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The nonlinear effect of somatic cell count on milk composition, coagulation properties, curd firmness modeling, cheese yield, and curd nutrient recovery

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ABSTRACT

The aim of this study was to investigate the relationships between somatic cell count (SCC) in milk and several milk technological traits at the individual cow level. In particular, we determined the effects of very low to very high SCC on traits related to (1) milk yield and composition; (2) coagulation properties, including the traditional milk coagulation properties (MCP) and the new curd firming model parameters; and (3) cheese yield and recovery of milk nutrients in the curd (or loss in the whey). Milk samples from 1,271 Brown Swiss cows from 85 herds were used. Nine coagulation traits were measured: 3 traditional MCP [rennet coagulation time (RCT, min), curd firming rate (k_{20}, min), and curd firmness after 30 min (a_{30}, mm)] and 6 new curd firming and syneresis traits [potential asymptotic curd firmness at infinite time (CF_P, mm), curd firming instant rate constant (k_{CF}, % × min^{-1}), syneresis instant rate constant (k_{SR}, % × min^{-1}), rennet coagulation time estimated using the equation (RCT_{eq}, min), maximum curd firmness achieved within 45 min (CF_{max}, mm), and time at achievement of CF_{max} (t_{max}, min)]. The observed cheese-making traits included 3 cheese yield traits ($\%CY_{CURD}$, $\%CY_{SOLIDS}$, and $\%CY_{WATER}$, which represented the weights of curd, total solids, and water, respectively, as a percentage of the weight of the processed milk) and 4 nutrient recoveries in the curd (REC_{FAT}, $REC_{PROTEIN}$, REC_{SOLIDS}, and REC_{ENERGY}, which each represented the percentage ratio between the nutrient in the curd and milk). Data were analyzed using a linear mixed model with the fixed effects of days in milk, parity, and somatic cell score (SCS), and the random effect of herd-date. Somatic cell score had strong influences on casein number and lactose, and also affected pH; these were traits characterized by a quadratic pattern of the data. The results also showed a negative linear relationship between SCS and milk yield. Somatic cell score influenced almost all of the tested coagulation traits (both traditional and modeled), with the exceptions of k_{20}, CF_P, and k_{SR}. Gelation was delayed when the SCS decreased (slightly) and when it increased (strongly) with respect to a value of 2, as confirmed by the quadratic patterns observed for both RCT and RCT_{eq}. The SCS effect on a_{30} showed a quadratic pattern almost opposite to that observed for RCT. With respect to the CF_t parameters, k_{CF} decreased linearly as SCS increased, resulting in a linear decrease of CF_{max} and a quadratic pattern for t_{max}. Milk SCS attained significance for $\%CY_{CURD}$, $\%CY_{WATER}$, and $REC_{PROTEIN}$. As the SCS increased beyond 3, we observed a progressive quadratic decrease of the water retained in the curd ($\%CY_{WATER}$), which caused a parallel decrease in $\%CY_{CURD.}$ With respect to $REC_{PROTEIN}$, the negative effect of SCS was almost linear. Recovery of fat and (consequently) REC_{ENERGY} was characterized by a more evident quadratic trend, with the most favorable values associated with an intermediate SCS. Together, our results confirmed that high SCS has a negative effect on milk composition and technological traits, highlighting the nonlinear trends of some traits across the different classes of SCS. Moreover, we report that a very low SCS has a negative effect on some technological traits of milk.
Key words: somatic cell count, milk coagulation property, curd firming, cheese yield, whey loss

INTRODUCTION

The consumption of milk and dairy products is growing worldwide (International Dairy Federation, 2013), making increased milk production a key dairy breeding goal in recent decades (VanRaden, 2004; Miglior et al., 2005). However, selection for higher milk production has led to deteriorations of milk quality and cow welfare (Oltenacu and Broom, 2010). For instance, unfavorable genetic correlations between milk yield and diseases (e.g., mastitis and ketosis) have been reported (Ingvartsen et al., 2003). Bovine mastitis is one of the most economically important diseases in dairy herds;

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the consequent high SCC, which is measured as a standard indicator trait of udder health and milk quality, reduces the price paid for milk (Seegers et al., 2003; Viguier et al., 2009). Moreover, milk with a high cell count is reported to have lower casein (Haenlein et al., 1973; Auldist and Hubble, 1998) and lactose (Kitchen, 1981; Auldist and Hubble, 1998) contents, due to increased proteinase-mediated degradation and decreased biosynthesis, respectively. The influence of SCC on fat concentration is more controversial; although some authors (Harmon, 1994; Schallibaum, 2001) found lower values due to reduced synthetic activity of the mammary gland, others observed a higher fat content due to a reduced milk volume (Shuster et al., 1991; Bruckmaier et al., 2004).

Alterations in the chemical composition of high-SCC milk make it less suitable for consumption and cheese processing, with the latter issue reflecting slower coagulation, weak consistency of the curd, and reduced cheese yield (Barbano et al., 1991; Auldist and Hubble, 1998). The technological quality of the milk used in cheese making is commonly evaluated by measuring milk coagulation properties (**MCP**; Annibaldi et al., 1977; McMahon and Brown, 1982) with computerized renneting meters. The 3 traditional parameters that define the clotting ability of milk, and that can be measured by mechanical lactodynamograph (Formagraph; Foss Electric A/S, Hillerød, Denmark), are rennet coagulation time (**RCT**, min), curd-firming time (**k_{20}**, min), and firmness of the curd at 30 min after the addition of rennet (**a_{30}**, mm). An association between elevated SCC and an increase in RCT has been observed by different authors (Ng-Kwai-Hang et al., 1989; Barłowska et al., 2009).

The large majority of relevant published studies have included SCC as a linear covariate in the model, or compared the results obtained using milk with "normal" versus "high" SCC. In these studies, when several classes of SCC are used, they normally do not include classes <100,000 cells/mL, so the detailed effects of very low to very high SCC on milk technological traits have not been fully studied.

Recent studies introduced the strategy of prolonging the observation time and modeling curd firmness (**CF**) using new time (**CF_t**) parameters (Bittante, 2011; Cipolat-Gotet et al., 2012; Bittante et al., 2013). Milk coagulation properties are of interest for 2 main reasons: first, they have technological value for optimizing the cheese-making process and predicting possible abnormalities both during the process and in the final product; and second, they may be used to indirectly predict cheese yield (**CY**) through their relationships with losses of fines in whey and with moisture retained in the curd. This second aspect is important because MCP are relatively easy to measure in multiple samples at the laboratory level, whereas direct measurements of CY and nutrient recovery traits are expensive and time-consuming.

Given the complexity of cheese making, the fat and protein contents of milk have frequently been used as proxies for measuring CY. However, the efficiency of the cheese-making process is better defined by the recoveries of milk components in the curd and their losses in the whey (Banks, 2007). More recently, percentage cheese yield (**%CY**) and nutrient recovery (**REC**) of individual milk samples have been analyzed using a model cheese-making procedure developed by Cipolat-Gotet et al. (2013), which mimics all phases of cheese production. However, there is little information available regarding the relationships between technological traits of milk and SCC.

Even if bulk tank milk is used for cheese production, information at the cow level might be useful in order to include milk technological traits as breeding goals in dairy cows. Moreover, the individual variation, which is higher compared with that of bulk samples, helps to clarify the relationships between milk SCC and cheese-making traits. Therefore, the aim of this study was to elucidate the relationship between SCC and milk quality and technological traits at the individual cow level. In particular, we performed a detailed investigation of the effects of a range of SCC (from very low to very high) on (1) the milk yield and composition (i.e., fat, protein, casein, casein number, lactose, urea, and pH); (2) the coagulation properties (traditional MCP and the new CF model parameters); and (3) the cheese yield and recovery of milk nutrients in the curd and loss in the whey.

MATERIALS AND METHODS

Milk Sample Collection

This study is part of the Cowability-Cowplus Projects, which were described in detail by Cipolat-Gotet et al. (2013) and Cecchinato et al. (2013). Briefly, individual milk samples of 1,271 Brown Swiss cows were collected once from 85 herds (a maximum of 15 cows/herd, 1 or 2 herds per week, 13 mo in total) located in Trento Province, northern Italy. The relevant environmental conditions were described in detail by Sturaro et al. (2013). The milk samples (one per cow) were collected during the evening milking. After collection, each sample was divided into 2 subsamples, which were refrigerated (4°C, without preservative). One subsample (50 mL) was transferred to the Milk Quality Laboratory of the Breeders Federation of Trento Province (Trento, Italy) for milk composition analysis. The other (2,000

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