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RESEARCH NOTE

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Rheological Behavior of Sweet Potato Starch-Glucose Composites

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Abstract Rheological properties of sweet potato starch (SPS)-glucose composites (5%, w/w) at different concentrations (0, 10, 20, and 30%, w/w) of glucose were investigated in steady and dynamic shear. The steady shear rheological properties of SPS-glucose composites were determined from rheological parameters for power law and Casson flow models. At 25°C all the samples showed a pronounced shear-thinning behaviors (n=0.29-0.37) with high Casson yield stress. In general, the presence of glucose resulted in the decrease in consistence index (K), apparent viscosity ($\eta_{a,100}$), and yield stress (σ_{oc}). Storage (G') and loss (G") moduli increased with an increase in frequency (ω), while complex viscosity (η^*) decreased. Dynamic moduli (G', G", and η^*) of the SPS-glucose composites at higher glucose concentrations (20 and 30%) were higher than those of the control (0% glucose) and also increased with increasing glucose concentration from 10 to 30%. The effect of glucose on steady and dynamic shear rheological properties of the SPS pastes appears to greatly depend on glucose concentration in the range of 10-30%.

Keywords: sweet potato starch, glucose, rheology, viscosity, dynamic modulus

Introduction

Starch paste is formed by heating aqueous starch granules above the gelatinization temperature. A starch paste can be described as a composite material consisting of swollen granules dispersed in a continuous amylose/amylopectin phase (1). Therefore, the properties of the dispersed phase, the continuous phase, and interactions between the components cause a great change in rheological properties of starch pastes. Their rheological properties are very sensitive to several factors, including the type of starch, amylose/amylopectin ratio, temperature, starch concentration, pH, and the presence and concentration of other components, such as macromolecules (proteins and other polysaccharides) and soluble low-molecular weight solutes (acids, salts, and sugars) (2). In general, the addition of sugar to starch in food system has been used to optimize the process operation and to improve the storage stability and rheological properties in addition to its role as a sweetening agent. In particular, knowledge about the rheological properties of starch-sugar composites is very important for understanding the molecular interactions between sugars and starches during gelatinization and retrogradation. Since many starch-based products contain sugars, recently, many researchers have studied the effect of sugars on rheological properties of various native starches, such as rice (2), corn (3,4), wheat (5,6), potato (6), sago (7), and amioca starch (8). They found that the rheological properties of starch-sugar composites depended on the type and concentration of sugar, and the nature of starch.

Sweet potato (*Ipomea batatas* L. Lam), which has been a traditional starch source in Korea, is widely used to prepare a variety of products. Sweet potato starch (SPS) is frequently used as an ingredient of processed sweet potato products, such as noodles, soups, sauces, snacks, and bread. Previous studies have shown that SPS exhibits wide variation in granule size range (3-40 μm) and amylase content (15-30%), has a gelatinization temperature between 61-70°C, and gives both A and C type of X-ray diffraction pattern. The use of SPS has mainly been determined by its physicochemical and rheological properties. Although extensive literature is available on the rheological properties of starches in the presence of sugars, as described above, there is little information on the effect of glucose on rheological properties of SPS pastes. Therefore, the overall objective of this study was to examine the effect of glucose concentration on the steady and dynamic rheological properties of SPS pastes.

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Materials and Methods

Materials and preparation of starch pastes Sweet potato starch (SPS) and glucose used in this study were purchased from Seoyong Food Co. (Jeju, Korea) and Shinyo Pure Chemicals Co. (Osaka, Japan), respectively. Starch dispersions (5%, w/w) were prepared by mixing starch with distilled water, and glucose to obtain 10, 20, and 30% (weight basis) sugar levels. A dispersion with no added sugar (control) was also prepared. The starch-glucose dispersion was moderately stirred for 1 hr at room temperature, and then was heated at 95°C in a water bath for 30 min with mild agitation provided by a magnetic stirrer, as described by Chang *et al.* (3). At the end of the heating period, the hot starch paste was immediately transferred to the rheometer plate for the measurement of rheological properties.

Rheological measurements Steady and dynamic shear properties were obtained at 25°C with a rheometer (AR 1000; TA Instruments, New Castle, DE, USA) using a parallel plate system (4 cm dia.) at a gap of 500 μm. For

steady shear measurements, the sample was sheared continuously from 1 to 1,000/sec. 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 (Eq. 1) and Casson (Eq. 2) models,

$$\sigma = K\dot{\gamma}^n \quad (1)$$

$$\sigma^{0.5} = K_{oc} + K_c\dot{\gamma}^{0.5} \quad (2)$$

where σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (1/sec), K is consistency index (Pa·sec^n), and n is the flow behavior index (dimensionless), and $(K_c)^2$ is the Casson plastic viscosity (η_c). Casson yield stress (σ_{oc}) according to the Casson model (Eq. 2) was determined as the square of the intercept (K_{oc}) that was obtained from linear regression of the square roots of shear rate-shear stress data. Using magnitudes of K and n, apparent viscosity ($\eta_{a,100}$) at 100/sec was calculated.

Dynamic shear properties were obtained from frequency sweeps over the range of 0.63-63 rad/sec at 3% strain. The 3% 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 each experiment, a fresh sample was used and after loading it was allowed to rest for 5 min to restore structures that might have disturbed. All experiments were conducted at least 2 times. Results reported were an average of the 2 measurements.

Swelling power The swelling power of the starch was determined in triplicate using starch dispersion at 0.5%(w/w), as presented by Yoo and Yoo (2). Starch pastes with different glucose concentrations (10-30%) were prepared, as described previously. The hot starch paste was cooled to room temperature in an iced water bath and centrifuged at 8,000×g for 20 min. The supernatant was decanted and the swelling power was determined as the ratio of weight of sediment to weight of dry starch (9). No correction for solubles was made due to the high sugar concentrations used.

Results and Discussion

Steady shear properties Table 1 shows the magnitudes of rheological parameters from the power law and Casson models, which were used to describe the flow curves of SPS pastes with different glucose concentrations (0, 10, 20, and 30%). Experimental data of shear stress (σ) and shear rate ($\dot{\gamma}$) were fitted well to 2 models, power law model and Casson model, with high determination coefficients (R^2= 0.95-0.99). All SPS-glucose composite samples exhibited high shear-thinning behavior with values of flow behavior indexes (n) as low as 0.34-0.37, which were higher than that (0.29) of the SPS paste without glucose (control), indicating the less pseudoplastic behavior of the SPS-glucose composites. Such higher shear-thinning behavior of the control may be attributed to the increased breakage of the intra- and inter-molecular associative bonding systems in the starch network micelles due to higher shear rates (10). This is in good agreement with Genovese *et al.* (8) who found a similar trend with amioca starch pastes-sugar composites.

All the samples showed high magnitudes of Casson yield stress (σ_{oc}) in the range of 28.1-60.2 Pa. In general, the magnitudes of consistence index (K), apparent viscosity ($\eta_{a,100}$), and yield stress (σ_{oc}) of the SPS-glucose composites, except for the K value at 30%, were lower than those of the control (0% glucose), and increased progressively with an increase in glucose concentration, indicating that the rheologcial parameters obtained from flow models were reduced in the presence of glucose and depended on the glucose concentration in the concentration range studied. In particular, the magnitudes of rheological parameters (K, $\eta_{a,100}$, and σ_{oc}) at low concentration of glucose, such as 10%, exhibited markedly low values. This is in contrast to the results of Ahamad and Williams (7) who found that the presence of glucose causes an increase in the apparent viscosity of sago starch, suggesting that the steady shear rheological properties seem to be dependent on the botanical source of the starch. The rheological parameters of the SPS-glucose composites also increased with increasing glucose concentration from 10 to 30%. The swelling power at the control and a high glucose concentration (30%) had approximately the same values (Table 1). Nevertheless, the swelling power values of the SPS-glucose composites tended to increase with increasing glucose concentration from 10 to 30%. Therefore, such increase of K, $\eta_{a,100}$, and σ_{oc} values of the SPS-glucose composites in a given range of glucose concentration could generally regarded as a result of enhanced swelling power of starch granules and also the viscosity of the glucose solution in which the starch granules were heated, as noted by Acquarone and Rao (11).

Dynamic shear properties Figure 1 shows changes in storage modulus (G'), loss modulus (G"), and complex viscosity (η^*) as a function of the frequency (ω) for the SPS-glucose composite pastes at 25°C. The magnitudes of G' and G" were found to increase with increase in ω, and

Table 1. Effect of glucose concentration on steady shear rheological properties and swelling power of SPS-glucose composites at 25°C

Glucose concentration (%)	Apparent viscosity $\eta_{a,100}$ (Pa·sec)	Consistency index K (Pa·sec^n)	Flow behavior index, n	Yield stress σ_{oc} (Pa)	Swelling power (g/g)
0 (no glucose)	1.57±0.02	40.9±0.03	0.29±0.00	60.2±0.63	30.8
10	0.97±0.00	17.7±0.27	0.37±0.00	28.1±0.53	15.0
20	1.45±0.04	31.1±0.19	0.34±0.01	47.1±1.32	20.9
30	1.91±0.05	35.4±1.78	0.37±0.01	54.5±0.85	29.2

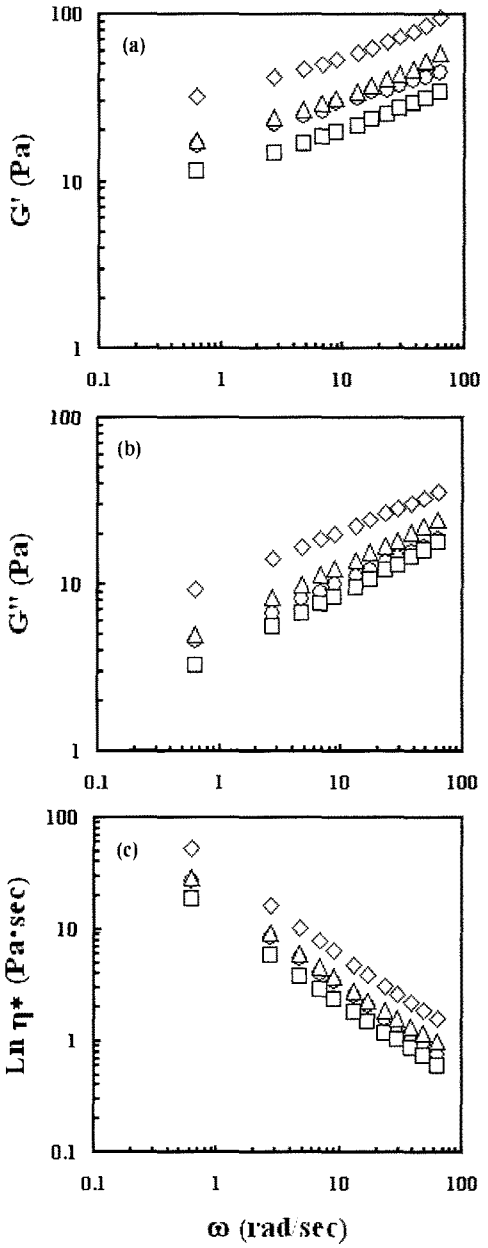

Fig. 1. Plots of log ω vs. log (G', G", and η*) for SPS-glucose composites at 25°C. Glucose concentration: (○) 0%, (□) 10%, (△) 20%, and (▽) 30%. (a) G', (b) G", and (c) η*.

G' was higher compared to the G" at all values of ω with the frequency dependency confirming the viscoelastic nature of the SPS-glucose composites. Log η* versus log ω plots also showed shear-thinning power law characteristics. Similar trend was reported with other starch-sugar composites, such as rice starch-sucrose (2), corn starch-sucrose (4), amioca starch-sugars (sucrose and fructose), and cross-linked waxy corn starch-sucrose composites (11). Table 2 lists G', G", η*, and tan δ values at 30 rad/sec for the SPS-glucose composites. The magnitudes of dynamic moduli (G', G", and η*) markedly decreased at a low concentration of glucose, i.e., 10%, while a further increase in glucose concentration had a greater increasing effect on the dynamic moduli compared to the control. The dynamic moduli of the SPS-glucose composites also increased with increasing glucose concentration from 10 to 30%. The observed greater dynamic moduli at higher glucose concentrations, i.e., 20 and 30%, can be attributed to a large increase in the rate of conformational ordering (double-helix formation), as described by Evageliou *et al.* (13). Such conformation ordering and intermolecular association of starch chains seem to be dependent on the type and concentration of sugar and the botanical source of the starch, as explained by Gunaratne *et al.* (6). From the dynamic rheological data, it was also found that all the samples exhibited weak gel-like behavior because the slopes (G'=0.24-0.27, G"=0.30-0.36 Pa·sec, respectively) are positive and the values of G' (26.1-75.6 Pa) are higher than those of G" (12.6-28.3 Pa).

For all the samples, tan δ (the ratio of G"/G') values of the SPS-glucose composites were in the range of 0.37-0.48, which are greater than 0.1, indicating the dominance of elastic properties over viscous ones and also a typical behavior of weak gel. In particular, the tan δ values (0.38-0.48) of the SPS-glucose composites were higher than that (0.37) of the control, indicating the more pronounced elastic behavior of native starch pastes due to the existence of network structures. The tan δ values of the SPS-glucose composites decreased with an increase in glucose concentration, indicating that G' increased more strongly than G". These observations suggest that the elastic properties of SPS paste are affected by the presence of glucose and depend on glucose concentration. The G' values in dependence on glucose concentration can be explained by the swelling power of the starch granules, as discussed previously. The elastic properties in the SPS-glucose composite systems also seem to be primarily governed by the volume fraction of the starch granules induced by heating. Therefore, it can be concluded that the increase in swelling power with increasing glucose concentration results in an increase of the elastic properties.

The dynamic rheological data of log (G', G") versus log ω were also subjected to linear regression, and the slope values were obtained (Table 2). The slopes values of G' and G" of all the samples were positive with high determination coefficients (R^2=0.98-0.99), and were in the range of 0.24-

Table 2. Dynamic moduli (G', G", and η*) and tan δ at 30 rad/sec, and the slope values of log G' and log G" vs. log ω curves of SPS-glucose composites at 25°C

Glucose concentration (%)	G' (Pa)	G" (Pa)	η* (Pa·sec)	Tan δ	Slope of G' (Pa·sec)	Slope of G" (Pa·sec)
0 (no glucose)	39.9±1.50	14.7±0.20	1.42±0.05	0.37±0.01	0.27±0.01	0.31±0.00
10	26.1±1.97	12.6±1.05	0.97±0.07	0.48±0.00	0.24±0.02	0.36±0.01
20	42.6±2.87	18.7±0.01	1.55±0.09	0.44±0.03	0.24±0.03	0.34±0.00
30	75.6±1.79	28.3±0.45	2.69±0.06	0.38±0.00	0.24±0.00	0.30±0.00

0.27 and 0.30-0.36 Pa·sec, respectively. The slopes of G' were much lower than those of G", indicating that the SPS-glucose composites are more elastic than viscous, and that G" is more dependent on frequency than G' with G'>G" (Table 2), which is typical of weak gel. The slope values of G" of the SPS-glucose composites decreased with an increase in glucose concentration, indicating that the elastic properties of SPS paste can be increased by the addition of glucose at a given range of concentration, as described earlier.

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References

1. Noel TR, Ring SG, Whittam MA. Physical properties of starch products: Structure and function. pp. 126-137. In: Food Colloids and Polymers: Stability and Mechanical Properties. Dickinson E, Walstra P (eds). Royal Society of Chemistry Special Publication, Cambridge, UK (1993)
2. Yoo D, Yoo B. Rheology of rice starch-sucrose composites. Starch/Starke 57: 254-261 (2005)
3. Chang YH, Lim ST, Yoo B. Dynamic rheology of corn starch-sugar composites. J. Food Eng. 64: 521-527 (2004)
4. Chang YH, Lim ST, Yoo B. Effect of sucrose on the rheological properties of corn starch. Korean J. Food Sci. Technol. 33: 700-705 (2001)
5. Al-Malah KI, Azzam MOJ, Abu-Jdayil B. Effect of glucose concentration on the rheological properties of wheat-starch dispersions. Food Hydrocolloid 14: 491-496 (2000)
6. Gunaratne A, Ranaweera S, Corke H. Thermal, pasting, and gelling properties of wheat and potato starches in the presence of sucrose, glucose, glycerol, and hydroxypropyl β-cyclodextrin. Carbohyd. Polym. 70: 112-122 (2007)
7. Ahmad FB, Williams PA. Effect of sugars on the thermal and rheological properties of sago starch. Biopolymers 50: 401-412 (1999)
8. Genovese DB, Acquarone VM, Youn KS, Rao MA. Influence of fructose and sucrose on small and large deformation rheological behaviour of heated amioca starch dispersions. Food Sci. Technol. Int. 10: 51-57 (2004)
9. Schoch TJ. Methods in Carbohydrate Chemistry. Vol. 4. Whistler RL, Smith RJ, BeMiller JN (eds). Academic Press, London, UK. pp. 106-108 (1964)
10. Evans IC, Haisman DR. Rheology of gelatinized starch suspension. J. Texture Stud. 10: 347-370 (1979)
11. Acquarone VM, Rao MA. Influence of sucrose on the rheology and granule size of cross-linked waxy maize starch dispersions heated at two temperatures. Carbohyd. Polym. 51: 451-458 (2003)
12. Rao MA, Okechukwu PE, Da Silva PM, Oliveira JC. Behavior of heated starch dispersions in excess water: Role of starch granule. Carbohyd. Polym. 33: 273-283 (2007)
13. Evageliou V, Richardson RK, Morris ER. Effect of sucrose, glucose, and fructose on gelation of oxidised starch. Carbohyd. Polym. 42: 261-272 (2000)