



Investigation of the interaction between sage seed gum and guar gum: Steady and dynamic shear rheology



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ABSTRACT

Herein, the rheological interaction of various SSG (sage seed gum) and GG (guar gum) blends were elaborated. With increasing SSG fraction, the extent of viscosity reduction in the range of $0.01\text{--}316\text{s}^{-1}$ increased from 58.68 for GG to 832.73 times for SSG which was not the same at different ranges of shear rate. Steady and dynamic shear tests suggested interaction with longer timescale in SSG chains in comparison with that in GG. Linear correlation ($p < 0.05$) between the relaxation time from mechanical spectra and that of Moore equation was achieved. With increasing the SSG fraction, the extent of departure from Cox–Merz rule increased from 11.45 in GG to 33.57 Pa for SSG. The yield stress values determined by stress ramp and extrapolation methods increased with increase in SSG fraction. The synergist effect of all measured viscoelastic parameters from frequency sweep test was observed for 3-1 SSG–GG blend.

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1. Introduction

Synergistic polysaccharide–polysaccharide interactions are attractive commercially because they offer the potential to create new textures and to manipulate the rheology of products in the food industry. Expensive polymers may be replaced by a low cost mixture. Also, to meet the demand for ingredients with more specific functionality, significant efforts have been dedicated to find new structure–functionality issues (Nor Hayati, Ching, & Rozaini, 2016). When two polysaccharides are mixed, the texture characteristics of the mixed systems depend on several parameters such as the nature of the components and their ratio (Tipvarakarnkoon & Senge, 2008).

Sage (Salvia macrosiphon) is a pharmaceutical endemic plant in Iran and distributed worldwide (Anon, 2013). Sage seed gum (SSG) has been optimally extracted and its rheological properties characterized by Bostan, Razavi, and Farhoosh (2010), Razavi, Taheri, and Quinchia (2011), and Razavi, Taheri, & Sanchez (2013). At optimum conditions, SSG contained 6.72% moisture, 0.85% lipid, 8.17% ash, 2.84% protein, 1.67% crude fiber and 79.75% carbohydrate.

Sage seed polysaccharide is a galactomannan with a 1.78–1.93:1 mannose/galactose ratio, a weight average molecular weight of 1.5×10^6 Da similar to guar gum (1.45×10^6 Da), intrinsic viscosity of 22.55 dl/g and 28.2–32.2% uronic acids, indicating typical polyelectrolyte behavior of the SSG biopolymer (Razavi, Cui, Guo, & Ding, 2014). The presence of carboxyl groups, which may serve as binding sites for ions had an important effect on the gel forming ability of SSG. Using Mark–Houwink–Sakurada, Razavi et al., (2014) also found that SSG adopt a rigid rod conformation in aqueous solution with more chain stiffness than xanthan. Also, deviation from the Cox–Merz rule proposed that SSG has a self-structured and ordered conformation like xanthan. SSG dispersion has high zero-shear viscosity, yield stress and very shear-thinning behavior, which were more pronounced than those reported for commercial hydrocolloids like xanthan and guar gums at the same concentration and temperature. Mechanical spectra obtained by frequency sweep test demonstrated that SSG (at the concentrations of 0.5–2% w/w) exhibited weak gel behavior like xanthan (Razavi, HasanAbadi, Ghadiri, & Salehi, 2013). According to aforementioned characteristics, SSG could be an alternative for some of the commercial gums as a stabilizer, thickener, binder, and gelling agents in food, cosmetics, and pharmaceutical systems, also, may be a good candidate in mixed gum systems.

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Guar gum (GG) is obtained from the endosperm of the guar plant (*Cyamopsis tetragonoloba*) seed, with linear chains of D-mannopyranosyl units with D-galactopyranose substituent protruding by (1 → 6) linkages, and has the general structure of galactomannans (Javidi, Razavi, Behrouzian, & Alghooneh, 2016).

Galactomannans can form gels with new properties when are associated with other polysaccharides, such as xanthan gum (Khouryieh, Puli, Williams, & Aramouni, 2015). The functional properties of galactomannans are connected to their molar mass and structural features, while the synergistic interactions appear to be determined by their mannose/galactose ratio (M/G) and their fine structure (Mysore & Rudrapatnam, 2015). Interchain associations could be characterized quantitatively by a variety of rheological techniques. The suitable technique is mainly determined by the nature of the association. Oscillatory shear measurements could monitor the structure in weak gels or viscoelastic fluids, while steady shear measurements may be employed to follow the breakdown of structure at different rates of shear (Dea et al., 1977). Yield stress is a well-known rheological property for liquid and solid materials. A precise, quantitative understanding of yield stress in foods is important for several practical applications—from process calculations to product development (Razavi et al., 2011).

Many studies have characterized the behavior of various polysaccharide–polysaccharide mixtures (Fitzpatrick, Meadows, Ratcliffe, & Williams, 2013). To the best of our knowledge, no work has been carried out on the evolution of the interaction of selected gums, widely addressing steady and dynamic rheological parameters. Therefore, the aim of the present work was to broadly investigate the rheological properties of different SSG–GG ratios. Herein, the viscoelastic and flow behavior of these polysaccharide blends have been investigated, in comparison with their individual components, to obtain a more complete rheological characterization and describe the influence of SSG–GG ratio on the various rheological parameters such as, loss modulus (G''), storage modulus (G'), complex modulus (G^*), loss tangent ($\tan\delta$), the limiting value of strain (γ_c), flow point stress (τ_f), with corresponding modulus (G_f : $G' = G''$), the slope of G' at the start of the n-LVE (non-linear viscoelastic) range, the slope of $\log\eta^*$, flow behaviour index (n), consistency index (k), zero and high-shear rate viscosity (η_0 & η_∞) and the relaxation time (τ) of Moore model. In addition, the generalized Maxwell relaxation time (λ_i), relaxation modulus (G_i), the stiffness parameter (A_a) and the order of relaxation function (α) were determined for all the dispersions. Besides, we determined the yield stress of SSG–GG blends using direct methods and compared them with yield stress values obtained by indirect methods. At the end, the applicability of the Cox–Merz relationship between apparent and complex viscosity was studied. Development of the viscoelastic properties database for biopolymers by using such supplementary dynamic and steady rheological parameters is critical to adjust processing parameters, monitoring consistency as well as predicting the stability of fluid food systems, and the final textural attributes of formulated foods (Yousefi & Razavi, 2015).

2. Materials and methods

2.1. Sample preparation

The extraction of SSG was performed using Bostan et al. (2010) method and the GG was purchased from Sigma Com, Spain. In this work, the following SSG–GG ratios have been employed and compared with individual SSG and GG, while the total polysaccharide concentration was kept constant at 1%(w/w): 1-3, 1-1, & 3-1. Solutions were prepared by thoroughly dispersing the desired amount of premix gum powders in de-ionized water, and stirring at

room temperature (25 °C) overnight to complete hydration. Sodium azide (0.02%) was added into all solutions to prevent the microbial contamination. The samples were stirred at 300 rpm for 24 h, and kept for further 24 h at ambient temperature (25 °C) to complete the hydration prior to experiments. The samples were then loaded onto the rheometer to evaluate the rheological properties.

2.2. Rheological tests

Steady shear, small deformation oscillatory and yield stress measurements were carried out using a strain/stress controlled ARES rheometer (TA Instruments, New Castle, USA) equipped with cone–plate geometry (4° cone angle, 50 mm of diameter, and 1 mm gap). The temperature was fixed, using a Peltier system, at 20 °C and then each sample was equilibrated, at least for 5 min before the rheological test and was coated around their periphery with light silicone oil, to minimize loss of water.

2.2.1. Steady shear measurement

Steady flow behavior of prepared gum dispersions was evaluated at strain controlled mode to obtain shear stress–shear rate data. The shear stress was measured at a logarithmically increasing scale of shear rates from 0.01 to 316 s⁻¹. Also, the apparent viscosity at a given shear rate was calculated as the ratio of shear stress to shear rate (Steffe, 1996).

2.2.1.1. Steady shear modeling. Shear stress–shear rate data were fitted using a well-known power-law flow equation (Eqn. (1)). Also, the Moore model was selected to fit the apparent viscosity–shear rate data (Eqn. (2)).

Power-law (Ostwald–De Waele) model (Steffe, 1996):

$$\tau = k_p(\dot{\gamma})^{n_p} \quad (1)$$

Where, τ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s⁻¹), k_p is the power-law consistency coefficient (Pa.s^{n_p}) and n_p is the power-law flow behavior index (dimensionless).

Moore model (Moore, 1963) (Rao, 1999):

$$\eta = \eta_\infty + \frac{\eta_0 - \eta_\infty}{1 + (\tau \times \dot{\gamma})} \quad (2)$$

Where, τ is the Moore relaxation time (s), η_0 is the limiting zero shear viscosity (Pa.s) and η_∞ is the limiting infinite shear viscosity (Pa.s).

2.2.2. Oscillatory shear measurements

2.2.2.1. Amplitude sweep test. Strain sweep tests in oscillatory shear were conducted in the range of 0.01–250% in controlled shear rate mode at 20 °C, and a constant frequency of 1 Hz. At this research, for comprehensive study in dynamic rheological properties of SSG, GG and their mixtures, the storage modulus (G'_{LVE}), viscous modulus (G''_{LVE}), loss tangent ($\tan\delta$), limiting value of strain (γ_{LVE}) at the LVE region, the slope of storage modulus at the start of n-LVE range, and flow-point stress (τ_f) with corresponding modulus (G_f : $G' = G''$) for all samples were determined by the amplitude sweep measurements (Yousefi & Razavi, 2015).

2.2.2.2. Frequency sweep test. Frequency sweep measurements were made within the LVE range (maximum strain of 1%), over a frequency range 0.01–10 Hz at a constant temperature of 20 °C. The mechanical spectra obtained were characterized by the storage modulus (G'), loss modulus (G''), complex modulus (G^*), complex viscosity (η^*), and the loss tangent ($\tan\delta$) as a function of frequency

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