Food Hydrocolloids 40 (2014) 64–70

Contents lists available at ScienceDirect

Food Hydrocolloids

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

Effect of sucrose fatty acid esters on pasting, rheological properties and freeze–thaw stability of rice flour

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ARTICLE INFO

Article history:
Received 1 December 2013
Accepted 14 February 2014

Keywords:
Sucrose fatty acid esters
Rice flour
Gelatinization
Rheological properties
Freeze–thaw stability

ABSTRACT

The present research is aimed to evaluate the effects of sucrose fatty acid esters (SEs) on the pasting, rheological properties and the freeze–thaw stability of rice flour. Four types of SEs including S-570, S-970, S-1170 and S-1570 with hydrophilic–lipophilic balance (HLB) values varying from 5 to 15 have been compared. Viscosity behavior of rice flour with different SEs was first measured with the Rapid Visco Analyzer (RVA). The RVA profile showed that pasting temperature, peak and final viscosities of rice flour gels increased with SEs addition except for S-570. Rheological properties including the steady shear characteristics, the viscoelastic parameters (storage and loss moduli) and the creep-recovery response were determined. The obtained steady shear and creep data were fitted by power law ($R^2 > 0.983$) and Burger's models ($R^2 > 0.993$) respectively. The results revealed that the addition of SEs except for S-570 increased the storage and loss moduli, apparent viscosity, flow behavior index and the retardation time, and decreased loss tangent. Finally, the freeze–thaw measurement demonstrated that all types of SEs enhanced the freeze–thaw stability of rice flour with the order of S-1570 > S-1170 > S-970 > S-570. These results could have important theoretical and practical implications in choosing suitable SEs for the particular requirements of final food products based on rice flour.

1. Introduction

Rice is the primary food grain consumed in China and other Asian countries (Sun & Yoo, 2011). There are many kinds of commercial rice products, such as baby foods, puffed grain, noodles, rice cakes and snack foods. Recently, rice was also studied as a wheat substitute in gluten-free food products (Lucisano, Cappa, Fongaro, & Mariotti, 2012; Sivaramakrishnan, Senge, & Chattopadhyay, 2004). However, the use of rice flour and starch as a wheat substitute exhibits some disadvantages, such as the weak ability to form viscoelastic dough (Lucisano et al., 2012), the tendency for extensive retrogradation and syneresis after freezing and thawing (Katekhong & Charoenrein, 2012).

In the food industry today, the application of various emulsifiers offers a good way to achieve suitable properties of final food products, optimize the production process, and guarantee constant quality (Stampfli & Nersten, 1995). Many researchers have demonstrated that the addition of commercial emulsifiers such as diacetyl tartaric acid esters of monoglyceride, glycerol monostearate, lecithin, sucrose esters, and milk proteins to raw starch can strongly improve the rheological and quality characteristics (Ashwini, Jyotsna, & Indrani, 2009; Ding & Yang, 2013; Stampfli & Nersten, 1995; Turabi, Sumnu, & Sahin, 2008). However, compared with other starches, much less effort has been devoted to studying the influence of emulsifiers on rice starch or flour (Banchathanakij & Suphantharika, 2009; Huang, Kennedy, Li, Xu, & Xie, 2007). Recently, Banchathanakij and Suphantharika (2009) studied the effect of β-glucans on the gelatinization and retrogradation properties of rice starch, while Correa, Ferrero, Puppo, and Brites (2013) investigated the influence of locust bean gum on rice flour gels focusing on the rheological properties.

Sucrose fatty acid esters (SEs), also known as sugar esters, are non-ionic type emulsifiers. Because sucrose has eight free hydroxyl groups, it can be esterified with up to eight fatty acids to form esters which consist of a hydrophilic sugar head and one or more lipophilic fatty acid tails. As a result, SEs can provide various hydrophilic–lipophilic properties with hydrophilic–lipophilic balance (HLB) values ranging from 1 to 16 (Chansanroj & Betz, 2010) which can meet specific needs for food products. Because of this variety, as well as other advantages such as tasteless and biodegradable properties, SEs have been widely used in food, pharmaceuticals and cosmetics industry (Szűts & Szabó-Révész, 2012). According to

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http://dx.doi.org/10.1016/j.foodhyd.2014.02.004
0268-005X/

previous studies (Addo, Slepak, & Akoh, 1995; Ebeler & Walker, 1984; Selomulyo & Zhou, 2007), the addition of SEs could improve the physicochemical and functional properties of wheat starch. For example, it was found that the alveograph rheological characteristics of wheat flour doughs improved as HLB value of the sucrose ester increased (Addo et al., 1995). However, there is no information available in the literature on the effect of SEs on rheological and functional properties of rice flour, especially on the use of SEs with different HLB values for particular product requirements.

The objective of this study is therefore to examine the influence of SEs on the pasting, rheological properties and freeze–thaw stability of rice flour. Physical properties, especially the rheological behavior, play an important role in controlling process conditions and producing rice flour based products with desirable textures (Sun & Yoo, 2011). Rheological properties including the steady shear characteristics, the viscoelastic parameters (storage and loss moduli) and the creep-recovery response were determined. The obtained steady shear and creep data were fitted by power law and Burger's models respectively. On the other hand, since the structure and physical properties of the amylose-emulsifier molecule complex mostly depend on the type of the emulsifier molecules (Bemiller, 2011), the effect of four SEs with different HLB values varying from 5 to 15 were compared in this study. The results could have important theoretical and practical implications in choosing suitable SEs for the particular requirements of final food products based on rice flour.

2. Materials and methods

2.1. Materials

Japonica rice provided by Zhejiang Wufangzhai Co., Ltd (Jiaxing, China) was cultivated in Wuchang, China. The rice was first ground to flour by using an electric mill, and then sieved through a 177 μm mesh size sieve. The composition of rice flour was analyzed by the standard AACC (2000) procedures. The composition of rice flour was as follows (*w*/*w*, wet basis): moisture content, 12.04%; crude starch, 80.03%; protein, 6.71%; and lipid, 0.84%. All SEs used in this study were kindly supplied by Mitsubishi-Kagaku Foods Corporation (Tokyo, Japan). The series of "S" is short for the sucrose stearate. The details of SEs used in this study are provided by the supplier Mitsubishi-Kagaku Foods Corporation (2003) and shown in Table 1. The ultra-pure water with resistivity of 18.2 MΩ cm was used for sample preparation.

2.2. Rapid Visco Analyzer (RVA) measurements

The pasting properties of rice flour (RF) or RF–SEs mixtures suspended in ultra-pure water were determined by a RVA (Model RVA-4, Newport Scientific Pty. Ltd, Warriewood, Australia). RF–SE mixtures were prepared by replacing 0.7% (*w*/*w*) of RF with S-570, S-970, S-1170 or S-1570 respectively. RF or RF–SE mixture (3 g at 12% moisture basis) was added with distilled water to reach a total weight of 28 g in the aluminum RVA canisters (Abiodun & Akinoso, 2014). The test temperature was first held at 50 °C for 1 min, then increased to 95 °C in 3.75 min at a constant rate, held at 95 °C for 2.5 min, decreased to 50 °C in 3.75 min at a constant rate, and then held at 50 °C for 1.5 min. The rotation speed of the plastic paddle was set at 960 rpm in the first 10 s and then maintained at 160 rpm.

Table 1
Details of different types of sucrose fatty acid ester used in this study.

Type	HLB	Ester composition (%)		Melting temperature	
		Monoester	Di-, Tri-, Polyester	Start point (°C)	Peak point (°C)
S-570	5	30	70	50	57–65
S-970	9	50	50	49	56
S-1170	11	55	45	49	55
S-1570	15	70	30	49	55

RVA characteristic parameters were determined from the RVA curves, including pasting temperature (PT), peak viscosity (PV), trough viscosity (TV, viscosity at the end of 95 °C), final viscosity (FV, viscosity at the end of test), breakdown value (BDV) and setback value (SBV). Results of each RVA characteristics were presented as means ± SD of triplicate determinations.

2.3. Rheological properties

The gelatinized gel of RF or RF–SE mixture was prepared by RVA with the same program as described above, and was cooled to 25 °C and held for 5 min (Zhang, Tong, Zhu, & Ren, 2013). Air bubbles formed and trapped in gels were removed by centrifuging at 1000 rpm for 1 min before all rheological measurements. These freshly prepared gels were used for rheological measurement by a controlled-stress rheometer (ARG2, TA Instruments, New Castle, USA) using a 40-mm parallel plate. All the steady, viscoelastic and creep-recovery properties were determined at 25 °C. An equilibration time of 2 min was applied to all samples before measurement.

2.3.1. Steady shear viscosity measurements

The plate was programmed to increase the shear rate from 0.01 to 100 s^{-1} with 5 points per decade and the gap was set at 1 mm. Shear stress and viscosity values were obtained as a function of shear rate. The flow behaviors of RF or RF–SE gels were analyzed by using a power law model as

$$\sigma = K \cdot \gamma^n \quad (1)$$

where σ is the shear stress (Pa), γ is the shear rate (s^{-1}), K is the consistency coefficient (Pa s^n), and n is the flow behavior index (dimensionless). Eq. (1) is often used to describe the behavior of non-Newtonian fluids (Samutsri & Suphantharika, 2012).

2.3.2. Dynamic viscoelastic measurements

The gelatinized gel mixtures obtained from RVA tests were used for the dynamic oscillatory measurement freshly and then kept at 4 °C for 30 days for testing again at the same conditions. A frequency sweep was conducted over the range of 0.1–10 Hz at 1% strain (within the linear viscoelastic region). The gap was set at 1 mm. Storage modulus (G'), loss modulus (G'') and loss tangent ($\tan\delta = G''/G'$) were obtained from TA rheometer Data Analysis software (version 5.7.1).

2.3.3. Creep-recovery measurements

The fresh gel was rested between the plates for 3 min before testing to allow residual stresses to relax and the gap was set at 3 mm. In order to minimize the water loss during measurements, the outer edge of sample was coated with silicone oil (Zhang et al., 2013). Creep-recovery test was carried out applying on the gel a constant stress (10 Pa) for 120 s and allowing strain recovery for 180 s after removal of stress. The strain values were collected as a function of time. All measurements were performed in triplicate at 25 °C.

2.4. Freeze–thaw stability measurements

Samples were prepared following the method of Muadklay and Charoenrein (2008). RF or RF–SE mixtures (0.7% SE on basis of RF,