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Effect of dairy farming system, herd, season, parity, and days in milk on modeling of the coagulation, curd firming, and syneresis of bovine milk

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ABSTRACT

The objectives of this study were to characterize the variation in curd firmness model parameters obtained from coagulating bovine milk samples, and to investigate the effects of the dairy system, season, individual farm, and factors related to individual cows (days in milk and parity). Individual milk samples (n = 1,264) were collected during the evening milking of 85 farms representing different environments and farming systems in the northeastern Italian Alps. The dairy herds were classified into 4 farming system categories: traditional system with tied animals (29 herds), modern dairy systems with traditional feeding based on hay and compound feed (30 herds), modern dairy system with total mixed ration (TMR) that included silage as a large proportion of the diet (9 herds), and modern dairy system with silage-free TMR (17 herds). Milk samples were analyzed for milk composition and coagulation properties, and parameters were modeled using curd firmness measures (CF_t) collected every 15 s from a lacto-dynamographic analysis of 90 min. When compared with traditional milk coagulation properties (MCP), the curd firming measures showed greater variability and yielded a more accurate description of the milk coagulation process: the model converged for 93.1% of the milk samples, allowing estimation of 4 CF_t parameters and 2 derived traits [maximum CF (CF_{max}) and time from rennet addition to CF_{max} (t_{max})] for each sample. The milk samples whose CF_t equations did not converge showed longer rennet coagulation times obtained from the model (RCT_{eq}) and higher somatic cell score, and came from less-productive cows. Among the sources of variation tested for the CF_t parameters, dairy herd system yielded the greatest differences for the contrast between the traditional farm and the 3 modern farms, with the latter showing earlier coagulation and greater instant syneresis rate constant (k_{SR}). The use of TMR yielded a greater t_{max} because of a higher instant curd-firming rate constant (k_{CF}). Season of sampling was found to be very important, yielding higher values during winter for all traits except k_{CF} and k_{SR}. All CF_t traits were affected by individual cow factors. For parity, milk produced by first-lactation cows showed higher k_{CF} and k_{SR}, but delays in achieving CF_{max}. With respect to stage of lactation, RCT_{eq} and potential asymptotic CF increased during the middle of lactation and stabilized thereafter, whereas the 2 instant rate constants presented the opposite pattern, with the lowest (k_{CF}) and highest (k_{SR}) values occurring in mid lactation. The new challenge offered by prolonging the test interval and individual modeling of milk technological properties allowed us to study the effects of parameters related to the environment and to individual cows. This novel strategy may be useful for investigating the genetic variability of these new coagulation traits.

Key words: dairy system, milk coagulation, curd firming, syneresis, modeling

INTRODUCTION

To characterize milk coagulation properties (**MCP**), researchers developed the lacto-dynamographic technique several decades ago. Lacto-dynamography is based on recording the movement of a small loop pendulum immersed in a linearly oscillating sample of coagulating milk, with the degree of movement taken to represent curd firmness (**CF**). At that time, oscillation of the pendulum was graphed on photographic paper and all measurements were performed manually (Annibaldi et al., 1977; Zannoni and Annibaldi, 1981). Three single-point measures (McMahon and Brown, 1982) were considered to be useful MCP: (1) rennet coagulation time (**RCT**, min), which is the interval between the addition of rennet to the time at which the baseline begins to widen due to milk gelation; (2) the time interval between RCT and a measured amplitude of oscillation of 20 mm on the paper (**k_{20}**, min), which represents the curd-firming rate; and (3) the amplitude of oscillation (representing the final CF) recorded 30 min after rennet addition (**a_{30}**, mm). Since these early

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studies, dairy cows have changed in terms of breed proportions, breeding values, productivity, type, and fitness. Furthermore, dairy farms have moved toward larger, more mechanized and intensive operations, in which cows are fed increasingly energy- and nutrient-dense diets and new milking systems and milk-storage methods are used. These changes and the worldwide diffusion of the Holstein breed have collectively contributed to delayed milk coagulation and a slower curd-firming process (Bittante et al., 2012). Increases have also been observed in the incidences of so-called noncoagulating samples (**NC**, samples that do not coagulate within 30 min from rennet addition and thus cannot yield RCT or a_{30} values; Ikonen et al., 1999; Cecchinato et al., 2011) and of milk samples that fail to yield k_{20} measures within 30 min (Cipolat-Gotet et al., 2012; Cecchinato et al., 2013). The delay in coagulation time has also reduced the time interval available for curd firming, reduced average a_{30} measures, and strongly increased the correlation between RCT and a_{30} because of the near-linearity of the CF increase soon after gelation. This has made the latter traits meaningless, such that traditional MCP have lost much of their informative value for the industry.

Furthermore, modern computerized instruments can simultaneously evaluate multiple milk samples, perform all measurements automatically, continuously store raw data for many measures per milk sample, and analyze the data to yield the 3 traditional single-point MCP (Bittante et al., 2012). Some researchers have attempted to study the dynamics of milk curdling using different rheometers (Douillard, 1973, 1986; Gervais, 1983; Dejmek, 1987; O'Callaghan and Guinee, 1996), but only limited research has been conducted on mechanical lacto-dynamographs (McMahon et al., 1984). The need to summarize all of the information recorded by modern instruments and identify more flexible and stable parameters (i.e., parameters that are independent of a few point measures and the length of data recording) led Bittante (2011) to model all CF data automatically recorded by computerized lacto-dynamographs (120 to 240 readings per sample during a 30-min test, depending on the instrument). He used a 3-parameter model that included (1) $\mathbf{RCT_{eq}}$, which was estimated by the model; (2) the asymptotic potential CF at infinite time ($\mathbf{CF_P}$, mm); and (3) an instant rate constant of curd firming ($\mathbf{k_{CF}}$, in %/min) from RCT to infinite time. These parameters were estimated using all available data points. They were also independent of any specific point on the curve, and could be estimated for final CF recordings <20 mm.

To address the increased frequency of NC samples and exploit new information derived from the tendency of many samples to decrease in CF after 30 min (instead of continuously increasing), Bittante et al. (2013b) proposed to prolong the duration of the test and model the instrument output according to a 4-parameter model that additionally included an instant rate constant for syneresis ($\mathbf{k_{SR}}$, %/min). This rate is much slower than k_{CF} and shows an opposing effect, in that over the long run it tends to lead the CF curve asymptotically toward zero.

The aims of the present study were (1) to test the applicability of the 4-parameter model to a large data set and characterize the distribution properties of the parameters; (2) to quantify and characterize the effects of the dairy farming system, season, and individual farm on the model parameters and shape of the curd firmness modeled on time ($\mathbf{CF_t}$) curve; and (3) to quantify and characterize the effects of individual cow-level sources of variation (parity and DIM) on the model parameters and CF_t curve shape.

MATERIALS AND METHODS

Dairy Farming Systems, Herds, and Seasons

The present study is part of the Cowability–Cowplus projects; it was carried out on 85 herds located in Trento Province (northeastern Italian Alps) and enrolled in the milk-recording program of the local Provincial Federation of Breeders (FPA, Trento, Italy). The herds were chosen from 610 farms and selected to represent different environments and dairy farming systems. The farming systems were analyzed and described by Sturaro et al. (2009, 2013), and classified as follows:

(a) Traditional systems (29 herds) consisting of small farms (average cultivated land 18.6 ha, excluding summer highland pasture) with old barns, relatively few (average, 28.2) lactating cows tied and milked in stalls, feeding year-round on the farm's meadow hay (60.9% DM daily intake, with a total of 68.3% represented by forage DM) and commercial compound feed (18.3% of total DM intake) distributed manually or via automated feeders in the stalls; and common summer transhumance to temporary farms on highland pastures when it is common to feed some concentrates.

(b) Modern dairy systems (30 herds) with traditional feeding methods but no TMR. The farms consisted of modern buildings, with, on average, 39.3 lactating cows that are loose housed and fed using the farm's hay (53.7% DMI with a total of 62.0% represented by forage) and com-