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Crystallization mechanisms in cream during ripening and initial butter churning

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ABSTRACT

The temperature treatment of cream is the time-consuming step in butter production. A better understanding of the mechanisms leading to partial coalescence, such as fat crystallization during ripening and churning of the cream, will contribute to optimization of the production process. In this study, ripening and churning of cream were performed in a rheometer cell and the mechanisms of cream crystallization during churning of the cream, including the effect of ripening time, were investigated to understand how churning time and partial coalescence are affected. Crystallization mechanisms were studied as function of time by differential scanning calorimetry, nuclear magnetic resonance and by X-ray scattering. Microstructure formation was investigated by small deformation rheology and static light scattering. The study demonstrated that viscosity measurements can be used to detect phase inversion of the emulsion during churning of the cream in a rheometer cell. Longer ripening time (e.g., 5 h vs. 0 h) resulted in larger butter grains (91 vs. 52 μm), higher viscosity (5.3 vs. 1.3 Pa·s), and solid fat content (41 vs. 13%). Both ripening and churning time had an effect on the thermal behavior of the cream. Despite the increase in solid fat content, no further changes in crystal polymorphism and in melting behavior were observed after 1 h of ripening and after churning. The churning time significantly decreased after 0.5 h of ripening, from 22.9 min for the cream where no ripening was applied to 16.23 min. Therefore, the crystallization state that promotes partial coalescence (i.e., aggregation of butter grains) is obtained within the first hour of cream ripening at 10°C. The present study adds knowledge on the fundamental processes of crystallization and polymorphism of milk fat occurring during ripening and churning of cream. In addition, the dairy industry will benefit from these insights on the optimization of butter manufacturing.

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INTRODUCTION

In many dairy products, such as butter, ice cream, and whipped cream, the presence of fat crystals in the fat globules of the emulsion and partial coalescence phenomenon are required to obtain the desired product (Darling, 1982; Barfod and Krog, 1987; Boode and Walstra, 1993; Goff, 1997). The partial coalescence phenomenon occurs when a crystal present at the interface of the fat globule penetrates the milk fat globule membrane and binds another fat globule (van Boekel and Walstra, 1981a; Boode and Walstra, 1993). When partial coalescence has started, oil will be release out of the globules, continuing until the formed network is wetted by oil (Boode et al., 1993). Thereafter, a network made of aggregated fat globules will be formed. Fat globules retain most of their original shape but are linked by a semisolid connection; therefore, the process is called partial coalescence (Boode, 1992; Goff, 1997). The semisolid connection supports the original shape of the globules aggregated against complete coalescence, which is driven by Laplace pressure (Boode et al., 1993). In general, partial coalescence is initiated by shear and halted by the resistance from the semisolid connections (van Boekel and Walstra, 1981b; Goff, 1997).

The thermal treatment of the cream influences the extent and rate of partial coalescence of milk fat globules, thereafter the macroscopic properties of the product (Boode, 1992; Drelon et al., 2006). The thermal treatment of the cream, also known as ripening, is the most time-consuming step in butter production; however, it governs the crystallization of the fat and thereafter the consistency of the butter. Consistency mainly refers to the hardness, stiffness, viscosity, adhesiveness, and spreadability of the product. The thermal treatment of the cream is designed based on the triacylglycerol (**TAG**) composition and on the iodine value (amount of unsaturation in FA) of the cream. An example of thermal treatment is the cold-warm-cold method, also known as the Swedish or Alnarp

6-12-6 method (Samuelsson and Petersson, 1937). This method is usually applied for winter cream and the resultant butter is softer, due to the higher amount of liquid fat in the continuous phase. After the ripening step, the cream is churned and worked and during these steps milk fat globules aggregate to form butter grains. Aggregation of butter grains leads to a phase inversion of the emulsion and entails the separation of the water phase (the buttermilk). Triacylglycerols have the ability to crystallize in different polymorphic forms with different lamellar stackings and hence have different melting points, which increase with increasing crystal stability. The longitudinal organizations (stackings) of TAG in lamellar structures correspond to double (**2L**) or triple (**3L**) chain length structures. The stackings of the TAG molecules, called long spacings, are studied by small-angle scattering and the measured thickness for the 2L and 3L structure is 40 to 50 Å and 55 to 75 Å, respectively (Small, 1986; Larsson and Larsson, 1994). The polymorphic forms are identified by the crystal subcellular structures that characterize the cross-sectional packing modes of the zigzag aliphatic chain, called short spacings (Sato, 2001). The polymorphic forms identified in milk are α, β′, and β, which correspond to the hexagonal, orthorhombic, and triclinic packing of the sub-cells, respectively. These packings are studied by wide-angle scattering. The α form is characterized by a diffraction peak at 4.15 Å, the β′ form by 2 diffraction peaks at 3.8 and 4.2 Å, and the β form by a peak at 4.6 Å among other peaks (Small, 1986; Larsson and Larsson, 1994).

Destabilization of the emulsion and partial coalescence occurring during churning of the cream is an extremely complex phenomenon. Previous studies have shown the role of fat crystals in the mechanisms of physical instability in oil in water food emulsions and in inducing partial coalescence of emulsion droplets (Rousseau, 2000; Fredrick et al., 2010). Funahashi and Horiuchi (2008) demonstrated, by using an artificial neural network, that the characteristics of the churning process in continuous butter manufacture are influenced by the fat content of the cream, the cream flow rate, and by the cream feed temperature, which influence the water content of the butter. Furthermore, Bugeat et al. (2011) showed the effect of unsaturated FA and emulsion droplet size on the crystallization behavior of milk fat TAG. Although milk fat crystallization is important for its functionality and application, the literature is scant on the mechanism of milk fat crystallization in emulsion systems. Knowledge on mechanisms leading to milk fat crystallization in emulsions, and thus to partial coalescence, will contribute to the optimization of the production process of fat-based dairy products. The aim of this study was to elucidate the mechanisms leading to milk fat crystallization in emulsions, and thus to partial coalescence, during churning of the cream, including the effect of ripening time.

MATERIALS AND METHODS

Materials

Commercial winter cream (Arla Foods, Viby J, Denmark) with 38% fat was used for the ripening and churning of the cream.

FA Determination

Fatty acid composition was determined by gas chromatography after methylation of the lipids, as described by Wiking et al. (2009).

Churning Experiment and Viscosity Measurements

Churning was simulated at a laboratory scale by using a rheometer (AR-G2; TA Instruments Inc., New Castle, DE) supplied with a starch cell. This geometry consists of a cup surrounded by a jacket and an impeller. A gap of 5.5 mm was used. One-third of the cell (30 mL) was filled with cream. To erase the thermal history of the cream, it was heated at 60°C for 15 min. Afterward, a ripening step was performed. The cream was cooled to 10°C at 5°C/min and held there for 0, 0.5, 1, 5, and 17 h, respectively. During the heating and the ripening steps, a shear equal to 0.5 rad/s was applied to produce homogeneous crystallization. After the ripening step, the temperature was increased to 13°C at 5°C/min, and churning was simulated. The shear applied was 100 rad/s and it was performed until butter grains aggregation occurred; thus, phase inversion of the emulsion was achieved. During the whole process, changes in viscosity (Pa·s) were investigated as a function of time. The viscosity of the crystallizing sample was plotted as a function of churning time. Each analysis was executed at least in triplicate.

Analysis of Butter Grain Size

By measuring the size distribution at different stages of ripening and churning of the cream, it was possible to follow the formation of the fat globule aggregation. Globule size distributions were measured by static light scattering (Mastersizer 2000; Malvern Instruments Ltd., Malvern, UK). Measurements were performed every hour during ripening, and approximately every 5 min during churning, with the exception of the cream ripened for 0.5 h, where the particle size was not measured after 5 min of churning. The refractive indices