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Article

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Application of time–intensity analysis in model system submitted to homogenization

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Abstract

The use of the high pressure homogenizer has been studied in fruit juices, but researches in model system for application in fruit nectar are scarce. Therefore, it is necessary to evaluate the application of these technologies and how the homogenization pressure (P_H) can interfere in the sensorial profile of the samples. To prepare the solutions we used guar gum (0.1%), organic acids (0.3%), and sucrose (10%), which were later homogenized (0—control, 25 and 50 MPa) at 25 °C. The rheological behavior and the temporal profile of the samples were evaluated. The model systems presented pseudoplastic behavior without residual tension and were fitted to the Ostwald–de Waele model. The consistency index reduced and the flow behavior index increased with processing. Apparent viscosity also decreased due to homogenization. In the time–intensity sensorial analysis, it was observed that the samples differed among the evaluated parameters, demonstrating that the samples with tartaric acid presented higher intensity for the sour taste. However, for sweetness, no change was observed. In the viscosity attribute, the model systems presented similar temporal profiles. Therefore, it was noted that the homogenization process favored a greater temporal profile of sour taste, making sensory perception more lasting in a model system for fruit nectar.

Keywords

Homogenization, rheology, temporal analysis, guar gum, organic acids

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INTRODUCTION

Food additives have a high potential for application in the food industry and play an important role in the development of new products. Thickeners are food additives with thickening and stabilizing functions that provide desired texture to food and high viscosity, and are able, even at low concentrations, to increase the viscosity of solutions, emulsions, and suspensions, improving the texture of the products (Hong et al., 2012).

Guar gum is obtained from the endosperm of *Cyamopsis tetragonolobus*, being formed by chain linear mannose (β-1,4) with galactose residues as side chains, in the ratio of one unit of galactose to two units of mannose. Guar gum has as main property the feature of rapid hydration in cold water and formation of viscous solutions with pseudoplastic behavior. It is considered as a low cost product, besides being compatible with other gums, starches, hydrocolloids, and gelling agents (Nieto and Akins, 2011).

In the food industry, organic acids are extensively used as acidulant additives and acidity regulators.

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They influence directly the taste and the quality of the processed foods, improve digestibility, and exert a preservative action by lowering the pH (Damodaran et al., 2010; Theron and Lues, 2011).

Emerging nonthermal technologies, such as high pressure homogenization, have been studied as partial or total substitute for food thermal processing, mainly in fruit products (Augusto et al., 2012), whether for the development of new products or to improve existing technological processes. In the use of a high pressure homogenizer, the fluid is forced to flow through a homogenizing valve under high pressure conditions in the order of micro seconds, with consequent increase in speed due to sudden decrease in volume (gap), followed by depressurizing, resulting in high shear stress, turbulence, and cavitation (Dumay et al., 2013).

Research in the fields of nonthermal food processing technologies have stood out for their focus on the preservation and modification of the functional properties of food components while maintaining the quality attributes of the food. Processing in high pressure homogenizer has been applied in different fruit juices (Calligaris et al., 2012; Guan et al., 2016; Leite et al., 2015; Zhou et al., 2017), as well as in polysaccharides (Harte and Venegas, 2010; Wang et al., 2011). Thus, this study is of great interest since it evaluates the effect of P_H on the rheological and sensory behavior in guar gum model systems with applicability for fruit nectars.

Through rheological behavior one can determine the functionality of an ingredient in product development, as well as correlate the data obtained by sensory analysis (Holdsworth, 1993). Time–intensity sensory analysis provides information about the perceived sensations in food over time. Therefore, they describe the mean velocity, duration, and intensity perceived for a single stimulus (Amerine et al., 1965). Time–intensity analysis has been used in research on different types of products (Freitas et al., 2015; Palazzo and Bolini, 2009, 2014).

Thus, the aim of this study was to evaluate guar gum model systems acidified with organic acids, and with sucrose additives, determining the influence of the P_H in the time profile and in rheological behavior.

MATERIALS AND METHODS

Materials

To elaborate the model systems, we used the guar gum thickener (AtiViva®, Barretos, São Paulo, Brazil) at a concentration of 0.1% (w/v) (Brasil RDC no. 8, 2013), and the organic acids (0.3%) (w/v) of citric, malic, and tartaric acid (Synth®, Diadema, São Paulo, Brazil) were used separately in each thickener solution. The model systems were sweetened with refined sucrose sugar (10%) (w/v) (União®, São Paulo, Brazil).

Preparation of the model systems

To prepare the model systems, the guar gum was mixed to sucrose and then dissolved in deionized water at room temperature, under stirring (Shaker Fisatom, 713D) for 3 h. Simultaneously with the preparation of the thickeners, the organic acid was added. The procedures were carried out under stirring, with inlet temperature of $24.5 \pm 2\,^{\circ}C$ and a pH of 2.65 ± 0.02. All rheological and sensory analyses were performed in triplicate.

Homogenization

After preparing the samples, the homogenization process was carried out at 0 (control), 25, and 50 MPa, in a high pressure homogenizer (Panda Plus, GEA Niro Soavi, Italy). The samples were processed at 25 °C and immediately after stored in plastic bottles (330 ml) under refrigeration ($7 \pm 2\,^{\circ}C$) for 21 days. Afterwards, the rheological and sensorial analyses were conducted at room temperature ($24 \pm 2\,^{\circ}C$). At the end of the process, we obtained nine samples, each with a different acid (citric acid, malic acid, and tartaric acid) and processed at 0, 25, and 50 MPa.

Rheological analysis

The rheological characteristics of the samples were studied and analyzed in a voltage-controlled rheometer (σ) (AR2000ex, TA Instruments), with cone-plate geometry (60 mm diameter, 2°). During the analyses the temperature was kept constant (25 °C) using a Peltier system. The rheological properties were measured at steady state with decreasing shear rate (0.1–300 s^{-1}) for 5 min and 30 points readings for each curve. After obtaining the behavior to the flow, the model system was adjusted using the Ostwald–de Waele model (equation (1))

$$\sigma = k \cdot \dot{\gamma}^{\,n} \tag{1}$$

The model parameters of equation (1) were modeled as a function of P_H using linear or nonlinear regression with the CurveExpert Professional Software v.1.6.3 and a 95% significant probability level.

Sensory analysis

The sensory tests were conducted at the Laboratory of Sensory Science and Consumer Studies from the Food and Nutrition Department (FEA/UNICAMP). The samples were presented in a monadic way through complete balanced blocks (MacFie et al., 1989), with three repetitions and in individual booths with white light. The guar gum solutions were presented in (disposable) plastic cups encoded with three-digit numbers. The assessors were advised to use water between the samples to clean the palate.

This research project was submitted and approved by the Research Ethics Committee of UNICAMP, CAAE: 52934315.7.0000.5404. The Free and Informed Consent Form containing information about the research was prepared and presented to the assessors.

Time–intensity analysis. The individuals were recruited among UNICAMP undergraduate and graduate students and staff by invitation and posters set at the university. The volunteers who showed interest in participating in the project were trained about the importance of the research and the methodology to be applied.

In the time–intensity analysis, it is necessary for to preselect, train, and subsequently select the individuals. Thus, to evaluate the discriminative power of each volunteer, triangular tests were performed. A control sample and two samples of solutions of thickeners acidified with organic acids, with a 0.1% level significant difference in relation to viscosity, were evaluated by the participants. Posteriorly the Wald's sequential analysis was applied to the data (Amerine et al., 1965). For preselection, using Wald's sequential analysis, values of $\rho_0 = 0.45$, $\rho_1 = 0.70$, $\alpha = 0.05$, and $\beta = 0.05$ were used.

Training session. At this stage, the assessors were trained to use the data collection program *Time-Intensity Analysis of Flavors and Tastes* (Universidade Estadual de Campinas—UNICAMP, 2012) developed at the Laboratory of Sensory Science and Consumer Studies at the Faculty of Food Engineering (UNICAMP).

Thus, the evaluators used the TIAFT software and formed a sensory memory with the extremes of the scale for the sweetness, sourness, and viscosity attributes. At this stage, it is also necessary that the evaluators should have a good discriminability between the samples, the repeatability of their results, and agreement with the team (Damásio and Costell, 1991).

With the parameters (maximum intensity (Imax), time at which the maximum intensity was perceived (Timax), total time of attribute duration (Ttot), and area under the curve (Area)) analyzed through TIAFT, the time–intensity curve is obtained.

For the time–intensity analysis of the sweetness and sourness attributes, we standardized the initial waiting time (5 s), residence time in the mouth (25 s), time after ingestion (10 s), and scale (10), while for the viscosity attribute were expected initial waiting time (5 s), residence time in the mouth (10 s), time after ingestion (40 s), and scale (10).

Selection of assessors for time–intensity analysis. At this stage, training was performed with preselected individuals (16). They used the time–intensity method evaluating three experimental samples with different concentrations of thickeners. This training was conducted to select the assessors. Eleven were selected with discriminative power between samples and repeatability of their results (Damásio and Costell, 1991).

The participants evaluated samples for the sweetness, sourness, and viscosity attributes. The samples were presented in monadic form and evaluated with three repetitions. The intensity of each analyzed attribute was recorded as a function of the time used with the mouse, in an eleven-point scale with numbers from 0 to 10. In the time–intensity scale, 0 corresponds to none (left side), 5 corresponds to moderate (center), and 10 corresponds to strong/very (right side).

To evaluate the sweetness and sourness attributes, the following steps were used: at the first warning issued by the computer (5 s) one ought to press start, the assessor put the sample in their mouth and indicated the intensity of the sensory attribute on the scale using the mouse. When hearing the second warning tone (25 s), the evaluator swallowed the sample, and a third warning (10 s) indicated the end of the test. To evaluate the viscosity stimulus, when the first warning was issued by the computer (5 s) one ought to press start, the assessor put the sample in their mouth and indicated the intensity of the sensory attribute on the scale using the mouse. When hearing the second warning tone (10 s), the evaluator swallowed the sample, and a third warning (40 s) indicated the end of the test.

For the selection of the assessors, a two-factor (sample and repetition) analysis of variance (ANOVA) was performed with respect to each parameter of the curve obtained. The 11 selected assessors showed ability to discriminate the samples ($pF_{sample} < 0.30$), repeatability of the results ($pF_{repeat} > 0.05$), and consensus with the team (Damásio and Costell, 1991).

Evaluation of the attributes by time–intensity analysis. The temporal analyses of the guar gum model systems for the sweetness, sourness, and viscosity attributes were carried out by the assessors in monadic form and with three repetitions.

Sweetness was defined as the one characteristic of a sucrose solution and sourness as the one characteristic of a citric acid solution. Viscosity was defined as the internal resistance that the particles of a substance present when ''sliding'' on top of each other.

Thus, the assessors recorded their temporal perception of the attributes analyzed for the parameters for which they were trained (Imax, Timax, Area, Ttot). Based on the results, the mean values of each curve were determined and the curves were then overlapped.

Statistical analysis

The results of the effect of homogenization process and the parameters obtained through the time–intensity curves were evaluated through ANOVA and Tukey's mean test ($p \leq 0.05$) using the program *Statistical Analysis System*—SAS 9.4. With the data of the time–intensity analysis, we also performed the principal component analysis (PCA).

RESULTS AND DISCUSSION

Time–intensity analysis

Table 1 shows the mean values of the guar gum model systems with acidulants for the parameters of the curves of the time–intensity analysis, corresponding to the sourness stimulus. We can observe that the homogenization process did not differ significantly ($p < 0.05$) for the time of maximum intensity and total time of perception of the sourness attribute between the control model systems and the homogenized ones (25–50 MPa). The time of perceived maximum intensity presented mean values between 8.47 and 9.32 s. The sample (G50T) showed the highest total time (23.34 s) of sourness perception, as well as the highest maximum intensity value (5.00) and area (68.42). We observed that the guar gum model systems with tartaric acid (GCT, G25T, and G50T) showed higher values in all parameters, indicating that tartaric acid was considered by the assessors as being the most intensive for the sourness attribute.

Table 1. Mean values of the parameters of time–intensity curves for sourness attribute in model systems of guar gum

Samples	Timax (s)	Imax	Ttot (s)	Area
GCC	8.86a	3.57d	20.88a	43.94cd
GCM	8.98a	4.06bcd	21.09a	48.71bcd
GCT	9.31a	4.54ab	22.90a	58.49ab
G25C	8.93a	3.78cd	21.13a	46.37cd
G25M	8.64a	4.08bcd	21.40a	50.28bcd
G25T	9.32a	4.54ab	22.41a	58.47ab
G50C	8.47a	4.27bc	21.47a	51.61bc
G50M	8.95a	3.43d	20.52a	39.21d
G50T	9.27a	5.00a	23.34a	68.42a

Area: area under the curve; GCC: citric control guar; GCM: malic control guar; GCT: tartaric control guar; G25C: citric 25 MPa guar; G25M: malic 25 MPa guar; G25T: tartaric 25 MPa guar; G50C: citric 50 MPa guar; G50M: malic 50 MPa guar; G50T: tartaric 50 MPa guar; Imax: maximum intensity; Timax: time at which the maximum intensity was perceived; Ttot: total time of attribute duration.
Means followed by the same letter in the column, do not differ by Tukey's test ($p \leq 0.05$).

In the evaluation of the parameters' maximum intensity and area, the samples acidified with tartaric acid did not differ statistically from each other ($p < 0.05$), whereas GCM and G 25 M did not differ from the citric acid or tartaric acid samples. On the other hand, the tartaric acid solutions were statistically different from the citric acid solutions. The homogenized model systems at 50 MPa showed a statistical difference ($p < 0.05$) among them, and the G50T sample showed a higher value of maximum intensity and area.

Shallenberger (1996) reported that sour taste is related to the concentration of hydrogen ions. However, other studies claim that the sour taste intensity of organic acid solutions is not simply related to the concentration of hydrogen ion. Thus, in addition to hydrogen ions, the concentration of protonated organic acids executes a role in the determination of the sour taste intensity of organic acids (Da Conceição Neta et al., 2007; Johanningsmeier et al., 2005).

The different organic acids used and the homogenization process did not affect the sweetness perception in guar gum model systems, as they did not show significant difference ($p < 0.05$) in the parameters' time of maximum intensity, maximum intensity, and total time (data not shown). The model systems needed between 8.65 and 9.71 s to reach the time of maximum intensity and between 3.82 and 4.49 s for maximum intensity, while the total time of perception of sweetness was between 18.86 and 21.34 s. It was also observed that the areas of the samples with citric acid (GCC, G25C, and G50C) presented higher values, indicating that sweetness was better perceived by the assessors in these samples. This can occur because citric acid is considered a weaker acid (Theron and Lues, 2011).

In the time–intensity analysis for the viscosity attribute (Table 2), we observed that the GCC sample differed from G50C for the parameter of maximum time of intensity and that the other samples did not differ among themselves ($p < 0.05$). The homogenized sample (G50C) reached the maximum intensity in the shortest time (7.56 s). The maximum intensity of the control samples presented values of 3.12 and 3.31. Whereas, the guar gum model systems processed in the high pressure homogenizer showed maximum intensity for viscosity, with values between 2.48 and 3.04. Although these values are slightly lower, we noted from Table 2 that the sample (G50T) differed significantly ($p < 0.05$) from the control samples (GCC, GCM, GCT) and G25C. Nevertheless, no significant difference was observed among the other samples ($p < 0.05$).

The total viscosity time was between 24 and 26 s, but the samples did not differ ($p < 0.05$). Thus, in spite of the breakdown of polysaccharides during the process in high pressure homogenizer (Harte and Venegas, 2010; Lagoueyte and Paquin, 1998; Wang et al., 2011), the

Table 2. Mean values of the parameters of time–intensity curves for viscosity attribute in model systems of guar gum

Samples	Timax (s)	Imax	Ttot (s)	Area
GCC	9.62a	3.31a	26.22a	62.51a
GCM	8.78ab	3.31a	24.75a	59.19ab
GCT	8.47ab	3.12a	24.87a	55.24abc
G25C	8.77ab	3.04a	24.56a	53.67abc
G25M	8.36ab	2.99ab	24.89a	52.29abc
G25T	8.80ab	2.87ab	24.99a	51.63abc
G50C	7.56b	3.00ab	25.34a	55.37abc
G50M	8.05ab	2.86ab	24.34a	49.86bc
G50T	8.34ab	2.48b	25.43a	44.18c

Area: area under the curve; GCC: citric control guar; GCM: malic control guar; GCT: tartaric control guar; G25C: citric 25 MPa guar; G25M: malic 25 MPa guar; G25T: tartaric 25 MPa guar; G50C: citric 50 MPa guar; G50M: malic 50 MPa guar; G50T: tartaric 50 MPa guar; Imax: maximum intensity; Timax: time at which the maximum intensity was perceived; Ttot: total time of attribute duration.
Means followed by the same letter in the column do not differ by Tukey's test ($p \leq 0.05$).

guar gum model systems exhibited a similar total time of sensory perception of viscosity. In the area parameter, the sample (GCC) presented a higher value (62.51) and differed statistically from the samples (G50M and G50T), which presented lower values.

Through the time–intensity analysis one can verify changes in the sensorial perception of a certain attribute over time. For a more comprehensive view of how these changes occur, this study graphically presented the multiple temporal perceptions of the attributes analyzed. Therefore, multiple time–intensity analysis (MTIA) graphically represents the temporal profile of the curves of two or more sensory attributes of a given sample (Palazzo and Bolini, 2009).

Figure 1 represents the curves of the MTIA for the three attributes (sweetness, sourness, and viscosity) as a function of time. Through the curves it can be observed that the guar gum model systems show similar temporal profiles for the sweetness and sourness. The samples with tartaric acid (GCT, G25T, and G50T) had an intensity and total perception time of the sourness slightly higher than the other samples. This contributes to meet the expectations of a product with a more accentuated and lasting sourness, and less prolonged sweetness. The guar gum model systems also presented similar sensory profiles for the viscosity stimulus, despite the homogenization process reducing viscosity; this factor did not present significant difference in the temporal profile of the samples. Thus, the use of different organic acids and the processing in high pressure homogenizer (25 and 50 MPa) present a viable alternative for use in fruit nectars, since the evaluated guar gum model systems showed similar temporal profiles. The use of model systems in scientific research has the advantage of having experimental reproducibility and being economical, without significantly changing the products (Augusto et al., 2011; Berto et al., 2003).

Figure 2 shows the analysis of PCA of the guar gum model systems with organic acids for sourness. In this figure, the parameters evaluated in the time–intensity analysis are represented by vectors. Similar model systems occupy close regions in the graph and are characterized by vectors that are close to them. The two main components accounted for 89.8% of the total variability observed between the samples. It is noted that the vectors (Imax, Ttot, and Area) are turned to the samples with tartaric acid (GCT, G25T, and G50T), characterizing them as having the highest intensity for the sourness attribute. However, the other guar gum model systems are all opposed to the vectors of maximum intensity, total time, and area, revealing that they have lower sourness intensity when compared with the samples containing tartaric acid.

PCA of the sweetness attribute presented an explanation of 83.3% (data not shown); it is noticed that the positioning and the proximity of the samples may indicate that they have similar temporal profiles in guar gum model systems for sweetness stimulus. The G25C sample was positioned far from the others, being characterized by the area parameter.

Time–intensity analysis has been widely used in different food matrices, such as fruit nectar (Freitas et al., 2015), chocolate (Palazzo and Bolini, 2014), fruit jelly (Souza et al., 2013), and white wine (Sokolowsky and Fischer, 2012), mainly to verify sensory perception of sweet, acid and bitter taste, viscosity, and melting in various products.

In Figure 3, we can observe that the two main components used jointly explained 83.0% of the total variability observed among the samples. The PCA allows the visualization of the relations between the parameters and the samples. Thus, each sample can be characterized more intensely by some specific parameters. The control model systems (GCC, GCM, and GCT) were characterized by the vectors of maximum intensity and area, indicating higher viscosity in relation to the samples homogenized at 25 and 50 MPa. Conversely, the GCC sample was characterized by the four analyzed parameters (Timax, Imax, Ttot, and Area). The G50T sample is contrasted to the vectors of maximum intensity and area, revealing that it has a lower viscosity.

Rheological behavior

The homogenization process altered the flow behavior of the guar gum model systems with organic acids. In

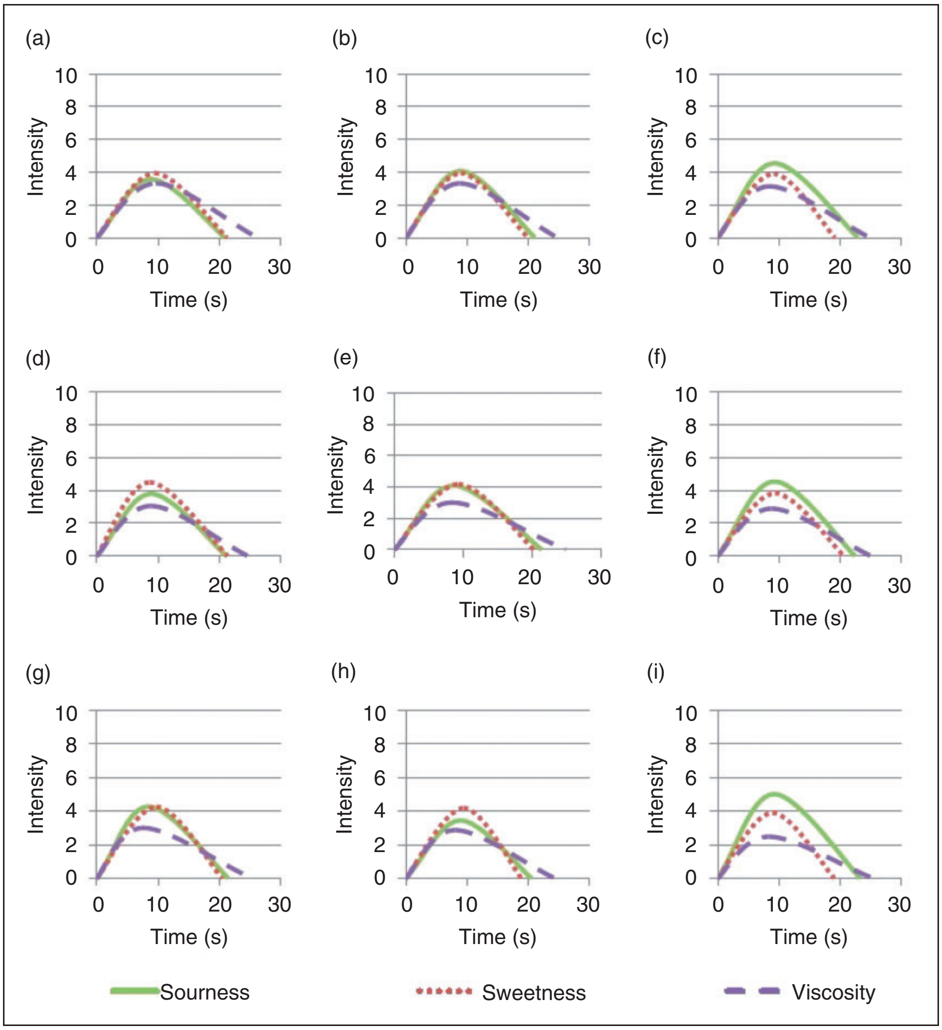

Figure 1. Multiple time–intensity curves in model systems of guar gum. (a) GCC—citric control guar, (b) GCM—malic control guar, (c) GCT—tartaric control guar, (d) G25C—citric 25 MPa guar, (e) G25M—mahc 25 MPa guar, (f) G25T—tartaric 25 MPa guar, (g) G50C—citric 50 MPa guar, (h) G50M—malic SOMPa guar, (i) G50T—tartaric 50 MPa guar.

Figure 4, it can be seen that the homogenized samples at 25 and 50 MPa exhibited a decrease of the behavior to the flow, as we observed that at a fixed shear rate the shear stress values are lower in the homogenized samples. The effects of the P_H and the rheological behavior were similar between the different organic acids used.

Similarly, in Figure 5, it can be observed that the apparent viscosity reduced with the homogenization process, as the nonhomogenized model systems presented higher values, independently of the shear rate. The apparent viscosity of the guar gum model systems presented a reduction of approximately 1.5–2.0% of their initial value when the samples were processed. Relating those data to the sensorial viscosity attribute, we observed that, in Table 2, the maximum intensity values were slightly higher for the control model systems (GCC, GCM, and GCT), characterizing them with greater intensity for the viscosity attribute. It was also noticed that the homogenized samples presented values of maximum intensity close to those of the control samples. Thereby, the guar gum model systems showed no difference ($p < 0.05$) in the maximum intensity parameter, except for G50T which differed significantly ($p < 0.05$) from the control samples (GCC, GCM, and GCT) and from G25C. This can be considered favorable since there was no significant difference between the control model systems and the homogenized ones.

According to Augusto et al. (2012), the rheological properties of serum are slightly affected by processing in high pressure homogenizer. They evaluated a serum model for application in tomato juice and observed a reduction in the viscosity of the fluid.

Therefore, we can state that P_H changed the behavior to the flow, but this was not sensorially perceived by

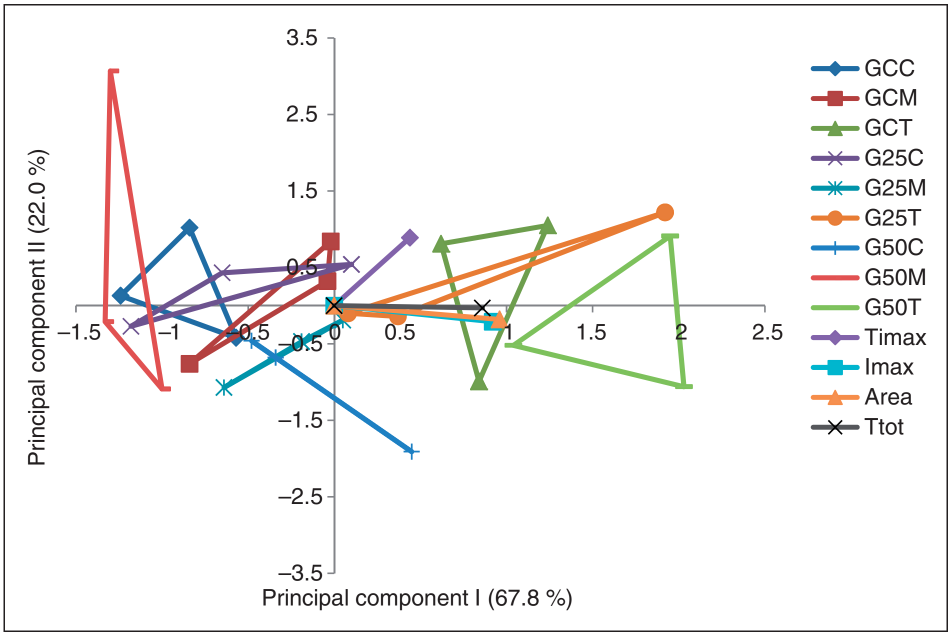

Figure 2. PCA of sourness in guar gum model systems.
Area: area under the curve; GCC: citric control guar; GCM: malic control guar; GCT: tartaric control guar; G25C: citric 25 MPa guar; G25M: malic 25 MPa guar; G25T: tartaric 25 MPa guar; G50C: citric 50 MPa guar; G50M: malic 50 MPa guar; G50T: tartaric 50 MPa guar; Imax: maximum intensity; Timax: time at which the maximum intensity was perceived; Ttot: total time of attribute duration.

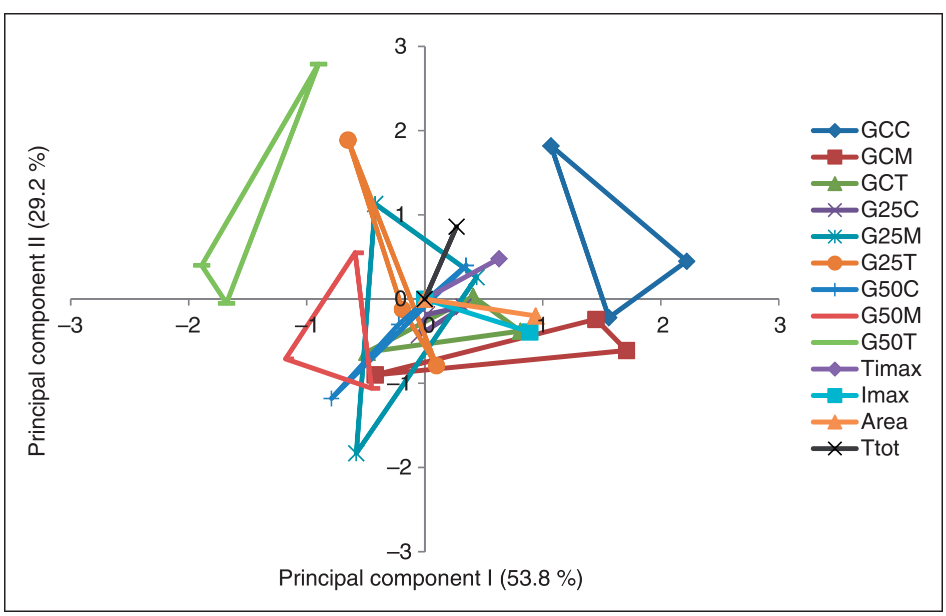

Figure 3. PCA of viscosity in guar gum model systems.
Area: area under the curve; GCC: citric control guar; GCM: malic control guar; GCT: tartaric control guar; G25C: citric 25 MPa guar; G25M: malic 25 MPa guar; G25T: tartaric 25 MPa guar; G50C: citric 50 MPa guar; G50M: malic 50 MPa guar; G50T: tartaric 50 MPa guar; Imax: maximum intensity; Timax: time at which the maximum intensity was perceived; Ttot: total time of attribute duration.

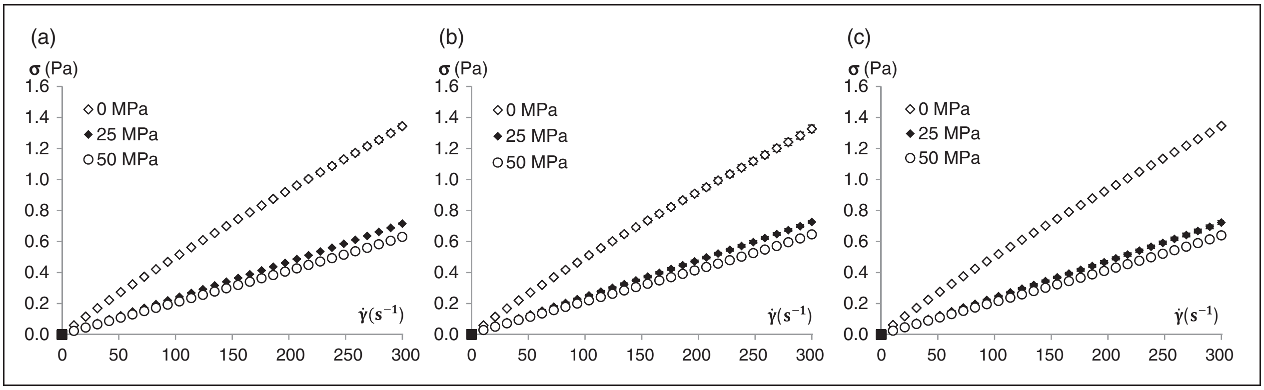

Figure 4. Flow behavior at 25 °C in model systems of guar gum with (a) citric acid, (b) malic acid, and (c) tartaric acid (c) (the points are the mean values, and the vertical bars are standard deviation).

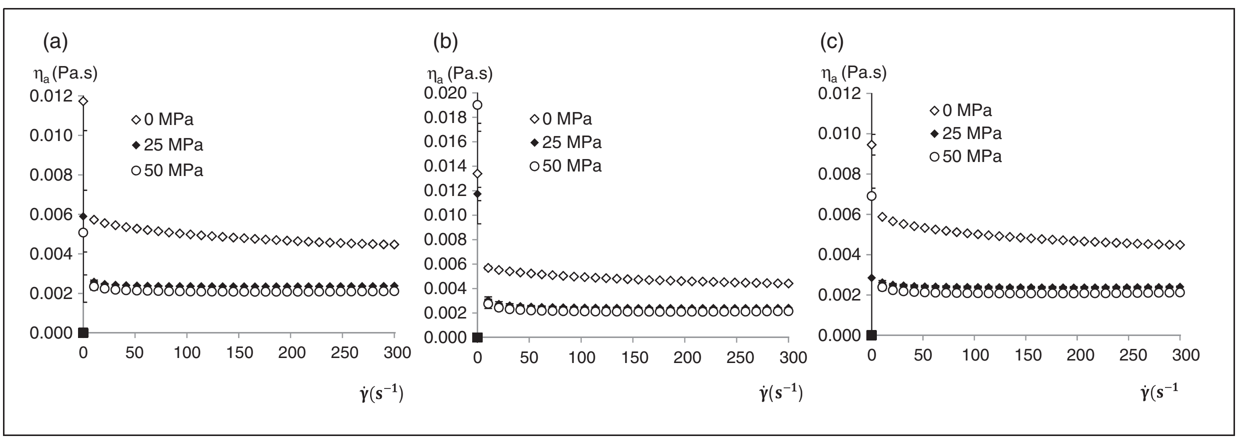

Figure 5. Apparent viscosity at 25 °C in model systems of guar gum with (a) citric acid, (b) malic acid, and (c) tartaric acid (c) (the points are the mean values, and the vertical bars are standard deviation).

the assessors. Also, the different organic acids used did not affect the sensory perception of the samples. In the food area, the correlation between rheological and sensory data is critical to determining the functionality of an ingredient in product development; for applications in projects; and evaluations of processes, quality control, and shelf-life testing (Holdsworth, 1993; Tabilo-Munizaga and Barbosa-Cánovas, 2005).

The Ostwald–de Waele model (Power Law) is used to describe the flow behavior of guar gum model systems with organic acids. Model systems were characterized as non-Newtonian fluids with pseudoplastic characteristics, with no residual stress. In Table 3, the effect of P_H on the parameters of the Ostwald–de Waele model can be observed for the analyzed model systems. The Ostwald–de Waele model has been widely used to describe the rheological behavior in juices and nectars (Faraoni et al., 2013; Leite et al., 2014).

It can be observed that the consistency index (k) had a slight reduction with the increase of pressure, and the flow behavior index (n) had a slight increase with the homogenization process. For the consistency index parameter, values ranging from 0.008 to 0.002 Pas^n were obtained, and for the flow behavior index, results ranged from 0.897 to 1.000 (Table 3). Values of the flow behavior index (n) equal to 1 show that the flow alignment effect was practically null in the samples processed. It was also observed that there was a reduction in the pseudoplastic characteristics of the homogenized model systems; thus, these samples presented a behavior close to the Newtonian. A general trend can be considered, as the different organic acids used did not interfere in the rheological behavior of the flow, since the guar gum model systems showed statistically equal values of the consistency index ($p < 0.05$); similarly, the flow behavior values were similar. Research on different polysaccharides (Floury et al., 2002; Lagoueyte and Paquin, 1998) also showed that with the increase of homogenization pressure there was a reduction in the consistency index (k) and an increase in the flow behavior index (n).

Table 3. Effect of homogenization pressure (P_H) on flow properties in guar gum model systems: Parameters of the Ostwald–de Waele model at 25 °C

P_H (MPa)	Citric acid			Malic acid			Tartaric acid		
	k (Pa s^n)	n (–)	R^2	k (Pa s^n)	n (–)	R^2	k (Pa s^n)	n (–)	R^2
0	0.008 ± 0.0001	0.900 ± 0.003	0.989	0.007 ± 0.0002	0.899 ± 0.002	0.977	0.008 ± 0.0001	0.897 ± 0.001	0.987
25	0.002 ± 0.0000	1.000 ± 0.000	0.994	0.003 ± 0.0002	0.986 ± 0.015	0.988	0.002 ± 0.0001	0.999 ± 0.002	0.993
50	0.002 ± 0.0001	1.000 ± 0.000	0.992	0.002 ± 0.0004	0.990 ± 0.018	0.990	0.002 ± 0.0001	1.000 ± 0.000	0.989

The processing using high pressure homogenizer has been much studied in different food matrices, among them fruit juices (Calligaris et al., 2012; Leite et al., 2014; Tribst et al., 2011; Zhou et al., 2017), dairy beverages (Martínez-Monteagudo et al., 2017), dietary supplements (Martínez-Sánchez et al., 2016), as well as in different polysaccharides (Harte and Venegas, 2010; Villay et al., 2012; Wang et al., 2011). Hence, the knowledge of rheological behavior is fundamental for the development of new products, not only as a quality measure, but also in the design, evaluation, and operation of food processing equipment such as pumps, agitation systems, and pipes (Ibarz et al., 1996).

CONCLUSIONS

The processing of guar gum model systems in a high pressure homogenizer is a viable alternative for application in fruit nectar. Through the sensorial time–intensity analysis and the rheological behavior we can indicate new perspectives on the intensity of tastes and viscosity. Therefore, the viscosity in the control and homogenized samples presented similar temporal profiles, and the tartaric acid model systems showed higher maximum intensity for the acid taste, presenting potential of application for nectars with characteristics of acid taste more intense and prolonged.

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APPENDIX

Notation

k	consistency index, Ostwald–de Waele model (equation (1)) (Pa s^n)
n	flow behavior index, Ostwald–de Waele model (equation (1)) (–)
$\dot{\gamma}$	shear rate (s^{-1})
η_a	apparent viscosity ($=\sigma/\gamma$) (Pa s)
σ	shear stress (Pa)