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Shreddability of pizza Mozzarella cheese predicted using physicochemical properties

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ABSTRACT

This study used rheological techniques such as uniaxial compression, wire cutting, and dynamic oscillatory shear to probe the physical properties of pizza Mozzarella cheeses. Predictive models were built using compositional and textural descriptors to predict cheese shreddability. Experimental cheeses were made using milk with (0.25% wt/wt) or without denatured whey protein and renneted at pH 6.5 or 6.4. The cheeses were aged for 8, 22, or 36 d and then tested at 4, 13, or 22 °C for textural attributes using 11 descriptors. Adding denatured whey protein and reducing the milk renneting pH strongly affected cheese mechanical properties, but these effects were usually dependent on testing temperature. Cheeses were generally weaker as they aged. None of the compositional or rheological descriptors taken alone could predict the shredding behavior of the cheeses. Using the stepwise method, an objective selection of a few (<4) relevant descriptors made it possible to predict the production of fines (R^2 = 0.82), the percentage of long shreds (R^2 = 0.67), and to a lesser degree, the adhesion of cheese to the shredding blade (R^2 = 0.45). The principal component analysis markedly contrasted the adhesion of cheese to the shredding blade with other shredding properties such as the production of fines or long shreds. The predictive models and principal component analysis can help manufacturers select relevant descriptors for the development of cheese with optimal mechanical behavior under shredding conditions.
Key words: Mozzarella cheese, rheological properties, shreddability, texture

INTRODUCTION

The ability of cheese to be shredded, sliced, or diced is a critical concern for cheese manufacturers. Given the continuous growth of the cheese ingredient sector, a size reduction process that has not been optimized may reduce cheese quality and result in significant economic losses. When shredding problems do occur, manufacturers commonly describe them as excessive shattering of cheese into fine particles (fines), uneven distribution of shred sizes, or sticking of cheese to the processing equipment (Kindstedt, 1995; Childs et al., 2007). In all cases, shredding defects are related to inappropriate mechanical properties of the cheese. It is well known that cheese ingredients must meet narrow specifications for meltability, stretchability, and free oil release (Kindstedt et al., 2010). In addition, the physicochemical properties of cheese to the point of shredding must be controlled for optimal shredding.

Despite the obvious importance of cheese shreddability to the cheese industry, the factors influencing shreddability have received little attention, and thus their effects remain largely unclear. According to Kindstedt (1995) and Childs et al. (2007), the lack of a suitable method to characterize or predict shredding properties is responsible for the limited information in this field. Indeed, most reports on the subject are based on empirical observations (Kindstedt, 1995; Rankin et al., 2006; Lucey, 2008). Some authors have proposed that shreds be visually characterized for quality control purposes (Apostolopoulos and Marshall, 1994; Ni and Gunasekaran, 2004). Childs et al. (2007) directly measured the production of fines and the adhesion to the blade in Mozzarella cheeses with varying fat and dry matter contents using controlled, small-scale shredding equipment. Banville et al. (2013) recently adapted this method to evaluate the effects of different cheesemaking conditions on the shreddability of pizza Mozzarella cheese. Despite those advances, there is a clear need for physicochemical descriptors that could predict the shredding properties of cheese before it is shredded.

From a materials science approach, shreddability is an overall indication of the complex mechanical behavior of cheese when it is submitted to high shear. In other words, the shredding behavior of a cheese is assumed to be strongly dependent on its rheological

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properties, such as plastic deformation, fracture, and friction (Gunasekaran and Ak, 2003; Goh et al., 2005; Childs et al., 2007). Over the last few decades, the rheological properties of cheese have been characterized using an impressive number of descriptors, testing apparatuses, and protocols (IDF, 1991; Gunasekaran and Ak, 2003), including the extensive use, for research and quality control purposes, of tests that induce large deformation. More recently, advanced rheological techniques such as dynamic rheometry performed under small deformation were successfully applied to study macromolecular interactions in cheese structure (Lucey et al., 2003; Choi et al., 2008; Tunick, 2011). Some authors proposed that the information obtained under low deformation could shed some light on the physical properties observed under larger deformation (Drake et al., 1999; Muliawan and Hatzikiriakos, 2007). It is well accepted that the rheological properties of cheese are governed by the structural elements of the material (e.g., fat, casein, and minerals) and by the way in which they are arranged in a substructure (i.e., the microstructure and the number, strength, and nature of interacting bonds). Therefore, the combination of different rheological techniques is, in the present authors' view, of primary importance for obtaining an overall global portrait of the effect of intrinsic and extrinsic factors on cheese texture and shredding behavior.

In a previous study, we showed that the shredding behavior of pizza Mozzarella cheese was strongly affected by cheese-making conditions (Banville et al., 2013). The first objective of the present study was to characterize the rheological properties of pizza Mozzarella cheese using descriptors from both small and large deformation techniques. The second objective was to use rheological and compositional descriptors to build predictive models for the shredding behavior of pizza Mozzarella cheese.

MATERIALS AND METHODS

Pizza Mozzarella Cheeses

Pizza Mozzarella cheeses were produced in a pilot plant as described by Banville et al. (2013). In that study, the effects of 36 combinations of cheese-making, aging, and testing conditions on the shreddability and meltability of pizza cheese were determined. For that purpose, a factorial split-split-plot experimental design was applied. Briefly, the cheese milks were standardized with 2 concentrations (0 or 0.25% wt/wt in milk) of denatured whey protein (**WP**) and were then renneted at a pH of 6.5 (**R6.5** cheese) or 6.4 (**R6.4** cheese). The draining pH of the R6.4 cheeses was also decreased by 0.1 unit compared with that of the R6.5 cheeses. The WP used originated from a single batch and was produced using a proprietary process from Agropur Cooperative (Granby, QC, Canada). After manufacture, the cheeses were allowed to age for 8, 22, or 36 d (subplot) at 4°C, and then physical analyses were performed on the cheeses at 4, 13, or 22 °C (sub-subplot). Three independent cheese batches were made. The detailed composition and the shredding and melting properties of the cheeses were previously reported (Banville et al., 2013).

Rheological Analysis

The rheological properties of the cheeses were measured at 3 temperatures (4, 13, or 22 °C) using large and small deformation systems. Large deformation testing was performed with a uniaxial texture analyzer (TA-XT2; Stable Micro Systems, Scarsdale, NY). Three protocols were used: (1) texture profile analysis (**TPA**) test; (2) the single lubricated compression (**SLC**) test; and (3) the wire-cutting test.

For the TPA and SLC tests, cylindrical cheese samples (20 mm in diameter, 25 mm in height) were compressed using a 38-mm Plexiglas cylinder fixture mounted on the moving head of the TA-XT2 texture analyzer. The TPA test consisted of a double compression (50% Hencky strain) that had a relaxation interval of 15 s and was performed at a constant crosshead speed of 1 mm/s. Hardness, adhesiveness, and cohesiveness were calculated from the TPA profiles, as proposed by Bourne (1978).

For the SLC test, the cheese sample surfaces were coated with paraffin oil (Fisher Scientific, Whitby, ON, Canada). In this case, deformation reached 80% of the cheese height and was applied at a constant strain rate of 2.5%/s. The Young's modulus ($\mathbf{Y_m}$) was determined as the initial slope of the stress–strain curve, calculated between 2.5 and 5% Hencky strain. As reported by Charalambides et al. (2001), at larger strains, the stress–strain curve of Mozzarella cheese is characterized by an inflection point followed by a fairly linear portion between 50 and 70% deformation. This portion of the stress–strain curve represents cheese flow under imposed deformation, and the slope corresponds to the flow modulus ($\mathbf{F_m}$). No fracture was observed within this strain range for all conditions tested.

For the wire-cutting test, stainless-steel wires measuring 0.35 or 0.9 mm in diameter and mounted on a U-shaped tool were used to cut cheese cubes (25-mm edges) at 0.5 mm/s. Kamyab et al. (1998) demonstrated that the force measured at steady-state cutting ($\mathbf{F_c}$) for a constant length of cheese (**B**) is proportional to the wire diameter (**d**), the yield stress of cheese ($\boldsymbol{\sigma_y}$), and