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Sucrose substitution by polyols in sponge cake and their effects on the foaming and thermal properties of egg protein

Yuehui Hao [a], Feng Wang [b], Weining Huang [a,*], Xiaojuan Tang [a], Qibo Zou [b], Zhibin Li [c], Akihiro Ogawa [d]

[a] The State Key Laboratory of Food Science and Technology, School of Food Science and Technology, Jiangnan University, Wuxi, 214122, China
[b] Fortune Bakery Co. Ltd., Zhangjiagang, Jiangsu, 215632, China
[c] Fujian WheatCity Food Development Co., Ltd., Jinjiang, 362200, China
[d] Mitsubishi-Kagaku Foods Corporation, Yokohama, 227-8502, Japan

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A B S T R A C T

Three polyols (maltitol, xylitol, and erythritol) were used to replace sucrose in sponge cake formulation and their effects on the foaming and thermal properties of egg protein in liquid whole egg (LWE) and the qualities of resulted sponge cake were investigated. It turned out that, the presence of maltitol acted closest to sucrose in sponge cake system. LWE with both sucrose and maltitol had relatively higher apparent viscosity and temperature of protein denaturation, while the substitution by xylitol and erythritol increased these parameters to a smaller extent. Surface tension and pH values of LWE solution with different sweeteners presented no significant difference. The replacement of sucrose by polyols increased %overrun and air phase fraction of LWE foam, indicating an increase in foaming ability, while the replacement by xylitol and erythritol reduced the foaming stability significantly ($P < 0.05$). The observation of microstructure of LWE foam also confirmed the effects of sucrose and polyols on the foaming properties of LWE. When compared to sucrose, the treatment with maltitol resulted in similar specific volume of sponge cake, while xylitol and erythritol significantly ($P < 0.05$) decreased this parameter. Positive linear relationship was observed between foam stability and specific volume of resulted sponge cake in this study.

1. Introduction

As a principal ingredient in sponge cakes, sucrose exerts its effect not only by providing energy and sweetness, but also by: (1) retarding and restricting gluten network formation during mixing; (2) increasing the viscosity of cake batter and improving its air holding capacity; (3) increasing the temperatures of egg protein denaturation and starch gelatinization; (4) causing Maillard reaction and Caramel reaction, which contributes to both color and flavor of the cake (Wilderjans, Luyts, Brijs, & Delcour, 2013). So the utilization of sucrose in sponge cake is of importance, which can affect the color, texture and flavor of the final baked products. However, foods being rich in added sucrose are a known risk factor for obesity, diabetes, and cardiovascular disease (Horton & Jeanrenaud, 1990; Liu et al., 2002; Quatromoni et al., 2002). Hence, it is necessary to explore possible substitutes for traditional sweeteners to produce healthier foods with reduced sugar or sugar free. Several studies have been done along this line (Attia, Shehata, & Askar, 1993; Baeva, Terzieva, & Panchev, 2003; Hicsasmaz, Yazgan, Bozoglu, & Katnas, 2003). Polyols are typical sucrose replacers low in calories and low in glycemic index, that when consumed may lower the risk of obesity and diabetes (Kroger, Meister, & Kava, 2006). The applications of polyols in bakery products have been studied for decades (Baeva et al., 2003; Kamel & Rasper, 1988; Kroger et al., 2006). Lin, Hwang, and Yeh (2003) studied the replacement of sucrose with erythritol in chiffon cake. Ronda, Gómez, Blanco, and Caballero (2005) evaluated the application of maltitol, mannitol, xylitol, sorbitol, isomaltose, polydextrose and oligofructose in sucrose free sponge cakes. Akesowan (2009) used a mixture of erythritol and sucralose to produce fat-reduced chiffon cakes. Recently, Psimouli and Oreopoulou (2012) researched the possibility of replacing sugar in cake formulations by an equal amount of mannitol, maltitol,

* Corresponding author.
E-mail address: wnhuang@jiangnan.edu.cn (W. Huang).

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sorbitol, and lactitol. It's observed that, most of these studies were focused on the effects of substitution by polyols on the thermal and rheological properties of cake batter or/and sensory and texture properties of bakery products. Also, the effects of polyols as sucrose substitutes on starch gelatinization have sometimes been investigated (Akesowan, 2009; Psimouli & Oreopoulou, 2012). However, the difference between the effects of sucrose and polyols on the functional properties of egg proteins has not been conclusively elucidated, as well as the correlations between the properties of egg proteins and the end-use quality of sponge cake.

As foam type cake, sponge cake depends on the air trapped in the beaten egg for most of their leavening (Conforti, 2006; Wilderjans et al., 2013). Its batter is made in two basic steps. After egg and sugar are whipped into a thick, pale foam, the other ingredients such as flour and oil/melted butter are folded in (Wilderjans et al., 2013). Considering the importance of egg protein in sponge cake making, it is necessary to study its functional properties after being treated with sucrose/polyols. In this study, three kinds of polyol (maltitol, xylitol, and erythritol) were used to replace sucrose in sponge cake formulation. The object of this study was to evaluate the different effects of sucrose and polyols on the foaming and thermal properties of liquid whole egg, and to explore possibility of polyols used as sucrose substitution in sponge cake producing, which will provide useful information in developing foods with reduced sugar or sugar free.

2. Materials and methods

2.1. Materials

Commercial wheat flour with 13.9% moisture content, 8.5% crude protein content and 0.8% ash content measured according to methods 44-15A, 46-12, 08-01 (AACCI 2000), respectively, was purchased from Nanshun Flour Co., Ltd (Jingyuan, Shenzhen, China). Maltitol, xylitol, erythritol and sucrose were obtained from Lvjian Biotech Co., Ltd (Shandong, China), Shandong Longlive Biotech Co., Ltd (Shandong, China), Shandong Sanyuan Bio-tech Co., Ltd (Shandong, China), and Guangzhou Huaqiao Sugar factory (Guangzhou, China), respectively. Soybean oil and fresh eggs were purchased from local market in Wuxi, China. Liquid whole egg (LWE) with protein content of 13.96% (method 984.13, AOAC, 2006) was prepared by breaking fresh egg manually and mixing egg white and yolk evenly. All other reagents used in this study were purchased from Sinopharm Chemical Reagent Co., Ltd (Shanghai, China) and were of analytical grade.

2.2. pH, surface tension and apparent viscosity measurement of LWE solution and differential scanning calorimetry (DSC) measurement

To evaluate the effects of sucrose replacement by polyols on pH value, surface tension and apparent viscosity of LWE, LWE solutions were prepared. According to the formulation of sponge cake, 180 g LWE and 100 g sweeteners were poured into a mixer bowl (5K5SS Kitchen Aid Mixer, St. Joseph's, MI, USA) and mixed by a wire whip at room temperature (25 °C), until the sweeteners were completely dissolved. To avoid bubble formation, low mixing speed was adopted (speed 1 for about 2 min). The apparent viscosity of LWE solution was directly analyzed using a NDJ-1 rotational viscometer (Shanghai Precision Instrument Co., Ltd., China) with a #3 spindle revolved at a speed of 30 rpm at room temperature. After LWE solution was diluted with distilled water at the ratio of 1:10 (v/v), the surface tension was measured by a DCAT21 automatic surface tension meter (Dataphysics, German) and the pH value was measured with MP225 pH meter (Mettler-Toledo, Switzerland).

The denaturation temperature was also tested using the LWE solution by DSC. A portion (10 mg) of LWE-sucrose/polyols solution was placed into an aluminum DSC pan. The pan was hermetically sealed and scanned from 20 °C to 130 °C at a heating rate of 10 °C/min. An empty sealed pan was used as a reference. The denaturation temperature of egg proteins was evaluated from the thermograms using a Pyris 1 DSC (PerkinElmer, Ltd., Waltham, MA, USA).

2.3. Gelling characteristic

For gel hardness test, 50 g LWE-sucrose/polyols solution was poured into a cylindrical aluminum tube with inner diameter 40 mm, height 70 mm, and then the tube was sealed with plastic wrap. Samples were pretreated according to the method reported by Raikos, Campbell, and Euston (2007): Tubes were heated in a water bath at 90 °C for 30 min and then cooled down in ice water for 30 min. Texture profile analysis (TPA) was performed using Brookfield CT3 Texture Analyzer (Brookfield Engineering Laboratories, Inc., MA, USA) according to Raikos et al. (2007) with slight modification: A cylindrical plunger (TA11/1000, diameter 25.4 mm) was used to penetrate the gel in tube to 50% of its original height at a test speed of 1.0 mm/s. The hardness defined as the maximum peak force measured during the first penetration was recorded.

2.4. Foam preparation and foam characteristics

According to the exact manipulation of sponge cake preparation, egg foams with sucrose/polyol (maltitol, xylitol, erythritol) were generated using a 5K5SS Kitchen Aid Mixer (St. Joseph's, MI, USA) at room temperature (25 °C). Sucrose/polyols (100 g) and LWE (180 g) were whipped with wire whip at speed 4 for 4 min, followed by mixing at speed 6 for 20 min, and then the egg foam was obtained.

The foam ability of egg protein affected by sucrose/polyols was measured as overrun and air phase fraction according to the method reported by Yang and Foegeding (2010) with slight modification:

$$\%\text{Overrun} = (\text{wt.}100\text{ mL solution} - \text{wt.}100\text{ mL foam}) \times /\text{wt.}100\text{ mL foam} \times 100. \quad (1)$$

$$\text{Air phase fraction } (\Phi) = \%\text{ overrum}/(\%\text{ overrun} + 100) \quad (2)$$

At the same time, liquid drainage of the egg foam was measured to assess the foam stability following the method reported by Wang, Huang, Rayas-Duarte, Wang, and Zou (2013) with slight modification: Liquid drainage was calculated as the volume of liquid separated from 250 g of egg foam in a 3 h holding period at room temperature.

2.5. Foam microstructure observation

The egg foam bubble distribution was determined using microscopy methods and a digital camera (Motic, Motic China Group Co., Ltd, China). The egg foam was spread on a slide and covered with a cover glass, then mounted onto the microscope. A magnification of x 4 was used. Microstructure of egg foam with different sweeteners was evaluated using software Image J by the method of Li et al. (2011). The scanned color image was first cropped to a field of view of known size and converted to grayscale. Pixel values were then converted into distance units based on a given bar of known length. The grayscale image was thresholded with the Otsu algorithm through the Image J software. The contrast between the two phases (pores and solids) was compared by the software. Pore area