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Strain hardening and anisotropy in tensile fracture properties of sheared model Mozzarella cheeses

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ABSTRACT

We studied the tensile fracture properties of model Mozzarella cheeses with varying amounts of shear work input (3.3–73.7 kJ/kg). After manufacture, cheeses were elongated by manual rolling at 65°C followed by tensile testing at 21°C on dumbbell-shaped samples cut both parallel and perpendicular to the rolling direction. Strain hardening parameters were estimated from stress–strain curves using 3 different methods. Fracture stress and strain for longitudinal samples did not vary significantly with shear work input up to 26.3 kJ/kg and then decreased dramatically at 58.2 kJ/kg. Longitudinal samples with shear work input <30 kJ/kg demonstrated significant strain hardening by all 3 estimation methods. At shear work inputs <30 kJ/kg, strong anisotropy was observed in both fracture stress and strain. After a shear work input of 58.2 kJ/kg, anisotropy and strain hardening were absent. Perpendicular samples did not show strain hardening at any level of shear work input. Although the distortion of the fat drops in the cheese structure associated with the elongation could account for some of the anisotropy observed, the presence of anisotropy in the elongated nonfat samples reflected that shear work and rolling also aligned the protein structure.
Key words: tensile testing, strain hardening, anisotropy, Mozzarella cheese

INTRODUCTION

Hot water stretching and kneading is an essential step in the traditional manufacture of Mozzarella cheese. This process step causes the proteins to flow, giving a plastic appearance and forming a fibrous protein network aligned in the direction of stretching (McMahon et al., 1999). The fibrous structure is visible on a macroscopic level (Oberg et al., 1993; Sharma et al., 2016a). Sharma et al. (2016a,b, 2017) studied the effect of shear work input during this stretching and working step on the rheology and microstructure of model Mozzarella cheeses manufactured in a twin-screw Blentech cooker (Blentech Corp., Rohnert Park, CA) at 70°C. Shear work inputs were extended well beyond normal manufacturing limits to exaggerate any changes in the cheese caused by working. Mechanical properties were characterized using a range of rheological methods, including steady shear viscosity, strain sweeps, frequency sweeps, temperature sweeps, and creep behavior. With increase in shear work input, cheeses showed increases in steady shear viscosity and storage modulus. Frequency sweeps at 70°C demonstrated a shift from viscoelastic liquid to viscoelastic solid. These changes all indicate work thickening of the cheese. Very high shear work inputs (>70 kJ/kg) led to major macroscopic structural changes to the cheese network, with disappearance of the fibrous structure, loss of stretch and melt, and serum syneresis. Microstructures of the overworked cheeses indicated disappearance of the fibrous character and the creation of a homogeneous structure with a fine dispersion of fat particles in a brittle protein network (Sharma et al., 2017). The observed phenomena were attributed mainly to an increase in the strength of protein–protein interactions with prolonged working.

Bast et al. (2015) developed a tensile testing method to quantitate anisotropy and strain hardening of commercial Mozzarella cheese. The method involved deliberate elongation of cheese at 60°C by manual rolling on a cooled metal surface to ensure that the structure was systematically aligned. Mozzarella cheeses showed strong anisotropy for both fracture stress and strain after elongation and also showed significant strain hardening in the longitudinal or fiber direction. The study indicated that tensile testing was a good method to explore anisotropy and strain hardening because fracture location and mode of failure were clearly visible. Other studies on strain hardening in dairy protein systems

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explored fine-stranded whey protein isolate gels (Lowe et al., 2003), weak β-lactoglobulin gels (Pouzot et al., 2006), and gels formed by acidifying transglutaminase cross-linked casein (Rohm et al., 2014).

Rheological properties, microstructure, and extent of anisotropy are all closely related to the functional characteristics of Mozzarella cheese for pizza application such as meltability, stretchability, elasticity, oiling-off, and blister formation (Kindstedt and Fox, 1993; Olivares et al., 2009).

Strain hardening behavior expresses the underlying arrangement of structural units and is therefore useful for understanding functional properties of food materials. Strain hardening is well explored in gluten networks because it is important to attain optimum baking performance of bread dough by aiding holding capacity and stability of gas bubbles in the bread (van Vliet et al., 1992; Kokelaar et al., 1996; Peighambardoust et al., 2006; Peressini et al., 2008; van Vliet, 2008). The effect of mechanical work on tensile fracture properties and strain hardening of flour dough has also been studied. Peighambardoust et al. (2006) and Peressini et al. (2008) observed a decrease in strain hardening upon prolonged working of flour doughs and attributed this to breakdown in the gluten network structure. The structural analogy of the anisotropic nature of gluten network and Mozzarella cheese indicates the possibility of adapting testing procedures from dough rheology for better understanding of strain hardening in Mozzarella type cheeses.

The objectives of this paper were to (1) measure the tensile fracture properties and anisotropy of model Mozzarella cheeses with varied shear work inputs (3.3–73.7 kJ/kg) to complement the other rheological tools we have used; (2) explore whether our model Mozzarella cheeses strain harden and to see the effect of shear work input on this strain hardening; and (3) apply to Mozzarella cheese a wider range of strain hardening measures as used for flour doughs.

MATERIALS AND METHODS

Materials

Frozen blocks (−20°C) of renneted, acidified protein gel prepared from skim milk were obtained from the Fonterra Research and Development Centre (FRDC) pilot plant (Palmerston North, New Zealand). The protein gel was typically about 50% moisture and 46% protein. The frozen blocks were thawed for 1 d at 11°C and ground to a 6-mm grind size. Cream was obtained from FRDC as a fresh lot on each trial day. Cheese salt and trisodium citrate (**TSC**) were procured from Dominion Salt (Mount Maunganui, New Zealand) and Jungbunzlauer (Basel, Switzerland), respectively.

Manufacture of Model Mozzarella Cheeses

Model Mozzarella cheese was manufactured by mixing, cooking, and working protein gel, cream, water, and salt together using 150 rpm at 70°C in a counter rotating twin-screw cooker (Blentech model CC-0045, Blentech Corp.; Sharma et al., 2016a). Three model cheeses were prepared: full-fat cheese, nonfat cheese, and full-fat cheese with 0.5% TSC as a chelating agent. The target composition of full-fat cheese was 23% fat, 21% protein, 53% moisture, and 1.4% salt. The same protein-to-salt and protein-to-moisture ratios as in full-fat cheese were used in nonfat cheese. Further details of processing methods, sampling times, sample storage conditions, and product compositions are given in Sharma et al. (2016a). Each experimental run was repeated twice on different days at an interval of at least 1 mo to ensure no variation arising from raw materials with similar composition but obtained from different lots.

All cheeses used in this study were frozen after manufacture. Shear work input was estimated by numerical integration of power–time curves (Sharma et al., 2016a). Shear work inputs ranged from 3.3 to 73.7 kJ/kg.

Sample Preparation for Tensile Testing

Cheese samples were prepared for tensile testing using the method of Bast et al. (2015) with some variations. Cheese samples (~300 g) were melted by placing in closed containers at 65°C water bath for about 2 h. Melted cheese was manually rolled on a cooled (4°C) aluminum plate using a granite rolling pin (4°C) to form a sheet. Aluminum guide strips were attached to the plate sides to achieve a sheet thickness of 3 to 4 mm. The term "elongation" is used throughout the paper for this process. Elongation was performed for 120 s at 10 rolls/min. Dumbbell-shaped samples were cut in both longitudinal (n = 8) and perpendicular (n = 9) orientations. Samples were kept at 21°C for at least 1 h before tensile testing. Each rolling treatment was performed twice.

Tensile Testing and Data Analysis

Tensile testing on elongated cheese samples was performed on a TA.XT2plus Texture Analyzer (Stable Micro Systems Ltd., Godalming, UK) using tensile grips at 21°C. Crosshead speed was 2 mm/s and trigger force was 0.01 N. The initial dimensions of the central section of each sample were measured using Vernier