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A method for the inline measurement of milk gel firmness using an optical sensor

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ABSTRACT

At present, selection of cutting time during cheesemaking is made based on subjective methods, which has effects on product homogeneity and has prevented complete automation of cheesemaking. In this work, a new method for inline monitoring of curd firmness is presented. The method consisted of developing a model that correlates the backscatter ratio of near infrared light during milk coagulation with the rheological storage modulus. The model was developed through a factorial design with 2 factors: protein concentration (3.4 and 5.1%) and coagulation temperature (30 and 40°C). Each treatment was replicated 3 times; the model was calibrated with the first replicate and validated using the remaining 2 replicates. The coagulation process was simultaneously monitored using an optical sensor and small-amplitude oscillatory rheology. The model was calibrated and successfully validated at the different protein concentrations and coagulation temperatures studied, predicting the evolution of storage modulus during milk coagulation with coefficient of determination values >0.998 and standard error of prediction values <3.4 Pa. The results demonstrated that the proposed method allows inline monitoring of curd firming in cheesemaking and cutting the curd at a proper firmness to each type of cheese.
Key words: gel firmness, milk coagulation, cheese making, cutting time

INTRODUCTION

Determining gel firmness values from inline optical measurements has long been a goal for milk gels, because the monitoring and control of its evolution over time can bring many benefits in the manufacturing of different dairy products, particularly cheese. In cheese manufacturing, cutting time (**CT**) selection depends on the type of cheese being made. Early cutting enables much rearrangement to occur after cutting, increasing syneresis and reducing cheese moisture content, whereas late cutting has opposite effects (Fagan et al., 2007). Therefore, cutting should be initiated at a consistent curd firmness that is optimized for the type of cheese being made.

In most cheese plants, gel is usually cut after a predetermined reaction time or upon the operator's visual judgment of textural properties. The first method is questionable because of factors that affect the coagulation process, such as milk composition, could vary the optimum CT. In the second method the decision depends on the experience of a cheesemaker, but it is not objective (Castillo, 2006a).

Numerous devices have been developed to assess the coagulation of milk and determine optimal coagulum CT (Kübarsepp et al., 2005; Castillo, 2006a; Klandar et al., 2007). Among these are the Formagraph (Foss Electric A/S, Hillerød, Denmark), based on the drag force technique (Dal Zotto et al., 2008; Bittante et al., 2012); the low-amplitude dynamic oscillatory rheometer (Hemar et al., 2004; Frederiksen et al., 2011; Jakob et al., 2011); ultrasonic sensing devices (Cosgrove, 2000; Taifi et al., 2006; Koc and Ozer, 2008); and the hot wire probe (Hori, 1985; Passos et al., 1999; O'Callaghan et al., 2001). However, several of these methods are intrusive, destructive, do not work inline, or are not practical for in-plant implementation; for more than 6 decades, the industry has lacked an efficient and reliable, nondestructive, easy-to-clean, and sanitary inline monitoring curd-firming sensor, which is a serious hindrance to complete cheesemaking automation.

Study of network formation has often been achieved using light scattering. In milk and, especially, in the visible and near infrared ranges, light scattering predominates over absorption. Light scattering changes during coagulation are directly related to the rate of aggregation and curd firming if total casein concentra-

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tion does not vary during the measurements (Castillo, 2006a).

According to Payne et al. (1993), the logarithmic period observed in the diffuse reflectance profile of coagulating milk appeared to follow the same pattern as the rheological changes. The optic inline sensor CoAguLite, developed by Payne et al. (1990), measures near infrared light backscatter (**LB**) and has been successfully applied to determine cutting time of cow milk (Payne et al., 1993), goat milk (Castillo et al., 2000), sheep milk (Nicolau et al., 2011), low-fat milk with inulin (Arango et al., 2013), and milk mixtures (Abdelgawad et al., 2014). This technique is currently commercially available for inline monitoring of cheesemaking, especially in the United States.

One reason for further modeling the coagulation process is to have an objective way to determine a measure of the gel firmness at cutting, as this is thought to be important for controlling yield and cheese moisture content. The objective of our work was to develop and evaluate a method for the inline measurement of milk gels firmness using an optical sensor.

MATERIALS AND METHODS

Experimental Design

The method for prediction of storage modulus (**G′**) values (curd firming) during milk coagulation, using data from an optical sensor, was evaluated through a factorial design replicate 3 times with 2 factors: coagulation temperature (30 and 40°C) and milk protein concentration (3.4 and 5.1%). In the cheese industry, coagulation temperature is kept constant but may be different depending on the type of cheese being made. On the other hand, milk protein content varies naturally; in some cases protein concentrates may be added to increase yield. Accordingly, the factor levels were selected with the aim of evaluating the proposed method in a broad spectrum of coagulation conditions. In addition, temperature and protein concentration are 2 of the most relevant factors known to affect the curd G′ value (Castillo et al., 2003a). The coagulation process was simultaneously monitored using an inline LB sensor and small-amplitude oscillatory rheometry. For each treatment, the first replication was used to calibrate the model and the other 2 were used to validate the model.

Near-Infrared LB Sensor

The laboratory equipment with a near-infrared LB sensor used to carry out our study is shown in Figure 1. A detailed description has been presented in Castillo et al. (2006b) and Tabayehnejad et al. (2012).

The laboratory equipment had 2 identical vats (98-mL capacity), allowing simultaneous coagulation tests. Averaging the measurements improved the accurate of the optical parameters. In the sensor, light from a light-emitting diode was transferred to the milk through a fiber, and the light backscattered from the milk was transmitted through an adjacent fiber to an optical detector. Sample temperature in the 2 milk sample vats was controlled using a circulating water bath (Lauda RM 20, Brinkmann Instruments Inc., Westbury, NY) and was measured with a precision thermistor thermometer. A light backscatter ratio (***R***) profile was calculated starting immediately after enzyme addition by dividing the voltage output from the detector by the average of the first 10 voltage data points collected, according to the procedure described by Castillo et al. (2000). Values of R were collected every 6 s, which allowed us to obtain an accurate profile showing the evolution of milk coagulation. The changes that occurred in the milk during coagulation were correlated with the signal changes derived from the optical sensor, and the R value increased as aggregation and gel assembly proceeded.

Rheological Monitoring of Milk Coagulation

Small-amplitude oscillatory dynamic trials were carried out with a concentric-cylinders sensor (Z34 DIN) in a ThermoHaakeRS1 rheometer coupled to a Thermo-Haake water bath (Thermo-Haake GmbH, Karlsruhe, Germany) for the precise control of temperature. The frequency and the strain were set up at 1 Hz and 3%, respectively (Hallén et al., 2007). An aliquot of 40 mL of milk with enzyme was transferred to the cylinder of the rheometer that was prewarmed to the assay temperature. The sample surface was covered with a thin layer of vegetable oil to avoid evaporative cooling during the coagulation. The rheological parameters storage (G′) and viscous (G″) moduli were collected around every 25 s up to a G′ of 60 Pa, using Rheowin Job Manager Software (Thermo Fisher Scientific, Karlsruhe, Germany). Gelation time ($\boldsymbol{t_{G'1}}$) was defined as the time when the gels had a G′ of 1 Pa.

Procedure of the Tests

Low-heat, spray-dried milk powder with 34% protein and 0.9% fat (Chr. Hansen, Barcelona, Spain) was reconstituted to prepare the milk for the tests. Skim milk powder was selected for the study because it had a constant composition that allowed minimizing the ex-