Food Chemistry 230 (2017) 516–523

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Effects of oligosaccharides on pasting, thermal and rheological properties of sweet potato starch

Da-Nian Zhou [1], Bao Zhang [1], Bo Chen, Han-Qing Chen *

School of Food Science and Engineering, Hefei University of Technology, 193 Tunxi Road, Hefei, Anhui 230009, PR China

ARTICLE INFO

Article history:
Received 17 January 2017
Received in revised form 9 March 2017
Accepted 14 March 2017
Available online 16 March 2017

Keywords:
Sweet potato starch
Oligosaccharide
Pasting
Thermal property
Rheology

ABSTRACT

Effects of sucrose, raffinose and stachyose on pasting, thermal, and rheological properties of sweet potato starch (SPS) were investigated. The results indicated that pasting temperature of SPS increased with increasing sugar concentration in the order of stachyose > raffinose > sucrose. Addition of sugars significantly decreased the peak, trough, and final viscosities as well as setback value. The gelatinization temperatures of SPS-sugar mixtures markedly increased with increasing sugar concentration in the order of stachyose > raffinose = sucrose, gelatinization enthalpy also increased when sugar was added at high concentration compared with native starch. The addition of sugars increased the yield stress and consistency coefficient of SPS-sugar mixed pastes. The SPS-sugar mixed pastes exhibited a pseudoplastic and shear-thinning behavior under yield stress condition. Moreover, storage moduli (G′) of SPS-sugar mixed pastes decreased with addition of sugars. This study also showed that addition of sugars promoted liquid-like characteristics of SPS-sugar mixed pastes.

1. Introduction

Starch is one of the most abundant storage polysaccharide in plants, and it is widely used in food industry as food thickener, stabilizer, gelling agent, and water retention ingredient to improve the viscosity, textural properties, and stability of food products (Galkowska, Dlugosz, & Juszczak, 2013; Singh, Singh, Kaur, Sodhi, & Gill, 2003; Zhang, Tao, Niu, Li, & Chen, 2017; Zhang, Pan, et al., 2017). However, native starch sometimes does not meet the requirements of production due to its retrogradation tendency and instability under shear and acidic conditions. These changes would result in undesirable effects on the qualities of starch-based food products. To enhance the properties of starch-based products, non-starch hydrocolloids are often used to improve stability and maintain overall qualities during processing and storage of food products by controlling rheological and textural properties (Chaisawang & Suphantharika, 2005; Nagano, Tamaki, & Funami, 2008; Pongsawatmanit & Srijunthongsiri, 2008; Samutsri & Suphantharika, 2012). The effects of various hydrocolloids including xanthan gum, guar gum, carrageenan, or flaxseed gum on starch gels or pastes have been extensively studied in recent years. These studies have demonstrated that the addition of polysaccharide gums to starch pastes can increase viscosity and elasticity, and restrict retrogradation and syneresis of the starch-based systems (Achayuthakan & Suphantharika, 2008; Chaisawang & Suphantharika, 2005; Nagano et al., 2008; Tischer, Noseda, Freitas, Sierakowski, & Duarte, 2006; Wang et al., 2008).

The compositions of starch-based foods are generally complicated, and starch and gum usually co-exists with other ingredients (such as sugars) in many food products. As a low molecular weight component, sugars are widely used in starch-based food for taste and stability modification. The addition of sugars could alter the gelation, retrogradation, and rheological properties of starch, depending on the types as well as concentrations of both sugar and starch (Acquarone & Rao, 2003; Ahmad & Williams, 1999; Chang, Lim, & Yoo, 2004; Wang et al., 2016). Sugars can increase the peak viscosity and pasting temperature, restrict swelling and amylose leaching of starch (Ahmad & Williams, 1999; Baek, Yoo, & Lim, 2004; Krüger, Ferrero, & Zaritzky, 2003; Richardson, Langton, Bark, & Hermansson, 2003). Among sugars, sucrose is one of the major food ingredients that is used in the food products as a sweetener. Some previous studies have shown that sucrose can alter the thermal and physical properties of various starches and starch-gum mixtures (Ahmad & Williams, 1999; Chantaro & Pongsawatmanit, 2010; Gunaratne, Ranaweera, & Corke, 2007; Hirashima, Takahashi, & Nishinari, 2005; Lee & Yoo, 2014; Pongsawatmanit, Temsiripong, & Suwonsichon, 2007; Wang et al., 2009; Zhang, Tong, Zhu, & Ren, 2013).

* Corresponding author.
E-mail address: hanqchen@hfut.edu.cn (H.-Q. Chen).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.foodchem.2017.03.088
0308-8146/

Sweet potato (*Ipomea batatas* L.) is a dicotyledonous plant that belongs to the family *Convolvulaceae*. In China, annual production of sweet potato is 117 million tons, which accounts for about 90% of worldwide sweet potato production (Abegunde, Mu, Chen, & Deng, 2013). Sweet potato roots have been widely used in starch-based noodles, bakery foods, snack foods, confectionery products, starch syrup, alcohol and the brewing industries in China (Chen, Schols, & Voragen, 2003). Starch is the major component of sweet potato root, accounting for around 50–80% of the root on the basis of dry weight (Zhu, Yang, Cai, Bertoft, & Corke, 2011). Cho and Yoo (2010) reported that the addition of sucrose had the ability to retard retrogradation of sweet potato starch (SPS).

In recent years, some studies have explored the effects of sucrose on the pasting, thermal and rheological properties of various starches. However, few studies regarding the effects of raffinose or stachyose on pasting and rheological properties of SPS have been reported. Therefore, the aims of this study were to determine the pasting, thermal, rheological properties of SPS in the presence of sucrose, raffinose or stachyose according to different mixing ratios of SPS and sugar.

2. Materials and methods

2.1. Materials

Sweet potato starch (SPS) was supplied by Anhui Tianlong Potato Industry Co., Ltd., China. The sucrose (analytical reagent) was supplied by Shanghai Sinopharm Chemical Reagent Co., Ltd., China. Raffinose was obtained from Hefei Bomei Biotechnology Co., Ltd., China and the purity of raffinose was 98%. Stachyose was purchased from Xiya Chemical Industry Co., Ltd., China and the purity of stachyose was 99%. All other chemical reagents used were of analytical grade (Sinopharm Chemical Reagents Co. Ltd, Shanghai, China).

2.2. Determination of pasting properties

Effects of sugars on the pasting properties of sweet potato starch were determined by a Rapid Visco-Analyzer (RVA-4500, Perten Instruments, Sweden) according to the modified procedure of Chen, Fu, and Luo (2015). Firstly, sweet potato starch slurry was prepared by dispersing 1.5 g (dry basis) sweet potato starch into 23.5 g distilled water in RVA aluminum container. And then starch-sugar mixtures containing different levels of sucrose or raffinose or stachyose were prepared by adding 0.5, 1.0 or 1.5 g sugar into the sweet potato starch slurries according to different mixing ratios (starch/sugar = 3:1, 3:2, 3:3, w:w), respectively. The starch/sugar mixture samples were stirred manually using the plastic paddle before insertion into the RVA machine. The pasting parameters were measured according to the general pasting method (STD 2). The slurries were first held at 50 °C for 1 min, heated to 95 °C within 7.5 min, and then held at 95 °C for 5 min. The hot samples were subsequently cooled to 50 °C within 7.5 min, and maintained at 50 °C for 2 min. The agitation speed of paddle was started at 960 r/min for the first 10 s and fixed at 160 r/min throughout the rest of the run. The measurements were performed in triplicate and the averages were reported.

2.3. Thermal property measurements

The thermal properties of starch and starch/sugar mixtures were determined using a differential scanning calorimeter (Q200, TA instruments, New Castle, DE, USA) with an empty pan as reference using the method described by Zhang et al. (2013) with minor modification. Briefly, sweet potato starch (3 g) was accurately weighed and put into a 25-mL beaker. Distilled water or sugar was added into the beaker to obtain the samples (starch/water = 1:3, w:w) containing different levels of sugars (starch/-sugar = 3:1, 3:2, 3:3, w:w) or no sugar (the control). To avoid the endothermic peak of the dissolution of sugar, sugar solution rather than sugar crystals was put into the beaker. The samples were agitated uniformly by a magnetic stirrer, quantitatively moved into the aluminum DSC pans and the pans were hermetically sealed. All samples were allowed to equilibrate at 4 °C for 24 h and heated from 30 °C to 100 °C at a rate of 10 °C/min. The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and gelatinization enthalpy (ΔH) were analyzed and calculated by DSC software (TA instruments, New Castle, DE, USA). Experiments were conducted in triplicate.

2.4. Rheological measurements

Rheological properties of starch and starch-sugar mixed pastes obtained from the RVA experiments were determined using a rheometer (DHR-3, TA Instruments Inc., USA) equipped with a parallel plate geometry (40 mm diameter, 1.0 mm gap) according to the method of Lu, Luo, and Xiao (2012) with some modification. For steady shear measurements, shear rates ranging from 1 to 100 (s^{-1}) were used and the shear time was 2 min. The relationship between shear stress and shear rate was recorded at 25 °C. The experimental data were fitted by a Herschel-Bulkley's model:

$$\tau = \tau_0 + K\varepsilon^n$$

where τ is shear stress (Pa), τ_0 is yield stress (Pa), K is consistency coefficient ($Pa \cdot s^n$), ε is shear rate (s^{-1}) and n is flow behavior index.

The samples were also subjected to dynamic oscillatory deformation at frequencies ranged from 0.1 to 100 rad/s at a strain of 1%, which was within the linear viscoelastic region. The mechanical spectra were obtained by recording the storage modulus (G′), loss modulus (G″) and loss tangent ($\tan\delta = G''/G'$) as a function of angular frequency.

The experimental data were fitted by a power law equations:

$$G' = K'\omega^{n'}$$

$$G'' = K''\omega^{n'}$$

where G′ is storage modulus (Pa), G″ is loss modulus (Pa), ω is angular frequency (rad/s), K′, K″ and n′, n″ are constants. The values of $\tan\delta$ at 6.28 rad/s were calculated by the above equations (Galkowska et al., 2013). All rheological tests were carried out at 25 °C and all measurements were performed in triplicate.

2.5. Statistical analysis

Results are expressed as the mean ± standard deviation of triplicate experiments. Data were analyzed by one-way analysis of variance (ANOVA), followed by Duncan's multiple range test using SPSS 17.0 Statistical Software Program (SPSS Incorporated, Chicago). A value of $P < 0.05$ was considered statistically significant.

3. Results and discussion

3.1. Pasting properties

The pasting behaviors of the sweet potato starch slurry (6%) and SPS-sugar mixtures containing different levels of sucrose, raffinose or stachyose (starch/sugar = 3:1, 3:2, 3:3, w:w) were recorded by RVA and the pasting curves of SPS and SPS-sugar mixtures were presented in Fig. 1. As shown in Fig. 1, the native starch had the highest peak viscosity and final viscosity. However, the peak and