Goat cheese yield and recovery of fat, protein, and total solids in curd are affected by milk coagulation properties

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ABSTRACT

The aims of the present research were to quantify the effects of each coagulation trait, traditional milk coagulation properties [MCP: rennet coagulation time (RCT), curd-firming time (k_{20}), and curd firmness at 30 min (a_{30})], and modeled curd-firming over time (CF_t) parameters [estimated rennet coagulation time (RCT_{eq}), curd-firming instant rate constant (k_{CF}), and potential curd firmness (CF_p)] directly on the following: (1) recovery of 3 milk components in the curd (%REC), (2) 3 measures of cheese yield (%CY), and (3) 3 daily cheese yield traits (dCY) from goat milk. Cheese-making traits were analyzed using 2 mixed different models, the first to test MCP and the second to test CF_t parameters. Pearson correlations were also calculated. Significant and favorable relationships (negative for time intervals and positive for CF measures) were found between the traditional MCP and the CF_t parameters and %REC and %CY traits. The effects of milk fat and protein contents were particularly important on all cheese-making traits, with the only exception being the effect of fat content on water retention in cheese (%CY_{WATER}). We found an optimum value of milk k_{20} , associated with the highest recovery of components and cheese yield in solids (%CY_{SOLIDS}). In addition, a lower level of curd water retention and an increased fresh curd yield (%CY_{CURD}) were associated with greater recovery of fat. The collection of all available information during the process of milk coagulation and curd-firming allowed us to discover the effect of RCT_{eq} on %REC traits and %CY_{SOLIDS}, which had not previously been revealed for traditional RCT. Moreover, higher k_{CF} values were associated with increased %CY_{CURD} and %CY_{SOLIDS}. Given that CF_t parameters showed a high level of independence from one another, these can also be easily used and characterized in future applications at the industry level. Information provided

by traditional and modeled coagulation properties could efficiently support the goat dairy industry and lay the foundations for a quality payment scheme for goat milk.

Key words: rennet coagulation time, curd firmness, curd-firming time, modeling

INTRODUCTION

Milk fat and protein contents, together with casein genetic variants, are the major contributors to cheese yield (%CY; Guo et al., 2004; Wedholm et al., 2006) and to the recovery of each component (%REC) from milk in the curd (Pazzola et al., 2019). Milk composition also strongly affects milk coagulation properties (MCP; Caravaca et al., 2011; Stocco et al., 2018b; Amalfitano et al., 2019). However, the actual relationship between MCP and cheese-making traits is yet to be clarified.

The available research on bovine milk does not resolve the contradictory results about coagulation traits and %CY, nor does it fill in the lack of information about those aspects of the cheese-making process that enhance %CY, such as the recovery of each milk component in the curd. Indeed, no information is available for goats on the effect of coagulation traits on recovery of fat, protein, and total solids in the curd. Since the 1980s, bovine MCP have been evaluated using mechanical lactodynamographs, but only in the last few decades has research been conducted on MCP from small ruminants (Bencini, 2002; Mestawet et al., 2013; Inglingstad et al., 2014). The lactodynamograph is the instrument most commonly used at laboratory level to assess MCP of a large number of milk samples per day. This instrument simulates the cheese-making process through the heating of milk and the addition of rennet, and records 3 single-point traits: rennet coagulation time (RCT, min), curd-firming time (k_{20} , min), and curd firmness 30 min after enzyme addition (a_{30} , mm; McMahon and Brown, 1982). However, the traditional single-point MCP are sometimes considered ineffective for evaluating milk from small ruminants,

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because the coagulation process is faster in their milk than in the milk of cows. In the meantime, the development of computerized lactodynamographs recording 1 value of curd firmness (**CF**) every 15 s has made more information available. Thus, to provide new insights into the MCP of small ruminants, the model proposed by Bittante (2011), using all the CF values available for each milk sample, has been successfully applied to the coagulation process of milk samples from sheep and goats (Bittante et al., 2014; Vacca et al., 2015; Pazzola et al., 2018). That model provides 3 novel parameters: the asymptotic potential value of curd firmness at an infinite time (**CF_P**, mm), the curd-firming instant rate constant (**k_{CF}**, % per min), and the RCT predicted from the modeling of all available data (**RCT_{eq}**, min).

In the literature, there is no general agreement about the effect of MCP on cheese-making traits. Ng-Kwai-Hang et al. (1989) report that MCP are weakly correlated with moisture-adjusted CY. Johnson et al. (2001) have found that slow RCT are associated with increases in cheese moisture and cheese yield, and that the percentage of fat recovered in cheese is inversely correlated with curd firmness. Ikonen et al. (1999) suggest that improvement of bulk MCP would improve the efficiency of cheese-making, although several factors are confounded (i.e., milk composition, herd groups). Moreover, to date, there have been no reliable results for goats about this topic, so new information is needed to increase our knowledge, especially for the goat dairy industry. The present research was carried out to directly quantify the effects of each coagulation trait, traditional (RCT, k_{20} , and a_{30}) and modeled (RCT_{eq}, k_{CF} , and CF_P), on the following: (1) recovery of 3 milk components (fat, protein, and total solids) in the curd (%REC), (2) 3 measures of cheese yield (%CY), and (3) 3 daily cheese yield traits (**dCY**) from goat milk.

MATERIALS AND METHODS

Milk Sampling and Laboratory Analyses

A total of 560 individual milk samples were collected from goats belonging to 6 different breeds (Saanen, Camosciata delle Alpi, Murciano-Granadina, Maltese, Sarda, and Sarda Primitiva) and reared on 35 Sardinian farms (Italy). Details of farm characteristics and description of the breeds have been previously reported by Vacca et al. (2018a). In brief, farms were of 3 management types: 14 farms were traditionally managed (extensive system, grazing of natural pastures, family-operated); 11 were intermediate (semiextensive system, control of kidding season); and 10 were modern (semi-intensive system, housing in modern buildings, use of

TMR, out-of-season kidding, operated by hired workers, consultancy of experts in animal feeding).

Milk fat, protein, and total solids were determined using a MilkoScan FT6000 milk analyzer (Foss Electric A/S, Hillerød, Denmark) calibrated according to FIL-IDF references (ISO-IDF, 2010; ISO-IDF, 2013).

The laboratory milk cheese-making assessment (9-MilCA) proposed by Cipolat-Gotet et al. (2016b) was used to measure single-point MCP, %REC, and %CY traits. The following procedure was performed with 2 replicates each, of 560 individual milk samples (2 aliquots of 9 mL of the same milk sample), for a total of 1,120 analyses. Each milk replicate (9 mL) was poured into a glass tube, inserted into the modified sample rack of the lactodynamograph instrument, heated to 35°C for 15 min, and mixed with 0.2 mL of a rennet solution [Hansen Standard 215, with $80 \pm 5\%$ chymosin and $20 \pm 5\%$ pepsin; 215 international milk clotting units (IMCU)/mL (Pacovis Amrein AG, Bern, Switzerland); diluted to 1.2% (wt/vol) in distilled water]. The sample rack was then moved to the lactodynamograph set at 35°C, for a 30-min duration test. The recorded MCP were as follows: RCT, as the time interval between rennet addition and gelation; k_{20} , as the time between gelation and the achievement of curd firmness of 20 mm; a_{30} , as curd firmness at 30 min after rennet addition.

At the end of the analysis, coagulated replicates of milk samples were manually cut using a steel spatula and moved to the heater at 55°C, for the 30-min curd-cooking phase. During the cooking phase, each replicate was subjected to a further manual cutting by the same operator, and the curd particles were allowed to sit quiescently in their own whey after cutting. At the end, each glass tube was removed from the sample rack, and the curd was separated from the whey. The curd was pressed and suspended above the whey for 15 min at room temperature to favor the draining. The obtained curd and whey were weighed using a precision scale. Whey composition was assessed using an infrared spectrophotometer (MilkoScan FT2, Foss Electric). The weights of the curd and whey (g) and the chemical composition of milk and whey also allowed us to estimate curd composition by calculating the difference between milk and whey contents. The cheese yield (%CY) traits were %CY_{CURD}, %CY_{SOLIDS}, and %CY_{WATER}, calculated as the ratios of the weight (g) of fresh curd, curd DM, and water retained in curd, respectively, to the weight of the milk processed (g), multiplied by 100. The component recovery (%REC) traits were as follows: %REC_{PROTEIN}, %REC_{FAT}, and %REC_{SOLIDS}, calculated as the ratios of the weight (g) of the curd components (protein, fat, and DM, respectively) to the same component of milk (g), and multiplied by 100.

Daily cheese yields (dCY_{CURD} , dCY_{SOLIDS} , and dCY_{WATER} , kg/d) were calculated by multiplying the 3 %CY traits ($\%CY_{CURD}$, $\%CY_{SOLIDS}$, and $\%CY_{WATER}$, respectively) by the daily milk yield of each goat.

Modeling of Curd Firmness

The 3-parameter model (Bittante, 2011) was applied to the 120 individual point observations of curd firmness recorded by the Formagraph (Foss Italia S.P.A., Padova, Italy) during the lactodynamographic analysis (curd firmness recorded every 15 s). During a 30-min test, 120 individual curd firmness observations are recorded for each milk sample. The model tested was as follows:

$$CF_t = CF_P \times \left[1 - e^{-k_{CF} \times (t - RCT_{eq})} \right],$$

where CF_t is curd firmness at time t (mm); CF_P is the asymptotic potential value of CF at an infinite time (mm); k_{CF} is the curd-firming instant rate constant (% per min); and RCT_{eq} is RCT estimated by CF_t equation on the basis of all data points (min). Because the model uses all information available from the lactodynamographic analysis, the 3 estimated parameters are not single-point measurements, as the traditional MCP are. The parameter CF_P is conceptually independent from both test duration and RCT, unlike a_{30} . The parameter k_{CF} describes the shape of the curve from the time of coagulation using all available CF points and provides information about the speed of the process. Last, the parameter RCT_{eq} is the equivalent trait of the traditional RCT trait, but here it is estimated using all available data.

Statistical Analysis

Curvilinear regressions were fitted to the 120 CF_t observations available for each sample and analyzed using the nonlinear procedure (PROC NLIN) of SAS version 9.4 (SAS Institute Inc., Cary, NC). The parameters of each individual equation were estimated by employing the Marquardt iterative method, with 350 iterations and 10^{-5} level of convergence.

Cheese-making traits from 560 milk samples in 2 replicates, for a total of 1,120 analyses, were analyzed using a MIXED procedure in SAS, according to the following model:

$$Y_{efghijklmnop} = \mu + DIM_e + Parity_f + Fat_g + Protein_h + RCT_i + k_{20j} + a_{30k} + Farm_l + Breed_m + Animal_n + Glass Tube_o + e_{efghijklmnop}, \quad [M1]$$

in which $Y_{efghijklmnop}$ is the observed trait (%CY, %REC, dCY); μ is the overall intercept of the model; DIM_e is the fixed effect of the eth class of days in milk ($e = 1$ to 4, as reported in Pazzola et al., 2019); $Parity_f$ is the fixed effect of the fth parity ($f = 1$ to 3; Pazzola et al., 2019); Fat_g is the fixed effect included in the model as linear covariate; $Protein_h$ is the fixed effect included in the model as linear covariate; RCT_i is the fixed effect of the ith class of RCT ($i = 7$ classes); k_{20j} is the fixed effect of the jth class of k_{20} ($j = 7$ classes); a_{30k} is the fixed effect of the kth class of a_{30} ($k = 7$ classes); $Farm_l$ is the random effect of the lth farm ($l = 1$ to 35); $Breed_m$ is the random effect of the mth breed ($m =$ Saanen, Camosciata delle Alpi, Murciano-Granadina, Maltese, Sarda, and Sarda Primitiva); $Animal_n$ is the random effect of the nth class of animal ($n = 1$ to 560); $Glass Tube_o$ is the random effect of the oth glass tube of the rack of the lactodynamograph instrument ($o = 1$ to 8); and $e_{efghijklmnop}$ is the random residual $\sim N(0, \sigma_e^2)$, where σ is the standard deviation.

A model derived from [M1], without the effects of MCP (RCT, k_{20} , and a_{30}), was used to test the effect of CF_t parameters (RCT_{eq} , k_{CF} , and CF_P) on cheese-making traits:

$$Y_{efghijklmnop} = \mu + DIM_e + Parity_f + Fat_g + Protein_h + RCT_{eqi} + k_{CFj} + CF_{Pk} + Farm_l + Breed_m + Animal_n + Glass Tube_o + e_{efghijklmnop}, \quad [M2]$$

in which RCT_{eqi} is the fixed effect of the ith class of RCT_{eq} ($i = 7$ classes); k_{CFj} is the fixed effect of the jth class of k_{CF} ($j = 1$ to 7 classes); and CF_{Pk} is the fixed effect of the kth class of CF_P ($k = 7$ classes). Unlike previous papers based on the same data set, specifically dealing with the effect of the 6 breeds of goats, in this study breed was considered as a random effect. This allowed us to quantify the variance component due to breed and to obtain estimates of the relationships between MCP and CF_t traits, and %CY and %REC traits corrected for a breed effect and not specifically related to the different 6 breeds.

Traditional MCP and CF_t parameters tested in [M1] and [M2] were not included in a single model, so as to avoid multi-collinearity problems. Each of the 7 classes of RCT, k_{20} , a_{30} , RCT_{eq} , k_{CF} , and CF_P (Supplemental Table S1; <https://doi.org/10.3168/jds.2019-16424>) was designed on the basis of distribution of the variables: each single class explained 0.5 SD of the variable; the fourth was centered on the mean value; and the first and the seventh represented the tails of the distribution (class 1: < -1.25 SD; class 2: -1.25 to -0.75 SD; class 3: -0.75 to -0.25 SD; class 4: -0.25 to $+0.25$ SD; class

5: +0.25 to +0.75 SD; class 6: +0.75 to +1.25 SD; class 7: > +1.25 SD). Orthogonal polynomial contrasts (linear, quadratic, and cubic patterns) were performed between the least squared means of RCT, k_{20} , a_{30} , RCT_{eq}, k_{CF} , and CF_P classes to investigate whether the differences among the classes of a specific trait were due to a continuous pattern and whether the shape of this pattern was different among traits. All fixed effects and orthogonal contrasts have been tested using the variance of animal as the error line, to avoid inflated degrees of freedom and overfitted *F*-statistics. Pearson product-moment correlations were performed between milk coagulation traits and cheese-making traits.

RESULTS AND DISCUSSION

Correlations of Coagulation Traits with Component Recovery and Cheese Yield

Table 1 reports the mean and standard deviation (SD) and the Pearson product-moment correlations of individual traditional single-point MCP and CF_t parameters, %REC, %CY, and dCY traits of goat milk samples. It is worth noting that 38 of the 42 correlation coefficients between the traditional MCP and the CF_t model parameters on one side and the cheese traits on the other (%REC and %CY traits) are significant and favorable (negative for time intervals and positive for CF measures). These findings confirm previous results from bovine milk (Cecchinato and Bittante, 2016).

The comparison of the results regarding the 2 groups of traits describing milk coagulation, MCP and CF_t model parameters, with cheese yields evidenced that the correlation coefficients of RCT_{eq} with cheese traits was characterized by higher values than for the equivalent RCT trait (Table 1). The single-point traits describing curd-firming pattern (k_{20} and a_{30}) could not be directly compared with the other CF_t model parameters (k_{CF} and CF_P), but the former showed higher values of correlation with cheese traits than did the latter, and this could be attributable to the high interdependence observed among the 3 MCP (Bittante, 2011).

The value of %REC_{FAT} was much more correlated with all coagulative traits than was %REC_{PROTEIN}, whereas %REC_{SOLIDS} showed intermediate correlation values. As regards %CY traits, the solids fraction was more correlated with coagulative traits than was the moisture retained, and the sum of the 2 (%CY_{CURD}) was intermediate (Table 1).

On the other hand, the correlation coefficients with dCY showed a different scenario. Except for RCT and RCT_{eq}, 11 of the 12 coefficients showed significant unfavorable correlation (positive for k_{20} ; negative for a_{30} , k_{CF} , and CF_P) between daily cheese yields of the goats on one side and the curd-firming pattern on the other (Table 1).

It is important to highlight that both coagulative and cheese yield traits are normally influenced by milk composition (especially fat and protein composition and content), farm management and feeding, and

Table 1. Mean and SD and Pearson product-moment correlations between individual traditional single-point milk coagulation properties (MCP) and curd-firming over time (CF_t) parameters obtained from the modeling of all recorded curd firmness values (120 per milk sample), and component recovery (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of goat milk samples

Item	Mean	SD	Traditional single-point MCP ¹			CF _t parameters ²		
			RCT, min	k_{20} , min	a_{30} , mm	RCT _{eq} , min	k_{CF} , %/min	CF _P , mm
MCP descriptive statistics								
Mean ± SD	—	—	13.8 ± 4.8	4.5 ± 2.0	33.2 ± 11.6	14.1 ± 5.2	19.0 ± 8.6	40.5 ± 11.7
Component recovery, %								
%REC _{FAT}	80.86	5.84	−0.24***	−0.53***	0.52***	−0.33***	0.26***	0.33***
%REC _{PROTEIN}	81.63	2.51	−0.13***	−0.11***	0.17***	−0.19***	0.11***	0.05
%REC _{SOLIDS}	55.75	5.54	−0.10***	−0.45***	0.40***	−0.17***	0.25***	0.29***
Cheese yields, %								
%CY _{CURD}	15.73	2.83	−0.07*	−0.39***	0.31***	−0.09**	0.22***	0.24***
%CY _{SOLIDS}	7.97	1.49	−0.05	−0.42***	0.37***	−0.06	0.22***	0.29***
%CY _{WATER}	7.74	1.76	−0.07*	−0.24***	0.15***	−0.08	0.13***	0.09**
Daily cheese yields, kg/d								
dCY _{CURD}	0.29	0.15	0.04	0.18***	−0.15***	0.07	−0.10***	−0.08**
dCY _{SOLIDS}	0.15	0.08	0.03	0.13***	−0.10**	0.05	−0.09**	−0.04
dCY _{WATER}	0.14	0.07	0.04	0.20***	−0.18***	0.02	−0.11***	−0.12***

¹RCT = measured rennet gelation time; k_{20} = time interval between gelation and attainment of curd firmness of 20 mm; a_{30} = curd firmness after 30 min from rennet addition.

²RCT_{eq} = RCT estimated according to curd-firming change over time modeling (CF_t); k_{CF} = curd-firming instant rate constant; CF_P = asymptotic potential curd firmness.

P* < 0.05; *P* < 0.01; ****P* < 0.001.

animals' individual traits (breed, age, lactation stage). This means that the Pearson correlations quantify the combined covariation of all these factors and cannot give us an estimate of the proper effect of a coagulative trait on a cheese yield trait per se (corrected for all the other factors involved).

Effects of Non-Coagulative Factors on Component Recovery and Cheese Yield

All the main sources of variation, and not only the coagulative traits (model [M1] with the 3 traditional MCP and model [M2] with the 3 CF_i model parameters), were included in the statistical mixed models to quantify the true contribution of each source on goat cheese traits. The objective of this study was focused on the relationships between coagulative traits and cheese traits, so the other non-coagulative factors affecting cheese traits were considered as nuisance factors, to be removed in order to obtain a specific effect of coagulative traits.

The proportion of variance of cheese traits explained by the random effects included in both models [M1] and [M2] is depicted in Figure 1. The farm variance accounted for 11 to 21% of the total variance for %REC traits, 10 to 29% for %CY traits, and 32 to 39% for dCY traits. The variability among farms and the results regarding the farm effect are in accordance with

the paper by Vacca et al. (2018a). The breed effect accounted for a lower proportion, from about 7 to 13% for %REC traits, 3 to 10% for %CY traits, and 27 to 37% for dCY traits. The animal variance was the highest for %REC and %CY traits (69 to 81%, and 44 to 76%, respectively) and much lower for dCY traits (31 to 32% of total variance). This suggests that the improvement of %REC and %CY traits is mainly controlled by the genetics of the animal, whereas farming system (i.e., management and feeding) played a much more important role in the level of production. Glass tube had almost no incidence, and residual variance showed high values for %CY traits (3 to 24%) and low values for %REC (0.1 to 2.8%) and dCY traits (0.1 to 3%). These results are different from previous findings for other species. Bovine herd date incidence ranges from 11 to 17% for %REC traits, from 19 to 29% for actual %CY traits, and from 42 to 46% for dCY traits (Stocco et al., 2018a). Large difference are found for sheep milk (Cipolat-Gotet et al., 2016a), because the effect of flock is higher than our results for %REC (13 to 56%) and %CY traits (43 to 49%) and lower for dCY (18 to 42%).

The significance of the fixed factors included in the mixed models is shown in Table 2 for model [M1] and Table 3 for [M2], respectively. The stage of lactation showed a minor influence on %REC_{PROTEIN} and %REC_{SOLIDS} with both models, whereas parity affected %REC_{PROTEIN}, %CY_{CURD}, and, as expected, all 3 dCY

Figure 1. Proportion of variance (in percentage) explained by random effects from models [M1] and [M2] for component recovery (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of milk samples from individual goats (n = 560) of 6 breeds.

Table 2. ANOVA (*F*-value and significance of the fixed effects and of the orthogonal contrasts) of model [M1], including traditional single-point milk coagulation properties (MCP: RCT, k_{20} , and a_{30})¹ for component recovery in curd (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of milk samples from individual goats ($n = 560$) of 6 breeds

Trait	DIM	Parity	RCT			k_{20}			a_{30}			Fat	Protein
			Linear	Quadratic	Cubic	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic		
Component recovery, %													
%REC _{FAT}	1.7	1.1	0.1	0.6	1.8	0.4	0.0	0.9	0.1	0.1	0.0	4.3*	50.6***
%REC _{PROTEIN}	3.1*	7.8***	1.5	1.0	0.6	0.1	0.0	0.6	0.6	0.1	1.4	30.0***	5.2*
%REC _{SOLIDS}	3.0*	0.7	1.7	0.1	0.3	1.3	2.4	5.8*	0.1	0.2	0.1	311.4***	111.1***
Cheese yield, %													
%CY _{CURD}	0.7	3.5*	3.1	3.4	0.1	8.8**	5.1*	12.7***	0.0	1.4	2.5	245.1***	24.5***
%CY _{SOLIDS}	1.5	1.9	2.4	0.1	0.3	2.4	2.8	7.9**	0.2	0.2	0.1	3201.7***	541.0***
%CY _{WATER}	0.7	2.4	1.2	0.1	0.3	5.1*	0.4	5.6*	4.2*	0.1	1.9	23.6***	15.9***
Daily cheese yield, kg/d													
dCY _{CURD}	1.6	5.0**	0.1	0.5	0.7	0.0	0.2	0.6	0.0	0.8	0.0	16.5***	14.7***
dCY _{SOLIDS}	1.4	4.6**	3.3	1.0	0.9	0.8	0.0	1.1	2.1	0.2	0.1	25.2***	6.0*
dCY _{WATER}	2.1	6.0**	0.1	0.0	0.2	0.2	0.0	0.1	0.0	1.1	0.0	2.6	13.2***

¹RCT = measured rennet gelation time; k_{20} = time interval between gelation and attainment of curd firmness of 20 mm; a_{30} = curd firmness 30 min after rennet addition.
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 3. ANOVA (*F*-value and significance of fixed effects and of orthogonal contrasts) of model [M2], including curd-firming over time parameters (CF_t; RCT_{eq}, k_{CF} , and CF_P)¹ for component recovery in curd (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of milk samples from individual goats ($n = 560$) of 6 breeds

Trait	DIM	Parity	RCT _{eq}			k_{CF}			CF _P			Fat	Protein
			Linear	Quadratic	Cubic	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic		
Component recovery, %													
%REC _{FAT}	1.7	1.1	1.7	0.4	1.0	0.0	1.2	0.1	0.2	4.5*	0.2	6.6*	51.2***
%REC _{PROTEIN}	3.0*	7.7***	8.5**	0.3	0.2	0.1	0.8	0.5	0.7	3.7	0.1	29.3***	5.2*
%REC _{SOLIDS}	2.7*	0.7	6.2*	0.2	0.1	3.1	0.1	0.6	3.6	1.6	0.0	305.0***	117.8***
Cheese yield, %													
%CY _{CURD}	0.6	3.0*	1.0	0.4	0.9	11.6***	1.7	0.1	3.9*	0.5	0.8	238.7***	33.2***
%CY _{SOLIDS}	1.4	1.9	5.4*	0.1	0.0	5.3*	0.0	0.7	3.9*	1.0	0.0	3097.7***	553.4***
%CY _{WATER}	0.7	1.8	0.1	0.1	0.0	1.7	0.1	0.2	0.5	4.7	3.7	25.0***	17.9***
Daily cheese yield, kg/d													
dCY _{CURD}	1.6	5.0**	0.2	0.0	1.7	0.8	0.4	0.7	0.1	0.4	0.7	15.6***	14.7***
dCY _{SOLIDS}	1.5	4.6*	8.7	0.1	0.8	1.0	2.3	0.0	0.1	5.5	0.1	25.1***	6.0*
dCY _{WATER}	2.3	6.0**	1.4	0.7	1.1	0.6	0.1	0.2	0.3	0.3	1.8	2.5	14.6***

¹RCT_{eq} = RCT estimated according to curd-firming change over time modeling (CF_t); k_{CF} = curd-firming instant rate constant; CF_P = asymptotic potential curd firmness.
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Figure 2. Effect of curd-firming time (k_{20}) on percentage of recovery of milk solids, %REC_{SOLIDS} (a) and cheese yield traits, %CY (%CY_{CURD} as the percentage of fresh curd, %CY_{SOLIDS} of DM, and %CY_{WATER} of water retained in curd; b). Details of statistical analysis are shown in Table 2. Effect of curd-firming time (k_{20}) on percentage of recovery of milk solids (%REC_{SOLIDS}; a) and percentage cheese yield of curd (%CY; b). Details of statistical analysis are shown in Table 2.

traits. The effects of milk fat and protein content were particularly important on all cheese traits, with the exception only of the effect of fat content on dCY_{WATER} . This result is in agreement with a previous study by Pazzola et al. (2019) about the effect of milk composition on goat cheese-making traits. A possible explanation regarding the non-significant effect of fat content on water retention in cheese could be the very low variability of dCY_{WATER} ($SD = 0.07$).

The positive relationship between milk fat and protein contents and %CY has been previously reported by other studies on goat (Guo et al., 2004; Zeng et al., 2007), sheep (Jaramillo et al., 2008; Manca et al., 2016), cow (Verdier-Metz, et al., 2001), and buffalo milk (Shakerian et al., 2016). As regards %REC traits, very few studies have investigated the effect of milk composition. Cipolat-Gotet et al. (2018) have described in detail the effect of the different protein fractions of bovine milk, and Sales et al. (2018) have evidenced that, in buffaloes, milk protein is positively associated with recovery of protein and casein in the curd. In sheep, recovery of fat (Jaeggi et al., 2005) and protein in the curd (Pirisi et al., 2000; Jaeggi et al., 2005) have been studied on the basis of somatic cell content or season effects but not milk composition. Cipolat-Gotet et al. (2016b), in a study dealing with phenotypic correlations between cheese-making traits and sheep milk composi-

tion, evidence that the correlations among REC traits and milk total solids, fat, protein, and casein are low for %REC_{PROTEIN} (0.14 to 0.21), moderate for %REC_{FAT} (0.27 to 0.37), and high for %REC_{SOLIDS} (0.64 to 0.82).

Effects of Traditional Single-Point MCP on Component Recovery and Cheese Yield

The F -values and significance of the effects, and the orthogonal contrasts for traditional single-point milk coagulation properties (model [M1]), for %REC, %CY, and dCY traits are reported in Table 2. Because composition of milk affects both cheese yield and coagulation ability of milk (Jaramillo et al., 2008; Pazzola et al., 2014; Amalfitano et al., 2019), we corrected the model for milk fat and protein, to quantify the true independent effect of MCP and CF_t parameters on the considered traits. The studies that have investigated the effect of coagulation properties on CY have rarely included milk composition in their statistical models, and to our knowledge, no previous study has investigated the effects of 6 different coagulative traits on different measures of cheese yield and recovery of components of goat milk. In some studies describing the associations between bovine MCP and CY, milk samples characterized by short RCT also show higher %CY_{SOLIDS} compared with milk samples characterized

Figure 3. Effect of curd firmness (a_{30}) on percentage of water retained in curd (%CY_{WATER}). Details of statistical analysis are shown in Table 2.

by longer RCT (Walsh et al., 1998; Buchberger and Dovč, 2000). However, in those studies it is not possible to separate the effect of milk composition (in particular of milk protein and its fractions) from the specific effect of MCP. In some other studies based on cheese-making experiments comparing milk samples characterized by good or poor aptitude to coagulate (Ikonen et al., 1999; Wedholm et al., 2006), associations between MCP and

CY traits have not been clear, especially because the effects of MCP are sometime confounded with the factors responsible for their variation (i.e., milk composition, breed, herd). Hence, information provided by those studies should be considered prudently. Jaramillo et al. (2008), after the inclusion of milk composition in their statistical model, found no correlation for RCT and a_{30} with cheese yield in sheep milk. Manca et al. (2016), in

Figure 4. Effect of estimated rennet coagulation time (RCT_{eq}) on percentage of recovery of protein and solids (%REC_{PROTEIN} and %REC_{SOLIDS}, respectively; a), and percentage of DM in curd (%CY_{SOLIDS}; b). Details of statistical analysis are shown in Table 3.

their work on multivariate analysis among milk composition, coagulation, and cheese-making traits in sheep milk, found a substantial independence of %CY from the traditional MCP and, as expected, large correlations between individual %CY and milk fat content. The disagreements among the cited studies can be partly attributed to the wide variability observed among studies about experimental conditions and methods.

Among the traditional MCP, the information provided by k_{20} is very important for the cheese-making process, as it indicates the optimal moment for curd cutting (Bynum and Olson, 1982). It represents the first step of the progressive dehydration by which milk components are recovered and concentrated in the cheese curd. In this study, curd-firming time induced a cubic pattern on %REC_{SOLIDS} (Figure 2a) with an optimum value between 2 and 4 min, which was recorded for all 3 %CY traits (Figure 2b). Therefore, milk samples characterized by very early (under approximately 2 min) or late curd-firming (over approximately 4 min) were associated with lower recovery of total solids in the curd and a general decrease of %CY. Some previous studies have reported that cutting the curd when it is too soft results in a decreased %CY, and delaying the cutting time tends to induce the opposite effect (Lawrence, 1991; Fagan et al., 2007). However, the increase of CY after a delayed cutting time is most probably due to increased water retention in the curd (%CY_{WATER}) and

not to improvement of component recovery (Martin et al., 1997; Castillo et al., 2006).

Curd firmness was negatively associated with %CY_{WATER} (Figure 3). The contrary is found for bovines by Cecchinato and Bittante (2016), as %CY_{WATER} is positively associated with higher curd firmness parameters (i.e., curd firmness at 30 and 45 min, and CF_P). In bovine milk, Aleandri et al. (1989) have found that the effect of curd firmness on CY during production of Parmesan cheese is affected by the fat content, with a favorable effect for milk with low fat content and unfavorable for high fat content. Water retention in cheese is influenced by several factors, including the breed of the animal (Vacca et al., 2018b), processing conditions (Remeuf et al., 1991), and the concentrations of milk fat and protein (Pazzola et al., 2019).

Effects of Estimated CF_t Parameters on Component Recovery and Cheese Yield

In the literature no information is available on the effects of CF_t parameters on goat cheese-making traits. Because technical improvements have been achieved for the Formagraph instrument, the information obtained at any time during coagulation can now be stored and easily accessed. That information, if properly modeled, is more informative than the traditional MCP for both cows (Malchiodi et al., 2014; Stocco et al., 2017) and

Figure 5. Effect of curd-firming rate constant (k_{CF}) on percentage of fresh curd and DM in curd (%CY_{CURD}, %CY_{SOLIDS}). Details of statistical analysis are shown in Table 3.

small ruminants (Vacca et al., 2015; Pazzola et al., 2018). Moreover, the 3 estimated parameters are less interdependent than traditional MCP, and the practical and scientific utility of the parameters, the relationship

among them, and their genetic and genomic aspects have been also investigated (Cecchinato and Bittante, 2016; Dadousis et al., 2017). The suitability of information from all points recorded by the Formagraph rather

Figure 6. Effect of asymptotic potential curd firmness (CF_p) on percentage of recovery of fat ($\%REC_{FAT}$; a) and percentage of fresh curd ($\%CY_{CURD}$; b). Details of statistical analysis are shown in Table 3.

than via single points was evidenced by comparison of the effects of traditional RCT (Table 2) with estimated RCT_{eq} (Table 3). Unlike RCT, longer RCT_{eq} values were associated with lower protein and total solids recovered in the curd (Figure 4a) and with lower $\%CY_{SOLIDS}$ (Figure 4b). Data provided by RCT_{eq} were more effective than those provided by traditional single-point RCT in explaining the cheese-making process and yield. In addition, k_{CF} influenced $\%CY_{CURD}$ and $\%CY_{SOLIDS}$ (Figure 5). In accordance with a previous study reporting that k_{CF} is positively affected by fat content (Stocco et al., 2018b), we can speculate that because of the tightening of the casein net, a faster increase of curd-firming rate allowed more total solids to be retained in the curd, with consequent increase of $\%CY_{CURD}$. The asymptotic CF_P , which represents the maximum potential curd firmness of a given sample after infinite time, was positively associated with $\%REC_{FAT}$ (quadratic trend; Figure 6a) and with $\%CY$ of fresh curd and solids (linear trend; Figure 6b). The difference in mean values between CF_P and a_{30} confirms that the lower value of a_{30} is due to the short time available for the curd-firming process to reach its potential. Moreover, a_{30} is related to RCT, as the delay of gelation time causes a reduction of the 30-min interval from gelation available for curd-firming (Caballero-Villalobos et al., 2018). Hence, the negative correlation between RCT and a_{30} could be attributable to the effect of the decreasing time available for measuring CF rather than to an intrinsic smaller potential of CF in late-coagulating milk samples. Unlike a_{30} , CF_P is not dependent on RCT.

Because of the much larger level of independence among CF_t parameters, these traits can also be more easily characterized from the perspective of possible application at the industry level. A recent study on this topic among bovine milk samples revealed that the CF_t parameters describing the late part of the coagulation process (in our case, only CF_P) are more genetically correlated with CY traits than are the traditional MCP (Cecchinato and Bittante, 2016). Moreover, we may expect further progress in the dairy sector through the use of Fourier-transform infrared spectroscopy, coupled with chemometric models, to predict coagulation traits and include this information in the milk payment system (Ferragina et al., 2017).

CONCLUSIONS

Results presented in this study provide new knowledge about the relationships between coagulation and cheese-making traits in goats. The simultaneous inclusion of both milk composition and the information from traditional MCP and CF_t parameters in the statistical models were suitable to ascertain the specific effects of

coagulation on both $\%CY$ and $\%REC$ traits. In particular, we found an optimum range of k_{20} values for goat milk to obtain the highest recovery of components and $\%CY_{SOLIDS}$. This finding clarifies that high curd firmness associated with high $\%CY$ is not derived only from higher retention of water in the curd. On the contrary, samples with high curd firmness values were characterized by a greater $\%REC_{FAT}$, lower $\%CY_{WATER}$, and increased $\%CY_{CURD}$. The collection of all the available information during the process of milk coagulation and curd-firming evidenced the effect of RCT_{eq} on $\%REC$ traits and $\%CY_{SOLIDS}$ (which was not revealed for traditional RCT), and the positive correlation of the curd-firming instant rate constant with $\%CY_{CURD}$ and $\%CY_{SOLIDS}$. In light of these findings, it could be stimulating to hypothesize a quality payment scheme for goat milk that would also include the information provided by coagulation traits, and to address future research to test predictive $\%CY$ and $\%REC$ formulae using rapid and low-cost techniques, such as infrared spectroscopy, to improve the goat dairy industry.

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