \frac{72.17}{1 + (0.018 \cdot T_C)^{0.34}}
\]

The observed behavior is different than those observed in other products, although there are just few studies which have modeled the values of \( k', k'', n' \) and \( n'' \) as function of temperature.

Ahmed et al. (2007) and Ahmed and Ramaswamy (2006) described that the temperature effect was not systematic in the evaluation of \( k', k'', n' \) and \( n'' \) of baby food (20–80 °C).

Augusto et al. (2011) have modeled the values of \( n' \) and \( n'' \) as a quadratic function (2nd order polynomial function) in relation to temperature in peach juices with fibers (0–40 °C). The values of \( k' \) and \( k'' \) were modeled using the Arrhenius Equation.

It is important to highlight that the property behavior in relation to temperature is function not only of the product itself, but also of the studied temperature range.

3.3. Applicability of the Cox-Merz rule

When the applicability of the Cox-Merz rule was evaluated, it was not possible to use it straight. As commonly observed in food products, the complex viscosity \( (n'') \) magnitudes were always higher than the apparent viscosity \( (n_H) \) magnitudes (Fig. 5).

Although the Cox-Merz rule has been confirmed experimentally for several polymers dispersions and solutions, in complex systems as food products it is generally necessary to modify the original rule (Rao, 2005; Gunasekaran and Ak, 2000). The non-fitting of the Cox-Merz rule for complex dispersions is attributed to structural decay due to the extensive strain applied (Ahmed and Ramaswamy, 2006), presence of high-density entanglements or to the development of structure and intermolecular aggregation in solution (Da Silva and Rao, 1992). Thus, the rheological properties of the \( S. \) purpurea pulp differ from those of the polymer solutions and are more similar to structured systems (Ahmed and Ramaswamy, 2006).

The rheological oscillatory and steady-state shear rheological properties of foods are generally correlated by modifications to the Cox-Merz rule (Rao, 2005; Gunasekaran and Ak, 2000). Bistany and Kokini (1983) have proposed a power modification of the original rule (Eq. (11), which has been used for the evaluation of different food products. Table 5 shows the values for the parameters of this modified Cox-Merz rule for \( S. \) purpurea pulp, with \( R^2 \) always higher than 0.96.
babies, ketchup and tamarind juice (Table 6), although those described by other fruit products as potato puree, fruit based
modified Cox-Merz rule, the pulse difference between the apparent (\(\eta_a\)) and complex (\(\eta'\)) viscosities, while the \(\alpha\) value is related to the behavior difference. Thus, the small \(\beta\) values indicate that both \(S. purpurea\) pulp apparent (\(\eta_a\)) and the complex (\(\eta'\)) viscosities magnitudes are closed, which in fact can be seen in Fig. 5. Moreover, as observed by Ahmed et al. (2007) and Alvarez et al. (2004), the values of \(\alpha\) and \(\beta\) have not shown a particular trend in relation to temperature.

The obtained results indicate that the rheological properties of \(S. purpurea\) pulp can be determined by either oscillatory or steady-state shear experiments.

\[ \beta \cdot [\eta_a'(\gamma)]^2 = \eta_a(\omega) \cdot \eta' \]

(11)

\(\beta\cdot [\eta_a'(\gamma)]^2 = \eta_a(\omega) \cdot \eta'\)

It can be seen that the obtained values are in accordance to those described by other fruit products as potato puree, fruit based baby foods, ketchup and tamarind juice (Table 6), although \(S. purpurea\) pulp \(\beta\) values are proportionally small. In the evaluated modified Cox-Merz rule, the \(\beta\) value is related to the magnitude difference between the apparent (\(\eta_a\)) and complex (\(\eta'\)) viscosities, while the \(\alpha\) value is related to the behavior difference. Thus, the small \(\beta\) values indicate that both \(S. purpurea\) pulp apparent (\(\eta_a\)) and the complex (\(\eta'\)) viscosities magnitudes are closed, which in fact can be seen in Fig. 5. Moreover, as observed by Ahmed et al. (2007) and Alvarez et al. (2004), the values of \(\alpha\) and \(\beta\) have not shown a particular trend in relation to temperature.

The obtained results indicate that the rheological properties of \(S. purpurea\) pulp can be determined by either oscillatory or steady-state shear experiments.

3.4. General discussion

As consumer demand for native and exotic products is growing, it is necessary to conduct scientific studies in order to better understand their processing and properties.

The rheological characterization of fruit pulps and juices is essential for their processing and product design and optimization. We highlighted the need for carry other works related with physical properties of those fruit products.

The present work has evaluated the rheological properties of a commercial siriguela (\(S. purpurea\) L.) pulp as function of temperature. The product flow behavior was described by the Herschel–Bulkey’s model. The siriguela pulp viscoelastic behavior was described as a weak gel, and its storage and loss modules were described using a power function of the oscillatory frequency. A power modified Cox-Merz rule was used for describe the pulp rheology, i.e., it was shown that the pulp rheological properties can be determined by either oscillatory or steady-state shear experiments.

The obtained data are potentially useful for future studies on food properties and process design. However, other studies are needed for understanding the influence of each unit operation (as pulping or thermal processing) on the siriguela (\(S. purpurea\) L.) pulp rheological pulp.

4. Conclusions

The present work has evaluated the steady and dynamic shear rheological properties of siriguela (\(S. purpurea\) L.) pulp as function of temperature. The product flow behavior could be well described by the Herschel–Bulkey’s model, whose parameters were modeled as function of temperature. The storage and loss modules could be well described by a power function of the oscillatory frequency, whose parameters were modeled as function of temperature. Moreover, a power modified Cox-Merz rule could describe the rheological properties of \(S. purpurea\) pulp. The obtained data is potentially useful for future studies on food properties and process design.

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References


