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Flow Behavior of Sweet Potato Starch in Mixed Sugar Systems

– Research Note –

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Abstract

Flow behaviors of sweet potato starch (SPS) pastes (5% w/w) were studied in the presence of various sugars (xylose, glucose, fructose and sucrose) and sugar alcohols (xylitol and sorbitol). The flow properties of SPS-sugar mixtures were determined from the rheological parameters of power law model. The vane method was also employed for determining yield stresses of SPS-sugar mixtures directly under a controlled low shear rate. At 25°C all the samples showed shear-thinning behaviors (n=0.35～0.44) with yield stress. The consistency index (K) values of SPS-sugar mixtures increased in the following order: sorbitol> xylitol> control (no sugar)> sucrose> fructose> glucose> xylose, showing that the addition of sugar alcohols enhanced the K values. The yield stress values were reduced in the presence of sugars and sugar alcohols and they also increased with an increase in swelling power of starch granules in the SPS-sugar mixture systems.

Key words: sweet potato starch, sugar, flow behavior, viscosity, vane yield stress

INTRODUCTION

Sugars have functional properties other than providing sweetness. The addition of sugars to starch in food systems has been known to improve the storage stability and to modify the rheological properties. In particular, knowledge about the rheological properties of starch-sugar mixtures is very important for understanding the role of sugar interactions on gelatinization and retrogradation of starch (1). Therefore, several researchers have studied the effect of various sugars on rheological properties of native starches, such as sago (2), corn (3,4), potato (4,5), wheat (4,6) and oxidized starches (7). They found that the rheological properties of starch-sugar mixtures were influenced by sugar concentration, sugar type, and the nature of starch.

Viscosity measurements can also be conducted using vane geometry in order to estimate yield stress of food suspensions and starch dispersions. In general, estimation of yield stress by extrapolation of the shear stress-shear rate data by applying flow models (Herschel-Bulkley and Casson models) requires great care in obtaining reliable results. As a result of this limitation, only a few researchers (8-10) have recently begun studying the yield stress of starch dispersions using vane rheometry. They found that the vane method was useful for directly measuring the yield stress of starch dispersions. However, a study on the vane yield stress of SPS pastes in the presence of various sugars has not been performed.

Although extensive literature is available on the rheological properties of starch-sugar mixtures, there is no comparative study of the effect of various sugars on rheological properties of SPS pastes. In particular, no attempt has been made to study rheological properties of SPS pastes as affected by the addition of sugar alcohols. Therefore, the overall objective of this study was to determine the effect of sugars or sugar alcohols on rheological properties of SPS pastes. The vane yield stress was also investigated to examine their flow behaviors.

MATERIALS AND METHODS

Materials and preparation of starch pastes

Sweet potato starch (SPS) (16.2% moisture and 24.4% amylose) was purchased from Keumdeung Agriculture and Fishery Co. (Jeju, Korea). Sucrose, glucose, fructose, xylose, xylitol, and sorbitol used in this study were analytical grades and purchased from Sigma Chemical Co. (St. Louis, MO, USA). Starch dispersions (5% w/w) at a constant sugar concentration (10%) were prepared by mixing starch with distilled water, and sugars or sugar alcohols. A dispersion with no added sugar (control) was also prepared. The starch-sugar 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. At the end of the heating period, the hot starch paste was immediately transferred to the rheometer plate for the measurement of flow properties.

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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 (11). Starch pastes were prepared, as described previously. The hot starch paste was cooled to room temperature in an iced water bath and centrifuged at 3,300 rpm 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. No correction for solubles was made due to the high sugar concentrations used.

Flow behavior measurements

Steady shear rheological data were obtained at 25°C with a Rheometer (AR 1000, TA Instruments, New Castle, DE, USA) using a parallel plate system (4 cm dia.) with a gap of 500 μm. Each sample was transferred to the rheometer plate at the desired temperature and excess material was wiped off with a spatula. For flow rheological measurements, the sample was sheared continuously from 1 to 1000 $\sec^{-1}$, and the data were fitted to the well-known power law (Eq. 1).

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

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

Each sample mixture prepared for the vane yield stress measurements was immediately poured into a jacketed glass vessel (8-cm dia., 12-cm height) connected to a constant temperature circulator (Model DS50-K10, Haake GmbH, Karlsruhe, Germany) which can provide the working temperatures in the range of 0～90°C (±0.1°C). Magnitudes of yield stresses were obtained with a Haake VT550 viscometer (Haake Inc., Germany) at 25°C using a six-blade vane (4-cm dia., 6-cm height). The vane was gently placed in the sample and allowed to rest for 1 hr to recover its structure and reach the measurement temperature. Magnitudes of torque values were obtained at the lowest shear rate, 0.01 $\sec^{-1}$. The magnitudes of vane yield stress (σ_o) were calculated from the maximum torque value (T_m), the diameter (D), and the height (H) of the vane according to the equation (Eq. 2).

$$T_m = \frac{\pi D^3}{2}\left(\frac{H}{D} + \frac{1}{3}\right)\sigma_o \tag{2}$$

RESULTS AND DISCUSSION

Flow behavior

Rheograms of SPS pastes in the presence of sugars or sugar alcohols at 25°C indicated the non-Newtonian (pseudoplastic) nature with yield stress (Fig. 1). Table 1 also shows the magnitudes of rheological parameters from the power law model, which was used to describe the flow curves of all samples. The flow behavior indexes (n) of all mixtures were higher than that (0.35) of the SPS paste without sugar (control), indicating the less pseudoplastic behavior of the all mixtures. In particular, the n values of SPS-sugar alcohol mixtures were

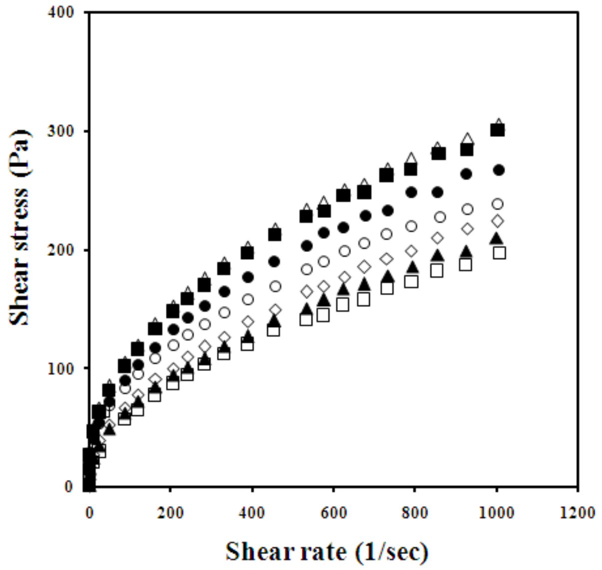

Fig. 1. Shear stress-shear rate plots for sweet potato starch pastes in the presence of sugars or sugar alcohols: (○) control, (□) xylose, (▲) glucose, (◇) fructose, (●) sucrose, (■) xylitol, and (△) sorbitol.

Table 1. Effect of sugars and sugar alcohols on steady shear rheological properties and swelling power of potato starch pastes at 25°C

Sugars	Consistency index K ($Pa{\cdot}s^n$)	Flow behavior index, n (-)	Vane yield stress σ_o (Pa)	Swelling power (g/g)
Control	18.2±0.00	0.35±0.00	12.7±0.00	21.5
Xylose	7.24±0.18	0.46±0.00	6.83±0.08	21.7
Glucose	9.02±0.04	0.44±0.00	7.24±0.12	23.6
Fructose	9.75±0.05	0.43±0.01	8.33±0.12	24.5
Sucrose	15.4±0.02	0.41±0.01	8.93±0.04	26.3
Xylitol	20.2±0.05	0.38±0.00	10.5±0.12	30.3
Sobitol	22.1±0.06	0.36±0.00	11.0±0.12	35.1

lower than those of SPS-sugar mixtures. The lower shear-thinning behavior of the mixtures compared to the control can be explained by recognizing that the presence of sugars or sugar alcohols reduces the rate of chain rearrangement in starches, reflecting the decrease in the elastic nature of starch, as indicated by Yoo and Yoo (11).

The consistency index (K) values (7.24～15.4 Pa·s^n) of SPS pastes mixed with sugars were much lower than that (18.2 Pa·s^n) of the control (Table 1), indicating that the order to deduce the K values was pentose (xylose) >hexose (glucose and fructose)>disaccharide (sucrose) >control. This is in contrast to the results of Abu-Jdayil et al. (6) and Genovese et al. (12) who found that the presence of sugars causes an increase in the K values of wheat and amioca starches, suggesting that the steady shear flow behaviors seem to be dependent on the botanical source of the starch. Among the sugars tested, the xylose was found to show the greatest reduction in K value. This is in good agreement with the results of a previous study of corn starch-sugar mixtures (3). Spies and Hoseney (13) and Baek et al. (14) proposed that larger sugar molecules can bridge longer gaps between starch chains and thus produce more crosslinks than smaller sugar molecules. Therefore, the increased K values of larger sugar molecules may result from the reduced chain flexibility caused by the crosslinks. In addition, the K values showed more pronounced effects on the addition of sugar alcohols compared to the corresponding sugars. According to Baek et al. (14), the higher number of OH groups in sugar alcohols can allow more chances for interactions with water, resulting in reduced water concentration. Therefore, the pronounced K values of SPS mixed with sugar alcohols can be attributed to the increased intermolecular association of starch chains due to the lack of effective water owing to hydration of sugar alcohol molecules. The K values can also be related to the swelling of starch granules in the SPS-sugar mixture systems, as shown in Table 1. The K values of all samples, except for the control, increased with an increase in the swelling power values, indicating that the increased K values could be regarded as a result of enhanced swelling power of starch granules. Cho and Yoo (1) also showed that the swelling power values of the SPS-glucose mixtures tended to increase with increasing K values at different glucose concentrations.

Vane yield stress

Fig. 2 shows changes in torque values as a function of time for the SPS-sugar mixtures. These curves exhibit ed an initial linear increase in stress that represents the elastic response of the material due to stretching of netw ork bonds. Following a peak stress where the material yielded, there is a stress decay that is related to the gradual structural breakdown (15). The addition of sugars or sugar alcohols had a greater decreasing effect on the vane yield stress compared to the control. In the SPS-sugar mixture systems, the order of effectiveness in increasing yield stress values follows the sequence: sorbitol> xylitol> sucrose> fructose> glucose> xylose (Table 1). The higher yield stress values of sugar alcohols (sorbitol and xylitol) compared to the corresponding sugars can be due to an increase in the elastic nature of the SPS pastes as a result of a large increase in the rate of conformational ordering and intermolecular association of starch chains, and due to the enhanced swelling power, as previously found in the flow behavior experiments. In addition, such increase in vane yield stress can be attributed to an increase in the binding energy of the network of the water-sugar-starch granule microstructures, as suggested by Acquarone and Rao (16). In the SPS-sugar mixture systems, the yield stress values also increased with an increase in swelling power, suggesting that the vane yield stress is strongly influenced by the swelling power. This increase was roughly proportional to the swelling power. From these observations, it was concluded that the swelling power of starch granules is an important factor affecting the flow behaviors of SPS-sugar mixtures, depending on the type of sugar.

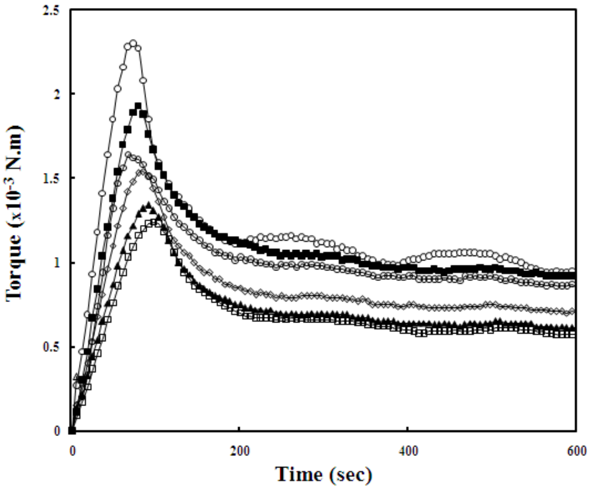

Fig. 2. Torque-time curves of sweet potato starch pastes in the presence of sugars or sugar alcohols: (○) control, (□) xylose, (▲) glucose, (◇) fructose, (●) sucrose, (■) xylitol, and (△) sorbitol.

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