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Effects of dissolved carbon dioxide in fat phase of cream on manufacturing and physical properties of butter

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ABSTRACT

Carbon dioxide (CO_2) is highly soluble in lipids that can take part in the crystallisation process, in turn, affecting the product property. The effects of infusion of CO_2 in fat phase of dairy cream, prior to churning, on butter making were investigated. CO_2 was dissolved into warm cream (40% w/w fat; 35 °C) when the fat phase was dominated by liquid state. The carbonated cream was then aged at 10 °C for 0, 3 or 17 h, churned at 10 °C and worked batch-wise. The dissolution of CO_2 in fat phase of cream modified its crystallisation behaviour, leading to shorter churning time in the butter making process, higher melting point and lower G′ in the resultant butter without alteration of microstructure, colour and sensory properties. The results suggested that it may be possible to use carbonation of warm cream to shorten the cream ageing step in commercial butter making and manipulate the physical properties of butter.

1. Introduction

Butter is manufactured by transforming dairy cream, an oil-in-water emulsion, to a water-in-oil emulsion by a mechanical phase-inversion process, known as churning. In the butter making, milk fat in the cream is partially crystallised during cooling and/or holding, in the “ripening” or “ageing” step, prior to churning. Upon churning the fat globules are subjected to mechanical destabilisation. The milk fat globule membrane (MFGM) is disrupted allowing non-crystalline oil phase leakage and coalescence of fat. Subsequently, phase inversion occurs, to form butter grains and butter milk. After separating out the butter milk, butter grains are worked into a mass of plastic fat by mechanical agitation and stirring (Kessler, 2002). The microstructure of the final butter consists of a continuous oil phase containing aggregates of crystalline fat, intact and damaged fat globules in which aqueous droplets and air cells are dispersed (Juriaanse and Heertje, 1988). In well-worked butter, intensive working is used to incorporate the aqueous phase as fine droplets (2.3–10.6 μm) (Van Dalen, 2002; Van Lent et al., 2008). Current international standards require that butter shall contain a maximum of 16% (w/w) of water (Codex Alimentarius, 2011).

The physical properties and complex microstructure on butter are governed by many different factors, including chemical composition of milk fat, thermal treatment of cream, processing conditions (shearing rate, churning temperature, working temperature etc.), water content and storage conditions (Buldo et al., 2013b; Hurtaud and Peyraud, 2007; Kulkarni and Murthy, 1985; Ronholt et al., 2012, 2014c; Rønholt et al., 2014; Schaffer et al., 2000; Shukla and Rizvi, 1996). Among them, for unfractionated, pure butter, the thermal treatment and “ageing” of cream has been regarded as the best economical approach to achieve desirable physical functionalities, through manipulation of parameters such as fat crystal size, shape and the presence of specific polymorphs (Precht, 1988). A range of manufacturing interventions have been investigated to manipulate the physical functionality of butter, particularly in relation to cold spreadability. These include modifying the composition of milk fat (Banks and Christie, 1990; Gerson and Escher, 1966; Hurtaud and Peyraud, 2007; Pabst et al., 1992; Precht et al., 2001), thermal treatment of cream prior to churning and varying time-temperature treatments during the ripening phase (Deman and Wood, 1958; Dixon, 1970; Dolby, 1954; Precht et al., 1990). Manipulation of gas content of the product is another approach that has been investigated for modification of spreadability. It was reported that the butter having reduced air content tended to possess glossy and smooth texture but firmer consistency (Swartling et al., 1956). Use of nitrogen to whip butter has been reported to enhance spreadability but the resulting texture was crumbly (Kleyn, 1992). Besides these reports, no

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information can be found on using gases to alter crystallisation conditions of cream prior to churning whereby crystal size, shape and fat polymorphs might be modified.

In previous research on pure, anhydrous milk fat (AMF) it was shown that dissolved CO_2 up to 2000 ppm in the AMF can modify the crystallisation kinetics of the triglycerides (Truong et al., 2017a). For instance, dissolved CO_2 concentration of 1379 ppm was found to induce higher onset crystallisation temperature of fat (25.3 ± 1.6 °C) than that of non-carbonated AMF (19.2 ± 0.4 °C) during cooling from 35 to 5 °C at 0.5 °C min^{-1}. In the presence of dissolved CO_2 AMF crystallised in mixed crystals of α, β′ and β polymorphs whereas non-treated AMF exhibited only β′ and β fat polymorphs. When 2000 ppm CO_2-treated AMF was isothermally crystallised at 28 °C for 20 min, the solid fraction (4% versus 1.5%) and crystal number (800 versus 300) were 2–3-fold greater than those of 1000 ppm and 0 ppm-carbonated AMF as quantifying by microscopic image analysis. The bulk properties of the fat appeared to mirror the microstructural differences, in that the texture of CO_2-treated AMF was harder (0.26–0.29 N versus 0.22 N) when being crystallised at 25 °C for 48 h. Hardness of the CO_2-treated AMF tended to have lower value (39–42 N versus 46 N) when allowing to cool from 35 to 5 °C and store at 5 °C for 48 h (Truong et al., 2017a). Based on these findings it was hypothesized, but not demonstrated, that modulation of milk fat crystallisation in cream by using dissolved CO_2 might provide a means to control crystallisation of milk fat and subsequently physical functionality of butter and other fat-based dairy products. Carbonation of cream and butter has been investigated previously in relation to its effect on CO_2 dissolution behaviour (Ma and Barbano, 2003), microbial growth, flavour and keeping quality (Hunziker, 1924; Prucha et al., 1925). Prucha et al. (1925) studied various effects of the injection of CO_2 during the entire churning process. In the first set of experiment CO_2 flow was supplied for 3 min through a glass tube inserted into sweet cream, which was kept at 4.5 and 21.1 °C and aged up to 4 days. In the second set of experiment CO_2 was introduced to the system at the time of churning process. According to their report, this injection method produced no measurable benefits on bacterial count and sensory attributes of the butter. Since this early work, there appear to be no more reports in the literature of any studies of cream carbonation in relation to butter quality.

The present study aimed to investigate the effects of dissolved CO_2 in cream on milk fat crystallisation and whether carbonation of cream prior to churning influences the processing and physical properties of butter. Carbonation was applied to warm dairy cream at 35 °C (when the fat phase was still in liquid state) and the carbonated cream was subjected to butter making at laboratory scale with batch churning method. Churning time of the cream and changes in physical properties of resulting butter were examined. The effects of ageing time (0, 3 and 17 h) alone and coupled with carbonation treatment were also investigated. Reference samples of commercial butter were also included in this study. We also investigate whether carbonation of cream prior to churning induces any sensory defects of produced butter as perceived by consumer panellists using a triangle test.

2. Materials & methods

2.1. Materials

Commercial cream (40% w/w fat, 2.1% protein) from Pauls® (Australia) and two commercial butter samples from Western Star and Devondale (Australia; referred as commercial butters 1 & 2, respectively) were purchased from a local grocery store. According to the manufacturers, fat contents of commercial butter 1 and 2 were 82.7% and 81.0% (w/w), respectively. Fat contents of the commercial cream and butters were verified by Roeder's weighing method as described by Dhungana et al. (2017). In brief, 5 g of cream was placed into a sample container, which was fitted into a cream butyrometer. Sulphuric acid (1.522 g mL^{-1}) was added into the cream-contained butyrometer, which was then placed in a hot water bath (70 °C) and shaken in order to assist a complete dissolution of the protein. Sulphuric acid was poured into the butyrometer for the second time until the level of sulphuric acid reached the beginning point of the scale. Following addition of amyl alcohol (1 mL) was undertaken and the butyrometer was kept in the 70° water bath for 5 min with repeated shaking. After centrifuging and tempering at 65 °C using a water bath, the fat content was determined by reading off the value at the lower meniscus.

Pelleted dry ice (1–3 g each pellet), the solid form of CO_2 (sublimation point at atmospheric pressure: −78.5 °C), used for carbonation was supplied by University of Queensland (Brisbane, Australia) and stored in a foam box at −80 °C to minimise sublimation. Unless otherwise specified, chemicals used were of analytical grade.

2.2. Experimental procedure

Butter making was undertaken at a laboratory scale using a batch churning method. Commercial cream (1.8 L) was heated at 60 °C for 10 min in a water bath to completely melt the milk fat. The molten cream was allowed to cool to 35 °C (cooling rate: 6.5 °C min^{-1}) and placed into a Stephan UMC 5 double-jacketed mixer (capacity 5L; Stephan Machinery GmbH, Hameln, Germany) previously set at 35 °C using a recirculating cooler (Julabo GmbH, Seelbach, Germany) connected to the mixer. Carbonation was carried out at 35 °C by placing a known amount of dry ice, corresponding to 0, 1000 or 2000 ppm (by mass), into the cream and closing the lid immediately. Our previous study performing on anhydrous milk fat system demonstrated that this method of CO_2 addition is reliable at low partial pressure (less than 150 kPa) (Truong et al., 2017b). The carbonated cream was gently stirred at 300 rpm for 1 min and kept at 35 °C for 30 min. Cooling was undertaken in the closed mixer from 35 °C to churning temperature (10 °C) at a cooling rate of 1.8 °C min^{-1}. It should be noted that the cooling process was undertaken under quiescent conditions. No mechanical agitation was applied in order to eliminate its effect on promoting secondary nucleation, impeding agglomeration and interlocking of crystals. The cooled cream was aged for 0, 3 and 17 h at 10 °C. For carbonated cream, the effect of ageing time was only examined at the 2000 ppm addition rate.

Churning was undertaken in the closed mixer by mixing at 3000 rpm using a granulating blade attachment as described elsewhere (Ronholt et al., 2014c). Phase inversion was considered completed when a clear separation of butter milk and butter grains was visible. Churning time was determined from the start of churning to the completion of phase inversion at 15 s intervals. Final churning temperature was recorded from the temperature display of the mixer. Butter milk was drained off by gently pressing the butter mass against a metal mesh. The working step was carried out immediately using a single screw extruder (a domestic scale meat mincer; Five Motori Elettrici S.R.L., Italy) within 2 min. Excess butter milk was also removed during working. The butter samples were packed in uniform amounts in 70 mL plastic containers and stored at 5 °C for 48 h.

Two reference samples with different thermal treatments were also prepared, to simulate both full crystallisation (cooled to 5 °C and held at 5 °C for 48 h) (Ronholt et al., 2012) and the Alnarp (cold-warm-cold) method (Dixon, 1970). Heat treatment applied to the latter samples consisted of 3 steps: (i) cooling to 8 °C and holding at 8 °C for 1 h; (ii) reheating to 20 °C and holding at 20 °C for 3 h; and