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Tempering of dairy emulsions: Partial coalescence and whipping properties

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ABSTRACT

This study investigates the effect of applying a time–temperature profile to natural and recombined cream to influence partial coalescence and, consequently, the whipping quality. To date, no clear relationship exists between the consequences of tempering on a microstructural level, partial coalescence, and whipping properties. Milk fat crystallisation was analysed using differential scanning calorimetry and the internal arrangement of fat crystals was visualised with cryo-scanning electron microscopy. Shear-induced partial coalescence and whipping properties were studied. Shear-induced partial coalescence was promoted, attributed to the observed changes in the fat crystal network. The effects on whipping properties were different for natural and recombined cream and thus dependent upon the interfacial composition. Consolidation of the partially coalesced fat droplet network by tempering increased the stability of whipped recombined cream during cold storage. Tempering is a promising tool to alter the susceptibility to partial coalescence by changing the internal fat crystal network, and influencing whippability.

1. Introduction

Dairy cream is an emulsion of milk fat droplets in a continuous aqueous phase. An important characteristic of dairy cream is the ability of transforming the oil-in-water (O/W) emulsion into a ternary system by whipping, which is a combination of shear and air inclusion. A good quality whipped cream has a high overrun, a desirable firmness, and a high stability. The basic mechanism occurring during whipping is partial coalescence. Firstly, shear-induced partial coalescence occurs when fat droplets connect by protruding fat crystals. These fat crystals penetrate the interface of another fat droplet forming a connection (Fredrick, Walstra, & Dewettinck, 2010). Secondly, surface-mediated partial coalescence takes place when fat droplets enter the air bubbles during whipping, liquid oil is released from the fat crystal network and spread over the air bubble surface. If this occurs between two fat droplets that are close to each other at the air bubble surface, a junction is formed leading to partial coalescence (Hotrum, Stuart, van Vliet, Avino, & van Aken, 2005). The combination of both mechanisms results in a network of partially coalesced fat droplets, giving structure to whipped cream by stabilising the air bubbles (Brooker, Anderson, & Andrews, 1986; Goff, 1997).

Natural cream, obtained by the physical separation of a high-fat phase from milk, is considered the gold standard. It has exceptionally good whipping properties and a nice taste. However, for many reasons (amongst others, health, technological and practical reasons) the food industry aims to develop recombined creams obtained by emulsification of fat in an aqueous phase. Ingredients can vary greatly, using different types of fat, emulsifiers, hydrocolloids, sugars, sugar replacers, and flavours. Nevertheless, the whipping properties should always be optimised by ensuring an efficient envelopment of the air bubbles by partially coalesced fat droplets. Diverse strategies may be followed in adapting partial coalescence, such as the composition of the cream (proteins, emulsifiers, hydrocolloids and the amount and type of fat), and the processing conditions (temperature, shear rate, cooling rate, homogenisation pressure and tempering) (Fredrick et al., 2010; Hotrum et al., 2005; van Aken, 2001). The latter is the main subject of this study, and consists of the application of a specific time–temperature profile in which the temperature is first increased to partly melt the fat, and then decreased again to induce heterogeneous crystallisation of the liquid fat (Boode-Boissevain, 1992; Drelon et al., 2006; Gravier, Drelon, Boisserie, Omari, & Leal-Calderon, 2006; Mutoh, Nakagawa, Noda, Shiinoki, &

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Matsumura, 2001; Mutoh, Kubouchi, Noda, Shiinoki, & Matsumura, 2007; Oortwijn & Walstra, 1982; Sugimoto et al., 2001; Thivilliers-Arvis, Laurichesse, Schmitt, & Leal-Calderon, 2010; Thivilliers, Drelon, Schmitt, & Leal-Calderon, 2006; Thivilliers, Laurichesse, Saadaoui, Leal-Calderon, & Schmitt, 2008).

The pioneering research of Boode-Boissevain (1992) on tempering of emulsions suggests that tempering increases the susceptibility to partial coalescence due to repositioning of the fat crystals. Increasing the temperature leads to partial melting of the fat crystals by which the three dimensional fat crystal network is broken. The remaining fat crystals can move freely to the energetically more favourable interface. Decreasing the temperature induces growth of the crystals near the interface, resulting in larger crystals that can penetrate further into the aqueous phase, increasing the susceptibility to partial coalescence. Emulsions with a fat content lower than 25% are not prone to the effect of tempering (Boode-Boissevain, 1992), and a minimal amount of solid fat during tempering, estimated to be between 1.5% and 8%, is necessary (Boode-Boissevain, 1992; Drelon et al., 2006; Mutoh et al., 2007).

Moens, De Clercq, Verstringe, and Dewettinck (2015) showed that tempering significantly influences fat crystallisation properties, depending upon the tempering temperature. Besides the change in melting properties and fat crystal polymorphism, the internal arrangement of the fat droplets is also influenced. Lamellar structures near the interface of the fat droplets were visualised in recombined cream tempered at 20 °C. The latter observation adds to the hypothesis that crystals move to the interface.

Although fat crystallisation properties largely determine the effect of tempering, the role of the interfacial composition may not be underestimated. Thivilliers et al. (2006) showed also that under quiescent conditions, partial coalescence may be promoted by tempering to such an extent that the emulsion forms a gel. Besides the fat crystallisation properties, the composition of the interface greatly influenced this gelling behaviour (Thivilliers et al., 2008). More specifically, tempering seems to have less effect on protein-stabilised O/W emulsions because of the thick interface. Conversely, O/W emulsions stabilised with low molecular surfactants have a thinner interface allowing crystals to pierce through, adding to the effect of tempering (Mutoh et al., 2007; Thivilliers et al., 2008). Mutoh et al. (2001) and Sugimoto et al. (2001) investigated the effect of tempering on protein-stabilised vegetable creams. Despite the thick interface, they observed increased flocculation after tempering which was not due to partial coalescence. It was suggested that the fat crystals near the interface could affect the adsorption of the proteins, consequently affecting interactions between the fat droplets.

Tempering is likely to affect the whipping properties. It was demonstrated that tempering of natural cream at 30 °C could improve its whipping properties by reducing the whipping time and serum loss, and increasing the overrun and firmness (Besner & Kessler, 1998); however, no link with partial coalescence or any other possible mechanism explaining the effects of tempering was provided in this study. Tempering the cream after it was whipped seemed to have similar effects. It was observed that for both natural and recombined cream, the elastic behaviour of the whipped cream increased when tempered at 25 °C due to an increased connectivity between the fat droplets. The latter is explained by surface-mediated partial coalescence occurring at the air bubble surface (Drelon et al., 2006; Gravier et al., 2006; Riaublanc et al., 2005).

In this current study, the relationship between tempering, partial coalescence kinetics, and whipping properties was studied. Two types of dairy cream, natural cream and recombined cream, were subjected to tempering at two temperatures (T_{max}) of 20 °C and 30 °C.

2. Materials and methods

2.1. Materials

Commercially available natural cream (NC; Debic, Friesland-Campina Professionals, Lummen, Belgium) with a fat content of 35% was used. Furthermore, recombined cream (RC) was produced by recombining anhydrous milk fat (FrieslandCampina butter, Noordwijk, The Netherlands), sweet cream butter milk powder (Westbury Dairies, Westbury, UK; containing 30.1 ± 0.1% proteins, 8.5 ± 0.1% fat and 51.5 ± 0.2% lactose), carrageenan (Satiagel ME4; Cargill Deutschland GmbH, Krefeld, Germany) and potable water. Sodium azide (Acros Organics, Geel, Belgium) was added to prevent microbial spoilage.

Sweet cream butter milk powder (7.6%) was dissolved in potable water and kept overnight for full hydration. Carrageenan (0.01%) and sodium azide (0.01%) were added to this aqueous phase and pre-heated to 50 °C. The anhydrous milk fat (35%) was melted and pre-heated to 50 °C. The pre-emulsion was prepared by thoroughly mixing the aqueous phase with the fat phase using an Ultra-Turrax (10,000 rpm) for 10 min at 50 °C. This pre-emulsion was then homogenised using a two-step laboratory scale homogeniser (APV cooling systems, Alberslund, Denmark) at 3–1 MPa. Finally, the emulsion was rapidly cooled to 5 °C and stored in a thermostatic cabinet at 5 °C for at least 7 d to complete fat crystallisation before tempering was applied.

2.2. Laser light diffraction

The size of the fat droplets in natural cream and in recombined cream was measured with laser light diffraction according to the method described by Fredrick et al. (2013b).

2.3. Tempering procedure

Cream (2.5 L) was heated to T_{max} (20 or 30 °C) using a Herbst HR-S3 Tempering Unit equipped with a double walled mixing bowl (Herbst Machinery Ltd, Omagh, Ireland) temperature-regulated with a Huber Thermostat (Peter Huber Kältemaschinenbau GmbH, Offenburg, Germany). The sample was kept isothermally for 30 min at T_{max} under continuous stirring before it was cooled to 5 °C by passing the cream through tubing that was fitted in a water bath at −5 °C. The cream was stored at 5 °C for at least 7 d to complete crystallisation before analysis.

2.4. Differential scanning calorimetry

Differential scanning calorimetry (DSC) with a refrigerated cooling system (model Q1000 DSC; TA Instruments, New Castle, DE, USA) was used to study the melting behaviour of (tempered) anhydrous milk fat (AMF), NC and RC. DSC was calibrated with indium (TA Instruments), azobenzene (Sigma–Aldrich, Bornem, Belgium) and undecane (Acros Organics) prior to analysis. Nitrogen was used to purge the system. Samples (5–15 mg) were sealed in hermetic aluminium pans, and an empty pan was used as a reference. The melting profile was analysed by heating the sample at 5 °C per min from 5 °C to 55 °C. Measurements were carried out in triplicate.

2.5. Nuclear magnetic resonance

A Maran Ultra 23 MHz pulsed-field gradient nuclear magnetic resonance (NMR) instrument (Oxford Instruments, Tubney Woods, Abingdon, UK) was used to measure the solid fat content profile of NC and RC. The solid fat content was determined 1 week after