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Modeling of coagulation, curd firming, and syneresis of milk from Sarda ewes

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ABSTRACT

This study investigated the modeling of curd-firming (CF) over time (CF_t) of sheep milk. Milk samples from 1,121 Sarda ewes from 23 flocks were analyzed for coagulation properties. Lactodynamographic analyses were conducted for up to 60 min, and 240 CF individual observations from each sample were recorded. Individual sample CF_t equation parameters (RCT_{eq}, rennet coagulation time; CF_P, asymptotic potential value of curd firmness; k_{CF}, curd-firming instant rate constant; and k_{SR}, curd syneresis instant rate constant) were estimated, and the derived traits (CF_{max}, the point at which CF_t attained its maximum level, and t_{max}, the time at which CF_{max} was attained) were calculated. The incidence of noncoagulating milk samples was 0.4%. The iterative estimation procedure applied to the individual coagulation data showed a small number of not-converged samples (4.4%), which had late coagulation and an almost linear pattern of the ascending part of the CF_t curve that caused a high value of CF_P, a low value of k_{CF}, and a high value of k_{SR}. Converged samples were classified on the basis of their CF_t curves into no-k_{SR} (18.0%), low-k_{SR} (72.6%), and high-k_{SR} (4.5%). A CF_t that was growing continuously because of the lack of the syneresis process characterized the no-k_{SR} samples. The high-k_{SR} samples had a much larger CF_P, a smaller k_{CF}, and an anticipation of t_{max}, whereas the low-k_{SR} samples had a fast k_{CF} and a slower k_{SR}. The part of the average CF_t curves that showed an increase was similar among the 3 different syneretic groups, whereas the part that decreased was different because of the expulsion of whey from the curd. The traditional milk coagulation properties recorded within 30 min were not able to detect any appreciable differences among the 4 groups of coagulating samples, which could lead to a large underestimation of the maximum CF of all samples (if predicted by a_{30}), with the exception of the no-k_{SR} samples. Large individual variability was found and was likely caused by the effects of the dairy system, such as flock size (on CF_{max}, t_{max}, and % ewes with no-k_{SR} milk), flock within flock size (representing 11 to 43% of total variance for % ewes with no-k_{SR} milk and CF_{max}, respectively), days in milk (on all model parameters and CF_{max}), parity (on RCT_{eq}, k_{SR}, and CF_{max}), daily milk yield (on RCT_{eq} and CF_{max}), and position of the individual pendulum that significantly affected model parameters and derived traits. In conclusion, the results showed that the modeling of coagulation, curd-firming, and syneresis is a suitable tool to achieve a deeper interpretation of the coagulation and curd-firming processes of sheep milk and also to study curd syneresis.
Key words: ovine milk, milk coagulation property, curd-firming modeling, syneresis, cheese-making property

INTRODUCTION

The production of milk from species other than bovine contributes significantly in certain countries (Claeys et al., 2014). World total production of ewe milk during 2001 to 2011 increased from 8.3 to 9.9 million tonnes, and gross production value increased from US$3,100 to 5,600 million (FAOSTAT, 2014). Because the large majority of sheep milk is used for the production of cheese, industries making cheese from sheep milk benefit from significant information about coagulation properties obtained in the laboratory and dairy. This information is often acquired with methods developed from studies on dairy cows.

The traditional milk coagulation properties (**MCP**), rennet coagulation time (**RCT**, min), curd-firming time (**k_{20}**, min), and curd firmness (**a_{30}**, mm), are single-point parameters that were introduced for the study and the evaluation of the requirements of cow milk for cheese making. The MCP are often determined by mechanical lactodynamographic instruments that measure curd formation and firmness during a 30-min test (McMahon and Brown, 1982; Cipolat-Gotet et al., 2012). Those measurements are often criticized because

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of concerns about the method: MCP are obtained from a time-consuming analysis and from milk samples with a delayed RCT (tests that are longer than 30 min and classified as noncoagulating samples, **NC**), it is not possible to determine any MCP values (Ikonen et al., 1999; Wedholm et al., 2006). The NC samples are often recorded for bovine species because some breeds (e.g., the Holstein-Friesian), are characterized by a late-coagulating milk (Verdier-Metz et al., 1998; Malacarne et al., 2006; Cecchinato et al., 2011). The NC samples are treated by extending the analysis for longer than 30 min (Auldist et al., 2004; Poulsen et al., 2013).

Modeling the entire output of computerized lactodynamographs and the introduction of the concept of curd-firming over time ($\mathbf{CF_t}$), which is independent from the traditional MCP, provides additional information about milk coagulation and the curd-firming processes (Bittante, 2011). This last approach has been first studied in dairy cows to provide novel parameters and to summarize all of the information collected by the continuous recording of CF_t observations for each sample, which includes the asymptotic potential value of curd firmness at an infinite time ($\mathbf{CF_P}$, mm) and the curd-firming instant rate constant ($\mathbf{k_{CF}}$, % × min^{-1}). The RCT is not predicted as a single point measurement but from the result of modeling all data available ($\mathbf{RCT_{eq}}$, min). Moreover, the modeling of data obtained from prolonging the lactodynamographic test beyond the usual 30 min also lead to information on the syneresis process: a syneresis instant rate constant ($\mathbf{k_{SR}}$, % × min^{-1}) that tends to reduce CF_t beyond a maximum curd firmness ($\mathbf{CF_{max}}$, mm) after a given time interval ($\mathbf{t_{max}}$, min), according to the 4 parameter model of Bittante et al. (2013).

Although the incidence is lower than in bovines, the presence of NC is observed in sheep (Pazzola et al., 2013) and goats (Devold et al., 2010; Pazzola et al., 2012, 2014b). Pazzola et al. (2014a) have analyzed the MCP of milk samples collected in a large survey on dairy Sarda ewes, and outlined the limitations of applying the traditional MCP for dairy cows to sheep species and the need for modeling of the available information. Modeling has been used for sheep species by Bittante et al. (2014), who have applied a 4-parameter model to a limited population of Alpine sheep breeds reared under experimental conditions.

The present study had the following objectives: (1) to test the adaptability of a 4-parameter model to depict the pattern of single point CF measurements recorded during an extended interval of time from rennet addition to sheep milk samples; (2) to classify milk samples collected during a large survey on Sarda sheep flocks according to the parameters of the models; and (3) to analyze the effects of flock, of individual ewe characteristics (parity, stage of lactation, and daily milk yield) and of instrument position (pendulum) on the model parameters and derived traits.

MATERIALS AND METHODS

Animals and Milk Sampling

Pazzola et al. (2014a) have described in detail the animals and milk sampling procedures adopted for the present study. Briefly, 1,121 ewes reared on 23 different commercial farms evenly distributed over the island of Sardinia, Italy, were used in the study. Lactating ewes were pasture-fed with a commercial concentrate supplementation given during the milking and were generally managed following the common semi-extensive and semi-intensive methods as described by Carta et al. (2009) and Carcangiu et al. (2011). The flock size (<300 ewes, 8 flocks; 300–600 ewes, 7 flocks; and >600 ewes, 8 flocks) was found to be the herd classification factor (flock size, geographic area, type of operation, type of farm on the basis of management, and feeding characteristics) that maximized the fit of the model and that avoided multicollinearity among different management factors (Pazzola et al., 2014a). Ewe milking was performed by manually operated milking machines twice a day (often at 600 and 1600 h). The daily milk yield was 1.61 ± 0.83 kg. Groups of ewes (32 to 82 per flock) in the second to the seventh month of lactation were sampled once (DIM 140 ± 42 d).

Analyses of Milk Traits and Coagulation Properties

Pazzola et al. (2014a) have described the analyses and the mean values for milk contents. The chemical composition (fat, protein, casein, urea, and lactose and pH) of individual milk samples was analyzed with a MilkoScan FT6000 (Foss Electric, Hillerød, Denmark). The SCC was determined with a Fossomatic 5000 (Foss Electric), and the total bacterial count (**TBC**) was measured with a BactoScan FC150 (Foss Electric). Both SCC and TBC were log-transformed: SCC to SCS [SCS = ($\log_2$ SCC × $100{,}000^{-1}$) + 3)] and TBC to log-bacterial count [TBC = $\log_{10}$ (total bacterial count × $1{,}000^{-1}$)]. The measures of MCP were obtained with the Formagraph instrument (Foss Italia, Padova, Italy). For each individual sample, 10 mL was heated to 35°C before the addition of 200 μL of the rennet solution [Hansen Naturen Plus 215 (Pacovis Amrein AG, Bern, Switzerland), with 80 ± 5% chymosin and 20 ± 5% pepsin and 215 international milk clotting units (**IMCU**)/mL, which was diluted to 1.2% (wt/vol) in distilled water to achieve 0.0513 IMCU/milk mL]. This analysis continued for 60 min after rennet