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Rheological properties of rice starch–xanthan gum mixtures

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Abstract

Rheological properties of rice starch–xanthan gum mixtures (5% w/w) at different xanthan gum concentrations (0%, 0.2%, 0.4%, 0.6%, and 0.8% w/w) were evaluated in steady and dynamic shear. The rice starch–xanthan gum mixtures at 25 °C showed high shear-thinning flow behavior ($n = 0.13$–0.24), and consistency index (K) and apparent viscosities ($\eta_{a,100}$) increased with the increase in xanthan gum concentration. In the temperature range of 25–70 °C, mixtures followed the Arrhenius temperature relationship. Activation energy (1.83–9.89 kJ/mol) decreased and storage (G') and loss (G'') moduli increased with the increase in xanthan gum concentration. The dynamic (η^*) and steady shear (η_a) viscosities at several xanthan gum concentrations followed the Cox–Merz superposition rule with the application of shift factor (α). Magnitudes of shift factor were in the range of 0.307–0.478. During aging at 4 °C for 10 h, the values of G' were found to increase rapidly the early stage and attained the plateau region after a few hours. The increase in rate constant (k) in gelation of rice starch–xanthan gum mixtures was a function of xanthan gum concentration.

Keywords: Rheology; Rice starch; Xanthan gum; Gelation; Dynamic property

1. Introduction

Xanthan gum, a well-known extracellular microbial polysaccharide, is used as a thickener in the pharmaceutical, cosmetic and food industries. When added to fluid foods, it increases low shear-rate viscosity while having little effect on the viscosity of the food at high shear rate (Speers & Tung, 1986). This behavior gives various advantages: as the viscosity decreases with the increasing shear rate, the product becomes easy to pour, mix or pump, and the organoleptic properties of food products are also favorably affected. The shear-thinning character of xanthan gum is more pronounced than those of other polysaccharide gums (guar gum, locust bean gum, hydroxyethylcellulose, sodium carboxymethylcellulose, sodium alginate, etc.) due to the unique rigid, rod-like conformation of xanthan gum which is more responsive to shear than a random-coil conformation (Urlacher & Noble, 1997).

The addition of gum to starch in food system is known to modify and control the rheological properties of starch. The specific adjustment of the rheological properties of starch is of significance in order to regulate production processes and to optimize applicability, stability, and sensory properties of food products (Kulicke, Eidam, Kath, Kix, & Hamburg, 1996). It is important to understand molecular interactions between starches and gums that are critical to functionalities they impart to food products (Shi & BeMiller, 2001). In general, it is well known that the addition of gum increases the viscosity of starch and influences the gelatinization and retrogradation of starch (Abdulmola, Hember, Richardson, & Morris, 1996; Alloncle, Lefebvre, Llamas, & Doublier, 1989; Christianson, Hodge, Osborne, & Detroy, 1981; Ferrero, Martino, & Zaritzky, 1994; Yoshimura, Takaya, & Nishinari, 1996, 1998).

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The observed enhancements in overall viscosity of starch–gum mixtures could be attributed to the increase in gum concentration due to swelling of the starch granules during gelatinization in starch–galactomannan (guar gum or locust bean gum) composite system (Alloncle et al., 1989). However, according to Abdulmola et al. (1996), the increase of viscosity in the starch–xanthan gum mixture is due to the interactions between gelatinized granules enhanced by xanthan gum. Gum affects gelatinization and retrogradation of starch through strong associations of amylose with gum, resulting in a decrease in the retrogradation of starch (Christianson et al., 1981).

Recently, several researchers have studied the effect of xanthan gum on rheological properties of various starches, such as corn starch (Biliaderis, Arvanitoyannis, Izydorczyk, & Prokopowich, 1997; Eidam & Kulicke, 1995; Ferrero et al., 1994; Sudhakar, Singhal, & Kulkarni, 1996) and wheat starch (Christianson et al., 1981; Sajjan & Rao, 1987). However, no attempt has been made to study rheological properties of rice starch as affected by the addition of xanthan gum. In particular, little information is available on the effect of xanthan gum on gelation properties of rice starch in the aging process in relation to viscoelastic dynamic moduli. The changes in dynamic moduli during aging may provide valuable information on the role of xanthan gum in starch because the gelation is a dynamic process (Grosso & Rao, 1998). The main objectives of this study were to determine the rheological properties of rice starch–xanthan gum mixtures in steady and dynamic shear, and the effect of xanthan gum concentration and temperature on rheological properties.

2. Materials and methods

2.1. Materials and preparation of samples

Rice starch and xanthan gum were purchased from Sigma Co. (St. Louis, MO, USA). Rice starch had moisture, ash, and protein of 11.6%, 0.14%, 0.55%, respectively, and the amylose content was 20.3%. The pH, moisture content, and viscosity of xanthan gum were 4.5–5.0, 11.2%, and 0.8–1.2 Pa s, respectively. Rice starch–xanthan gum mixtures (5% w/w) were prepared by mixing rice starch with distilled water, and xanthan gum to obtain 0.2%, 0.4%, 0.6%, and 0.8% (weight basis) gum levels. A starch dispersion with no added gum (0% xanthan gum) was also prepared. The mixture was moderately stirred for 1 h at room temperature, and heated at 95 °C in a water bath for 30 min with mild agitation provided by a magnetic stirrer. At the end of the heating period, the hot sample mixture was immediately transferred to the rheometer plate for the measurements of rheological properties.

2.2. Rheological measurements

For measurements of rheological properties of starch–gum mixtures the steady and dynamic shear rheological data were obtained with a Rheometer (AR 1000, TA Instruments, New Castle, DE, USA) using a parallel plate system (4 cm dia.) at gap 500 μm. Each sample was transferred to the rheometer plate at the desired temperatures and the excess material was wiped off with a spatula. Steady shear (shear stress and shear rate) data were obtained over the shear rate range of 1.0–1000 s^{-1} at different temperatures (25–70 °C). In order to describe the variation in the rheological properties of samples under steady shear, the data were fitted to the well-known power law model (Eq. (1)) which is used extensively to describe the flow properties of non-Newtonian liquids in theoretical analysis as well as in practical engineering applications (Barnes, Hutton, & Walters, 1989).

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

where σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), K is consistency index (Pa s^n), and n is the flow behavior index (dimensionless). Apparent viscosity ($\eta_{a,100}$) at 100 s^{-1} was calculated from magnitudes of K and n. The effect of temperature (25–70 °C) on apparent viscosity was studied. Dynamic shear data were obtained from frequency sweeps over the range of 0.63–63 rad/s at 2% strain. The 2% strain was in the linear viscoelastic region. Frequency sweep tests were also performed at 25 °C. TA rheometer Data Analysis software (version VI. 1.76) was used to obtain the experimental data and to calculate storage modulus (G'), loss modulus (G''), and complex viscosity (η^*). In order to relax the samples before the measurements in steady and dynamic shear, all samples were allowed to rest at the initial temperatures for 2 min. The rheological measurements in steady and dynamic shear were performed in triplicate. Results reported were an average of the three measurements.

For dynamic moduli measurements in the aging process at 4 °C, sample was loaded onto the 4 °C platen of the rheometer and the exposed sample edge was covered with a thin layer of light paraffin oil to prevent evaporation during measurements. Sample was also rested on 4 °C platen for 2 min before measurements. G' values were monitored for 10 h at 1 Hz and 2% strain. The rheological measurements during aging were conducted in duplicate.

3. Results and discussion

3.1. Rheological behavior

The shear stress (σ) versus shear rate ($\dot{\gamma}$) data for rice starch–xanthan gum mixtures at different xanthan