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Genetic parameters for rennet- and acid-induced coagulation properties in milk from Swedish Red dairy cows

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ABSTRACT

Milk coagulation is an important processing trait, being the basis for production of both cheese and fermented products. There is interest in including technological properties of these products in the breeding goal for dairy cattle. The aim of the present study was therefore to estimate genetic parameters for milk coagulation properties, including both rennet- and acid-induced coagulation, in Swedish Red dairy cattle using genomic relationships. Morning milk samples and blood samples were collected from 395 Swedish Red cows that were selected to be as genetically unrelated as possible. Using a rheometer, milk samples were analyzed for rennet- and acid-induced coagulation properties, including gel strength (G′), coagulation time, and yield stress (YS). In addition to the technological traits, milk composition was analyzed. A binary trait was created to reflect that milk samples that had not coagulated 40 min after rennet addition were considered noncoagulating milk. The cows were genotyped by using the Illumina BovineHD BeadChip (Illumina Inc., San Diego, CA). Almost 600,000 markers remained after quality control and were used to construct a matrix of genomic relationships among the cows. Multivariate models including fixed effects of herd, lactation stage, and parity were fitted using the ASReml software to obtain estimates of heritabilities and genetic and phenotypic correlations. Heritability estimates (h^2) for G′ and YS in rennet and acid gels were found to be high (h^2 = 0.38–0.62) and the genetic correlations between rennet-induced and acid-induced coagulation properties were weak but favorable, with the exception of YS_{rennet} with G'_{acid} and YS_{acid}, both of which were strong. The high heritability (h^2 = 0.45) for milk coagulating ability expressed as a binary trait suggests that noncoagulation could be eliminated through breeding. Additionally, the results indicated that the current breeding objective could increase the frequency of noncoagulating milk and lead to deterioration of acid-induced coagulation through unfavorable genetic associations with protein content (0.38) and milk yield (−0.61 to −0.71), respectively. The outcome of this study suggests that by including more detailed compositional traits genetically associated with milk coagulation or by including milk coagulation properties directly within the breeding goal, it appears possible to breed cows that produce milk better suited for production of cheese and fermented products.
Key words: milk coagulation, genetic correlation, heritability, noncoagulating milk

INTRODUCTION

There is increased interest to include technological properties and more detailed milk composition traits in the breeding goal for dairy cattle (Boichard and Brochard, 2012). Because of this, it is necessary to estimate genetic parameters for these traits. Milk coagulation is an important processing trait, being the basis for the production of cheese and fermented products. In Sweden, 45% of total cow milk production is processed into cheese and fermented products; 36% of total milk production goes to cheese manufacturing (International Dairy Federation, 2012). Additionally, the production of cheese and fermented products is expected to increase worldwide during the coming years (International Dairy Federation, 2012). Adding milk coagulation properties to the breeding goal would improve raw milk quality and thus increase the economic output for the dairy industry by improved processing parameters for these products.

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Rennet- and acid-induced coagulation are two of the most common milk coagulation processes. Both are based on destabilization of CN micelles, leading to aggregation (Lucey, 2009). Rennet-induced coagulation is the first step in cheese production. In this step, rennet destabilizes the CN micelles in the milk by hydrolysis of κ-CN, making the CN micelles aggregate to form a coagulum (Dalgleish, 1992; Walstra et al., 2006; Lucey, 2009). In contrast, acid-induced coagulation is applied in the production of fermented products such as yogurt. As a pretreatment, the milk is heated to approximately 90 to 95°C for 5 to 10 min to denature the whey proteins, mainly β-LG, which (in addition to self-aggregation) will interact with κ-CN and α_{S2}-CN on the CN micelles (Lucey and Singh, 1998; Lucey, 2002; Guyomarc'h et al., 2003). Acidification causes the pH to decrease such that, at pH 4.6, the net negative charge of the CN micelles is neutralized and a protein gel network is formed (Lucey and Singh, 1998; Lucey, 2009). Several milk composition traits have been shown to affect the properties of both rennet-induced gels (Ikonen et al., 2004; Wedholm et al., 2006; Amenu and Deeth, 2007) and acid-induced gels (Lucey and Singh, 1998; Allmere et al., 1999; Hallén et al., 2009), including contents of protein, CN, whey proteins, fat, and lactose, as well milk pH, traits that could thus be used as indicators for milk coagulation properties. However, it is important to elucidate the genetic correlations between these traits and milk coagulation properties to define suitable breeding goals.

Several studies have reported heritabilities for coagulation time (**CT**) and gel strength (**G′**) in rennet gels as reviewed by Bittante et al. (2012), with average heritability estimates of 0.26 (SD 0.06) and 0.27 (SD 0.11), respectively, showing the potential to change these properties through breeding. For milk composition traits, including fat, protein, CN, and lactose contents and milk yield, heritabilities are reported to range from 0.07 to 0.66 (e.g., Schopen et al., 2009; Penasa et al., 2010; Tiezzi et al., 2013). Furthermore, genetic correlations between rennet coagulation properties and milk composition traits have been reported, although the results are contradictory (Ikonen et al., 2004; Cassandro et al., 2008; Cecchinato et al., 2011). However, to our knowledge, no studies have reported heritabilities or genetic correlations for acid-induced coagulation properties. Genetic parameters are usually estimated based on pedigree relationships (Bittante et al., 2012); however, some uncertainty always exists in national pedigree databases (K. Johansson, Växa Sverige, Stockholm, Sweden, personal communication), which affects further estimations of genetic parameters. Therefore, using genomic data could give more accurate estimations (Veerkamp et al., 2011).

The aim of the present study was to estimate genetic parameters for milk coagulation properties, including both rennet- and acid-induced coagulation, in Swedish Red (**SR**) dairy cattle using genomic relationships. This study will give information on genetic relationships for milk coagulation properties that can be used to improve the current breeding goal and implement new traits within national breeding programs. To our knowledge, this is the first time that genetic parameters have been estimated for rennet-induced coagulation properties in SR and for acid-induced coagulation properties in any dairy cattle breed.

MATERIALS AND METHODS

Milk and Blood Sampling

As part of the Danish-Swedish Milk Genomics Initiative, morning milk samples and blood samples were collected from 395 SR cows during the indoor period from April to May 2010 as well as September 2010 to April 2011. The sampled cows, which originated from 20 conventional farms located in the same geographical region in the southern part of Sweden, were fed according to standard practices and milked 2 or 3 times per day. The cows were selected to be as genetically unrelated as possible; the cows were progenies of 160 different sires. Data were obtained for lactation stage and parity, ranging from wk 3 to 61 (2% before lactation wk 7 and 10% after lactation wk 40) and parity 1 to 4 (1% in parity 4), respectively. A representative aliquot of each milk sample was collected and cooled for further transport to Lund University (Lund, Sweden) and Aarhus University (Aarhus, Denmark) on the same day as sampling. After arriving at Lund University, the samples were defatted by centrifugation at 2,000 × g for 30 min to reduce the number of variables influencing coagulation properties. Furthermore, the samples were subsampled and stored at either 4°C or −20°C until further analyses.

Milk Composition

The contents of total protein, CN, fat, and lactose in fresh milk samples were predicted by infrared spectroscopy (MilkoScan FT2, Foss Electric, Hillerød, Denmark). Somatic cell count was analyzed in fresh milk samples using flow cytometry (Combifoss 5000, Foss Electric) at a certified dairy analysis laboratory (Eurofins Steins Laboratory, Jönköping, Sweden). The fresh milk samples were analyzed the day after sampling. Furthermore, relative concentrations of κ-CN and β-LG relative to total protein content were determined by capillary zone electrophoresis according to Gustavsson