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Microstructural transformations in anisotropy and melt-stretch properties of low moisture part skim mozzarella cheese

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ABSTRACT

Mozzarella cheese is primarily consumed in its melted form due to its desirable melt and stretch characteristics when heated. Understanding the relationship between the anisotropic structure and melt-stretch properties is critical for controlling functionality. A novel ex situ sample extraction system was developed to produce melted and stretched mozzarella. New structure analytics were established to reveal transient changes during deformation of mozzarella under dynamic heat-shear conditions. Transformations in anisotropy were examined using various microscopy techniques coupled with image analysis. Coalescence of milk fat aggregates into large droplets upon heating caused loss of anisotropy. However, fat droplets broke down into channels on stretching, comprising agglomerates of smaller droplets, and anisotropy was regained. When stretched further, adhesion between agglomerated fat droplets was broken by forces exerted from the contracted protein fibres. Large fat droplets are necessary as they act as shock absorbers that enable protein fibres to become pliable, allowing greater stretch.

1. Introduction

Mozzarella cheese is a widely used ingredient in both home cooking and the food services sector. Mozzarella production is growing: in 2015 in the US alone it represented (at 1.8×10^6 kg) the largest volume cheese sold to restaurants, accounting for 29% of total cheese usage (largely driven by demand for pizza; Dequaine, 2016). Consumers' perception of mozzarella is dominated by its desirable melt, stretch and stringy characteristics that emerge upon heating. These signature textural attributes are classified as functional properties (Gunasekaran & Ak, 2003) and are frequently attributed to the pasta-filata structure (McMahon & Oberg, 1999).

The pasta-filata microstructure in the final mozzarella product originates from the critical stretcher-cooker process during manufacture (Kindstedt & Guo, 1997; McMahon, Oberg, & McManus, 1993). The structure is a heterogeneous and anisotropic combination of networks of long parallel aligned para-casein fibres, with elongated channels of fat oriented in the direction of stretch (Everett & Auty, 2008; Kindstedt, 2004; Kindstedt & Guo, 1997; McMahon & Oberg, 1999). Cheese manufacturers aim to produce mozzarella with structures that deliver the physical functional properties specified by the end-user (Kindstedt & Guo, 1997; McMahon et al., 1993). By quantifying the link between structure and property, manufacturers can design and fabricate products using a more methodical and controlled basis (McClements, 2007).

Meltability and stretchability, the signature attractive characteristics of mozzarella, are the key functional properties that emerge on baking (Chen, Wolle, & Sommer, 2009; Guinee, Feeney, Auty, & Fox, 2002; Rowney, Roupas, Hickey, & Everett, 1999). However, whilst these properties are frequently attributed to the anisotropic microstructure, little attention has been paid to the transformation of that structure during melting.

Meltability is defined as the ability of the cheese structure to flow and form a uniform continuous melt upon heating, and it is the first point of major alteration in the structure during cooking (Kindstedt, Carlc, & Milanovic, 2004; Rowney, Roupas, Hickey, & Everett, 1998). As the mozzarella is heated, aggregates of milk fat globules between the protein fibres liquefy at 40 °C (Joshi, Muthukumarappan, & Dave, 2004; Lopez, Camier, & Gassi, 2007). The liquid fat coalesces and enhances the meltability by lubricating the surfaces of adjacent para-casein network to facilitate displacement of adjoining layers of the protein matrix and effectively increases cheese flow (Kindstedt, 1993; Lucey, Johnson, &

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Horne, 2003). However, there is currently a lack of structural information on melted mozzarella.

Stretchability is known to be one of the most significant functional properties of mozzarella, yet it is the most difficult aspect to measure (Fife, McMahon, & Oberg, 2002). Stretchability is defined as the capacity of melted cheese to form fibrous strands that extend without breaking under tension (Rowney et al., 1999). Lucey et al. (2003) have provided a more precise definition: stretch is the ability of the casein network to maintain its integrity when a continuous stress is applied to the cheese.

Many authors (Ak & Gunasekaran, 1995; Ak, Bogenrief, Gunasekaran, & Olson, 1993; Apostopoulos, 1993; Cavella, Chemin, & Masi, 1992; Fife et al., 2002; Ma, James, Zhang, & Emanuelsson-Patterson, 2012; Wang, Muthukumarappan, Ak, & Gunasekaran, 1998) have implemented objective stretch tests that provide quantitative rheological measurements of the cheese stretched under controlled environmental conditions. However, even with the possibility of quantifying stretch, the mechanism of stretch still remains unclear as to how the microstructure deforms.

One difficulty in directly visualising the effect of heat on the microstructure of mozzarella arises from the difficulty in handling soft mozzarella because of its viscoelastic behaviour. As strained materials are sampled, stress relaxation immediately alters the structure. Simply put, cutting a sample from stretched cheese alters the microstructure before analysis.

Thus, designing a method to extract the strained structure with the loading orientation and strained microstructure intact is critical to producing samples for microstructural analysis. The purpose of the current study was to reveal changes in microstructure on melting and stretching to quantify their role in mechanism of melt flow and stretchability. Melted and stretched mozzarella samples were produced using a sampling system capable of extracting samples with the loading orientation and the strained microstructure intact. These samples were then analysed using advanced complementary microscopy techniques combined with image analysis to quantify key structural parameters in the mozzarella microstructure under controlled heat-shear conditions.

2. Materials and methods

2.1. Mozzarella samples

Low moisture, part-skim mozzarella samples (Galaxy Mozzarella Cheese, Fonterra Brands Ltd., Auckland, New Zealand) were purchased as 200 g blocks from a local supermarket. The composition of the mozzarella was (per 100 g cheese): 19.9 g fat, 26.7 g protein, 50.9 g water and 0.5 g salt. The mozzarella was reported to be packed at the age of approximately 4–8 weeks, vacuum sealed and stored at 2 °C.

2.2. Sample extraction system

A sample extraction system was designed and fabricated based on modifications of the stretching apparatus of Ma et al. (2012) to produce melted and stretched mozzarella to capture in-built strain in the structure, and to arrest the deformation of fat during melting and stretching for microstructure characterisation.

A 10 g sample of mozzarella was placed into a stainless steel tube and covered with aluminium foil to prevent dehydration. The tube and cheese was then heated in a hot water bath at 75 °C for 15 min to achieve a melt temperature of 70 °C. After heating, a Teflon sleeve (which was also heated in the same water bath) was slid onto the tube to insulate and reduce the change in temperature of the sample. A 3-prong hook attached to the Instron crosshead was lowered into the pool of mozzarella, 5 mm above the rig base, as shown in Fig. 1a.

The hook was subsequently rotated clockwise by 90° and locked into position. The mozzarella was pulled vertically at 1000 mm min^{-1}. The strained structure was immediately frozen in place by pouring liquid N_2 into the rig as illustrated in Fig. 1b. Removing the sample from the rig prior to freezing could not be accomplished without further deformation of the sample. As such, quenching the stretched mozzarella using liquid nitrogen was found to be the most effective method of preserving the strained microstructure and arresting the transient deformations. Instantaneous solidification prevented further deformation from gravity and minimised artefacts during handling of samples that were in a viscous or malleable state.

The mozzarella sample was taken (Fig. 1c) from the centre of the stretched sample. Extracted samples were placed inside an airtight container and immediately stored at −20 °C in a freezer. Samples were taken at stretched lengths of 50 mm, 100 mm and 150 mm, giving strains of 280%, 580% and 900%, respectively, at a strain rate of about 10 s^{-1}. Unstretched samples were also taken by melting the cheese using the steps above, freezing then unsealing the tube.

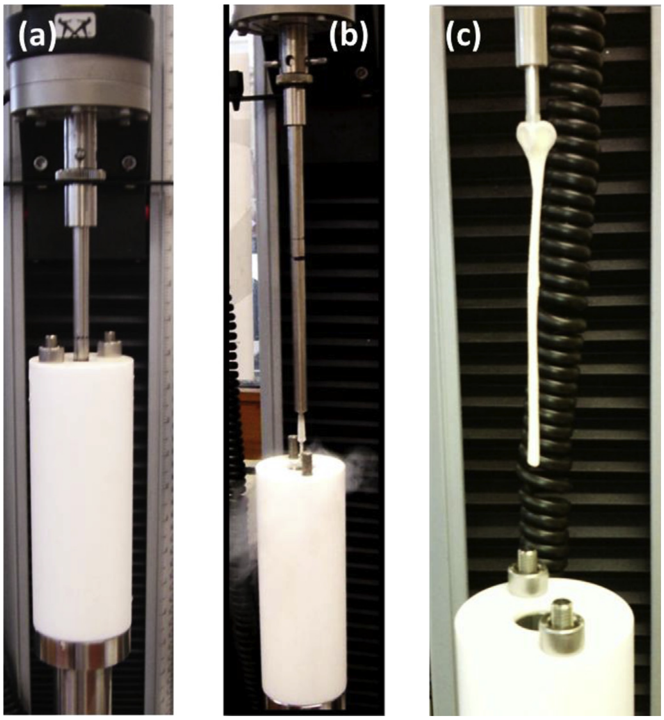

Fig. 1. Extraction of sample stretched to 100 mm and quenched: (a) starting position, zero strain; (b) at required strain sample is rapidly frozen with liquid nitrogen; (c) frozen sample removed from stretching apparatus.

2.3. Microstructure characterisation

Confocal laser scanning microscopy (CLSM), environmental scanning electron microscopy (ESEM) and cryo-SEM were used to observe the microstructure of the unmelted, melted and strained mozzarella. This set of microscopy techniques were selected as they accommodate the inspection of fully hydrated samples, use mild or no sample preparation and less inclined to introduce artefacts (James, 2009).

2.3.1. Confocal laser scanning microscopy

CLSM was used to observe the change in fat size and shape of fat globules and channels within the protein matrix for unmelted,