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Post-processing of fermented milk to stirred products: Reviewing the effects on gel structure

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ABSTRACT

Background: The structure of stirred fermented milk products such as yoghurt, Greek-style yoghurt and fresh cheese is an essential criterion for consumer acceptance. It is determined by various factors ranging from the milk base composition to starter culture to mechanical forces occurring during filling. The effect of upstream processing parameters and fermentation conditions on the structure of stirred fermented milk gels have been extensively studied and reviewed by different authors.
Scope and approach: This review examines the effect of mechanical stresses in different unit operations downstream of fermentation, or post-processing, on the milk coagulum, often referred to as a microgel suspension. The process steps can be indispensable, e.g. pumping, cooling and filling, and concentration for concentrated milk products, or optional, e.g. mechanical or thermal treatment. They are evaluated with regards to their impact on the structure of microgel suspensions. In-situ laboratory scale experiments in rheometers provide an insight into structural changes of milk gels due to shearing.
Key findings and conclusions: The structural properties, including rheological parameters, of the microgel suspension depend on the cumulative effect of the type, magnitude and duration of the mechanical stresses occurring in the different post-processing unit operations. The latter can be optimised to achieve the desired gel properties and save raw material, mainly protein and stabilisers. It can also be adjusted for low viscosity at high protein contents. Thus, the efficiency of the process can be improved by considering the design of the process downstream of fermentation.
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1. Introduction

The fermentation of milk by lactic acid bacteria (LAB) is employed to extend the shelf life of milk, the two main types of fermented milks being yoghurt and concentrated fermented milks such as fresh cheese, Greek style yoghurt and labneh. The industrial production of yoghurt typically proceeds as follows (Fig. 1). The raw milk undergoes upstream processing which includes separation, standardisation, homogenisation and pasteurisation. It is then inoculated with the thermophilic starter culture, usually a 5:1 mixture of *Streptococcus salivarius* subsp. *thermophilus* to *Lactobacillus delbrueckii* subsp. *bulgaricus* (Tamime & Robinson, 2007) at a fermentation temperature of 37–45 °C. The inoculated liquid milk is fermented to a final pH 4.5–4.6.

Set yoghurt is fermented, then cooled to 4–6 °C in the retail packaging. For stirred yoghurt, the milk is fermented in a large tank followed by post-processing. It is pre-cooled to about 20 °C to suppress the starter culture activity, blended with fruit mix, inclusions or flavouring, packaged and further cooled to 4–6 °C. The process for fresh cheese and other concentrated fermented milks such as "Greek style" concentrated yoghurt and Skyr is similar up to the formation of the milk coagulum. It is then concentrated to a higher dry matter content, usually by centrifugation or ultrafiltration, prior to cooling and filling (Fig. 1). The continuous set milk coagulum breaks up on application of mechanical stresses, including shear, elongation and normal stresses, in the post-processing steps to form a microgel suspension, resulting in structural losses (Whittle & Dickinson, 1998).

Consumers expect a characteristic texture and mouthfeel for fermented milk products (Cayot, Schenker, Houzé, Sulmont-Rossé, & Colas, 2008; Krzeminski et al., 2013). This largely depends on the structure. It influences the mechanical and surface properties and has an impact on flavour too (Heilig, Hahn, Erpenbach, Kübler, & Hinrichs, 2013). The structure of stirred fermented milk products

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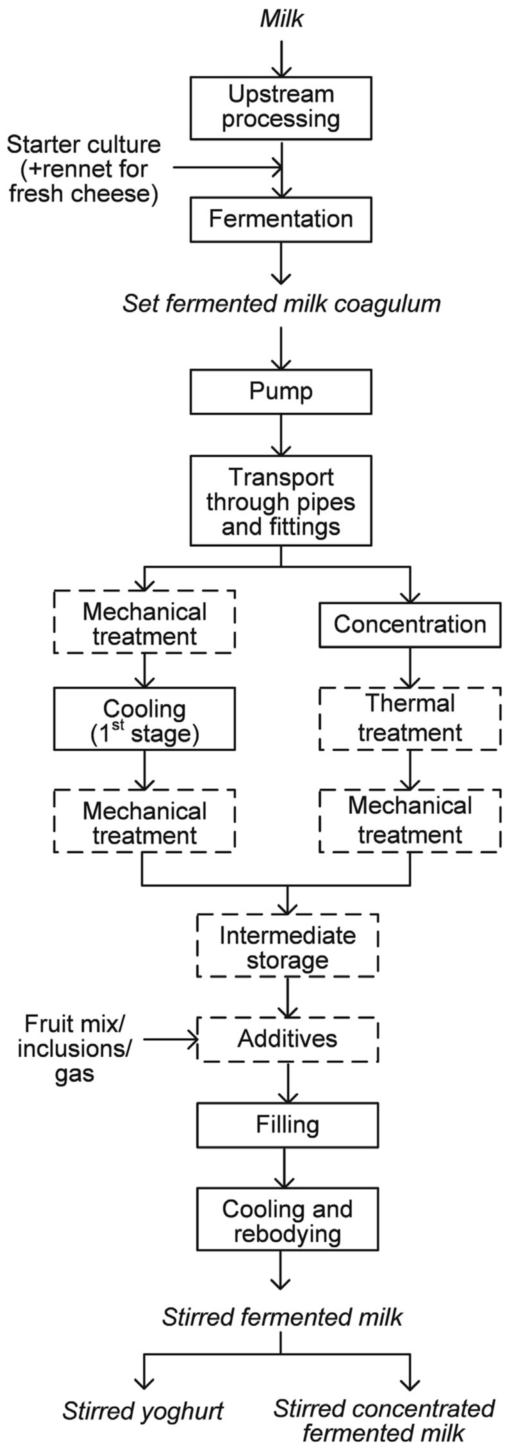

Fig. 1. Manufacture of stirred fermented milk products.

depends on a number of variables, including milk base composition, heat treatment, homogenisation, added hydrocolloids, starter culture, incubation conditions, pH at which fermentation is stopped, shearing and cooling.

The effect of numerous pre-processing and fermentation parameters on the structure of fermented milk products has been extensively studied and reviewed by various authors (Kücükcetin, Weidendorfer, & Hinrichs, 2008; Lee & Lucey, 2010; Sodini, Remeuf, Haddad, & Corrieu, 2004). The structure of the milk gel subject to mechanical stresses depends on the initial set coagulum. For example, whey proteins are denatured and attach to the surface of casein micelles during heat treatment of milk, e.g. at 95 °C for 3–5 min (Dannenberg & Kessler, 1988). The resulting stirred yoghurt has higher storage moduli and viscosities (Cayot, Fairise, Colas, Lorient, & Brulé, 2003; Lucey, Tet Teo, Munro, & Singh, 1997). Similarly, firmer set gels are formed at lower than at higher fermentation temperatures. After stirring, a firmer microgel suspension is obtained (Cayot et al., 2003).

This review examines changes to the structure of stirred fermented milk products, especially stirred yoghurt and fresh cheese, occurring in processing steps after fermentation, referred to as post-processing steps. The structural changes occurring due to mechanical forces in laboratory scale experiments, including in-situ rheological investigations, are considered. Different post-processing unit operations are then discussed, followed by structure regeneration. Finally, the implications of downstream processing on the fermented milk gel are evaluated.

2. Structure of stirred fermented milk gels

Food structuring is a multi-step process involving various phase transitions (van der Sman & van der Goot, 2009). First, the initial food structure is destabilised to create a new phase. The latter is then adjusted to achieve the desired intra- and interparticle interactions and size distribution for appealing sensory properties, often by applying hydrodynamic forces. The resulting structure should be retained until consumption. This is applicable to fermented milk products.

Caseins are the main proteins (80% w/w) in milk and exist at the submicron scale with an average diameter of 150 nm. During lactic acid fermentation, the pH gradually decreases and the milk colloidal dispersion is destabilised (de Kruif et al., 1995). The milk proteins aggregate at their isoelectric point of pH 4.6 to form a continuous particle gel with strands between 100 and 1000 μm in which the serum is enclosed (Chardot, Banon, Misiuwianiec, & Hardy, 2002; Lucey, 2004). The milk gel is stabilised by mainly hydrophobic interactions at approximately 70% (Keim & Hinrichs, 2004). A viscoelastic microgel suspension with partially reversible thixotropic characteristics forms due to mechanical stresses as shown in Fig. 2 (Van Vliet, Lakemond, & Visschers, 2004).

Large protein particles are formed at shear rates less than 10 s^{-1} which break down to primary aggregates at shear rates between 10 s^{-1} and 447 s^{-1}. At even higher shear rates, the gel structure is destroyed completely and protein particles with the size of the initial casein micelles are formed (van Marle et al., 1999). The breakdown of the continuous gel structure results in a decrease in gel firmness and viscosity as well as an increased predisposition towards syneresis as previously entrapped serum is released from the pores or cavities of the microgel particles. The structural losses and whey expulsion can be seen as product defects. The microstructure is also altered by shearing. Some authors observed more dense protein aggregates in stirred yoghurt due to a breakdown of the initial continuous coagulum and the rearrangement of particles into weak aggregate structures (Lee & Lucey, 2006; Teggatz & Morris, 1990).

In industrial processing, friction occurs between the milk coagulum and pipe wall as well as between the gel particles due to flow. The shear stresses thus arising cause disintegration of the microgel particles and a corresponding decrease in viscosity. However, constant shear rate experiments are generally preferred for laboratory scale in-situ rheological investigations into the effect of shear on structure. The shear stress and shear rate are interdependent (Norton, Spyropoulos, & Cox, 2010).

The structure of fermented milk gels can be described by various

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