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Effect of thermal treatment on physical properties and stability of whipping and whipped cream

Viet Nguyen *, Cua T.M. Duong, Vi Vu

Department of Chemical Engineering and Processing, Nong Lam University-Ho Chi Minh City, Viet Nam

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ABSTRACT

The effect of tempering (20, 30 and 40 °C) and the cooling rate (0.5 and 2 °C/min) on physical properties and stability of whipping and whipped cream was investigated. Rheological behavior and light microscope observations showed that tempering at 30 °C and fast cooling created convenient condition for forming partial coalescence between fat globules in whipping cream. This special linkage helped to prevent serum leaking out of whipped cream when storing them at low temperature (4 °C). However, tempering at 20 °C would have been a more appropriate choice to stabilize structure of products through balance different types of partial coalescence in whipped cream during storage.

1. Introduction

Whipped cream is an aerated emulsion which is formed through whipping dairy cream, an oil-in-water (O/W) emulsion with at least 35% fat content. In this process, fat globules in cream were absorbed by serum protein and milk fat globule membrane (MFGM) fractions at the air/water interface (Dewettinck et al., 2008; Hasenhuettl and Hartel, 2008). These fat globules then form a partial crystal network cover air bubbles through a phenomenon called as the surface-mediated partial coalescence (Hotrum et al., 2005). Partial coalescence is a specific case of the collision between fat globules: fat crystals at the O/W interface can pierce the separated membranes and combine with the fat liquid to form a crystal network in oil neck which contributes to prevent the completely coalescence of these globules (Fredrick et al., 2010). Beside surface-mediated partial coalescence, churning partial coalescence also occurs between remaining fat globules in serum (Walstra et al., 2006). In the other hand, partial coalescence plays an important role in stabilizing structure of whipped cream and brings desirable texture for this product.

In many years, understanding about partial coalescence in dairy emulsion was enhanced significantly through previous studies (Boode et al., 1993; Fredrick et al., 2010, 2011; Goff, 1989, 1997; Hotrum et al., 2005; Zhao et al., 2008). However, there are some limitations in theories around this phenomenon. Firstly, there is not a perfect method to evaluate partial coalescence in O/W emulsion. Thickening was a popular method in the evaluation of partial coalescence (Boode et al., 1991) but it did not provide a detail sight about the mechanism of this phenomenon. In another study (Goff, 1989), spectro-turbidity was used to estimate partial coalescence but this was not really a high precisely method. Moreover, partial coalescence degree could be determined by combining dye Oil Red O with UV–Vis spectrometer (Zhao et al., 2008) but it was very difficult to apply this method on an aerated emulsion. Recently, rheology was used to predict the stability of many dairy emulsions (Allen et al., 2008; Drelon et al., 2006; Ihara et al., 2010; Long et al., 2012; Sajedi et al., 2014) and it could be a potential method in evaluating partial coalescence (Fredrick et al., 2011). Secondly, at low temperature, the interdroplet heterogeneous nucleation can co-appear with partial coalescence. In this case, penetrated fat crystals establish a bridge between fat globules and then induce the coalescence. According to some authors (Dickinson and McClements, 1995), this phenomenon is similar to partial coalescence but it often leads to an increase of solid fat content (SFC). Lastly, partial coalescence can be affect by too many factors such as SFC (Dickinson and Miller, 2001), protein and surfactant concentration (Goff, 1997) and by processes such as stirring and tempering (Boode et al., 1991; Vanapalli and Coupland, 2011; Walstra et al., 2006; van Lent et al., 2008). Therefore, control partial coalescence in dairy emulsion is always a difficult challenge and needs to be studied more.

Tempering is a thermal processing which has strong influence on the partial coalescence mechanism (Boode et al., 1991; Drelon et al., 2006; Fredrick et al., 2010). At low temperature (<5 °C), fat

* Corresponding author at: Quarter 6, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Viet Nam.
E-mail address: nbviet@hcmuaf.edu.vn (V. Nguyen).

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liquid in dairy cream was entrapped in fat crystal network. When heating, this structure partial collapsed and released fat crystals to the O/W interface. According to Fredrick et al. (2010), the number and the contact angle of these crystals at the surface of fat globules have a relationship with the formation of partial coalescence during whipping and these factors depend on applied temperature during tempering. Boode et al. (1991) assumed that higher temperature helped "rebodying" fat globules more effectively and induced partial coalescence more easily but this conclusion mainly depended on the viscosity of tempered samples. Drelon et al. (2006) suggested that tempering whipped cream at suitable temperature helped to improve the physical properties of product but the role of partial coalescence in this conclusion was not clear. The cooling step after tempering also contributes to the partial coalescence mechanism because this process determines the size of crystals. Bigger crystals were assumed to help penetrate fat globule membrane penetration more efficiently and thus support the linkage between fat globules (Boode et al., 1991; Fredrick et al., 2010; Coupland, 2002; McClements and Dungan, 1997).

The aim of this study is to investigate the effect of tempering and cooling on partial coalescence of dairy emulsion. Besides, we tried to establish a relationship between thermal treatment conditions and the quality of whipped cream during storage. Rheology analysis, light microscope observations and texture analysis of product were combined to evaluate the role of partial coalescence in whipping and whipped cream.

2. Materials and methods

Whipping cream from the brand Anchor of Fonterra (New Zealand) was purchased from the local supermarket. This is an ultra high temperature (UHT) product containing 35.5% milk fat, 2.4% protein and 3.1% carbohydrate. Cream was kept in fridge at 4 °C during storage.

2.1. Tempering and cooling

Cream must be kept in fridge at least 24 h before tempering. In each experiment, 300 mL cream was tempered during 60 min at different temperatures (20, 30 and 40 °C) using Memmert waterbath (MEMMERT, Germany). After tempering, samples were cooled to 4 °C at two different cooling rates: 0.5 °C/min in cooling chamber (CC) or 2 °C/min in freezing chamber (FC). Then, they were kept in fridge at 4 °C during storage.

2.2. Whipped cream

After cooling, cream must be kept at 4 °C in 2 h before being whipped at speed of 860 RPM by a cream maker (Phillips HR1565, China). 300 mL cream was used in each experiment. About 50 ± 0.25 g whipped cream was filled in plastic cups (diameter: 50 mm, height: 30 mm) and kept in fridge at 4 °C during storage.

2.3. Serum loss

30 mg whipped cream was filled in a glass filter which was put above a 100 mL erlen. The serum loss was calculated based on the weight of water in erlen after 2 h, 24 h and 48 h at 4 °C.

$$SL\% = \left(m_{serum}/m_{whipped\ cream}\right) * 100\% \quad (1)$$

2.4. Overrun

The densities of both whipping cream and whipped cream were determined by filling them in 50 mL cup and weighed. Overrun of whipped cream was calculated based on the following equation:

$$OR\% = \left(\left(\rho_{whippingcream} - \rho_{whipped\ cream}\right)/\rho_{whipped\ cream}\right) * 100\% \quad (2)$$

2.5. Viscosity measurement

After tempering and cooling, whipping cream was stored at 4 °C during 2 h, 24 h and 48 h before measuring. The viscosities of whipping cream were measured by viscometer RV-DVE (Brookfield, USA) using coaxial cylinder (ULA Adapter) and spindle 304 s/s with 15 mL sample for each experiment. Data was collected at different rotational speeds from 2.5 to 50 RPM. The temperature of sample was kept at 4 °C during measurement.

2.6. Light microscope analysis

Whipping cream after stored at 4 °C during 2 h was diluted five times with distilled water (4 °C). Image was recorded through a Light Microscope (MBL2000, Kruss, Germany) using a 3.0 megapixel camera. Temperature of environment was kept at 4 °C during experiment. The magnification for all observations was 100×.

2.7. Texture analysis

The hardness, consistency and adhesiveness of whipped cream were measured by TA.XT Plus (Stable Microsystem, USA) using aluminum cylinder probe (model P-35, diameter: 35 mm). Compression mode was applied with the trigger force of 5 g. The probe speed was 1 mm/s (for both up and down) and the penetration distance was 15 mm (50% the height of sample). Data were calculated by software Texture Exponent version 5.1.2.0 (Stable Microsystem, USA). The hardness was the maximum value of force while the consistency and the adhesiveness were the positive and the negative area of graphs, respectively. Whipped cream was stored during 2 h, 24 h and 48 h at 4 °C before measuring.

2.8. Statistical analysis

Each experiment was replicated 3 times. Software SPSS version 16 (IBM, USA) was used to analyze result. LSD method was applied to compare values. The normality and the equal-variance requirement of data were assured by Komogrov–Smirnoff and Levene Test. The confidence interval was 95%.

3. Results and discussion

3.1. Effect of thermal treatment on the rheological properties of whipping cream

The rheological behavior of whipping cream after tempering and cooling was displayed in Fig. 1. Firstly, it can be seen that cooling rate did not affect viscosity of samples tempered at 40 °C (T40). This can be explained based on the thermal behavior of milk fat in dairy cream. Studies of Timms (1980) and van Aken et al. (1999) stated that most milk fat crystals have melting points under 40 °C. Therefore, after tempering at this temperature, there were very few crystals in fat globules of dairy cream that led to the slowdown of the re-crystallization in these fat globules during cooling period even at high rates. Consequently, the lack of necessary fat crystals at the O/W interface for partial-coalescence between fat globules limited the formation of bigger clusters which could contribute to a viscosity increase in cream. Secondly, rapid cooling helped samples tempered at 20 and 30 °C (T20 and T30) to have higher viscosities. According to Boode et al. (1991, 1993), the high viscosity of tempered oil/water emulsion was a clear signal of partial-coalescence between fat globules. In the other hands, in this