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Effects of soy-to-milk protein ratio and sucrose fatty acid ester addition on the stability of ice cream emulsions

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ABSTRACT

The protein composition and emulsifier adsorbed at the oil/water interface are very important in controlling the stability of fat droplets. In this study, the effect of soy-to-milk protein ratio in the presence or absence of sucrose fatty acid ester on the stability of ice cream emulsions was investigated. Parameters such as particle size distribution, dynamic surface pressure, surface protein adsorption, rheological properties and crystallization behavior of fat in the bulk and emulsified state were determined. The results indicated that destabilization of fat droplets depended on the protein surface adsorption activity, protein–protein and protein-sucrose fatty acid ester interactions at the interfacial layers. The addition of soy protein isolate significantly increased the flocculation of fat droplets during pasteurization. Emulsions containing sucrose fatty acid ester were distinguished by a higher partial coalescence degree (19.8–252.7%) of fat droplets compared to emulsions without sucrose fatty acid ester (5.5–37.3%) with the same protein composition. The particle size and adsorbed protein results showed a direct negative relationship between protein surface coverage and partial coalescence degree for emulsions with sucrose ester. The increased protein coverage when the soy-to-milk protein ratio was above 5:5 probably resulted from the enhanced protein–protein interactions. The supercooling needed for detection of crystalline fat was found to increase with the increase in soy-to-milk protein ratio up to 7:3. However, no significant correlation was found between the proportion of crystallized fat content and partial coalescence degree. These findings provided a theoretical basis for controlling the stability of aerated food emulsions with soy/milk protein mixture.

1. Introduction

A wide variety of food products are oil-in-water emulsions in which an oil phase is dispersed into a continuous aqueous phase. Emulsions are thermodynamically unstable due to the unfavorable contact between oil and water molecules. As a consequence, their physical structures tend to change over time by various mechanisms such as creaming, flocculation, and coalescence (Bouyer, Mekhloufi, Rosilio, Grossiord, & Agnely, 2012). Therefore, maintaining the stability of emulsions has been the focus of many studies (Damianou & Kiosseoglou, 2006; Long et al., 2012). However, in some food emulsions such as ice cream containing semi-solid dispersed phase, partial destabilization upon whipping/freezing is essential to perceived quality and texture (Fredrick et al., 2013a; Fredrick et al., 2013b; Zhang & Goff, 2005). The susceptibility of the fat globules towards partial coalescence depends on the composition, thickness and viscoelasticity of the adsorbed stabilizing layer at the oil/water interface (Dickinson, 1992a). Further, fat crystallization is of high importance for emulsion partial coalescence. The proteins and emulsifier present at the fat globule interface related, at least partly, to lipid surfactant interfacial crystallization and solid fat content (Mutoh, Nakagawa, Noda, Shiinoki, & Matsumura, 2001; Thanasukarn, Pongsawatmanit, & McClements, 2004a; Thanasukarn, Pongsawatmanit, & McClements, 2006).

Milk proteins (caseins and whey proteins) are mainly used in ice cream production. Ice cream mix contains an excess of protein, approximately 4% that is required to cover the surface area of the fat droplets (10–14% fat) created by homogenization (Segall & Goff, 1999). These newly created droplets are surrounded by a saturated and thick coating of adsorbed proteins. This layer of adsorbed proteins prevents the close association of droplets necessary for

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partial coalescence to occur as evidenced by the low levels of destabilized fat found in ice creams formulated without added emulsifier (Barfod, Krog, Larsen, & Buchheim, 1991; Segall & Goff, 2002). However, the presence of an emulsifier would decrease the strength of the interfaces through a competitive adsorption with proteins (Bolliger, Goff, & Tharp, 2000; Segall & Goff, 2002; Zhang & Goff, 2005). As a result, part of the protein that was initially adsorbed at the fat droplet interface was squeezed out from the surface and released into the aqueous phase (Granger, Barey, Veschambre, & Cansell, 2005). This produces a thinner, more fragile membrane on the droplets and allows partial coalescence, which enhances the development of fat structure (Tual et al., 2006). Sucrose fatty acid esters, commonly called sugar esters, are nonionic small molecule emulsifiers that contain a hydrophilic sucrose group and a lipophilic fatty acid group. Sucrose fatty acid esters are manufactured from pure sugar and vegetable oils. They are available in a broad spectrum of hydrophilic-lipophilic balance values. Those with values ranging from 1 to 16 are widely used in food additives, pharmaceuticals and cosmetics (Leong et al., 2011). There is growing interest in sucrose fatty acid esters due to their enhanced performance and environmental compatibility in comparison with petrochemically derived products. They are readily biodegraded in an aqueous environment, and have the potential to be non-toxic and non-allergenic (Rincon-Cardona, Agudelo-Laverde, Martini, Candal, & Herrera, 2014).

Protein composition and protein-emulsifier interactions, especially at the O/W interface, have a great impact on the properties of interfacial film, which further affect the emulsion stability (Wilde, Mackie, Husband, Gunning, & Morris, 2004). Numerous investigations have reported the effect of milk protein composition and emulsifier type on the stability of O/W emulsions or ice cream (Bolliger et al., 2000; Mendez-Velasco & Goff, 2012; Relkin, Fosseux, & Aubry, 2002; Relkin & Sourdet, 2005; Relkin, Sourdet, Smith, Goff, & Cuvelier, 2006; Sourdet, Relkin, & Cesar, 2003; Zhang & Goff, 2005). In the case of milk protein/sucrose fatty acid ester stabilized emulsions, the presence of sucrose fatty acid ester weakened the interfacial layer of emulsion fat globules by displacing proteins (Tual et al., 2006). Similarly, some authors also found that the interfacial characteristics of O/W emulsion were affected by the interactions between milk proteins and sucrose fatty acid ester, which further changed its physical properties (Ariyaprakai, Limpachoti, & Pradipasena, 2013; Zhao et al., 2014). As a consequence, the relationship between protein-surfactant interactions and the properties of food emulsions is of practical importance. As far as the protein composition in whipped-frozen emulsions is concerned, many of the reported studies on food-dispersed systems have focused mainly on milk proteins. The stability of whipped-frozen emulsions was found to be influenced by the protein type (caseins/whey proteins), conformation (native or denatured proteins) (Relkin et al., 2002, 2006; Relkin & Sourdet, 2005; Sourdet et al., 2003) and crystalline fat content (Relkin & Sourdet, 2005). However, limited reports exist on the role of soy proteins in aerated emulsions. Soy proteins provide several functionalities such as high water-holding, binding, and emulsifying properties. Of all soy protein products, soy protein isolate has been found to exhibit a mild flavor and shows several functional and nutritional properties (Akesowan, 2009; Arrese, Sorgentini, Wagner, & Anon, 1991). The use of soy protein isolate may influence food product quality. Consequently, fortification of food with soy protein isolate would be an approach to provide additional health benefits in a well-accepted food such as ice cream. The use of soy proteins to alter the physicochemical and sensory properties of ice cream products has been reported (Akesowan, 2009; Friedeck, Karagul-Yuceer, & Drake, 2003; Pereira, de Resende, de Abreu, Giarola, & Perrone, 2011; Sutar, Sutar, & Singh, 2010). The physicochemical and sensory properties were influenced depending on different substitution levels of skim milk powder for soy proteins (Akesowan, 2009; Friedeck et al., 2003; Pereira et al., 2011; Sutar et al., 2010). However, no literature exists on the stability of ice cream emulsions containing soy protein isolate. Moreover, little is known about the influence of the crystallization behavior of emulsified fat on the resulting stability characteristics. Therefore, this study investigates the effect of soy-to-milk protein ratio and protein-sucrose fatty acid ester interactions on the stability of ice cream emulsions. This study will provide insight on how to enhance and retard partial coalescence in ice cream emulsions containing soy protein isolate.

2. Materials and methods

2.1. Emulsion preparation

Oil-in-water emulsions typifying ice cream formulations were prepared based on (all in weight proportion) 10% coconut oil, 4% protein, 14% sucrose and 0.27% stabilizer (0.25% carboxymethylcellulose and 0.02% κ-carrageen) (Segall & Goff, 2002; Vega, Dalgleish, & Goff, 2005). Coconut oil (43.9 g/100 g C12:0, 22.7 g/100 g C14:0, 10.9 g/100 g C16:0) was purchased from the local market. The protein sources used in this study differed by the initial protein structure and their component. Skim milk powder (SMP, 33.4% protein, 54.1% lactose, 7.9% minerals, 3.8% moisture and 0.8% fat) was produced by spray drying (Fonterra Ltd., Auckland, New Zealand). A commercial spray-dried soy protein isolate (SPI, T901: 90% protein, 5% moisture, and 5% ash) was kindly provided by Harbin Hi-Tech Soybean Food co., Ltd. Various weight proportions of SMP and SPI were used to get the following five emulsions: ① SMP (100% protein in SMP came from SMP), ② SMP7SPI3 (SMP:SPI = 7:3, i.e. 70% protein in SMP7SPI3 came from SMP, and 30% from SPI, same for the following emulsions), ③ SMP5SPI5 (SMP:SPI = 5:5), ④ SMP3SPI7 (SMP:SPI = 3:7), ⑤ SPI. Lactose content was adjusted to keep the total solids content constant. Furthermore, for each emulsion, sucrose fatty acid ester (0.30%) was added or not to get a total of ten emulsions. The selected concentration was within the range commonly used in ice cream. Ryoto sucrose ester (P1570) was supplied by Mitsubishi-Kagaku Foods Corporation (Tokyo, Japan). P1570, with HLB value of 15 contained approximately 80% palmitic acid. The monoester and di, tri, polyester content of P1570 are approximately 70% and 30%, respectively.

All of the ingredients, except the coconut oil, were dry blended and mixed with water at 55 °C. Then, the melted coconut oil was added slowly at 7500 rpm with shear emulsifying mixer in 10 min to obtain the coarse emulsion. The pre-emulsions were homogenized with a two-stage single-piston homogenizer using 20 MPa pressure on the first stage and 4 MPa on the second stage, subsequently pasteurized at 65 °C for 30 min. The freshly prepared emulsions were quenched to 4 °C by putting the sample containers in a chilled low temperature water bath at 0 °C (DC-0506, BaiDianTech, Shanghai, China).

After the ageing step (4 °C for 24 h), all the emulsions were whipped and frozen in a scraped-surface continuous ice cream freezer (IC6308C, Petrus Ltd., Beijing, China) for 50 min. The whipped-frozen emulsions were then stored at −18 °C for 2 weeks, and then defrost at 4 °C overnight before characterization.

2.2. Determination of droplet size and fat destabilization

The droplet size distribution and average particle diameter ($D_{4,3}$) were determined by laser scattering using a Malvern Mastersizer 2000 (Malvern Instruments Ltd, Worcestershire, UK) (Palazolo, Sobral, & Wagner, 2011). The refractive indices of fat and