J. Dairy Sci. 95:6843–6870
http://dx.doi.org/10.3168/jds.2012-5507


# *Invited review:* Genetics and modeling of milk coagulation properties

**G. Bittante, M. Penasa,[1] and A. Cecchinato**
Department of Agronomy, Food, Natural Resources, Animals and Environment (DAFNAE), University of Padova, Viale dell'Università 16, 35020 Legnaro (PD), Italy

## ABSTRACT

Milk coagulation properties (MCP) are conventionally measured using computerized renneting meters, mechanical or optical devices that record curd firmness over time ($CF_t$). The traditional MCP are rennet coagulation time (RCT, min), curd firmness ($a_{30}$, mm), and curd-firming time ($k_{20}$, min). The milk of different ruminant species varies in terms of $CF_t$ pattern. Milk from Holstein-Friesian and some Scandinavian cattle breeds yields higher proportions of noncoagulating samples, samples with longer RCT and lower $a_{30}$, and samples for which $k_{20}$ is not estimable, than does milk from Brown Swiss, Simmental, and other local Alpine breeds. The amount, proportion, and genetic variants (especially κ-casein) of milk protein fractions strongly influence MCP and explain variable proportions of the observed differences among breeds and among individuals of the same breed. In addition, other major genes have been shown to affect MCP. Individual repeatability of MCP is high, whereas any herd effect is low; thus, the improvement of MCP should be based principally on selection. Exploitable additive genetic variation in MCP exists and has been assessed using different breeds in various countries. Several models have been formulated that either handle noncoagulating samples or not. The heritability of MCP is similar to that of other milk quality traits and is higher than the heritability of milk yield. Rennet coagulation time and $a_{30}$ are highly correlated, both phenotypically and genetically. This means that the use of $a_{30}$ data does not add valuable information to that obtainable from RCT; both traits are genetically correlated mainly with milk acidity. Moreover, $a_{30}$ is correlated with casein content. The major limitations of traditional MCP can be overcome by prolonging the observation period and by using a novel $CF_t$ modeling, which uses all available information provided by computerized renneting meters and allows the estimation of RCT, the potential asymptotic curd firmness, the curd-firming rate, and the syneresis rate. Direct measurements of RCT obtained from both mechanical and optical devices show similar heritabilities and exhibit high phenotypic and genetic correlations. Moreover, mid-infrared reflectance spectroscopy can predict MCP. The heritabilities of predicted MCP are higher than those of measured MCP, and the 2 sets of values are strongly correlated. Therefore, mid-infrared reflectance spectroscopy is a reliable and cheap method whereby MCP can be improved at the population level; this is because such spectra are already routinely acquired from the milk of cows enrolled in milk recording schemes.
**Key words:** milk coagulation time and curd firmness, syneresis, genetic parameter, mid-infrared spectroscopy

## INTRODUCTION

### *Milk Coagulation Properties Are Relevant in the Dairy Industry*

Cheese making requires milk coagulation and development of syneresis. Milk coagulation properties (**MCP**) have received a great deal of attention from the dairy industry, principally because the amount of milk used for cheese production is growing worldwide (International Dairy Federation, 2011). In the last decade, the fraction of total milk destined to cheese production has increased by about 10% in the European Union and North America, and it is now slightly higher than 50% in the former continent and slightly lower in the latter. An increase in the amount of milk used to manufacture cheese has been reported in other European countries, Oceania, and Latin America, and the amount used is much lower in Asia and Africa.

Several studies have confirmed that analysis of MCP yields information relevant for cheese processing, yield, and quality at the laboratory level (Ng-Kwai-Hang et al., 1989; Riddell-Lawrence and Hicks, 1989; Walsh et al., 1998; Wedholm et al., 2006; Alipanah and Kalashnikova, 2007) and industrial level (Bynum and Olson, 1982b; Grandison et al., 1985; Aleandri et al., 1989; Ikonen et al., 1999b; Buchberger and Dovč, 2000; Johnson et al., 2001; Summer et al., 2003; De Marchi et al., 2008). In addition, MCP influence the sensory

Received March 5, 2012.
Accepted August 5, 2012.
[1]Corresponding author: mauro.penasa@unipd.it

properties of cheese (Martin et al., 1997). Milk coagulation properties are of particular importance in the preparation of Protected Designation of Origin (**PDO**) cheeses (Mariani and Battistotti, 1999; Bertoni et al., 2005; Bittante et al., 2011a). Such cheeses are produced using traditional processing methods, and cheese quality relies on MCP. In some instances, the MCP of herd bulk milk used to produce PDO cheeses are periodically analyzed and the data used to reward or penalize producers (Calamari et al., 2005; Bittante et al., 2011b).

The objective of this review paper is to provide an insight into the genetic aspects of MCP by considering the effects of species, breed, major genes, and polygenes. The limitations of current MCP testing will also be reviewed. The need to develop new models of milk coagulation, curd firming, and syneresis will be emphasized.

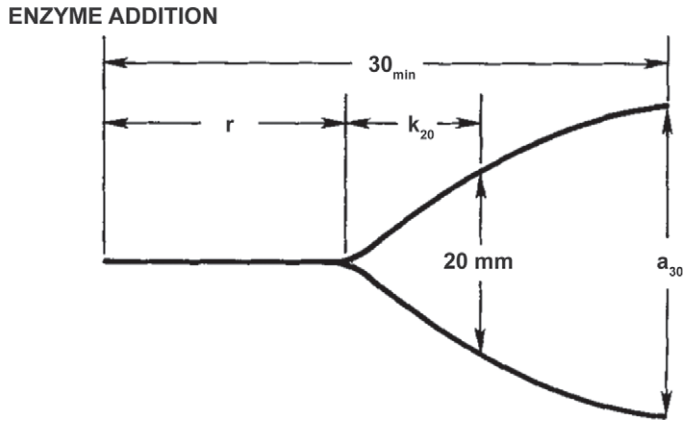


**Figure 1.** Diagram of rennet coagulation time (r = RCT, min) and curd firmness traits [time to curd firmness of 20 mm ($k_{20}$, min), and curd firmness 30 min after enzyme addition ($a_{30}$, mm)] as a function of time (lactodynamographic curve) as recorded with the original Formagraph (Foss Electric A/S, Hillerød, Denmark). Reproduced with permission from McMahon and Brown (1982).

### *MCP Are Measured with Various Instruments and Yield Different Traits*

The most common approach toward analysis of MCP, at both the research and industry levels, is lactodynamography. This technique monitors the viscosity of milk samples, maintained at a fixed temperature, following addition of rennet. Several approaches can be used to determine MCP (Bynum and Olson, 1982a; O'Callaghan et al., 2002; Kübarsepp et al., 2005; Fagan et al., 2007a,b; Klandar et al., 2007). Although dynamic rheometry is often used in research laboratories (Glantz et al., 2010; Frederiksen et al., 2011; Jakob et al., 2011), the Formagraph (from the Italian word *formaggio*, for cheese; Foss Electric A/S, Hillerød, Denmark) has been customized to permit simultaneous evaluation of several milk samples and has been widely used for decades (Annibaldi et al., 1977; Zannoni and Annibaldi, 1981; McMahon and Brown, 1982; Okigbo et al., 1985a,b,c). Formagraph-based MCP measurement involves analysis of the behavior of small-loop pendula immersed in linearly oscillating samples of coagulating milk. Minute forces are applied to the pendula because of gel formation in the moving milk (McMahon and Brown, 1982). These forces are recorded and produce a typical Formagraph output, as shown in Figure 1 (McMahon and Brown, 1982). In the earlier versions of the instrument, each output was graphed on photographic paper and all measurements were performed manually. Three single-point parameters are considered to be useful MCP: (1) rennet coagulation time (**RCT**, min), obtained by measuring the interval from time zero (the moment of addition of rennet to milk) to the time at which the baseline begins to widen; (2) the time to a curd firmness (**CF**) of 20 mm ($\mathbf{k_{20}}$, min), which is the interval from the start of gel formation (RCT) to the time at which the oscillation width becomes 20 mm; and (3) the CF 30 min after enzyme addition ($\mathbf{a_{30}}$, mm), which corresponds to the width of the graph 30 min after rennet addition.

Since the earliest studies of MCP, different shapes of lactodynamographic curve have been recognized (Figure 2; Annibaldi et al., 1977). Combinations of the 3 MCP have been used to classify milk as optimal, suboptimal, defective, and noncoagulating (**NC**; Table 1). Compared to the optimal curve (type A), type B is a late-coagulating milk with normal curd firming and is frequent in late lactation; type C, in contrast, is an early-coagulating milk with slow curd firming and is more frequent at the beginning of lactation; type D is an early-coagulating milk with fast and intense curd firming and is typical of milks very rich in casein or slightly acid milks; type E is a late-coagulating milk with very slow curd firming, denoting a low reactivity to rennet and is frequent in cows with secretion disorders and high SCC and in cows with some genetic variants of κ-casein; type F is a more-extreme variant of type E, with only a very late beginning of some coagulation, frequent in high-pH milk from cows with clinical mastitis; type DD, in contrast, is a very early coagulating milk with a rapid and strong $a_{30}$, frequent in very acid milks; and last, type FF is an NC milk (Annibaldi et al., 1977). It is evident that MCP are characterized by intermediate optimum values and by equilibrium among them. The defects of late or no coagulation and slow curd firming are more severe and frequent than the opposite defects.

Currently, the lactodynamograph performs all measurements automatically, continuously stores the raw