



Rheological characterization of *vinal* gum, a galactomannan extracted from *Prosopis ruscifolia* seeds



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ABSTRACT

Prosopis ruscifolia (or *vinal* tree) is an abundant plant from Argentina semiarid areas, whose seeds contain a galactomannan type interesting gum: *vinal* gum. The aim of this work was to analyze the rheological behavior of *vinal* gum suspensions and the consequences of its interactions with commercial gums widely employed in the food industry. *Vinal* gum aqueous suspensions were in good agreement with the Cox-Merz rule at concentrations lower or equal to 1% (w/w), which establishes an empirical relationship between complex and apparent viscosity. The flow curves of *vinal* gum could be defined only by two parameters -Newtonian viscosity (η_0) and strain rate ($\dot{\gamma}_{0.1}$) - and the shear-thinning behavior of *vinal* gum complied with the generalized curve for other polysaccharides. In mixtures with xanthan gum, *vinal* gum exhibited a synergistic relationship on its elastic behavior (at a total gum concentration of 1% (w/w)). On the other hand, *vinal* gum showed no synergism with κ -carrageenan or sodium alginate at the same total concentration of polymer. Apparent viscosity of *vinal* gum aqueous suspensions showed Arrhenius type dependence with temperature, as other galactomannans. The rheological behavior was not dependent on shear time, and the thickening power of *vinal* gum was slightly affected by pH and ionic strength changes. The present work provides detailed information on rheological characteristics of a non-traditional galactomannan extracted from an abundant and available source, being a starting point for possible applications of *vinal* gum as thickening and/or stabilizing agent in food, pharmaceutical, paper, textile, oil and cosmetics industries.

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1. Introduction

In recent years the incorporation of gums in various industrial applications, particularly in the oil, gas and textile industries, coupled with their sustained use in traditional industries (food, cosmetics and pharmaceuticals), has led to a growing demand and price increase, promoting the search for new unconventional sources. Seed endosperm of *Leguminosae* species is generally composed by polysaccharides that may be used in a range of industrial applications as dispersions stabilizers and thickening agents. Mesquite species, or *Prosopis* spp., grow all around the

world and many species had shown in their endosperm a galactomannan type gum (*Prosopis glandulosa* from Mexico, Martínez-Ávila et al., 2014; *Prosopis juliflora* from Brasil, Azero & Andrade, 2006; *Prosopis pallida* from Peru Chaires-Martínez, Salazar-Montoya, & Ramos-Ramírez, 2008; *Prosopis flexuosa* from Argentina, Ibañez & Ferrero, 2003; *Prosopis velutina* from Mexico, Saunders, Becker, Meyer, Valle, Marco, & Torres, 1986; *Prosopis Africana* from Senegal and Nigeria, Nwokocha & Williams, 2016; *Prosopis chilensis* from Chile, Estevez, Escobar, & Sepúlveda, 2012). In particular, *Prosopis ruscifolia* (or *vinal* tree) is an abundant plant from South America semiarid areas, that has industrial applications related with exploitation of its wood for construction and furniture as also to obtain charcoal; fruits are also appreciated to feed animals (Freyre et al., 2010). The sustainable use of the species represents an opportunity for the native populations and an alternative for the food industry (Cejas, Maldonado, & Ríos, 2008).

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Seeds contain a galactomannan interesting gum (*vinal* gum- VG-), with a mannose/galactose ratio of 1.6, and a viscosimetric molecular weight of $1.43 \pm 0.04 \cdot 10^6$ Da (Busch, Kolender, Santagapita, & Buera, 2015a).

Vinal gum suspensions showed shear-thinning and a macromolecular solution behavior when exposed to rotational and oscillatory assays and a coil overlap concentration (C^* - gum concentration which divides dilute with semidilute suspensions, the limit when polymer chains superpose to each other and interactions between them arise) of 0.14 g/dL (Busch et al., 2015a). However, some rheological parameters of *vinal* gum have not been studied yet. The rheological characteristics of these gums are fundamental since their implementation as thickener depends heavily on their ability to increase the viscosity at low concentration and on their response in different media conditions. The purpose of this work is to evaluate the rheology affecting *vinal* gum aqueous suspensions, in order to promote its applications as thickening and stabilizing agent. Time dependence of viscosity, Cox-Merz rule compliance, and ionic strength, temperature and pH dependences of *vinal* gum water suspensions flow curves were studied in order to know about their rheological performance. Besides, the elastic response and synergism evaluation of *vinal* gum with other hydrocolloids were also determined.

2. Materials and methods

2.1. Materials

Vinal gum (VG) was extracted from *Prosopis ruscifolia* seeds as reported by Busch et al. (2015a). The viscosimetric molecular weight of VG is $1.43 \pm 0.04 \cdot 10^6$ Da, the protein content of 19 ± 2 g kg^{-1} of dry gum, and its mannose/galactose (M/G) ratio is 1.6. Xanthan gum (viscosity of 1200–1600 mPa s and 92% purity), κ -carrageenan (1 sulfate for 2 sugar units, semi-refined) and sodium alginate ($M_w = 1.97 \cdot 10^5$ g/mol, with mannuronate/guluronate ratio = 0.6) from Cargill (Cargill S.A.C.I., San Isidro, Buenos Aires, Argentina).

2.2. Rheological measurements

Flow curves were evaluated by means of rotational trials in a controlled strain rheometer (AR-G2 TA Instruments, New Castle, USA) with a 40 mm diameter plate–plate geometry and 1 mm of gap space. Shear stress at different shear rates (0.005–1000 s^{-1}) was measured. All measurements were performed in duplicate using 1.5 mL of aqueous polymer suspensions in the range of 0.1–1.5% (w/w). For oscillatory tests, amplitude sweep with frequency control was performed to set the range of linear viscoelasticity for all hydrocolloids and concentrations analyzed. The elastic or storage module (G'), loss or viscous module (G''), and the complex viscosity $|\eta^*|$ were recorded in the range of frequencies from 0.01 to 100 Hz with a constant strain of 5%. For all the assays, the temperature was controlled with a peltier plate at 20.0 ± 0.1 °C (TA Instruments).

2.2.1. Thixotropy

Thixotropy of VG was evaluated according to the method proposed by Wei et al. (2015). A program of three stages was designed at 20 °C: i) increasing the shear rate from 0.05 to 100 s^{-1} ; ii) Holding the shear rate constant at 100 s^{-1} for 50 s, and iii) decreasing the shear rate from 100 s^{-1} to 0.05 s^{-1} . VG suspensions in the range of 0.5, 1.0 and 1.5% (w/w) were studied. A non-thixotropic material showed overlap between flow curves obtained by increasing and decreasing the shear rate; instead, a fluid with time-dependent rheological behavior shows hysteresis

between these two curves, and the area between them allows studying the degree of thixotropy.

2.2.2. Cox-Merz rule

Cox and Merz (1958) observed that for certain polymeric systems there is a correspondence between the tangential viscosity in a steady state or apparent viscosity (η_{ap}), plotted against shear rate ($\dot{\gamma}$) and between the magnitude of the complex viscosity $|\eta^*|$ plotted against the angular frequency (ω). VG suspensions of 1.5, 1 and 0.1% (w/w) were analyzed by oscillatory and rotational deformation as detailed above. Cox-Merz rule compliance is seen as the overlap of both curves ($\eta_{ap} = \eta^*$).

2.2.3. Generalized polysaccharides curve

The generalized model of polysaccharides proposed by Morris, Cutler, Ross-Murphy, Rees, and Price (1981) was evaluated by studying the logarithm of the apparent viscosity divided by the “zero shear” or “Newtonian” viscosity ($\text{Log}(\eta_{ap}/\eta_0)$) was plotted versus the logarithm of the shear rate divided the shear rate at which the apparent viscosity (η_{ap} was graphed ($\dot{\gamma}_{0.1}$) = 0.1 * η_0) is a tenth of Newtonian viscosity ($\text{Log}(\dot{\gamma}/\dot{\gamma}_{0.1})$).

2.2.4. Synergism between VG and other hydrocolloids

Suspensions of different hydrocolloids (VG, xanthan gum (XG), alginate and κ -carrageenan) 1% (w/w) were prepared according to their ease of hydration and solubilization: XG, VG and alginate were stirred at room temperature (25 °C) for 12 h (Busch et al., 2015a; Fennema, 1993); and κ -carrageenan was stirred at 60 °C for 2 h (Fennema, 1993). VG was mixed with the other hydrocolloids at different ratios (20:80, 40:60, 60:40 and 80:20) by mixing the adequate volume of each hydrocolloid suspension (1% w/w) and stirring 30 min. All stock suspensions and mixtures had a total polymer concentration of 1% (w/w). Mechanical spectra of each polymer and mixture suspensions, were measured by evaluating the elastic modulus at 1–100 rad s^{-1} . In order to better differentiate synergism, the linear contribution of each biopolymer elastic module (G'_A or G'_B) was subtracted to the elastic module of the mixture $G'(xA:yB)$ at 50 rad s^{-1} according to Equation (1).

$$G(xA : yB)_{\text{synerg}} = G(xA : yB)_{\text{exp}} - G'_A * x + G'_B * y \quad (1)$$

Where A and B are polymers, $G'(xA:yB)_{\text{synerg}}$ is the G' value for the different mass fractions x-y of A-B mixtures; $G'(xA:yB)_{\text{exp}}$ is the experimental measured value for the mixture, and G'_B and G'_A are the elastic modulus values for 100% suspensions of A and B respectively (each containing 1% (w/w)).

2.2.5. Effect of temperature, ionic strength and pH on flow curves from rotational assays

Flow curves at 5.0–20.0 - 45.0–60.0 ± 0.1 °C were evaluated in order to study how they were affected by temperature. All curves were fitted with Ostwald power law (Equation (2)). Arrhenius equation (Equation (3)) was used to study the temperature effect.

$$\tau = k \cdot \dot{\gamma}^n \quad (2)$$

Where τ is the shear stress, $\dot{\gamma}$ is the shear rate, k represents the consistency index and n is the flow index (n = 1 referred to Newtonian behavior, n < 1 to shear thinning and n > 1 to dilatant flows, respectively).

$$\ln(\eta_{ap}) = \ln B + m \cdot \frac{1}{T} \quad (3)$$

Where η_{ap} is the apparent viscosity at 10 s^{-1} , Ln B is the Y axe

intercept and m is the slope of the line.

The effect of electrolyte concentration was evaluated at two different concentrations of NaCl: 1 M, 0.1 M and without NaCl. The effect of pH on the flow curves of the VG was studied in the 1 M NaCl solutions by adjusting the pH at 4, 6.5 and 10 using a pHmeter Mettler Delta 320 (Mettler Toledo AG, Greifensee, Switzerland). The NaCl concentration to evaluate the effect of pH was selected to minimize the effects of changes in ionic strength. The temperature was controlled with a peltier plate, making the calibration and zero inertial space between plate and base (zero gap) for every temperature tested.

2.2.6. Statistical analysis

The experimental data were fitted by the corresponding equations, by minimizing the square differences. One-way analysis of variance (ANOVA) with Tukey post-hoc test using Prism v5 (GraphPad Software, Inc., San Diego, CA, USA) was used to analyze the differences between mean values for each model.

3. Results and discussion

3.1. Thixotropy

Figure 1 shows the dependence of the rheological properties of

the VG with the shear time at three different gum concentrations (between 0.5 and 1.5% (w/w)). In the case of thixotropy or time dependence, hysteresis would be observed between the curves obtained increasing and decreasing the shear rate after holding the shear rate at 100 s^{-1} for 50 s (Lee, Moturi, & Lee, 2009). VG showed no dependence of the viscosity with time at the three concentrations studied, since the increasing and decreasing shear rate curves overlapped perfectly. Mathur (2012) found that guar gum presented thixotropy only at concentrations greater than 1% (w/v), due to entanglements at high concentration of gum that are oriented and fluidized under shearing. Wei et al. (2015) found for the fenugreek gum (a galactomannan extracted from *Trigonella foenum-graecum*), thixotropy was negligible at concentrations lower than 1% (w/v). However, suspensions with higher concentration of fenugreek gum (up to 2% (w/v)) showed increased thixotropy as a function of concentration. Ibañez and Ferrero (2003) reported the absence of thixotropy for galactomannan gum extracted from *Prosopis flexuosa* ($M/G = 2.1$) at 2.6% (w/w), but they use a less purified gum with a higher protein content (in the range of 13–21% depending on the extraction procedure) than the above-mentioned galactomannan gum analyzed (1.9 and 2.1% for VG and guar gums, Busch et al., 2015a, p. 2.4% for fenugreek gum, (Brummer, Cui, & Wang, 2003). Changes in rheological behavior over time and particularly thixotropy are related to temporal modifications in the

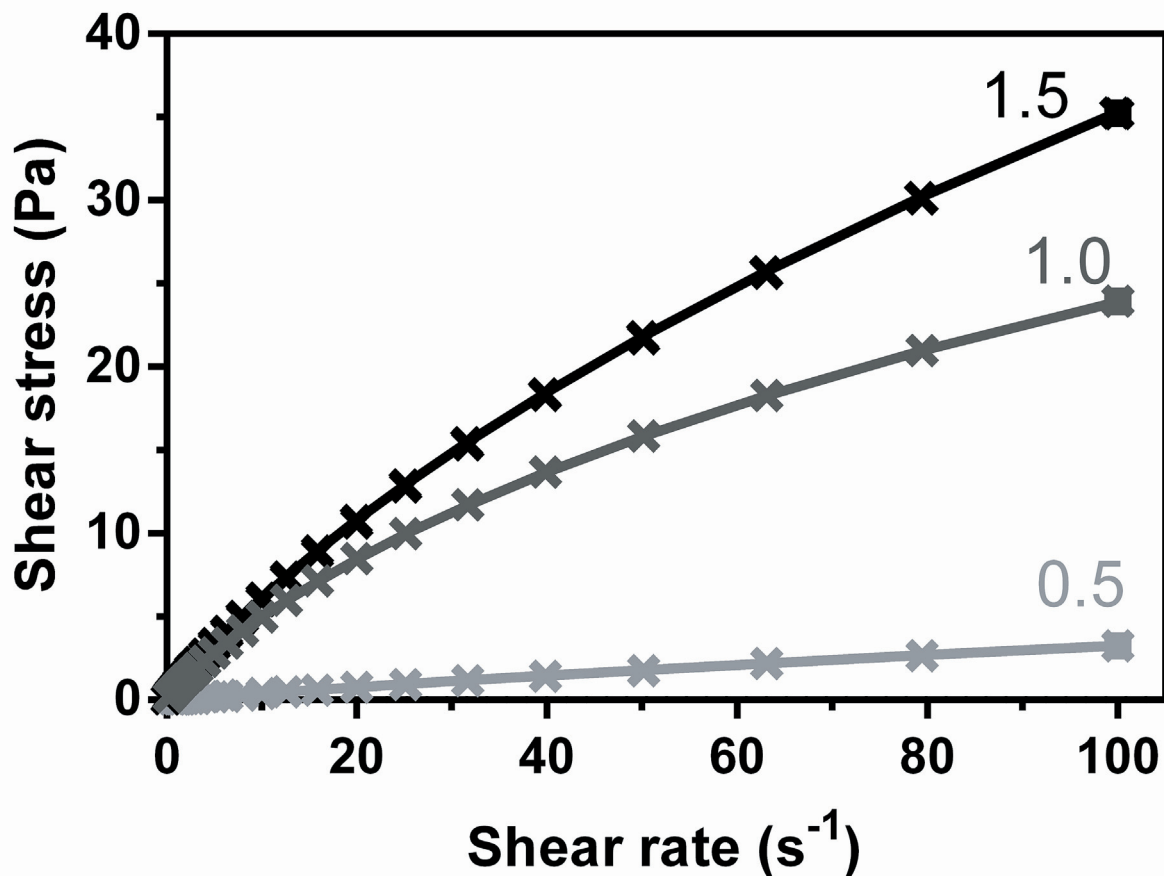


Fig. 1. Shear time dependence of vinal gum flow curves at 20°C . Stress as a function of shear rate for three different steps: increasing shear rate (symbols), constant shear rate for 50 s (squares, at 100 s^{-1}) and decreasing shear rate (lines). Three different concentrations of vinal gum aqueous suspension are shown: 1.5% (w/w) (black), 1.0% (w/w) (dark gray) and 0.5% (w/w) (light gray).

internal structure of the fluid. Interactions such as van der Waals forces are dynamically modified and may temporarily change the microscopic characteristics of the material, and consequently their flow conditions (Benchabane & Bekkour, 2008). The absence of thixotropy in VG suspensions implies a stable and constant polysaccharide structure towards shear, and without time modifications in the interactions in the polymer network, assuring the correct flowing of the suspension during industrial processing. It is important to note that this gum exhibited a rather high viscosity in water suspensions but showed no thixotropic behaviour.

3.2. Cox-Merz rule

Fig. 2 shows the complex viscosity (represented as the continuous lines in Fig. 2) and the apparent viscosity (represented by the symbols plotted in Fig. 2) as a function of angular frequency (ω) or shear rate ($\dot{\gamma}$) respectively, for three different concentrations of VG (0.5, 1.0 and 1.5% (w/w)). The rule established by Cox and Merz (1958) states that there is a correspondence between these two viscosities. As seen in Fig. 2, Cox-Merz rule is satisfied by VG suspensions at concentrations of 0.5 and 1% (w/w). However, a slight divergence can be observed at the higher concentration of VG studied (1.5% (w/w)), since the apparent viscosity values lay slightly above the complex viscosity curve Azero and Andrade (2006) reported a compliance of the Cox-Merz rule for other galactomannan

gums (GG and *Prosopis juliflora* gum), although they analyzed them at a lower concentration range (0.05–0.1% (w/v)). Rincón, Muñoz, Ramírez, Galán, and Alfaro (2014) found that for *Prosopis juliflora* gum (0.6–1.4% (w/v)) both viscosities had close but not equal values, and the differences increased with gum concentration and shear rates, similarly to the present results for VG. Torres, Hallmark, and Wilson (2014) found analogous results for GG at concentrations higher than 1.5% (w/v), and attributed the difference between both viscosities to the elastic structure that has different behavior towards oscillatory and rotational deformation. Morris et al. (1981) attributed this difference to the breaking and restructuration of hydrogen bonds in galactomannans, which is not the same for oscillatory and rotational deformation at higher concentrations than the C^* . Even though the three concentrations tested in this study were in the $C > C^*$ range (C^* for VG was 0.14% (w/v), Busch et al., 2015a), only at the higher concentration (1.5% (w/w)) the density of polymer chains was enough to make noticeable the described phenomenon.

3.3. Generalized random coil polysaccharides curve

Fig. 3 shows the generalized curve for shear-thinning galactomannan suspensions, consisting in the plot of the ratio of the apparent viscosity (η_{ap}) and the Newtonian viscosity (η_0), versus the ratio of the ($\dot{\gamma}$) and the shear rate ($\dot{\gamma}_{0.1}$), in a log - log scale. The

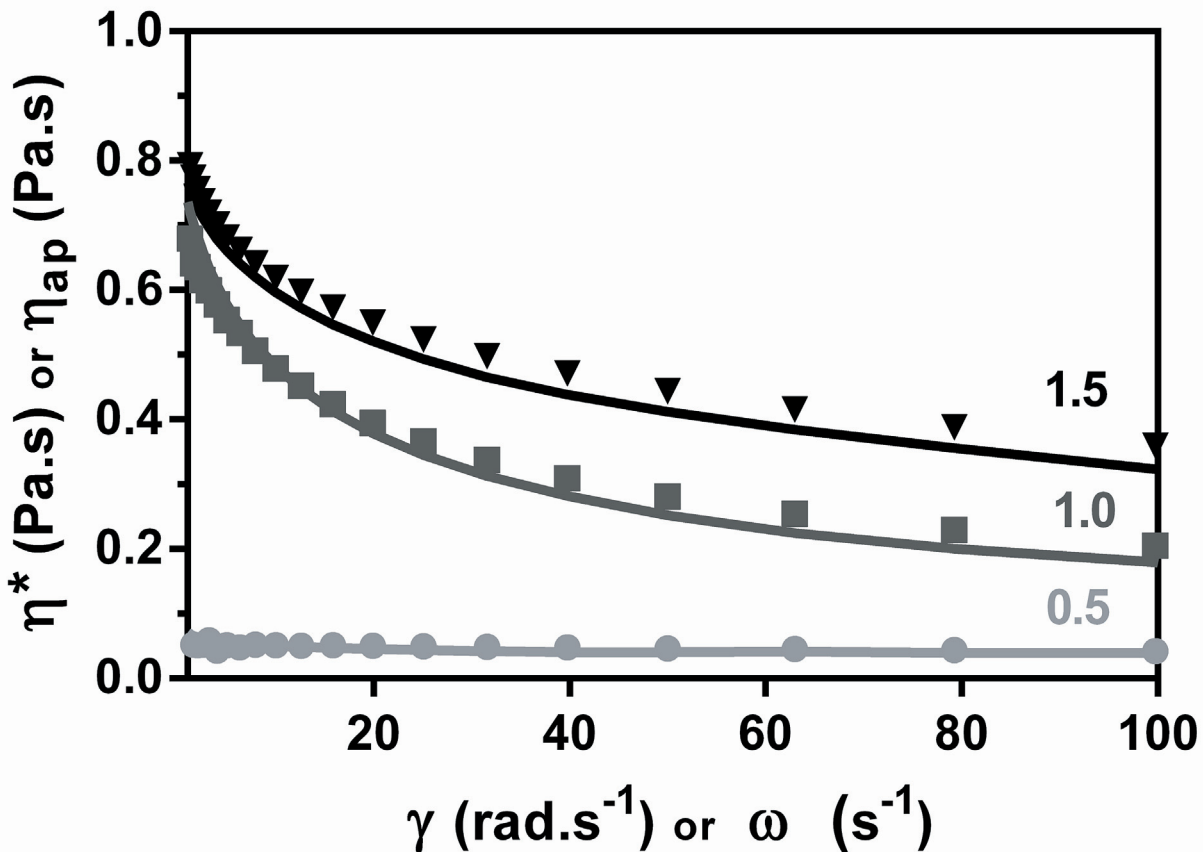


Fig. 2. Cox-Merz rule evaluation for vinal gum aqueous suspensions. Comparison between complex viscosity (represented by continuous curves) with apparent viscosity (represented by symbols) as a function of angular frequency (ω) or shear rate ($\dot{\gamma}$), respectively. Vinal gum suspensions were evaluated at three different concentrations: 1.5% (w/w) (black triangles), 1.0% (w/w) (dark gray squares) and 0.5% (w/w) (light gray circles).

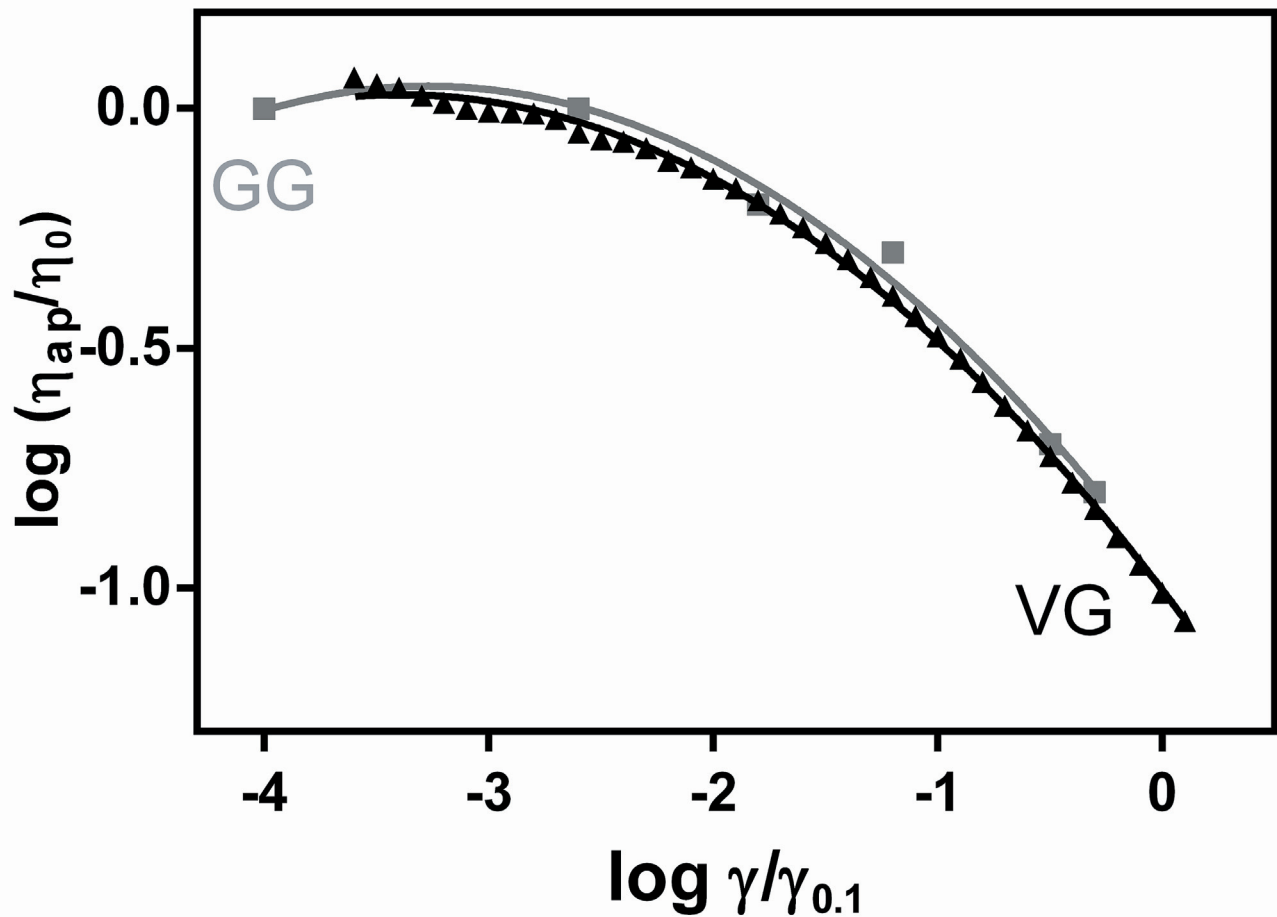


Fig. 3. Generalized curve for shear-thinning polysaccharide suspensions. The logarithm of the apparent viscosity (η_{ap}) divided by the Newtonian viscosity (η_0), versus the logarithm of the shear rate ($\dot{\gamma}$) divided by the shear rate ($\dot{\gamma}_{0.1}$) at which the $\eta_{ap} = 0.1 \cdot \eta_0$. Experimental data of vinal gum (black triangles) and for guar gum (gray squares, from Morris et al., 1981) were fitted by the model (solid lines).

model developed by Morris et al. (1981) shows that it is possible to normalize the apparent viscosity and the rate of deformation of gum suspensions at concentrations higher than the C^* . The same behavior is always obtained for different polysaccharides with random coil conformation regardless of their chemical structure, molecular weight, temperature and solvent of hydration, or even concentration (Rincón et al., 2014). Several authors have reported this generalized curve for other galactomannans (Morris et al., 1981 for GG; Rincón et al., 2014 for *Prosopis juliflora* gum, and Sittikijyothin, Torres, and Gonçalves (2005) for tara and locust bean gum, even though these last authors applied some correction factors to achieve overlapping curves). VG behaves similarly to GG and other reported galactomannans, showing a good agreement with the proposed model. Rincón et al. (2014) attributed the possibility of constructing the generalized galatomanann curve to the existence of non-specific physical bonds, which they do not change from one polymer to another. Then, flow curves differ from each other only in the parameters η_0 and $\dot{\gamma}_{0.1}$. The generalization of the shear-thinning of a polymer implies interesting practical consequences since it allows to characterize the entire flow curve just from the knowledge of two parameters (η_0 and $\dot{\gamma}_{0.1}$) constituting a

relevant procedure for normalization and predictive purposes. Thus, it simplifies the thickening application of the gums at industrial applications.

3.4. Synergism with other hydrocolloids

Figure 4 shows the elastic modulus of hydrocolloids mixtures (VG with xanthan gum, *k*-carragenan or sodium alginate at a total hydrocolloids concentration of 1% (w/w) extracted from the mechanical spectra (data not shown) at 50 rad. G' is plotted versus the percentage of VG suspension (VG 100% corresponds to a VG suspension with 1% (w/w) of VG and no addition of other gum) subtracting the linear elastic contribution of each hydrocolloid as explained in relation to equation (1). The percentage of the other gum was equal to $1-(\%VG/100)$ % w/w. In Fig. 4, the synergism can be observed as a positive deviation from the x-axis (Pinheiro et al., 2011). VG mixtures with *k*-carragenan or sodium alginate showed an absence of synergism in these conditions ($G' = 0.0 \pm 0.5$ Pa) for the entire frequency range, being the elastic modulus values the addition of the linear contribution of each hydrocolloid. However, the xanthan gum - VG mixture showed synergism in the elastic

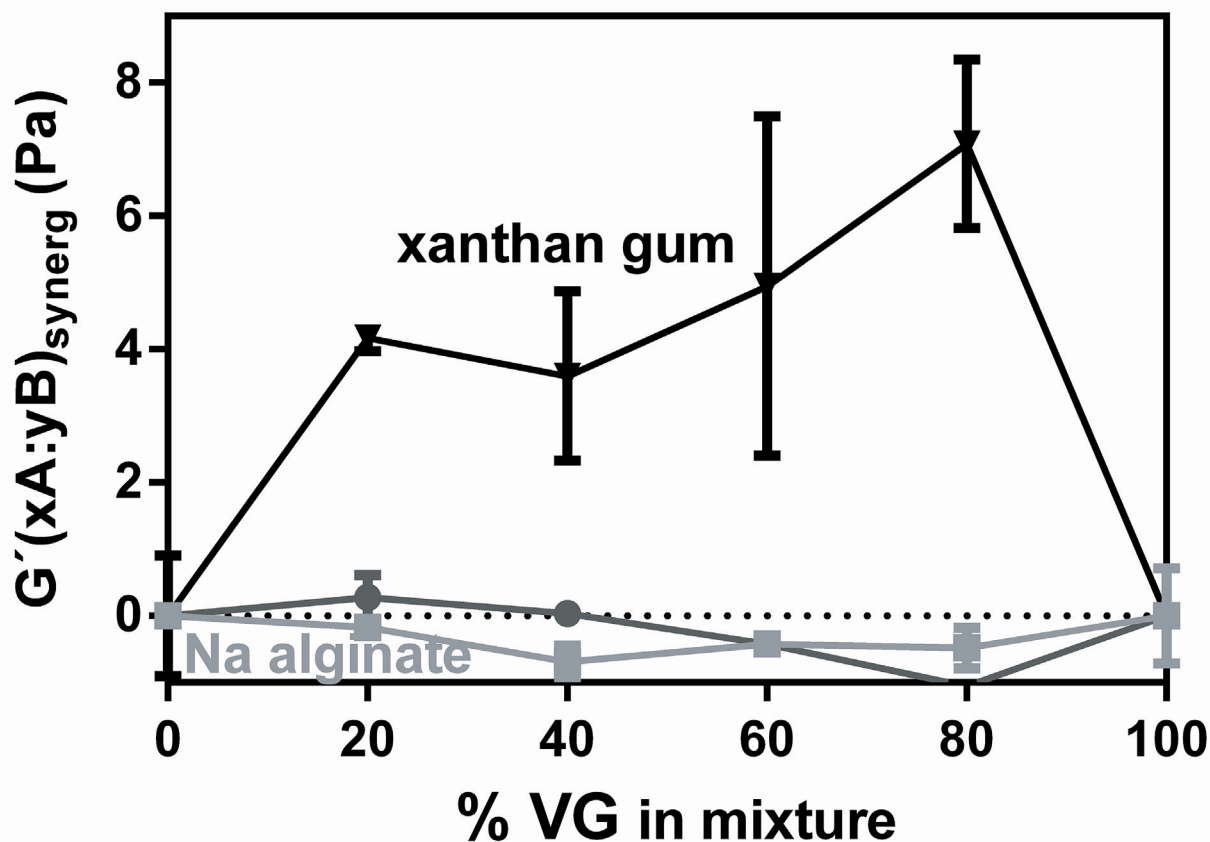


Fig. 4. Synergetic effect of vinal gum/hydrocolloid mixtures on the storage modulus (G') at a total polymer concentration of 1.0% (w/w), measured at 50 rad s^{-1} and at 20°C . Vinal gum (% VG) mixed with xanthan gum (black triangles); κ -carrageenan (dark gray circles) or sodium alginate (light gray squares) at different ratios. Lineal contribution of each gum was subtracted. Bars indicate standard deviation limits. The G' values of each hydrocolloid suspension at 1% (w/w) and 50 rad s^{-1} were: 1.2, 4.5, 12.2 and 41.6 Pa for alginate, κ -carrageenan, VG and XG.

response in the whole range of the studied concentrations, showing a maximum for the VG: xanthan gum ratio of 80:20. Synergism with xanthan gum has previously been observed for other galactomannans at the same concentrations ratio (GG, LBG, gums of *Sophora japonica* and *Gleditsia triacanthos*, Pinheiro et al., 2011). This phenomenon has been attributed to the presence of interactions called superunions or junction zones between xanthan gum trisaccharide and the galactose side chains (in this case of VG), which are mostly (but not exclusively) produced by hydrogen bonding. It has been observed that synergism is related to the M/G parameter in galactomannans (Dea, Clark, & McCleary, 1986; Fernandes, Gonçalves, & Doublier, 1992), but also by other factors such as the total polysaccharide concentration (Bresolin et al., 1997; Mannion et al., 1992) and temperature (Mannion et al., 1992). Higher values of M/G or zones of lower frequency of substitution provoke greater probability of establishing these superunions. Synergism with Xanthan gum has a particular interest because Xanthan and guar gums are often used together in the industry, especially in gluten-free products (Lorenzo, Califano, & Zaritzky, 2008; Sumnu, Koksel, Sahin, Basman, & Meda, 2010; Turabi, Sumnu, & Sahin, 2008). The VG - xanthan gum mixture (at a 80:20 ratio and 50 rad s^{-1}) showed an elastic response increased in a 40% relating to the sum of lineal contributions of each hydrocolloid.

3.5. Effect of temperature, ionic strength and pH on flow curves on rotational assays

Fig. 5 shows the apparent viscosity values (at shear rate of 10 s^{-1}) as a function of the inverse of the temperature ($1/T$) adjusted by the Arrhenius equation. Besides VG suspensions data, comparative information of another galactomannan (*Prosopis juliflora* gum) extracted from *Prosopis juliflora* seeds were included (Rincón et al., 2014). In general, increasing the shear rate or the temperature, or lowering the gum concentration produced a decrease in the apparent viscosity in an amount which depends on the type of hydrocolloid analyzed. A linear dependence of apparent viscosity with temperature for both VG concentrations and *Prosopis juliflora* gum was observed in the Arrhenius plot (Fig. 5). Similar results have already been reported for other galactomannans: GG and LBG (Doublier & Launay, 1981) and other galactomannans from non-traditional sources such as *espina corona* (Perduca et al., 2013) and *Prosopis juliflora* seed (Rincón et al., 2014) gums. This behavior is related to the preservation of the polysaccharide structure (Rincón et al., 2014), and to a lack of large changes in the studied temperature range ($5\text{--}60^\circ \text{C}$).

Besides Arrhenius-type analysis, the Power Law is frequently employed to analyze temperature dependence of viscosity (Perduca et al., 2013). Table 1 shows the parameters obtained by the

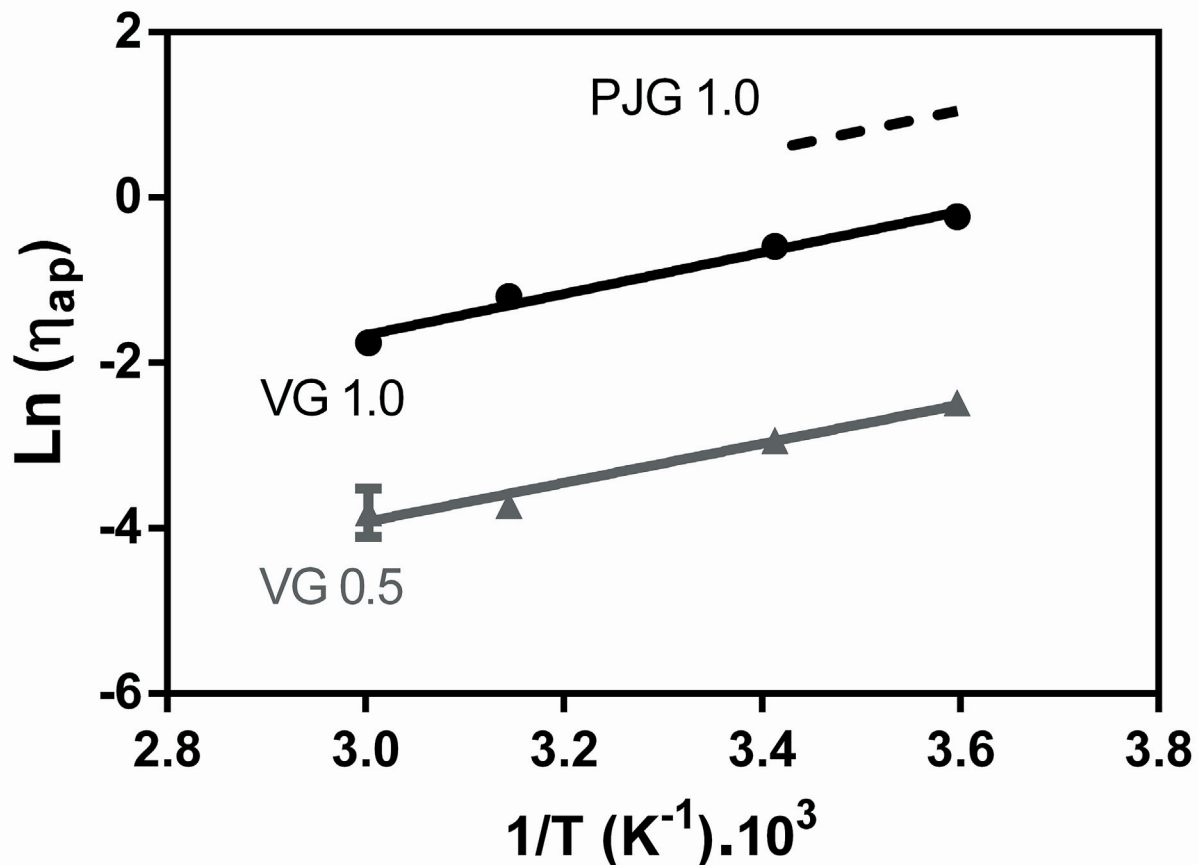


Fig. 5. Effect of temperature on apparent viscosity of VG suspensions. Logarithm of the apparent viscosity (at 10^{-1}) as a function of inverse temperature ($1/T$) for 1.0% (w/w) (black circles) and 0.5% (w/w) (dark gray triangles) of VG suspensions. The experimental data (symbols) were fitted with Arrhenius model (lines). Data from *Prosopis juliflora* gum (PJG 1.0% (w/v), in black dotted line) was taken from Rincón et al. (2014).

Table 1

Arrhenius parameters (a) and Power Law flow index (n) at different temperatures (b) for two vinal gum (VG) concentrations.

VG % (w/w)		0.5	1.0
(a) Arrhenius model	m	2.4 ± 0.3^a	2.5 ± 0.3^a
	B	4.7 ± 0.5^a	3.7 ± 0.3^b
(b) Power law n parameter	Temperature ($^{\circ}\text{C}$)		
	5	0.670 ± 0.004^c	0.458 ± 0.006^d
	30	0.725 ± 0.007^b	0.495 ± 0.006^c
	45	0.818 ± 0.007^a	0.572 ± 0.007^b
	60	0.831 ± 0.005^a	0.631 ± 0.007^a

Arrhenius model (a): for each row, different letters (a–b) indicate significant differences between means ($P < 0.05\%$).

Power law n parameter (b): different letters (a – d) indicate significant differences between means ($P < 0.05\%$) for different temperature values on the same column.

Mean of two determinations ($n = 2$) and standard deviation are given.

Arrhenius (a) and Power Law (b) modeling analysis for apparent viscosity. It can be observed that for both concentrations of VG the temperature dependence of viscosity (according to the Arrhenius slopes) was the same, and similar to the observed for *Prosopis juliflora* gum at 1% (w/w) (Rincón et al., 2014). On the other hand, B showed significant differences (Table 1a). It is important to point out that the temperature produced small changes in the apparent viscosity (related to B) of VG suspensions, but these changes are similar for suspensions of different concentrations and also for other galactomannans from *Prosopis* spp. sources.

The apparent viscosity varies greatly with gum concentration. It is to be noted that parameter n obtained from the Power Law is $= 1$ for Newtonian fluids. The obtained n values are < 1 (Table 1b), even for the higher concentrations of VG (n between 0.4 and 0.6 for VG 1% (w/w), in the temperature range between 5 and 60 $^{\circ}\text{C}$). It is interesting to note that there are no modifications of the n values by changing the temperature from 45 to 60 $^{\circ}\text{C}$ at concentrations of 0.5, but there are differences at VG 1% (w/w). This could have consequences in the choice of the gum concentration, according to the temperature treatment or technological process to be performed.

Table 2
Power Law flow index (n) at different vinal gum (VG) concentrations as a function of pH (a) and ionic strength (b).

VG % (w/w)		0.45	0.90
(a) pH	4	0.806 ± 0.004 ^a	0.635 ± 0.006 ^a
	7	0.806 ± 0.004 ^a	0.640 ± 0.008 ^a
	10	0.798 ± 0.004 ^a	0.58 ± 0.01 ^b
VG % (w/w)		0.5	1
(b) NaCl (M) at pH 7	Without NaCl	0.725 ± 0.006 ^{ab}	0.495 ± 0.006 ^{ab}
	0.1	0.716 ± 0.006 ^b	0.474 ± 0.006 ^b
	1	0.748 ± 0.006 ^a	0.509 ± 0.006 ^a

Different letters (^{a–b}) indicate significant differences between means ($P < 0.05$) on the same column (same gum concentration). Mean of two determinations ($n = 2$) and standard deviation are given.

Table 2 shows Power Law flow index (n) at different VG concentrations as a function of pH (a) and ionic strength (b). It can be observed that this n parameter remained constant at pH between 4 and 10 for the lower VG concentration, but decreased at pH alkaline for the highest concentration of gum. The increase in the shear-thinning character and the decrease in the flow index at alkaline pH are related to the higher repulsion of the polymer chains for a more negative VG zeta potential (Busch, Loosli, Santagapita, Buera, & Stoll, 2015b). It is important to notice that this effect is significant only at higher gum concentration, where the polymer chain density is enough to manifest these repulsion forces. The fact that there are no carboxyl groups in the VG structure gives to this type of polysaccharides great stability towards pH changes (Mathur, 2012). Other galactomannan gum also showed great stability to pH. For instance, GG stability to pH has already been reported by several authors, including Chudzickowski (1971), who established the range of stability and viscosity constancy of GG at pH lower than 10.5. Perduca et al. (2013) did not find variations in the apparent viscosity of suspensions of GG and *espina corona* gum (at 0.5% w/v) varying the pH between 4.6 and 6.6. Besides, the pH of food rarely reaches values greater than 8 (Food and Drug Administration, 2001) so VG suspensions will have a stable rheological behavior in the food pH range.

On the other hand, Table 2 b also shows the flow index at three concentrations of NaCl, for VG suspensions at two concentrations: 1% and 0.5% (w/w) at pH 7. NaCl addition did not produce any significant change in the flow curves index at any of the studied concentrations. Perduca et al. (2013) observed no differences in apparent viscosity for *espina corona* gum between 0 and 0.09 M NaCl, similarly to the VG results. On the contrary, Gittings, Cipelletti, Trappe, Weitz, and Lal (2001) observed that the presence of 1 M NaCl decreased the viscosity of a 0.46% (w/w) GG suspension. Several authors have already point out that galactomannans are not affected by ionic strength changes (Mathur, 2012; Mirhosseini & Tabatabaee Amid, 2012; Williams, 2007).

4. Conclusions

The present work provides detailed rheological information on a non-traditional galactomannan gum revealing the promising application of vinal gum as a stable thickener and stabilizer in food, pharmaceutical or other products.

The compliance of the Cox-Merz rule was confirmed for vinal gum suspensions at lower or equal concentration of 1% (w/w).

In mixtures with xanthan gum, vinal gum exhibited an elastic synergistic behavior related to superunion-type entanglements between both polymers, which could allow to manipulate formulation by using less polymer concentrations or different mixtures.

Vinal gum temperature dependence can be well described by

Arrhenius model and vinal gum flow curves are well characterized by the generalized model of polysaccharides, allowing an adequate prediction of its behavior during processing. Furthermore, vinal gum showed great stability towards time, pH and ionic strength changes, assuring rheological constancy.

The comprehension of the rheological vinal gum parameters as well as its interactions with other hydrocolloids, favor the normalization and comparison with other commercial gums, and support the effective and innovative application of this non-traditional gum.

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