Effect of sucrose on rheological properties of xanthan gum-locust bean gum mixtures

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Abstract The effect of sucrose (0, 10, 20, 30, and 40%) on flow and dynamic rheological properties of xanthan gum (XG) mixed with locust bean gum (LBG) at different mixing ratios (100/0, 75/25, 50/50, and 0/100) were evaluated. The addition of sucrose significantly changed the flow behavior index (n), consistency index (K), storage modulus (G'), and loss modulus (G'') of XG, LBG, and XG-LBG mixtures. When XG and LBG were mixed, there was a synergistic effect on K and G' values, and 50XG/50LBG mixture exhibited stronger synergy than 75XG/25LBG mixtures. However, the addition of sucrose reduced the magnitude of the synergistic effects, indicating that the presence of sucrose in XG-LBG mixtures negatively affected the synergistic interaction between gum molecules. Sucrose may competitively inhibit the binding of gum polymers to water molecules. The rheological properties of XG, LBG, and XG-LBG mixtures were affected by the addition of sucrose in a concentration-dependent manner.

Keywords Rheological property · Xanthan gum · Locust bean gum · Synergistic effect · Sucrose

Introduction

Gums have been extensively used as a thickening agent in foods. They are also used in developing food thickeners for dysphagic patients (Germain et al., 2006; Sopade et al., 2007). Dysphagia is defined as the impaired ability to swallow with symptom in which there are problems in the process of swallowing food from the mouth to the stomach through the esophagus (Germain et al., 2006). The most convenient and effective treatment method for complications caused by dysphagia is to control the rheological properties of fluid foods using food thickeners (Moret-Tatay et al., 2015). Recently, xanthan gum (XG)-based thickeners have been used in dysphagic diets since they retain a stable viscosity during consumption, have no taste or smell, and do not make the liquid turbid (Leonard et al., 2014; Rofes et al., 2014). Generally, various types of gums are used in the preparation of a food thickener to obtain the desired rheological properties (Paximada et al., 2016). A combination of XG and galactomannans (GMs) is the most commonly used in food applications due to their strong gelation ability at low concentrations, which may be attributed to synergistic interactions between the gums (Higiro et al., 2006; Khouryieh et al., 2006; Paradossi et al., 2002). Among the various GMs (e.g., guar gum, tara gum, and locust bean gum (LBG)), LBG is known to have the highest synergistic effect with XG (Renou et al., 2013; Rinaudo and Moroni, 2009). LBG consists of a main chain of mannose units with side-branches of galactose units. The distribution of galactose is non-regular and non-statistically random (Haddarah et al., 2014); thus, the substituted segments (hairy regions) and unsubstituted segments (smooth regions) are simultaneously present in one LBG molecule (Grisel et al., 2015). When XG is dispersed in a liquid, it forms a partially ordered (stable) double-helix structure

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and a disordered (unstable) random coil structure at the same time (Khouryieh et al., 2007). The rheological synergism of XG and LBG is known to occur through the intermolecular interaction between the disordered segments of XG and the smooth regions of LBG (Grisel et al., 2015; Renou et al., 2013).

Although dysphagic diets, to which food thickener is added, contain sucrose, there have been no in-depth studies on the changes in the rheological properties and the degree of synergistic interaction in the XG-LBG mixtures at different mixing ratios in the presence of sucrose. Most of the current studies have also been conducted using dilute gum solutions ($\leq 0.5\%$). The objective of this study was to examine the influence of sucrose on the flow and dynamic rheological properties of XG-LBG mixtures at different mixing ratios in a concentrated solution (1% w/w).

Materials and methods

Materials and sample preparation

The gums (XG and LBG) studied in this work were obtained from Sigma-Aldrich (St. Louis, MO, USA). The gum solutions (1% w/w) were prepared by mixing 1 g of gum with 100 g of deionized distilled water under stirring for 8 h at room temperature. For the preparation of LBG solution, it was heated for 1 h at 85 °C in a water bath following the dispersion at room temperature. Gum solutions were kept overnight at room temperature to hydrate them completely. The prepared XG and LBG solutions were mixed at different mixing ratios (XG/LBG: 100/0, 75/25, 50/50, and 0/100). To evaluate the effects of sucrose, it was added to each solution to obtain 10, 20, 30, and 40% sucrose (on a weight basis) and completely dissolved by stirring for 1 h at room temperature. A control solution with no added sucrose (0% sucrose) was also prepared.

Rheological measurements

Flow and dynamic rheological measurements were carried out using a controlled stress rheometer (Haake RheoStress 1, Haake GmbH, Karlsruhe, Germany). The plate–plate geometry was used (diameter, 35 mm). Each sample was loaded between the parallel plates at 25 °C and compressed up to obtain a gap of 500 μm . Temperature was controlled by a water bath connected to the Peltier system in the bottom plate. Steady flow tests were performed over the shear rate range of 0.1–100 s^{-1} . The data of shear stress against shear rate were used to estimate the power law parameters by using the equation $\sigma = K\dot{\gamma}^n$ (Eq. 1), where σ (Pa) is the shear

stress, $\dot{\gamma}$ (s^{-1}) the shear rate, K (Pa s^n) the consistency index, and n the dimensionless flow behavior index.

Dynamic viscoelastic properties were evaluated using small amplitude oscillatory rheological measurements. All samples were tested from frequency sweeps which were performed between 0.63 and 62.8 rad s^{-1} of angular frequency (ω) at 2% strain value in order to determine the storage modulus, G' , loss modulus, G'' , and loss tangent, $\tan \delta$ (G''/G'). All samples also remained between the plates in rest time (5 min) before measurement. All tests were carried out in triplicates.

Statistical analysis

Statistical significance was assessed by Analysis of variance (ANOVA) and Duncan's multiple range test using Statistical Analysis System (SAS) software version 9.2 (SAS Institute, Cary, NC, USA). The level of significance was set at $P < 0.05$.

Results and discussion

Flow behavior

The flow properties of XG, LBG, and XG-LBG mixtures with different sucrose concentrations (0–40%) at 25 °C were determined from rheological parameters, such as K and n , for the power law model (Eq. 1). The K and n values are known to be strongly related to the flow velocity of a food bolus and stickiness in the mouth, respectively (Funami, 2011; Szczesniak, 1963). For shear rates in the range of 0.1–100 s^{-1} , the experimental shear stress versus shear rate data of all samples were well fitted to the power law model. Table 1 provides the magnitudes of K and n values as well as the goodness of fitting (R^2). The n values (0.10–0.22) of XG alone and XG-based binary mixtures were much lower than those (0.61–0.70) of LBG alone, indicating that XG exhibited a more pronounced shear-thinning behavior. The lower shear-thinning behavior may be related to the progressive orientation of molecules in the direction of flow and the breaking of a network structure during shearing at higher shear rates (Morris et al., 1981). The n values of individual XG and LBG in the presence of sucrose were lower than those of the control (no added sucrose); however, the effect on n values with increasing sucrose concentration did not show a clear trend. When the two gums were mixed, the actual measured n values were lower than those calculated by the weight ratio of the two gums, and the difference between the measured and calculated values of most of the binary mixtures was also decreased with an increase in sucrose concentration. This result indicated that the binary

Table 1 Values of power law model parameters of XG-LBG mixtures at different concentrations of sucrose

Sample	Sucrose conc. (%)	Power law		
		K (Pa s ⁿ)	N (–)	R ²
XG100	0	10.3 ± 0.18 ^c	0.16 ± 0.00 ^a	0.99
	10	11.2 ± 0.30 ^b	0.13 ± 0.01 ^b	0.98
	20	11.9 ± 0.06 ^a	0.11 ± 0.00 ^{cd}	0.97
	30	11.5 ± 0.11 ^a	0.10 ± 0.00 ^d	0.97
	40	11.1 ± 0.10 ^b	0.11 ± 0.01 ^c	0.97
LBG100	0	3.79 ± 0.09 ^c	0.70 ± 0.00 ^a	0.99
	10	4.84 ± 0.38 ^a	0.64 ± 0.02 ^b	0.98
	20	5.14 ± 0.23 ^a	0.61 ± 0.01 ^c	0.98
	30	4.34 ± 0.25 ^b	0.65 ± 0.01 ^b	0.98
	40	4.66 ± 0.26 ^{ab}	0.63 ± 0.01 ^{bc}	0.98
XG75/LBG25	0	17.5 ± 0.50 ^a	0.11 ± 0.01 ^d	0.99
		(8.67)	(0.30)	
	10	11.9 ± 0.12 ^b	0.12 ± 0.00 ^d	0.97
		(9.61)	(0.26)	
	20	11.4 ± 0.06 ^c	0.14 ± 0.00 ^c	0.99
XG50/LBG50		(10.2)	(0.24)	
	30	10.7 ± 0.21 ^d	0.15 ± 0.00 ^b	0.98
		(9.71)	(0.24)	
	40	9.56 ± 0.13 ^e	0.17 ± 0.00 ^a	0.98
		(9.49)	(0.24)	
XG50/LBG50	0	17.0 ± 0.18 ^a	0.18 ± 0.00 ^b	0.99
		(7.05)	(0.43)	
	10	15.6 ± 0.45 ^b	0.11 ± 0.01 ^d	0.98
		(8.02)	(0.39)	
	20	12.3 ± 0.09 ^c	0.14 ± 0.00 ^c	0.96
		(8.52)	(0.36)	
	30	10.4 ± 0.44 ^d	0.18 ± 0.00 ^b	0.97
		(7.92)	(0.38)	
	40	8.10 ± 0.12 ^e	0.22 ± 0.00 ^a	0.98
		(7.88)	(0.37)	

Mean of three measurements ± standard deviation values in the same column with different letters are significantly different ($P < 0.05$)

Calculated values are given in parenthesis

mixtures of XG and LBG in the presence of sucrose could strengthen shear-thinning properties. This stronger shear-thinning behavior would allow thickened liquids prepared with XG-based thickeners to be easily swallowed with reduced organoleptic sliminess by patients with dysphagia, as reported by Yoon and Yoo (2017).

The K values of individual XG and LBG in the presence of sucrose were higher than those of the control. A similar trend in viscosity was reported by Chenlo et al., (2011). In contrast, the K values (8.10–15.6 Pa sⁿ) of binary mixtures in the presence of sucrose were significantly lower compared with those (17.0–17.5 Pa sⁿ) of the control and decreased with an increasing in the sucrose concentration. Although the K values of the XG75/LBG25 and XG50/

LBG50 with sucrose were much lower than those of the control, the experimental K values were larger than the calculated values by additivity of the values obtained for the two separate components, indicating the cooperative interactions of XG-LBG, as shown in Fig. 1. However, as the sucrose concentration increased from 10 to 40%, the difference between experimental and calculated values became smaller. In particular, there were smaller deviations (0.07–2.29) between the experimental and calculated values of XG75/LBG25 compared with those (0.22–7.58) of XG50/LBG50 in the presence of sucrose. This result indicated that the cooperative interactions of XG-LBG can be disrupted by the addition of sucrose; nevertheless, there was synergy between the gums. Therefore, the addition of

Fig. 1 Plots of K and G' values versus sucrose concentrations (%) of XG-LBG mixtures at different XG/LBG mixing ratios (75/25 and 50/50): (···) values calculated for XG-LBG. (A) XG75/LBG25, and (B) XG50/LBG50

sucrose seemed to decrease the K value of the binary mixtures of XG and LBG, possibly due to a decrease in polymer–polymer interactions or a reduction in solvent quality, as described by Behrouzian et al. (2013).

Dynamic viscoelastic properties

Table 2 shows G' and G'' of the XG-LBG at 6.28 rad s^{−1} and the different sucrose concentrations. G' values for the binary mixtures of XG-LBG and individual XG with sucrose (0–40%) at 25 °C was much higher than G'' values, indicating that all samples, except for LBG, showed an elastic characteristic. It is well known that the G' is a crucial rheological factor because it is strongly related to the ability of bolus formation during swallowing (Cho and Yoo, 2015; Yoon and Yoo, 2017). $\tan \delta$ (ratio of G''/G') takes into account the contribution of both elastic and viscous modulus and provides information on the balance of the viscoelastic properties. The $\tan \delta$ values (0.30–0.39) of all samples were within the range of 0.1–0.4, indicating a weak-gel like character (Ikeda and Nishinari, 2001). The G' and G'' values with sucrose were significantly lower compared with those of the control and also decreased with

the increasing of sucrose concentration. Overall, higher values of G' were observed in the binary mixtures of XG and LBG with sucrose than in those of individual gums, which were similar to the results observed for K values. Doyle et al. (2006) also found that in the aqueous biopolymer systems the concentration of water could be reduced in the presence of sugar, resulting in a decrease of polymer–solvent interactions in competition with polymer–polymer interactions and promotion of network formation. The improved network formation can be explained by an increase in the elastic properties of binary gum mixtures, as evidenced by the lower $\tan \delta$ values when compared with those of individual gums.

Synergistic interaction of XG-LBG mixtures

The interaction between XG and LBG was studied to examine their synergistic effect in the presence of sucrose. K and G' were plotted as a function of sucrose concentration in the binary gum systems (Fig. 1). The measured values for K and G' of XG-LBG mixtures were compared with their calculated values which mean there is no interaction between XG and LBG. Therefore, the positive

Table 2 Storage modulus (G'), loss modulus (G''), and $\tan \delta$ at 6.28 rad s^{-1} for XG-LBG mixtures at different concentrations of sucrose

Sample	Sucrose conc. (%)	G' (Pa)	G'' (Pa)	$\tan \delta$
XG100	0	23.3 ± 0.36^a	7.97 ± 0.05^a	0.34 ± 0.01^c
	10	21.4 ± 0.30^b	7.93 ± 0.10^a	0.37 ± 0.00^b
	20	21.8 ± 0.23^b	7.99 ± 0.14^a	0.37 ± 0.01^b
	30	19.5 ± 0.10^c	7.20 ± 0.07^b	0.37 ± 0.00^b
	40	18.0 ± 0.53^d	6.93 ± 0.06^c	0.39 ± 0.01^a
LBG100	0	7.74 ± 0.05^d	17.1 ± 0.23^a	2.21 ± 0.04^a
	10	8.24 ± 0.08^c	16.9 ± 0.15^a	2.05 ± 0.00^b
	20	8.30 ± 0.11^c	16.2 ± 0.26^b	1.95 ± 0.03^c
	30	8.61 ± 0.03^b	15.8 ± 0.04^{bc}	1.84 ± 0.01^d
	40	8.97 ± 0.17^a	15.6 ± 0.29^c	1.74 ± 0.01^e
XG75/LBG25	0	30.8 ± 0.87^a (19.4)	9.13 ± 0.24^a (10.0)	0.30 ± 0.01^d (0.80)
	10	28.8 ± 0.50^b (18.1)	9.04 ± 0.12^{ab} (10.2)	0.31 ± 0.01^c (0.79)
	20	26.4 ± 0.24^c (18.4)	8.83 ± 0.08^b (10.0)	0.33 ± 0.01^b (0.77)
	30	23.9 ± 0.38^d (16.8)	8.29 ± 0.04^c (9.35)	0.35 ± 0.00^a (0.74)
	40	22.7 ± 0.25^e (15.7)	8.08 ± 0.11^c (9.10)	0.36 ± 0.01^a (0.73)
XG50/LBG50	0	39.8 ± 0.69^a (15.5)	12.0 ± 0.14^a (12.4)	0.30 ± 0.00^c (1.27)
	10	33.1 ± 1.02^b (14.8)	12.0 ± 0.29^a (12.4)	0.36 ± 0.01^a (1.21)
	20	32.1 ± 0.68^{bc} (15.1)	12.0 ± 0.03^a (12.1)	0.37 ± 0.01^a (1.16)
	30	31.2 ± 0.16^{cd} (14.1)	10.2 ± 0.33^b (11.5)	0.33 ± 0.01^b (1.11)
	40	30.0 ± 0.93^d (13.5)	9.59 ± 0.61^c (11.3)	0.32 ± 0.02^{bc} (1.07)

Mean of three measurements $\pm$ standard deviation values in the same column with different letters are significantly different ($P < 0.05$)

Calculated values are given in parenthesis

deviations between measured and calculated values can be explained by the synergistic interaction between XG and LBG. Although the K and G' values of gum mixtures with sucrose were much lower than those of the control, the experimental K and G' values were larger than the calculated values, demonstrating the synergism of K and G' existed between XG and LBG, as shown in Fig. 1. In particular, there were greater deviations in G' when compared to K values, indicating the influence of sucrose on the great increase in the elastic properties of the binary gum mixtures. In general, the K and G' values of XG50/LBG50 in the presence of sucrose (10–40%) showed greater differences compared with those of XG75/LBG25, indicating that 50XG/50LBG mixtures exhibited stronger synergy than 75XG/25LBG mixtures. However, the

measured G'' values were lower than the calculated G'' values, showing that there was no synergistic effect on the G'' values regardless of the addition of sucrose (Table 2). The lower G'' may be due to the lower G'' of XG compared with LBG. These results indicated that there was a competition for water between sucrose and gum polymers, resulting in a tendency for polymer chain collapse and thus reducing the viscoelastic properties of binary gum mixtures (Braga and Cunha, 2005; Richardson, 1998). Based on these observations, it was found that the synergistic interaction between XG and LBG depended on the mixing ratio of the gums and the concentration of sucrose.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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