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Evaluation studies on effects of pectin with different concentrations on the pasting, rheological and digestibility properties of corn starch

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ABSTRACT

In this paper, the effects of pectin (PE) with different concentrations on the pasting, rheological and digestibility properties of corn starch (CS) were evaluated. The Rapid Visco-Analyzer results showed that the peak viscosity was decreased with the concentrations of PE (0.5% and 1.0%) and then increased when the concentration of PE exceeded 2.0%. PE resulted in lower breakdown and setback values of CS. Rheological results revealed that the CS and CS-PE mixtures exhibited a pseudoplastic and shear-thinning behavior. The storage modulus (G′) and loss modulus (G″) of CS were increased with increasing PE concentrations from 2.0% to 10.0%. PE resulted in a decrease in the starch susceptibility to α-amylase and promoted a remarkable reduction ($P < 0.05$) in the fraction of rapidly digested starch. The hydrolysis kinetic analysis suggested a decelerating effect of pectin on the hydrolysis rate of CS with lower values of equilibrium hydrolysis percentage (C_∞) and kinetic constant (k).

1. Introduction

Starch was one of the most abundant storage carbohydrate in plants, and had been extensively used in food fields due to its low cost and biocompatibility (Ahmadi-Abhari, Woortman, Hamer, Oudhuis, & Loos, 2013; Tan et al., 2012; Zhang, Mei, Chen, & Chen, 2017; Zhang, Tao, Niu, Li, & Chen, 2017). However, native starch sometimes failed to meet the requirements as a material in food industry because of its retrogradation and instability under acidic and heated conditions. According to previous researches, it was found that the digestibility, texture and stability of starch products could be improved with the addition of some components such as non-starch hydrocolloids (Shi, Fu, Tan, Huang, & Zhang, 2017; Xiong et al., 2018; Zhou, Zhang, Chen, & Chen, 2017).

Blends of starch with hydrocolloids such as konjac flour, guar and xanthan had been applied in foods to modify the texture and control moisture and water mobility. Achayuthakan and Suphantharika (2008) claimed that the viscosity and pasting temperature of waxy corn starch dispersion during pasting increased with increasing guar or xanthan gums concentration. Li, Zhu, Guo, Peng, and Zhou (2016) showed that the addition of barley β-glucan induced a significantly increase of pasting viscosities ($p < 0.05$). Chaisawang and Suphantharika (2005) claimed that xanthan and guar gum increased the RVA peak viscosity of cationic tapioca starch and played an important role in the rheological properties of pastes. Hydrocolloids could interfere in the formation of physical entanglements between starch and water. They could influence the melting, gel-formation, fragmentation, and starch retrogradation processes, which mainly depended on the hydrophilic group of hydrocolloids.

Pectin (PE) was one of the hydrocolloids, which was widely used in food industry as a stabilizing or gelling agent (Luo et al., 2017). It was reported that PE resulted in higher viscosity of gelatinized potato starch and lower digestibility (Sasaki, Sotome, & Okadome, 2015). The enthalpy of normal maize starch remained unchanged when the concentration of PE was at 0.5% (Tester et al., 2003). Most of the studies had reached a consensus that hydrocolloids affected the pasting and digestibility of various starch. However, there were few studies referring to the effects of PE with different concentrations on the pasting, rheological and digestibility properties of CS. Therefore, the purpose of our study was to provide insight into the pasting, rheological and digestibility properties of CS with different concentrations of PE.

2. Materials and methods

2.1. Materials

Corn starch (CS) was supplied by Xi Wang Group Co., Ltd., China. The amylopectin, amylose, lipid, protein and moisture contents of CS

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were 63.7%, 25.3%, 0.52%, 0.28%, and 10.2%, respectively. Pectin (PE) was purchased from Yantai Andre pectin Co., Ltd., China, and the degree of esterification of PE was 32.3%. Porcine pancreatic α-amylase (13U/mg) was purchased from Sigma-Aldrich Chemical Co., Ltd. (Shanghai, China). Amyloglucosidase (100 Umg) was purchased from Shanghai yuanye Bio-Technology Co., Ltd., China. All other chemical and reagents were of analytical grade (Sinopharm Chemical Reagents Co. Ltd, Shanghai, China).

2.2. Pasting properties

The pasting characteristics of starch system were determined using Rapid Visco-Analyzer (RVA-4500, Perten Instruments, Sweden) according to the method with some modifications (Zhang et al., 2018). Firstly, the CS slurry (8%, 25 g total weight) was suspended in deionized water in RVA aluminum container. Then the PE (0%, 0.5%, 1.0%, 2.0%, 5.0% and 10.0% of starch; w/w) was added, respectively. The calculated amounts of PE powder were primarily dissolved thoroughly by stirring of a plastic paddle before being put into the RVA machine. The pasting parameters of samples were measured in the following pasting method (STD_1). The slurries were held at 50 °C for 60 s, then heated to 95 °C within 240 s, held at 95 °C for 120 s, cooled to 50 °C within 240 s and held at 50 °C for 120 s, while the speed of paddle was kept at 160 rpm. At the beginning of 10 s, the paddle speed was 960 rpm. The measurements were performed in triplicate and the averages were reported.

2.3. Rheological properties

The rheological properties of the CS and CS-PE mixed pastes obtained from RVA were measured by a rheometer (DHR-3, TA Intruments Inc., USA). Samples were transferred to the rheometer plate (40 mm diameter, 0.5 mm gap) and equilibrated at 25 °C for 5 min before being determined. According to the modified method (Qiu et al., 2015; Wang, Zou, Gu, & Yang, 2018; Wang, Zou, Liu, Gu, & Yang, 2018), steady shear measurements were performed over the shear range of 0.1–100 s^{-1}. The Herschel-Bulkley's model was used to calculate the experimental curves (Chen, Zhang, Li, Xie, & Chen, 2018; Zhou et al., 2017):

$$\tau = \tau_0 + K\varepsilon^n \quad (1)$$

where τ was shear stress (Pa), τ_0 was yield stress (Pa), K was consistency coefficient (Pa·s^n), ε was shear rate (s^{-1}) and *n* was flow behavior index.

Before the test of frequency sweep, a strain sweep had been done and the linear viscoelastic range of samples was obtained. In the test of frequency sweep, the 1% strain was in the linear viscoelastic region according to the strain sweep results (data not shown). Dynamic oscillatory was also determined at a strain of 1% in the angular frequency of 0.1–100 rad/s. The mechanical spectra were obtained recording storage modulus (G'), loss modulus (G") as a function of frequency (ω).

2.4. In vitro digestibility and the digestion kinetics

The pastes of CS and CS-PE mixtures obtained from the RVA experiments were dried in a vacuum dry oven at 45 °C for 10 h and milled to pass through a 200-mesh sieve. The digestibility of resultant samples was measured according to the method with some modifications (Englyst & Hudson, 1996; Lv et al., 2018). Briefly, 100 mg of samples were put into a 100 mL conical flask and dispersed in sodium acetate buffer (pH 5.2). The sample solution was shaken with four glass balls at 37 °C for 5 min, and 5 mL of the enzyme solution (α-amylase 150 U/mL and amyloglucosidase 100 U/mL) was added into each flask. The hydrolyzed fluid was taken at time intervals of 20 and 120 min, and then mixed with 4.5 mL of absolute ethyl alcohol immediately to deactivate the enzyme. Subsequently, the solution was centrifuged at 1500*g* for 10 min, and the glucose content of supernatant was determined using a glucose oxidase–peroxidase assay kit (GAGO20, Sigma). The values of starch fractions (RDS, SDS, and RS) were calculated using the following formulas:

$$RDS(\%) = [\frac{G_{20} - FG}{TS}] \times 0.9 \times 100 \quad (2)$$

$$SDS(\%) = [\frac{G_{120} - G_{20}}{TS}] \times 0.9 \times 100 \quad (3)$$

$$RS(\%) = [(TS - RDS + SDS)/TS] \times 100 \quad (4)$$

where G_{20} and G_{120} represented the contents of glucose released after 20 min and 120 min, respectively. FG was the free glucose content, while TG was the total glucose after the starch was thoroughly hydrolyzed into glucose and 0.9 was the factor conversion from glucose to starch.

The rate of starch digestion kinetics were measured and calculated in accordance with the procedure established by Goñi, Garcia-Alonso, and Saura-Calixto (1997) with a minor modification. Digestibility curves were fitted to the first-order equation (Bai et al., 2017; Li & Gilbert, 2018):

$$C = C_\infty \times (1 - e^{-kt}) \quad (5)$$

where C was the percentage of starch digested at t time, C_∞ was the estimated concentration of hydrolyzed starch at ∞ time, k was the kinetic and t was the time of starch hydrolysis.

2.5. Statistical analysis

Each test was performed in triplicate, and the reported result was expressed as the mean ± standard deviation. Data were analyzed with Duncan's test using SPSS 17.0 Statistical Software Program (SPSS Incorporated, Chicago). A value of $p < 0.05$ was considered to be statistically significant.

3. Results and discussion

3.1. Pasting properties

The pasting characteristics of the CS slurry and CS-PE mixtures containing different ratios of PE (PE/CS = 0.5%, 1.0%, 2.0%, 5.0%, and 10.0%, w/w) were summarized in Fig. 1 and the pasting characteristics were presented in Supplementary Table 1. Peak viscosity was a measure of the swelling power of the starch in terms of the resistance of swollen

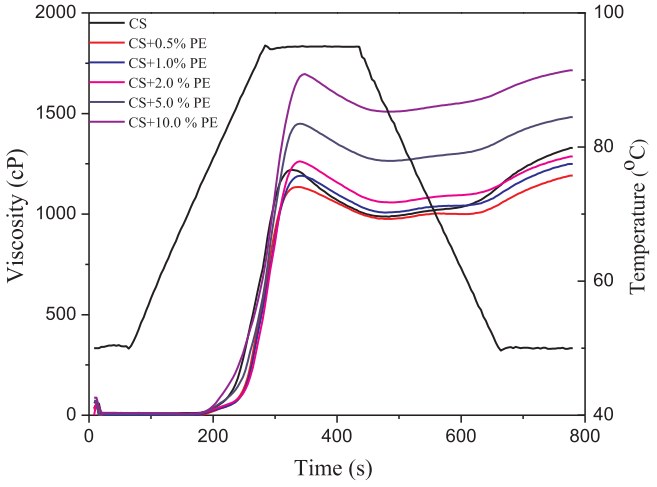

Fig. 1. RVA curves of CS and CS-PE mixtures at different mixing ratios (PE/CS = 0.5%, 1.0%, 2.0%, 5.0%, and 10.0%, w/w); CS indicates corn starch; PE indicates pectin.