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Research Article

Incorporation of Hydrocolloids and Aloe Vera Gel on Tree Tomato Beverages (*Cyphomandrabetacea*S.). Part I: RheologicalProperties

[1]Figueroa Flórez Jorge, [2]Ciro Velásquez Héctor and[2]Márquez Cardozo Carlos
[1]Facultad de Ciencias, Universidad Nacional de Colombia,
[2]Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Medellín, Colombia

Abstract: The aim of this study was to evaluate the effect of the addition of Xanthan Gum (XG), Carboxymethylcellulose (CMC) and aloe vera (*Aloe barbadensis* Miller) on the rheological properties of tree tomato beverages (*Cyphomandrabetacea* Sendt). The results were adjusted to different rheological models and the Arrhenius equation was used to study the dependence of rheological parameters on temperature. The rheological results indicate a pseudoplastic behavior with an excellent fit to the power law model. The weak gel-like characteristic responsewas observed in Tree Tomato Beverages (TTB), because of the predominance of the elastic modulus (G") over the viscous modulus (G"). The viscoelastic parameters did not showa linear relationship with temperature based on the Arrhenius equation. Treatments with concentrations of GX and CMC higher than 0.5% w/w were considered as the best formulations associated with increasing the viscosity of the continuous phase, more likely to be pseudoplastic and have low tangent values (tan $\delta < 0.5$). Thesecharacteristics are considered good indicators of the steric stability of suspensions.

Keywords: Juice, shear thinning, stability, suspensions, viscoelasticity

INTRODUCTION

Tree tomato (*Cyphomandrabetacea* Sendt) is considered an exotic fruit with unique nutritional properties (Meza and Méndez, 2009). Aloe vera gel (*Aloe barbadensis* Miller) has excellent functional properties and incorporation into food can increase its nutritional value (Lad and Murthy, 2013). However, both the pulp and aloe gel containsa lot of insoluble polymer particles, which affect the rheological behavior and physical stability mechanisms of the suspensions during storage and processing (Genovese and Lozano, 2006).

Consumers perceive physical instability in beverages as an indication of poor quality, which can be prevented by applying food hydrocolloids (Genovese and Lozano, 2006). Hydrocolloids are hydrophilic polymers used in food systems because they can modify the rheological properties, increase the viscosity, form gel-like structures, stabilize particles in the suspension, etc. (Saha and Bhattacharya, 2006). Several studies have examined the effect of hydrocolloids such as xanthan gum and carboxymethylcellulose on the stability, rheological behavior and sensory properties of fruit juice (Liang *et al*., 2006; Ibrahim *et al*., 2011; Abbasi and Mohammadi, 2013).

Rheological characterization in foods is necessary for quality assessment and process engineering applications (Dak *et al*., 2006). The flow behavior was assessed by estimating the parameters from rheological models. The power-law model is the most used model to describe the rheology of fruit juices, particularly in handling operations because it is convenient, simple and easy to use (Gratão *et al*., 2007; Ahmed *et al*., 2007; Quek *et al*., 2013). However, many rheological phenomena can-not be only described according to rotational tests and it is necessary to evaluate the viscoelastic behavior using dynamic oscillatory tests, which are made without altering the internal structure of the materials (Ahmed *et al*., 2007). These properties are used to assess and predict the stability of the suspensions during the processing, storage and consumption steps (Augusto *et al*., 2013a).

Studies highlight an increase in apparent viscosity, shear thinning behavior and an excellent fit to the power-law model in fruit juices. Also, a linear relationship coefficient consistency and viscosity with temperature were described from Arrhenius equation (Dak *et al*., 2006; Cabral *et al*., 2007; Chin *et al*., 2009; Vandresen *et al*., 2009). Abbasi and Mohammadi (2013) noted in orange juice the predominance of the elastic modulus (G') over the viscous modulus (G") and

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Corresponding Author: Figueroa Flórez Jorge, Facultad de Ciencias, Universidad Nacional de Colombia, Medellín, Colombia

loss tangent less than unity (tan δ<1.0) at high frequencies. They cited the steric stability because of the inclusion of hydrocolloids. Mezger (2006) noted that the pseudoplastic character suspensions with the predominance of G'>G" were thermodynamically stable because they had a weak gel-like structure. Therefore, the objectives of this study are to evaluate the effect of the addition of hydrocolloids and aloe vera on the rheological behavior of Tree Tomato Beverages (TTB) and correlate their incorporation into the degree of stability of the suspension.

MATERIALS AND METHODS

Materials: Fruits of tree tomato (*Cyphomandrabetacea*) of the Sendt variety were used as the raw material. Additionally, sucrose as a sweetener, stabilizers such as xanthan gum, carboxymethylcellulose and aloe vera gel with 98% purity and food grade preservatives were used. These additives were supplied by the company Bell Chem International S.A. (Medellín, Colombia).

Beverages' formulation (TTB): The formulationwas based on the Colombian Technical Standard (NTC, 1999) (NTC 3549/1999), which states that TTB must have a minimum pulp content of 18% and a concentration of Total Soluble Solids (TSS) of 10°Brix. The respective concentration of hydrocolloids and aloe verawas incorporated before preparation in a water suspension at 40°C. A mixture of 0.125% w/w preservatives were addedto a 50/50 ratio (potassium sorbate/sodium benzoate). TTB was homogenized in a disperser (Ultra Turrax, IKA T25, Germany) for 60 s at 5000 rpm and subjected to a slight pasteurization process for one 1 min at 60°C.

Rotational rheological test: The flow curves were determined in a viscometer (Brookfield, DV-III Ultra, USA) using a concentric cylinder geometry of diameter 2.5 mm. The temperature of the suspension was varied from 10 to 50°C using a circulating heating/cooling bath For eliminate possible thixotropy, strains sweeps between 0 to 200s^{-1} in the following order was performed: upward, downwardly and upward (Chin *et al*., 2009). The obtained curve from the last process was used as a reference to study the rheological behavior of TTB. The experiments were performed in triplicate and the results were adjusted to the following rheological models: Newton's law Eq. (1), Power Law Eq. (2), Herschel-Bulkley Eq. (3) and Casson Eq. (4):

$$\sigma = K\dot{\gamma} \tag{1}$$

$$\sigma = K\dot{\gamma}^{n} \tag{2}$$

$$\sigma = \sigma_0 + K(\dot{\gamma}^{n}) \tag{3}$$

$$\sigma^{0.5} = (\sigma_o)^{0.5} + K(\dot{\gamma}^{0.5}) \tag{4}$$

where,

$\dot{\gamma}$ = Strain rate
n = The flow index (dimensionless)
K = The consistency coefficient (Pa.s^{n})
σ = The shear stress (Pa)
σ_0 = The yield stress (Pa)

The effect of temperature was analyzed based on the consistency coefficient K and flow index n using Arrhenius equation Eq. (5) and (6):

$$K = K_o e^{\left(E_a/_{RT}\right)} \tag{5}$$

$$n = n_o e^{\left(E_a/_{RT}\right)} \tag{6}$$

Arrhenius equation was linearized to obtain the values of K_0 (Pa.s^{n}) and activation energy E_a (J/mol). In these equations, R is the universal gas constant (8.314 J/K mol) and T is the temperature (K).

Oscillatory rheological tests: The viscoelastic behavior was determined in a rheometer (Anton Paar, MCR 302, Austria) using a parallel plate geometry with a diameter of 25 mm and a space between plates of 1.0 mm (Augusto *et al.*, 2013b). Initially, an amplitude sweep was performed at a strain of 0.1-100% and frequency of 1.0 Hz to determine the Region of Linear Viscoelastic (RLV). Then, a frequency sweep from 0.01 to 10 Hz was performed with a constant shear stress of 0.5 Pa. The storage modulus (G'), loss modulus (G'') and loss tangent (tan δ) were directly obtained from the Rheocompass software (Version 1.12, Austria). The behavior of the variablesabove was studied as a function of the temperature from 10 to 50°C, where all analyses were performed in triplicate. Tan (δ) was evaluated at an oscillating frequency (ω) of 0.1 Hz to study the effect of the addition of hydrocolloids on the viscoelastic behavior and stability of beverages (Kuentz and Röthlisberger, 2003). The oscillatory modules were adjusted according to the frequency using the power law Eq. (7) and (8):

$$G' = K'(\omega)^{n'} \tag{7}$$

$$G'' = K''(\omega)^{n''} \tag{8}$$

where, K', K'', n' and n'' are the regression coefficients that relate the elastic and viscous moduli.

Experimental design: The rheological behavior of different formulations was studied using a regression analysis and the quality adjustment was established based on the coefficient of determination (R^2) and Mean Square Error (MSE).

A composite central rotational design was established with axial points and four replicates at the

Table 1: Experimental design

Treatments	Aloe vera (%)	GX (%)	CMC (%)	Aloe vera (X_1)	GX (X_2)	CMC (X_3)
T1	1.0	0.050	0.092	1.68	0	0
T2	1.0	0.008	0.050	0	0	-1.68
T3	0.16	0.050	0.050	0	-1.68	0
T4	0.5	0.075	0.075	1	-1	1
T5	1.5	0.025	0.075	1	1	-1
T6	1.0	0.050	0.050	0	0	0
T7	1.5	0.075	0.025	-1	1	1
T8	1.0	0.050	0.050	0	0	0
T9	1.5	0.025	0.025	-1	1	-1
T10	1.0	0.050	0.008	-1.68	0	0
T11	1.0	0.092	0.050	0	0	1.68
T12	1.84	0.050	0.050	0	1.68	0
T13	1.0	0.050	0.050	0	0	0
T14	1.0	0.050	0.050	0	0	0
T15	0.5	0.025	0.075	1	-1	-1
T16	1.5	0.075	0.075	1	1	1
T17	0.5	0.025	0.025	-1	-1	-1
T18	0.5	0.075	0.025	-1	-1	1
Control	-	-	-	-	-	-

* T17 (Minimum Point); T6, T8, T13, T14 (Central Points); T16 (Maximum Point)

center point. The established factors and levels in the study are defined in Table 1. The experimental data were statistically analyzed with a significance level of 5% with the response surface analysis, analysis of variance, lack of fit test and determination of regression coefficients using the Statgraphics Centurion XVI software (Version 16.1.18, USA). The experimental data were adjusted with the second-order model Eq. (9):

$$Y = \beta_O + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X^2{}_i + \sum \sum_{i<j=1}^{3} \beta_{ij} X_i X_j \quad (9)$$

where, β_O, β_i, β_j and β_{ij} are the regression coefficients for the intercept, linear and quadratic interaction terms, respectively and X is an independent variable.

RESULTS AND DISCUSSION

Rotational rheology: The rheological data of the TTB were adjusted to 4 rheological models: Newton, Power Law, Herschel-Bulkley and Casson. The models were statistically significant ($p<0.05$) with $R^2>0.90$. In the Herschel-Bulkley model, negative values for yield stress (σ_0) were estimated with no physical explanation (Gratão *et al*., 2007). The power-law model has the best goodness of fit with $R^2>0.99$ and notably low Mean Squared Error (MSE). Some studies have explained the flow behavior in fruit juices using the power-law model (Cabral *et al*., 2007; Chin *et al*., 2009; Quek *et al*., 2013).

A decrease in consistency coefficient (K) was observed with the increase in temperature, which indicates a reduction in viscosity (Table 2). This characteristic can be explained because the cohesive forces and momentum transfer in suspensions can diminish with increasing temperature and decrease the flow resistance (Quek *et al*., 2013). Similar behavior was reported in fruit juice (Ahmed *et al*., 2007; Vandresen *et al*., 2009). An important increase in K was observed in the TTB that was formulated with hydrocolloids concerning to the control, where the apparent viscosity increased. Some authors state that the addition of XG and CMC increased the viscosity of the continuous phase in vegetables such as carrot and apple juice, which improved the stability of the particles in the dispersion (Liang *et al*., 2006; Ibrahim *et al*., 2011). The consistency coefficient varied from 0.019 to 0.326 Pa.s^n. Similar results have been reported in fruit juices (Chin *et al*., 2009; Fasolin and da Cunha, 2012).

The flow behavior index was below unity ($n<1$) which indicate the pseudoplastic behavior of TTB (Table 3). A decrease in index values (n)was observed in the TTB formulated with hydrocolloids, concerning the control. The tendency towards pseudoplasticity occurred because to the incorporation of XG and CMC into the suspension. Saha and Bhattacharya (2006)

Table 2: Consistency coefficient K (Pa.s^n) estimated from the power law model adjusted to Arrhenius model

	Temperature (°C)					Arrhenius Parameters		
Treatments	10	20	30	40	50	K_o (Pa.s^n)	E_a (kJ/mol)	R^2
T1	0.138	0.097	0.084	0.092	0.071	1.29×10^{-3}	10.82	0.942
T2	0.073	0.051	0.044	0.053	0.035	2.83×10^{-4}	12.87	0.929
T3	0.111	0.092	0.072	0.086	0.065	2.46×10^{-3}	8.91	0.903
T4	0.326	0.233	0.179	0.146	0.115	8.37×10^{-5}	10.38	0.996
T5	0.084	0.063	0.044	0.046	0.039	1.78×10^{-4}	10.32	0.932
T6	0.149	0.127	0.090	0.095	0.075	6.15×10^{-4}	14.56	0.949
T7	0.163	0.148	0.183	0.109	0.078	6.15×10^{-2}	16.27	0.933
T8	0.146	0.124	0.088	0.093	0.074	6.93×10^{-3}	12.54	0.917
T9	0.093	0.069	0.073	0.048	0.040	1.31×10^{-4}	16.46	0.906
T10	0.100	0.082	0.069	0.067	0.046	3.46×10^{-4}	15.36	0.927
T11	0.271	0.232	0.183	0.185	0.162	9.49×10^{-2}	11.58	0.930
T12	0.178	0.136	0.099	0.108	0.087	7.54×10^{-4}	12.69	0.956
T13	0.150	0.129	0.092	0.098	0.077	7.89×10^{-4}	14.32	0.911
T14	0.106	0.115	0.090	0.095	0.074	2.94×10^{-2}	14.60	0.918
T15	0.175	0.122	0.084	0.068	0.052	1.64×10^{-5}	9.93	0.994
T16	0.326	0.244	0.177	0.164	0.131	2.36×10^{-2}	16.92	0.975
T17	0.131	0.090	0.065	0.065	0.053	1.18×10^{-4}	16.28	0.926
T18	0.226	0.177	0.147	0.119	0.106	4.51×10^{-4}	14.58	0.994
Control	0.063	0.035	0.032	0.037	0.019	1.02×10^{-6}	20.33	0.949

Table 3: Flow behavior index (*n*) estimated from the power law model adjusted to Arrhenius model

	Temperature (°C)					Arrhenius Parameters		
Treatments	10	20	30	40	50	n_o	E_a (kJ/mol)	R^2
T1	0.639	0.659	0.632	0.584	0.615	0.242	2.44	0.472
T2	0.703	0.724	0.690	0.625	0.675	0.160	0.63	0.428
T3	0.645	0.638	0.629	0.576	0.610	0.422	0.01	0.569
T4	0.566	0.561	0.561	0.568	0.573	0.416	0.21	0.448
T5	0.710	0.687	0.697	0.642	0.637	0.282	2.18	0.817
T6	0.634	0.625	0.624	0.584	0.612	0.486	0.65	0.479
T7	0.615	0.575	0.501	0.550	0.577	0.444	0.68	0.249
T8	0.634	0.626	0.623	0.586	0.609	0.380	0.65	0.561
T9	0.687	0.658	0.595	0.626	0.628	0.307	2.87	0.474
T10	0.664	0.625	0.614	0.601	0.631	0.300	1.83	0.388
T11	0.549	0.548	0.546	0.522	0.535	0.441	0.52	0.558
T12	0.618	0.623	0.622	0.578	0.602	0.428	0.94	0.399
T13	0.637	0.625	0.622	0.583	0.611	0.474	0.68	0.530
T14	0.605	0.626	0.621	0.583	0.613	0.489	0.61	0.476
T15	0.653	0.660	0.664	0.664	0.677	0.287	0.62	0.875
T16	0.565	0.569	0.564	0.560	0.567	0.488	0.37	0.562
T17	0.643	0.648	0.647	0.613	0.620	0.401	1.16	0.594
T18	0.581	0.572	0.555	0.563	0.550	0.387	0.95	0.812
Control	0.713	0.728	0.677	0.722	0.704	0.143	3.92	0.393

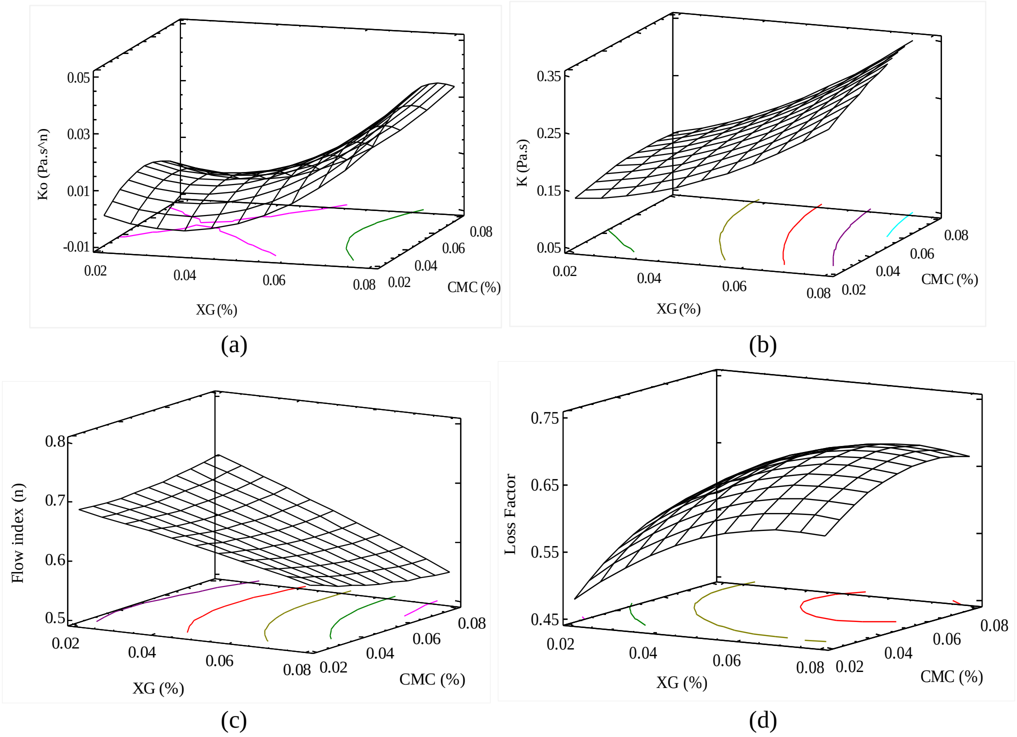
mentioned that hydrocolloids exhibited a pseudoplastic behavior because of the decrease in viscosity at high shear rates. Abbasi and Mohammadi (2013) also reported similar behavior in orange juice that was stabilized with Persian gum. The index *n* oscillated from 0.522 to 0.728. Similar values were reported for cherry and guava juice with a solids concentration of 20°Brix (Cabral *et al*., 2007; Quek *et al*.,2013).

The Arrhenius relationship was used to describe the effect of temperature on the consistency coefficient (Table 2). This model was statistically significant ($p<0.05$) with $R^2>0.90$ in the estimation of frequency factor K0 and activation energy E_a. The factor K_0changed from 1.02×10^{-6} to 9.49×10^{-2}, which were close to the reported values of Quek *et al*. (2013) for soursop juice in a temperature range of 10-50°C. Goula and Adamopoulos (2011), estimated similar values in kiwi juice with a TSS concentration of 15-30°Brix in a temperature range of 25-65°C. Nevertheless, Table 3 confirms that index n does not present a linear behavior with the temperature ($p>0.05$ and $R^2<0.80$). Similar results were reported in mango juices for a temperature range of 20-70°C (Dak *et al*., 2006).

Additionally, the concentrations of hydrocolloids and aloe vera were not statistically significant on the value E_a ($p>0.05$). E_a is known as the threshold energy that must be overcome for the elemental flow process (Quek *et al*., 2013). The estimated value of E_a from the consistency coefficient in TTB oscillated between 8.91 and 20.33 kJ/mol (Table 2). These results are below the estimatedvalues in grapefruit and soursop concentrates juice (Chin *et al*., 2009; Quek *et al*., 2013) with a TSS content of 20°Brix. These differences may be explained by the SST concentration and temperature ranges in each study. Nevertheless, a decrease in E_a was detected in the TTB that was formulated with hydrocolloids concerning the control. These decreases may be because of the incorporation of XG and CMC, which acquire a pseudo plastic behavior in the suspension. Krokida *et al*. (2001) argue that the value of E_a increases in suspensions where the flow behavior approaches the Newtonian behavior as simulated in the control TTB.

Several rheological parameters were analyzed because of the importance of evaluating the stability of the beverages. The XG concentration significantly affected the variation of factor K_0 (Fig. 1a). Moreover, it was estimated that the XG concentration affectedconsiderably ($p<0.05$) the rheological parameters *K* and *n* at 10°C, where the consistency and pseudoplasticity tend to increase. This behavior may be attributed to the increase in hydrocolloid concentration (Fig. 1b and 1c). García-Ochoa *et al*. (2000) define that the XG is a high-molecular-weight polymer that can increase the viscosity and decrease the rate of flow of suspended particles. Similar results have been reported in passion fruit pulp that was stabilized with XG (Moraes *et al*., 2011). This behavior coincides with Stokes law, where the phenomenon of particle sedimentation is inversely proportional to the increase in viscosity in the continuous phase, which favors the stability of the suspension (Genovese and Lozano, 2001). Also, studies highlight increase in viscosity of the continuous phase, control of sedimentation process and greater stability in fruit juices because of the XG incorporation (Genovese and Lozano, 2001, Liang *et al*., 2006, Ibrahim *et al*., 2011).

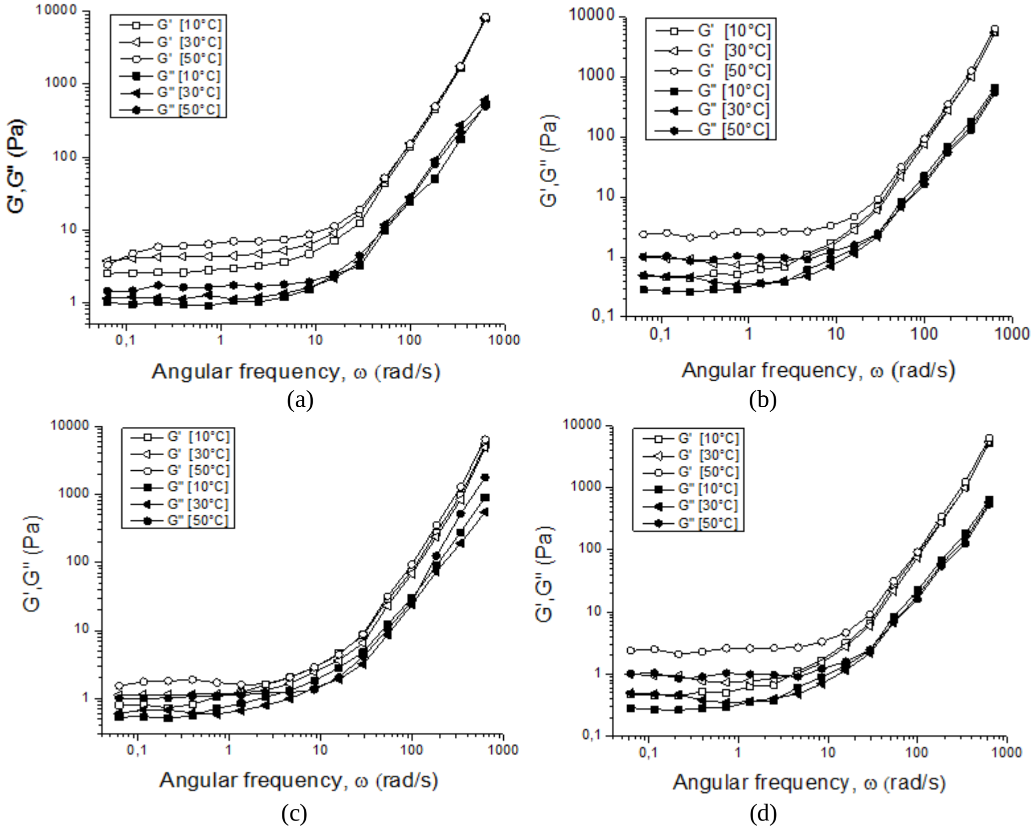
Oscillatory rheology: A predominance of $G'>G''$ is observed, which indicates that the elastic forces were dominant over the viscous effects and the TTB can be defined as a weak gel (Fig. 2a to 2d). This behavior is present in most suspensions as a particular network structure in vegetables and fruit-derived products (Augusto *et al*., 2013b). Similar results were reported for passion fruit and tomato juices that were stabilized



(a) (b)

(c) (d)

Fig. 1: Response surfaces; a): Frequency factor, K_0; b): Consistency coefficient (*K*)to10°C; c): Flow index (*n)* to10°C; d): Loss factor(tan δ) to 10°C y 0.1 Hz. The surfaces were designed to a concentration of 1.0% aloe vera



(a) (b)

(c) (d)

Fig. 2: Viscoelastic behavior at tree tomato beverages to various temperatures; (a): Control; (b): T17- minimun; (c): T6-central; (d): T16-maximum

Table 4: Viscoelastic parameters in tree tomato beverages estimated according to the power law model

		Temperature (°C)						
Parameters	Treatments	10	20	30	40	50	R^2	MSE
K'	Control	0.029	0.036	0.039	0.021	0.075	0.997	0.921
	T17-Minimun	0.011	0.006	0.008	0.013	0.027	0.998	0.985
	T6-Central	0.035	0.034	0.033	0.026	0.046	0.997	1.345
	T16-Maximun	0.043	0.014	0.019	0.013	0.027	0.998	1.159
K''	Control	0.029	0.009	0.032	0.011	0.050	0.999	1.376
	T17-Minimun	0.012	0.006	0.010	0.017	0.032	0.998	1.275
	T6-Central	0.036	0.042	0.053	0.014	0.028	0.999	0.731
	T16-Maximun	0.049	0.017	0.016	0.009	0.010	0.997	0.582
n'	Control	1.831	1.809	1.795	1.546	1.652	0.997	0.921
	T17-Minimun	1.942	2.084	1.983	1.945	1.762	0.998	0.985
	T6-Central	1.710	1.719	1.718	1.78	1.577	0.997	1.345
	T16-Maximun	1.620	1.875	1.769	1.942	1.771	0.998	1.159
n''	Control	1.461	1.769	1.468	1.762	1.357	0.999	1.376
	T17-Minimun	1.636	1.784	1.623	1.564	1.351	0.998	1.275
	T6-Central	1.466	1.429	1.287	1.641	1.485	0.999	0.731
	T16-Maximun	1.391	1.629	1.589	1.659	1.709	0.997	0.582

with XG and soy protein, respectively (Moraes *et al.*, 2011; Tiziani and Vodovotz, 2005).

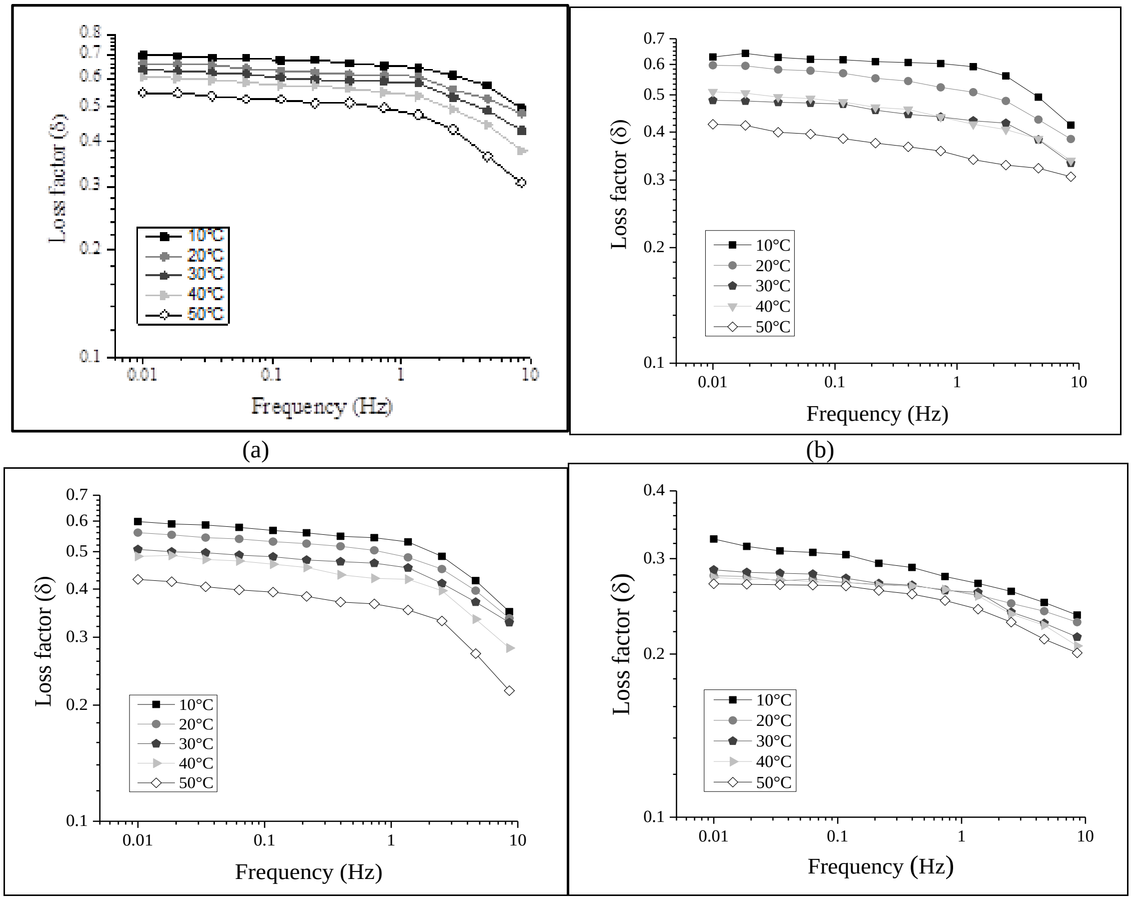
The modules G' and G'' slightly decreases with increasing temperature at high frequencies (>10 rad/s). However, at low frequencies (<10 rad/s), the behavior of the modules has a statistically significant decrease ($p<0.05$) with the temperature (Fig. 2a to 2d). This result may be related to the energy storage or loss mechanism in different frequency ranges. Chaikham and Apichartrangkoon (2012) argued that the energy storage at high frequencies was reversible and marked by the elastic stretching of the molecular chains. However, the mode of energy storage and loss depends on the translational motion of the molecules at low frequencies, which is considered a measure of the temperature. The decrease of G' and G'' with temperature is predominant in fruit products such as tomato juice in a temperature range of 0-50°C (Sharoba *et al.*, 2006). This behavior was reported for passion fruit pulp that was stabilized with guar gum and XG (Moraes *et al.*, 2011). The parameters K', K'', n' and n'' were fitted to evaluate the effect of temperature on the viscoelastic behavior of TTB to the Arrhenius equation. The estimated models were not significant ($p>0.05$) and the determination coefficients were relatively low ($R^2<0.70$). In other words, there is no linear relationship between the modules G' and G'' with temperature. Similar results were reported for tomato juice (Tiziani and Vodovotz, 2005).

The values of K' and K'' oscillated between 0.006-0.086 $Pa.s^{n'}$and0.009-0.063 $Pa.s^{n''}$, respectively (Table 4). These values are lower than those reported by Augusto *et al.* (2013b) for tomato juice possibly because of the concentration of solids in the product. The values of n' and n'' oscillated between 1.55-2.12 and 1.35-1.94, respectively. These values coincide with those reported for tomato juices that were treated at high pressures (Augusto *et al.*, 2013b). The rheological behavior of all beverages was described to be similar to weak gels because the magnitudes of $G'>G''$ and the values of n' and n'' were low but not zero. Similar results were reported by Moelants *et al.* (2013) or carrot suspensions. Sharoba *et al.* (2006) estimate positive values for n' and n'' and declared the physical system of tomato juices and weak gel-like pastes.

Moreover, it was inferred that the elastic component is more dependent on the frequency than the viscous element because of $n'>n''$ (Falguera and Ibarz, 2014). This behavior was observed when TTB were subjected to high frequencies (> 10rad/s). The effect of the frequency and the domain $G'>G''$ is proved to be typical in the suspension rheology of fruit juices and other vegetable-derived products (Ahmed *et al.*, 2007; Falguera and Ibarz, 2014). If the frequency increases, the period of the applied strain decreases and the time for structural rearrangement of the sample is too short. Therefore, the elastic deformations in the structure become more significant than the viscous properties (Ahmed *et al.*, 2007).

Figure 3a to 3d show the behavior of the loss tangent or factor ($\tan \delta$) as a function of the frequency. The loss factor is less than unity ($\tan \delta<1.0$), which confirms the viscoelastic gel-like behavior of TTB (Rao, 2006). A similar tendency in the variation of tan (δ) was found in orange juice and passion fruit pulp that was stabilized with Persian gum and XG, respectively (Moraes *et al.*, 2011; Abbasi and Mohammadi, 2013). The authors argue that the decrease in loss factor at high frequencies confirms the predominance of the elastic component associated with the incorporation of polymer substances as hydrocolloids, which behave like real gels in a suspension.

The loss factor significantly decreased with increase in temperature ($p<0.05$). However, a linear relationship was not found from Arrhenius equation. Similar results have been reported in tomato juices and paste (Sharoba *et al.*, 2006). Tiziani and Vodovotz (2005) also describe the variation of viscoelastic parameters in food dispersions because of thermal effects. They argued that the temperature could affect



(a)

(b)

(c)

(d)

Fig. 3: Temperature dependence of loss tangent Tan (δ) in tree tomato beverages; a): Control; b): T17-minimum; c): T6-central; d): T16-maximum

Table 5: Regression parameters for consistency coefficient (*K*), consistency factor (K_o), flow index (*n*) and loss tangent (*δ*) 0,1 Hz

Coefficients regression	K_o (Pa.s^n)	*K* (Pa.s^n), (10°C)	*n*, (10°C)	tan (*δ*), (10°C)
β_0	-0.01	0.26	0.64	0.43
β_1	0.02	-0.15	0.06	-0.19
β_2	-1.69	-3.82	0.24	1.77
β_3	1.36	-1.81	-0.05	8.72
β_{11}	0.84	0.66	NS	NS
β_{12}	-0.37	0.10	-0.22	3.80
β_{13}	NS	45.6	NS	-2.22
β_{22}	-0.02	0.05	NS	-47.21
β_{23}	19.39	34.92	-4.09	-11.20
β_{33}	NS	NS	10.33	-37.57
R^2	0.79	0.82	0.91	0.89
Model (p-value)	0.05	0.03	1	0.04
Lack of fit (p-value)	0.31	0.06	0.26	0.96

*NS: No significant coefficients

the physical system of fruit juices and cause slight damage to its structure. This phenomenon may be related to the weakening of the hydrophilic interactions between the hydrocolloids and the suspended particles of tomato pulp. Similarly, Lad and Murthy (2013) indicated that the temperature caused the reticulated structure to weaken and form the constituent polysaccharides of aloe vera gel, which altered the behavior of the viscoelastic modulus.

The behavior of the viscoelastic parameters *G'*, *G''* and tan (δ) was analyzed at a temperature of 10°C and frequency of 0.1 Hz to assess the physical stability of the TTB simulating storage conditions. The addition of hydrocolloids and aloe vera did not statistically significantly affect the behavior of viscoelastic modules ($p>0.05$) and maintained the tendency of *G'*>*G''*. However, the CMC and XG concentrations significantly affected the behavior of tan (δ) ($p<0.05$). The statistical model showed a value R^2 of 0.89; based on the goodness-of-fit test, it can be inferred that the model representsan excellent statistical estimate (Table 5).

Moreover, Falguera and Ibarz (2014) indicate that at low frequencies, the physical system of the suspension is simulated at low-deformation conditions, as occurs during storage and particle settling. The loss factor is considered an essential measure of the physical stability in dispersions. If tan (δ) <0.50, the suspensions are less susceptible to phase separation (Kuentz and

Röthlisberger, 2003). In addition, Mezger (2006) argued that the weak gel-like structure (tan $\delta<1.0$) was exhibited as a characteristic form of stability in food dispersions. A linear increase in hydrocolloids concentration with the loss factor, which conserves the weak gel-like structure in TTB, is observed in Fig. 1d. Similar results were reported in passion fruit juice that was treated with XG (Moraes*et al*., 2011). Thus, several authors state that hydrocolloids in suspension tend to form a highly ordered complex structure of aparticular rigid-molecules-shaped network of a weak gel, which contributes to the stability of suspended particles (Rao, 2006). This argument coincides with that of Meng and Rao (2005), who attributed the physical gel-like behavior in some food suspensions to the presence of polymeric substances. Chaikham and Apichartrangkoon (2012) found a predominance of the elastic component and highlighted the stabilizing effect of XG in phase separation for Dimocarpuslongan juice. Besides, Benchabane and Bekkour (2008) show that slightly concentrated suspensions with XG (<1.0%) might confer good stability because of their weak gel-like behavior. Moraes*et al*. (2011) argued that the hydrocolloids improved the texture and viscoelastic properties of suspensions, increasing the viscosity of the continuous phase and provide a gel-like structure, which favored the phase separation process control.

Thus, desirable rheological properties such as excellent consistency ($K>0.2$) and viscoelastic gel (tan $\delta<0.5$) at 10°C were perceived for the T11 and T16 treatments. Also, a pseudoplastic behavior ($n<1$) and a significant increase in viscosity of the continuous phase were observed at these concentrations. Meng and Rao (2005) found that the behavior shown by the aforementioned rheological parameters indicated the excellent physical stability in BTA that was associatedwith steric effects. Tiziani and Vodovotz (2005) argued that high water retention capacity and capacity to increase the viscosity of the continuous phase highlighted retention and ionization properties of hydrocolloids particles. A stronger gel-like structure was formed with stability in food suspensions. Moreover, XG can exercise better properties as a stabilizer than the CMC gum at lower concentrations. Saha and Bhattacharya (2006) highlight that despite its high cost, XG is the first choice because of its exceptional rheological properties. They assert that the ability the XG to infer higher viscosity at low shear rates ($<10s^{-1}$), increase viscoelastic properties and possess a smaller creep deformation explains its excellent stabilizing properties.

CONCLUSION

This study has demonstrated the significant effect of the addition of hydrocolloids on the rheological properties of Tree Tomato Beverages (TTB). The flow parameters and viscoelastic properties presented an excellent fit to the power-law model. The decrease of the flow index because of the incorporation of polymeric materials indicates the pseudo plastic behavior. The viscosity of the formulated beverages significantly decreased with temperature, where Arrhenius model was adjusted correctly to describe the effect of temperature on the consistency coefficient.

Dynamic oscillatory tests confirmed the weak gel-like behavior in TTB because the values of n' and n" were greater than unity and the elastic modulus is predominant over the viscous modulus ($G'>G''$). The increase in temperature did not show a linear trend of viscoelastic parameters based on Arrhenius principle. The variation of consistency coefficient K and loss tangent was significant with the addition of hydrocolloids. Based on the correlation of the rheological parameters K, n and tan (δ), it can be inferred that treatments with concentrations of GX and CMC higher than 0.5% w/w can confer colloidal stability and control the phenomenon of sedimentation and phase separation.

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CONFLICT OF INTEREST

There is no “Conflict of interest” of the authors, with the results of the investigation.

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