Food Hydrocolloids 24 (2010) 227–238

Contents lists available at ScienceDirect

Food Hydrocolloids

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

Effects of sucrose on egg white protein and whey protein isolate foams: Factors determining properties of wet and dry foams (cakes)

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ARTICLE INFO

Article history:
Received 4 June 2009
Accepted 26 September 2009

Keywords:
Sucrose
Whey
Foams
Interfacial rheology
Angel food cake

ABSTRACT

The effects of sucrose on the physical properties of foams (foam overrun and drainage ½ life), air/water interfaces (interfacial dilational elastic modulus and interfacial pressure) and angel food cakes (cake volume and cake structure) of egg white protein (EWP) and whey protein isolate (WPI) was investigated for solutions containing 10% (w/v) protein. Increasing sucrose concentration (0–63.6 g/100 mL) gradually increased solution viscosity and decreased foam overrun. Two negative linear relationships were established between foam overrun and solution viscosity on a log–log scale for EWP and WPI respectively; while the foam overrun of EWP decreased in a faster rate than WPI with increasing solution viscosity (altered by sucrose). Addition of sucrose enhanced the interfacial dilational elastic modulus (E') of EWP but reduced E' of WPI, possibly due to different interfacial pressures. The foam drainage ½ life was proportionally correlated to the bulk phase viscosity and the interfacial elasticity regardless of protein type, suggesting that the foam destabilization changes can be slowed by a viscous continuous phase and elastic interfaces. Incorporation of sucrose altered the volume of angel food cakes prepared from WPI foams but showed no improvement on the coarse structure. In conclusion, sucrose can modify bulk phase viscosity and interfacial rheology and therefore improve the stability of wet foams. However, the poor stability of whey proteins in the conversion from a wet to a dry foam (angel food cake) cannot be changed with addition of sucrose.

1. Introduction

Foams provide a variety of quality attributes to food products (Campbell & Mougeot, 1999). Globular proteins, such as egg white proteins, are extensively used in aerated systems to stabilize the foam and to enhance desirable features. A comparable foaming capacity between egg white and whey protein has been established (Foegeding, Davis, Doucet, & McGuffey, 2002; Peter & Bell, 1930; Richert, 1979). However, substitution of whey protein for egg white in angel food cake batters results in low cake volume and coarse cake structure (Arunepanlop, Morr, Karleskind, & Laye, 1996; Berry, Yang, & Foegeding, 2009; Pernell, Luck, Foegeding, & Daubert, 2002). The lack of stability during the transformation from a wet foam to a dry foam (i.e., cake structure) was postulated to be responsible for the poor functionality of whey proteins in angel food cakes (Arunepanlop et al., 1996; DeVilbiss, Holsinger, Posati, & Pallansch, 1974; Pernell, Luck, et al., 2002). Microstructural changes in foams and angel food cake batters during heating show that cake batters prepared from egg white foams form a network that stabilizes bubbles; while cake batters prepared from whey protein isolate have continuously growing bubbles that produce a coarse structured cake (Berry et al., 2009). Surprisingly, the appearance of large bubbles in whey protein cake batters is observed from the first images at 22 °C (room temperature), suggesting destabilization changes occur even before heating (Berry et al., 2009).

A critical step during cake batter preparation is blending of dry ingredients (sugar and flour) into a wet protein foam. This process involves a gentle stirring operation and addition of sugar (small molecules) and flour (polymers). The sugar concentration in an angel food cake is extremely high (39.6% w/w). Based on a comparison of cakes made with and without sugar, sugar contributes to the formation of the foam network and increases cake volume for angel food cakes containing a high percentage of egg white protein, but has minimal effect on the volume of angel food cakes prepared from whey protein isolate (Berry et al., 2009). This demonstrated an important role of sugar on egg white protein foam functionality in angel food cakes that is not observed with whey protein.

The effect of sucrose on the physical properties of protein foams has been investigated in several studies (Davis & Foegeding, 2007; Lau & Dickinson, 2005; Raikos, Campbell, & Euston, 2007; Yankov &

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doi:10.1016/j.foodhyd.2009.09.011

Panchev, 1996). Generally speaking, the addition of sucrose can decrease foam overrun and increase foam stability. The increase in foam stability is based on a decreased drainage rate; usually associated with an increase in continuous phase viscosity. A linear relationship is observed between foam drainage ½ life and solution apparent viscosity on a log–log scale for egg white protein with addition of different amounts of sugar (Lau & Dickinson, 2005), while a linear relationship on a log–linear scale was suggested for whey protein isolate foams (Foegeding, Luck, & Davis, 2006).

Destabilization of polyhedral foams is a dynamic process that includes disproportionation, coalescence in addition to drainage of the thin film between bubbles. All of these processes involve interfacial film properties (Bos & van Vliet, 2001; Foegeding et al., 2006; Murray, 2007; Rodríguez Patino, Sánchez, & Rodríguez Niño, 2008; Wilde, 2000). In addition to the bulk phase viscosity, interfacial properties of proteins can also be altered by sucrose. The impeding effect of sucrose (0–1.6 M) on interfacial adsorption rate of bovine serum albumin, at a low protein concentration (3×10^{-6} M), was attributed to an increase of solution viscosity (Guzey, McClements, & Weiss, 2003). At a higher protein concentration (1.5×10^{-5} M), Rodríguez Niño and Rodríguez Patino (2002) observed that addition of sucrose (0–1.0 M) increased protein adsorption rate during the first diffusion controlled period for bovine serum albumin. They suggested that the more compact protein molecules (smaller size) in the presence of sucrose caused a faster diffusion rate. Ruíz-Henestrosa, Sánchez, and Rodríguez Patino (2008) found that sucrose (0–1.0 M) slowed the adsorption of soy globulins (1×10^{-3}–1 wt. %), leading to a decrease of foam overrun. Although they established positive associations between foam drainage ½ life and the interfacial properties (the interfacial pressure and the interfacial elasticity), Ruíz-Henestrosa et al. (2008) attributed the enhancing effect of sucrose to an increase of solution viscosity. Berry et al. (2009) suggested that the enhancing effect of sucrose (12.8% w/v) on the interfacial elasticity of egg white protein (10% w/v) contributed to increased foam stability, which was not observed in systems (10% w/v proteins) containing whey protein isolates. Therefore, when observing the bulk drainage of a protein foam, the contributions of the continuous phase viscosity and interfacial properties are convoluted.

Although many studies investigated sucrose effects on protein foams and interfaces, most of them were conducted using a single level of sucrose content (Antipova, Semenova, & Belyakova, 1999; Davis & Foegeding, 2007; Herceg, Rezek, Lelas, Kresic, & Franetovic, 2007; Walsh, Russell, & FitzGerald, 2008), or focused on a single protein rather than compared a variety of proteins (Guzey et al., 2003; Lau & Dickinson, 2005; Raikos et al., 2007; Rodríguez Niño & Rodríguez Patino, 2002; Ruíz-Henestrosa et al., 2008). A comprehensive study, covering a range of sucrose concentrations and two proteins that are shown to respond differently to sucrose, will provide a more comprehensive view of how sucrose changes the characteristics of proteins in foams and at interfaces. Moreover, this will allow for developing quantitative associations between macroscopic foam and molecular interfacial properties, and explain the differences of foaming functionalities between proteins. In this study, the foams and interfaces formed from two major foaming ingredients – egg white protein (EWP) and whey protein isolate (WPI) – were evaluated in the presence of different amounts of sucrose. The physical properties of foams (overrun and drainage ½ life) were measured and described by mathematical models based on properties of the pre-foam solutions (apparent viscosity) and interfaces (interfacial pressure and interfacial dilational elasticity). Properties of wet foams were used to interpret changes observed when converting from a wet to a dry foam (i.e., angel food cake). Changes in wet foam properties based on microstructural considerations will be investigated and associated with these properties in a separate article.

2. Materials and methods

2.1. Materials

Spray dried egg white protein (82% protein, dry basis) was obtained from Primera Foods (Cameron, WI) and stored at 4 °C. Whey protein isolate (BiPro, 93% protein, dry basis) was supplied by Davisco Foods International, Inc. (Le Sueur, MN) and stored at room temperature (22 ± 2 °C). Cake flour and 10× powdered sugar were purchased from a local grocery store. Sucrose (ACS), obtained from Fisher Scientific Inc. (Fair Lawn, NJ), and all other chemicals were reagent grade quality. Deionized water was from a Dracor Water Systems (Durham, NC) purification system with a resistivity was a minimum of 18.2 MΩ-cm.

2.2. Protein solutions

Protein powders were mixed with deionized water and stirred overnight (14–16 h) at room temperature (22 ± 2 °C) to allow for full hydration. Before final adjustment to 10% (w/v) protein, the pH was adjusted to 7.0. When required, sucrose was added to the protein solutions on a *g/100* mL basis.

2.3. Foam generation

Protein foams were generated using a Kitchen Aid Ultra Power Mixer (Kitchen Aid, St. Joseph's, MI) with a 4.3 L stationary bowl and rotating beaters. 200 mL of protein solutions were whipped for 15 min for EWP or 20 min for WPI at a speed setting of 8 (planetary rpm of 225 and beater rpm of 737). The 15 min whip time for EWP solutions was used to prevent overbeating (Pernell, Foegeding, Luck, & Davis, 2002).

2.4. Overrun

Overrun was measured according to the method of Phillips, Haque, and Kinsella (1987). The foam was gently scooped into a standard weigh boat (100 mL), leveled using a rubber spatula, and weighed. This process was repeated 3 times per foam and was completed within 5 min after whipping. The mean of 3 weights was used for overrun and air phase fraction calculations according to Equations (1) and (2) (Campbell & Mougeot, 1999):

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

$$\text{Air phase fraction } (\phi) = \frac{\%\text{overrun}}{(\%\text{overrun} + 100)} \quad (2)$$

Each treatment was replicated a minimum of three times.

2.5. Foam stability (drainage ½ life)

Foam stability was measured by recording the length of time required for half of the pre-foam mass to drain (Phillips, Yang, Schulman, & Kinsella, 1989). A bowl with a 6-mm diameter hole in the bottom was used for stability measurements. Immediately after the final overrun measurement, the bowl was placed in a ring stand over a weigh boat on a scale, with the hole uncovered. The time necessary for half the mass to drain was recorded as the drainage ½ life. The mass of foam removed during the overrun measurements (less than 20%) was subtracted when calculating half of the pre-foam mass. The starting time for these measurements was taken as immediately after