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Effect of fat globule size on the churnability of dairy cream

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ABSTRACT

The churnability of commercial dairy cream as a function of fat globule size from micron to nanometric range (0.17–3.50 μm) was investigated. To achieve the lower fat globule size with increased interfacial area various amounts of sodium caseinate (NaCN) (0.15–4.9 wt%) or Tween 80 (0.25–1 wt%) were added to the cream. Under similar microfluidization and churning conditions, both fat globule size and emulsifier type had a significant influence on the churning time and proportion of fat in buttermilk. In general, churning time and buttermilk fat content were increased above 3.5 min and 4.4% fat (for untreated fat globule size), respectively with decreasing average fat globule size irrespective of the type of emulsifier used. The addition of Tween 80 reduced the churning time significantly and also decreased the fat content of buttermilk as compared to NaCN added cream.

1. Introduction

In milk, the fat, mainly composed of triacylglycerols, is dispersed in form of globules stabilised by a complex interfacial membrane (Keenan & Mather, 2006). The milk fat globule membrane accounts an average of 22 mg g^{-1} of fat globule and 11 mg m^{-2} of fat globule surface, of which 41 wt% is contributed by proteins and around 27 wt% by phospholipids (Fox & McSweeney, 1998). The milk fat globules vary in diameter from about 0.1 to 15 μm (Walstra, Walstra, Wouters, & Geurts, 2005). The natural fat globules may differ in composition as well as in size between cows and even between globules in one milk (Huppertz & Kelly, 2006). Cream is an emulsion resulting from the high concentration of milk fat globules, the fat content of which may range from 10% (half-and-half cream) to 80% or more (plastic cream). Cream for butter manufacturing would normally contain approximately 40% fat (Towler, 1994). Manufacturing process of butter by churning essentially involves shearing of ripened cream at low temperature, which partially breaks the oil-in-water emulsion resulting in a phase inversion trapping water into butterfat aggregates or grains and concentrates the fat to 80–82% w/w after drainage of buttermilk. Further working of fat mass produces a viscoelastic water-in-oil emulsion as butter (Keogh, 2006).

Texture of butter is one of the quality attributes determining functionality and consumer acceptance (Wright, Scanlon, Hartel, & Marangoni, 2001). Many factors effectively play role in determining the body and texture of butter and dairy spreads (Rønholt, Mortensen, & Knudsen, 2013). The normal process applied to change the texture of the butter has been to alter tempering conditions of the cream, temperature of churning, washing and working. These alterations are set to influence the solid-liquid proportion of fat in physically ripened cream, churning efficiency and in consequence the butter spreadability. Evidently, the size of milk fat globule of cream and/or dairy emulsion is also having impact on crystallisation temperature, size and polymorph of crystals, solid fat content, stability and rheological properties (Hussain, Truong, Bansal, & Bhandari, 2016; Lopez et al., 2002; Truong, Bansal, Sharma, Palmer, & Bhandari, 2014; Truong, Morgan, Bansal, Palmer, & Bhandari, 2015). These changes are presumed to make a difference to the churnability of cream and quality of butter made from reduced fat globule size. In a study reported by Goudédranche, Fauquant, and Maubois (2000), with different sizes of native milk fat globules in cream prepared by microfiltration, the churning abilities through conventional butter making method (12 °C churning temperature) after physical (overnight storage at 5 °C) and microbial (pH 5.2–5.3) ripening were shown to be similar for both small (below 2 μm) and large (above 2 μm) fat globules fractions. However, as per study conducted by Avramis, Wang, McBride, Wright, and Hill (2003), small fat globules (1.8 μm) secreted from cows fed with fish meal modified diet induced longer churning times than with cream from control milk (2.3 μm). In contrast, cream with smaller fat globules (3.49 μm; obtained from cows fed with an extruded linseed modified diet) took less time to churn (45 min) using conventional low shear drum churning method compared to the large globules of control cream (4.18 μm; churning time of 54.5 min) (Hurtaud, Faucon,

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Couvreur, & Peyraud, 2010). However, milk fat composition was also changed as a result of modification of cow diet which may also have an effect on churning time, hence making interpretation and comparison of these studies complicated. Comprehensively there is little information available in the literature on direct relationship between fat globule size and processability of dairy creams.

Formation of small droplets specifically submicron- to nano-scale requires large amount of surfactant and/or energy (Tadros, Izquierdo, Esquena, & Solans, 2004). Emulsifiers/surfactants are surface-active substances that adsorb to oil-water interfaces and form protective coatings around droplets that prevent droplet aggregation (McClements, 2011). Widely used emulsifiers in food industry include small molecule surfactants (e.g., Tweens, Spans), phospholipids (e.g., dairy lecithin, egg or soy), amphiphilic proteins (e.g., WPI, caseinate), amphiphilic polysaccharides (e.g., gum arabic, modified starch), etc. (McClements, 2011). To break up a droplet into smaller ones, it must be strongly deformed and this deformation increases Laplace pressure (the difference in pressure between inside and outside the droplet). Surfactants play major role in reduction of Laplace pressure by lowering the interfacial tension, and hence the stress needed to break up a drop is reduced (Tadros et al., 2004).

In stabilisation of food emulsions and foams, both low molecular weight surfactants and proteins play crucial role as having strong tendency to adsorb at oil-water or air-water interfaces (Bos & van Vliet, 2001). However, their mechanism of membrane formation is different. Proteins have a complex structural morphology, the emulsifying ability of which is closely related to surface hydrophobicity (Nakai & Li-Chan, 1993) and charge (Kim & Kinsella, 1985). Proteins stabilise emulsions by forming a viscoelastic adsorbed layer revealing high surface strength, the mechanical properties of which are thought to influence the stability of emulsions and foams (Izmailova, Yampolskaya, & Tulovskaya, 1999). Once adsorbed, reorientation of secondary and tertiary structure (interfacial denaturation) occur within protein molecule to facilitate electrostatic or hydrophobic interaction with the surfaces (Smith & Clark, 1992). However, thermal or pressure denaturation of proteins before adsorption at interfaces may lead to completely different surface and emulsification properties (Galazka, Dickinson, & Ledward, 1996). Upon usage of proteins as surfactant, the interfacial tension varies between 8 and 22 mN m^{-1} based on the type of oil used (Bos & van Vliet, 2001). Depending on the pH and ionic strength of the solution, an adsorbed amount of most proteins is found to be approximately 2–3 mg m^{-2} whereas that in case of low molecular weight surfactants varies from 1 to 2 mg m^{-2} (Bos & van Vliet, 2001). Protein adsorption may be considered being irreversible as no desorption of protein from emulsion droplets has been found (Bos & van Vliet, 2001) except their displacement by small molecular surfactants or other proteins adsorbing at interface (Chen & Dickinson, 1995; De Feijter, Benjamins, & Tamboer, 1987). In contrast, adsorption of low molecular weight emulsifiers is often regarded as being reversible. Emulsifiers do not form viscoelastic surface but a compact adsorbed layer (Wilde, Mackie, Husband, Gunning, & Morris, 2004). This layer relies on charge repulsion or the Gibbs-Marangoni mechanism to stabilise foams and emulsions (E Dickinson, 1994; Eric Dickinson, 2009; Kumar, Nikolov, & Wasan, 2001). The Gibbs-Marangoni mechanism requires rapid diffusion or migration of emulsifiers at the interface to reduce surface concentration gradients that may arise (Wilde et al., 2004). This results in an inward flow of associated continuous phase that tends to drive the droplets apart and hence prevents coalescence (Tadros et al., 2004; Wilde et al., 2004). Therefore, the structural properties of emulsifiers are extremely important for their surface and stabilisation properties (Wilde et al., 2004). For longer stability of the cream, we require a stable fat globule membrane while in butter making process a low stability of the fat globule membrane or cream is desirable.

The main aim of this study was to develop better understanding on the effect of fat globule size (from micron- to nano-size range) on churnability of the cream. To achieve the lower size of fat globules both emulsifiers and mechanical energy (microfluidization) were employed in the present work. Both small molecular surfactant (Tween80- non-ionic ester produced with sorbitan monooleate and ethoxylate) and proteins (NaCN) were utilised to evaluate the effect of emulsifier type along with droplet size on churnability of dairy cream.

2. Materials & methods

2.1. Materials

2.1.1. Commercial dairy cream

Two kinds of commercial cream were employed to enable addition of sufficient amount of protein to prepare range of fat globule size. Single cream obtained from Parmalat Australia Pty Ltd. (Brisbane, Queensland, Australia) and double cream was obtained from Coles Supermarkets Australia Pty Ltd. (Tooronga, Victoria, Australia). According to the manufacturer, the former contained 39.4 g fat and 2.1 g protein per 100 mL volume and the latter contained 55.0 g fat and 1.6 g protein per 100 mL volume. Both commercial creams were originated solely from milk without any addition of foreign ingredients. The age of the purchased cream was less than one week from the day of manufacture. Effect of age of the cream was eliminated in this research work as the ageing effects on fat crystals were erased by warming the cream to 45 °C.

2.1.2. Emulsifiers

Sodium caseinate (NaCN: 92.6% protein, 0.25% lactose-casein, 0.7% fat, 1.2% sodium) obtained from Murray Goulburn Co-op (Melbourne, Victoria, Australia) and Tween 80 (Tween80; LR CAS #9008-65-5; polyoxyethylene sorbitan monooleate $C_{64}H_{124}O_{26}$; Labtek Pty Ltd., Brendale, Queensland, Australia) were chosen to study the effect of dairy protein and small molecular surfactant respectively on resultant fat globule size and churnability of cream.

2.2. Methods

2.2.1. Preparation of NaCN solution

The calculated amount of NaCN powder was gradually added into the distilled water at room temperature (23 °C) under continuous stirring to make 15 wt% protein solution. The stirring was continued to make content homogenous and ensure that no lumps were present. The solution was then stored overnight under refrigeration (4 °C) to allow complete hydration of the protein. Subsequently, solution was warmed (~35 °C) before adding into the cream.

2.2.2. Preparation of differentiated-sized creams

2.2.2.1. Addition of NaCN and Tween80 prior to microfluidization process for stabilising the homogenised creams. Application of homogenisation and extra emulsifier allowed to reduce fat globule size and obtain wide range of size from micron- to nano-scale. Before addition of emulsifier, cream was heated to 45 °C to allow the fat crystals to melt completely. Single cream adjusted to 38 wt% fat and 2 wt% protein by adding water was considered as control sample. All other cream samples containing different amount of NaCN or Tween 80 were standardized to 38 wt% fat as summarised in Table 1 and detailed below.

2.2.2.1.1. Single cream and NaCN. The natural protein content in single commercial cream was 2.1 wt%. In this cream different levels of NaCN solution and water were added to prepare samples with 2.15, 2.20, 2.30, 2.40 and 2.50 wt% total protein. Upon addition of NaCN solution and water the native protein content in cream was reduced to 2.0 wt% as of control sample, thus extraneously added protein was in the range of 0.15–0.5 wt%.

2.2.2.1.2. Double cream and NaCN. To make up total protein content above 2.5 wt% and maintain minimum fat level of 38 wt%, double cream was utilised as base material (as single strength cream