Effects of indirect indicators of udder health on nutrient recovery and cheese yield traits in goat milk

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ABSTRACT

In dairy goats, very little is known about the effect of the 2 most important indirect indicators of udder health [somatic cell count (SCC) and total bacterial count (TBC)] on milk composition and cheese yield, and no information is available regarding the effects of lactose levels, pH, and NaCl content on the recovery of nutrients in the curd, cheese yield traits, and daily cheese yields. Because large differences exist among dairy species, conclusions from the most studied species (i.e., bovine) cannot be drawn for all types of dairy-producing animals. The aims of this study were to quantify, using milk samples from 560 dairy goats, the contemporary effects of a pool of udder health indirect indicators (lactose level, pH, SCC, TBC, and NaCl content) on the recovery of nutrients in the curd (%REC), cheese yield (%CY), and daily cheese yields (dCY). Cheese-making traits were analyzed using a mixed model, with parity, days in milk (DIM), lactose level, pH, SCC, TBC, and NaCl content as fixed effects, and farm, breed, glass tube, and animal as random effects. Results indicated that high levels of milk lactose were associated with reduced total solids recovery in the curd and lower cheese yields, because of the lower milk fat and protein contents in samples rich in lactose. Higher pH correlated with higher recovery of nutrients in the curd and higher cheese yield traits. These results may be explained by the positive correlation between pH and milk fat, protein, and casein in goat milk. High SCC were associated with higher recovery of solids and energy in the curd but lower recovery of protein. The higher cheese yield obtained from milk with high SCC was due to both increased recovery of lactose in the curd and water retention. Bacterial count proved to be the least important factor affecting cheese-making traits, but it decreased daily cheese yields, suggesting

that, even if below the legal limits, TBC should be considered in order to monitor flock management and avoid economic losses. The effect of NaCl content on milk composition was linked with lower recovery of all nutrients in the curd during cheese-making. In addition, high milk NaCl content led to reductions in fresh cheese yield and cheese solids. The indirect indicators of the present study significantly affected the cheese-making process. Such information should be considered, to adjust the milk-to-cheese economic value and the milk payment system.

Key words: lactose, somatic cells, bacterial count, cheese-making, NaCl

INTRODUCTION

Goat milk is mostly used for cheese-making, and among its components, fat and protein highly influence yield and traits of cheese (Guo et al., 2004; Stocco et al., 2018; Pazzola et al., 2019). In cattle, besides fat and protein, milk traits such as lactose levels, pH, NaCl content, SCC, and total bacterial count (TBC) are unequivocally associated with the udder health status of dairy cows (Charjan-Ku et al., 2000; Pyörälä, 2003), and are also linked to a deterioration of the cheese-making process. High SCC and TBC in cow milk are associated with a high pH, with markedly worsened protein quality, decreased fat and lactose contents (Ogola et al., 2007), and reduced cheese yield (%CY; Summer et al., 2015). However, very little is known about the effects of these indirect indicators of udder health on cheese-making from goat milk, and results in the literature about estimation of udder health status of goats using SCC and TBC, and their effects on milk composition, are sometimes controversial (Stuhr and Aulrich, 2010).

In dairy goats, clear relationships between the most common indirect indicators of udder health status (i.e., SCC and TBC) and worsening of milk quality have not been evidenced. Gelasakis et al. (2018) have recently shown that milk from goats with subclinical mastitis

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is characterized by lower fat and lactose contents and slightly higher protein content compared with healthy goats. However, SCC and TBC are the traits that can most easily and inexpensively give information on mammary gland health status, in dairy cows and also in dairy goats (Rupp et al., 2009). Besides SCC and TBC, other milk constituents have been proposed as indirect indicators of udder health. The negative relationship between lactose and SCC has also been demonstrated in goats. Indeed, in goats without any symptoms of clinical mastitis, lactose affects the coagulation ability of milk, with high levels of lactose associated with reduced coagulation time and weakened curd firmness traits (Stocco et al., 2019). In dairy cows, during udder inflammation (Batavani et al., 2007), an increase of milk pH and a consequent deterioration of milk coagulation (i.e., gelation and curd-firming) are expected (Fox et al., 2017), but the effect of goat milk pH on cheese-making traits is not well documented. Again, in dairy cows, the concentration of milk NaCl increases in cases of mastitis, with an adverse effect on the concentration of other milk constituents (Batavani et al., 2007). In goat milk, high levels of NaCl (i.e., higher than 319 mg/100 mL; Stocco et al., 2019) are associated with reduced fat, protein, and casein contents, as well as with worsened coagulation ability.

Large differences exist among species, and the contemporary effects of lactose levels, pH, SCC, TBC, and NaCl content on the recovery of nutrients in the curd, cheese yield traits, and daily cheese yields of goat milk have not yet been investigated. The aims of this study were to quantify the effects of a pool of indirect udder health indicators from individual goat milk (lactose level, pH, SCC, TBC, and NaCl content) on (1) selected milk nutrient recovery traits in the curd (%REC)—fat, protein, total solids, and energy; (2) selected cheese yield traits (%CY)—fresh curd, curd dry matter, and water retained in curd; and (3) daily cheese yields (dCY), obtained by multiplying each %CY trait by the daily milk yield of goats.

MATERIALS AND METHODS

Milk Sampling and Udder Health Indicator Analysis

Milk samples were collected from 560 goats belonging to 6 different breeds (Saanen, Camosciata delle Alpi, Murciano-Granadina, Maltese, Sarda, and Sarda Primitiva) and reared in 35 farms distributed over the whole island of Sardinia, Italy. Study animals were selected from those officially registered in the flock books and enrolled in the milk recording system of provincial associations of goat breeders. Goats were milk-sampled once (single-day sampling at each farm) during afternoon

milking. Details of farm characteristics and description of the breeds have been previously reported by Vacca et al. (2018a). Briefly, type of management on farms ranged from traditional (extensive goat dairy system with free grazing of natural pastures, seasonal milk production, family operated) to modern (semi-intensive system, housing in modern buildings and use of modern facilities, common use of TMR, out-of-season kidding and continuous milk production, operated by hired workers, consultancy of experts in animal feeding). Flock size ranged from small (fewer than 100 producing goats) to large (more than 200). Saanen goats ($n = 99$) were characterized by means $\pm$ standard deviation (SD) of parity at 3.3 ± 1.7 and DIM at 109 ± 72 ; Camosciata delle Alpi goats ($n = 98$) had parity and DIM very close to the Saanen breed (3.1 ± 2.0 and 78 ± 37 , respectively). Parity and DIM of the Murciano-Granadina goats ($n = 89$) were similar to those of the 2 dairy breeds of Alpine origin (Saanen and Camosciata delle Alpi), with parity at 3.0 ± 1.4 and DIM at 129 ± 38 . Maltese goats ($n = 104$) had parity at 3.8 ± 1.7 and DIM at 129 ± 49 . The Sarda and Sarda Primitiva are local breeds from the island of Sardinia, classified as Mediterranean types, as are the Murciano-Granadina breed. Sarda goats ($n = 86$) in this study had parity at 4.7 ± 2.0 and DIM at 129 ± 36 , and Sarda Primitiva ($n = 84$) were characterized by parity at 5.1 ± 2.5 and DIM at 124 ± 40 .

Milk fat, protein, total solids, and lactose levels (expressed as %), pH, and NaCl content (expressed as mg/100 mL) were determined using a MilkoScan FT6000 milk analyzer (Foss Electric A/S, Hillerød, Denmark), calibrated according to FIL-IDF references (ISO-IDF, 2010, 2013); SCC and TBC were measured using a Fossomatic 5000 somatic cell counter and a BactoScan FC150 analyzer (both from Foss Electric A/S), respectively. These traits were then transformed into the logarithmic somatic cell score [$SCS = \log_2(SCC \times 10^{-5}) + 3$] and logarithmic bacterial count [$LBC = \log_{10}(TBC/1,000)$], respectively.

Cheese-Making Traits

To measure cheese-making traits, we used the 9-mL milk cheese-making assessment (9-MilCA) method proposed by Cipolat-Gotet et al. (2016). The following procedure was performed in duplicate for each goat milk sample (2 replicates of 9 mL from the same milk sample), for a total of 1,120 observations. Each replicate (9 mL) was poured into a glass tube, inserted into the sample rack of the lactodynamograph instrument (Formagraph, Foss Italia S.P.A., Padova, Italy), 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 transferred to the lactodynamograph for curd firmness measurements (30 min at 35°C). At the end of curd firmness analysis, coagulated milk replicates were manually cut and moved to the heater for the curd-cooking phase (30 min at 55°C). In the middle of the cooking phase, each replicate was subjected to a further manual cutting by the same operator. Then each glass tube was removed from the sample rack, and the curd was separated from the whey. The curd was manually pressed with a stainless-steel spatula and suspended above the whey for 15 min at room temperature for draining. The obtained curd and whey were weighed using a precision scale. An infrared spectrophotometer (Foss Electric A/S) was used to analyze whey composition (fat, protein, lactose, and total solids). The weights of the milk, curd, and whey (in g), and the chemical composition of milk and whey allowed us to estimate curd composition by calculating the difference between milk and whey. The nutrient recovery traits for protein, fat, and solids were $\%REC_{PROTEIN}$, $\%REC_{FAT}$, and $\%REC_{SOLIDS}$, calculated as the ratio of the weight of the curd components (protein, fat, and total solids, respectively) to the weight of the same milk component, and multiplied by 100. Recovery of energy in the curd ($\%REC_{ENERGY}$) was calculated by estimating energy of milk and curd using an equation proposed by the NRC (2001), converted to MJ/kg and multiplied by 100. The cheese yield traits ($\%CY$) for curd, solids, and water were $\%CY_{CU}$, $\%CY_{SOLIDS}$, and $\%CY_{WATER}$, calculated as the ratio of the weight of fresh curd, curd dry matter, and water retained in curd, respectively, to the weight of the milk processed, and multiplied by 100. Daily cheese yields of curd, solids, and water (dCY_{CURD} , dCY_{SOLIDS} , and dCY_{WATER} ; kg/d) were calculated by multiplying $\%CY$ ($\%CY_{CURD}$, $\%CY_{SOLIDS}$, and $\%CY_{WATER}$, respectively) by the individual daily milk yield of goats. Daily milk yield of goats (dMY , kg/d) was calculated as the total yield of morning plus afternoon milking of the same day of milk sampling.

Statistical Analysis

Cheese-making traits ($\%REC$, $\%CY$, and dCY) were analyzed using a MIXED procedure (SAS Institute Inc., Cary, NC), according to the following model:

$$Y_{efghijklmnop} = \mu + DIM_e + Parity_f + Lactose_g + pH_h + SCS_i + LBC_j + NaCl_k + Farm_l + Breed_m + Glass\ Tube_n + Animal_o + e_{efghijklmnop}$$

where $Y_{efghijklmnop}$ is the observed trait; μ is the overall intercept of the model; DIM_e is the fixed effect of the e th class of days in milk [$e = 1$ to 4; class 1: ≤ 80 d (146 goats); class 2: 81–120 d (157 goats); class 3: 121–160 d (157 goats); class 4: > 160 d (100 goats)]; $Parity_f$ is the fixed effect of the f th parity [$f = 1$ to 3; class 1: 1st and 2nd (193 goats); class 2: 3rd and 4th (205 goats); class 3: ≥ 5 th (162 goats)]; $Lactose_g$ is the fixed effect of the g th class of lactose content ($g = 1$ to 7; class 1: $< 4.32\%$; class 2: 4.32–4.45%; class 3: 4.46–4.58%; class 4: 4.59–4.73%; class 5: 4.74–4.86%; class 6: 4.87–4.99%; class 7: $> 4.99\%$); pH_h is the fixed effect of the h th class of pH ($h = 1$ to 7; class 1: < 6.59 ; class 2: 6.59–6.63; class 3: 6.64–6.69; class 4: 6.70–6.75; class 5: 6.76–6.80; class 6: 6.81–6.85; class 7: > 6.85); SCS_i is the fixed effect of the i th class of SCS ($i = 1$ to 7; class 1: < 3.15 ; class 2: 3.15–4.12; class 3: 4.13–5.11; class 4: 5.12–6.11; class 5: 6.12–7.10; class 6: 7.11–8.08; class 7: > 8.08); LBC_j is the fixed effect of the j th class of LBC ($j = 1$ to 7; class 1: < 0.76 ; class 2: 0.76–1.16; class 3: 1.17–1.58; class 4: 1.59–2.01; class 5: 2.02–2.43; class 6: 2.44–2.83; class 7: > 2.83); $NaCl_k$ is the fixed effect of the k th class of NaCl ($k = 1$ to 7; class 1: < 184 mg/100 mL; class 2: 184–209 mg/100 mL; class 3: 210–235 mg/100 mL; class 4: 236–262 mg/100 mL; class 5: 263–288 mg/100 mL; class 6: 289–315 mg/100 mL; class 7: > 315 mg/100 mL); $Farm_l$ is the random effect of the l th farm ($l = 1$ to 35); $Breed_m$ is the random effect of the m th breed ($m =$ Saanen, Camosciata delle Alpi, Murciano-Granadina, Maltese, Sarda, or Sarda Primitiva); $Glass\ Tube_n$ is the random effect of the n th glass tube of the lactodynamograph instrument ($n = 1$ to 8); $Animal_o$ is the random effect of the o th animal ($o = 1$ to 560); $e_{efghijklmnop}$ is the random residual $\sim N(0, \sigma_e^2)$, where σ_e^2 is the residual variance. The 7 classes for lactose, pH, SCS, LBC, and NaCl were designed on the basis of distribution of the variables: each single class explained 0.5 SD of the variable; the fourth class was centered on the mean value; and the first and the seventh classes represented the tails of the distribution.

Orthogonal polynomial contrasts (linear, quadratic, and cubic pattern) were estimated between least squares means (LSM) of milk indirect indicators (lactose level, pH, SCS, LBC, and NaCl concentration) of udder health.

RESULTS AND DISCUSSION

Mean and SD of cheese-making traits ($\%REC$, $\%CY$, and dCY), fixed effects (DIM, parity), and random effects (farm, breed, animal, glass tube of the instrument) are summarized in Table 1. Their effects on cheese-making traits, using the same data set as the

Table 1. Descriptive statistics (mean and SD) and ANOVA for nutrient recovery (%REC), cheese yield (dCY), and daily cheese yield (dCY) traits of individual milk samples from 560 goats (1,120 total observations) across 6 breeds, with *F*-value and significance for fixed effects and the proportion of variance (percentage) explained by random effects

Trait ¹	Fixed effects: <i>F</i> -value and significance								Random effects ²					
	Mean	SD	DIM	Parity	Lactose	pH	SCS	LBC ⁴	NaCl	Farm	Breed	Animal	Glass tube	RMSE ³
Nutrient recovery, %														
%REC _{FAT}	80.86	5.84	0.6	1.0	1.1	1.5	0.8	1.4	9.6***	9	20	70	0.01	0.40
%REC _{PROTEIN}	81.63	2.51	2.8*	3.5*	8.5***	4.2***	6.1***	1.9	1.4	18	6	72	0.04	0.47
%REC _{SOLIDS}	55.75	5.54	2.4	3.6*	11.4***	5.2***	5.0***	1.1	5.2***	24	26	45	0.07	1.10
%REC _{ENERGY}	66.40	5.49	0.3	1.5	6.7***	2.4*	2.5*	0.8	5.2***	16	30	53	0.03	0.80
Cheese yield, %														
%CY _{CURD}	15.73	2.83	0.9	3.2*	1.7	7.8***	4.7***	2.3*	3.4**	30	18	43	0.00	0.88
%CY _{SOLIDS}	7.74	1.76	1.1	1.9	8.5***	8.9***	7.7***	1.7	11.6***	32	27	40	0.01	0.16
%CY _{WATER}	7.97	1.49	0.3	1.7	0.8	10.4***	4.1***	1.1	0.8	31	9	34	0.01	0.81
Daily cheese yield, kg/d														
dCY _{CURD}	0.29	0.15	1.9	2.8	0.1	1.4	1.5	2.1	1.2	36	31	32	0.00	0.02
dCY _{SOLIDS}	0.14	0.07	1.9	2.2	0.6	2.5*	3.4**	1.9	1.4	36	32	33	0.00	0.00
dCY _{WATER}	0.15	0.08	2.1	3.4*	0.9	1.1	1.0	1.7	1.1	38	28	29	0.02	0.02
%REC _{PROTEIN} = percent protein recovery; %REC _{FAT} = percent fat recovery; %REC _{SOLIDS} = percent solids recovery; %REC _{ENERGY} = percent energy recovery. %CY _{CURD} = percent curd yield; %CY _{SOLIDS} = percent solids yield; %CY _{WATER} = percent water yield. dCY _{CURD} = curd yield; dCY _{SOLIDS} = solids yield; dCY _{WATER} = water yield.														

¹%REC_{PROTEIN} = percent protein recovery; %REC_{FAT} = percent fat recovery; %REC_{SOLIDS} = percent solids recovery; %REC_{ENERGY} = percent energy recovery. %CY_{CURD} = percent curd yield; %CY_{SOLIDS} = percent solids yield; %CY_{WATER} = percent water yield. dCY_{CURD} = curd yield; dCY_{SOLIDS} = solids yield; dCY_{WATER} = water yield.

²Percent of total variance.

³RMSE = root mean square error.

⁴LBC = logarithmic bacterial count.

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

present study, are reported and discussed in a previous study (Vacca et al., 2018b).

Effects of Lactose

In goats, a few studies have focused on the relationship between SCC and lactose (Pirisi et al., 2000; Albenzio et al., 2004), but no information is reported about the effects of lactose on cheese-making. The effects of different concentrations of milk lactose on coagulation, curd-firming, and syneresis from 1,272 individual goat samples has been reported by Stocco et al. (2019). In that study, high levels of lactose were associated with decreases in milk fat, protein, and casein contents, worsened curd-firming rate, and weakened curd firmness traits. Moreover, as a consequence of the negative relationship between lactose and milk composition (fat and casein), decreased values of %REC_{PROTEIN} and %REC_{SOLIDS} were recorded for samples with high lactose content (Pazzola et al., 2019). Those findings, together with the negative association between lactose and curd firmness, could explain also the lower %CY_{SOLIDS} for goats with higher milk lactose (*P* < 0.001, Table 2). Because of these associations, and due to the fact that lactose is almost completely lost in the whey during cheese-making, %REC_{ENERGY} was also lower in curds made from lactose-rich milk samples. As for the other indirect health traits, the effects of milk lactose were tested, including DIM and parity in the model. For this reason, the aforementioned results cannot be related to the variability of DIM and parity among the goats.

Effects of pH

Milk pH is one of the most important traits influencing composition and coagulation properties (Calvo and Balcones, 2000). During cheese-making, when cow milk is acidified, gelation time decreases and curd firmness markedly increases (Stocco et al., 2015). Goat milk samples with increased pH values are associated with a worsening of coagulation abilities (i.e., longer coagulation time, weaker curd firmness) and with an enhancement of curd-firming and syneresis (Stocco et al., 2019). However, the results obtained for the effects of milk pH on coagulation were not completely associable to what we found for cheese-making traits. When compared with milk with lower pH, samples with high pH showed greater recovery of milk nutrients in the curd, especially %REC_{PROTEIN} and %REC_{SOLIDS} (*P* < 0.001, Table 3). Greater %REC also produced higher values of %CY traits, as reported in Table 3. The positive relationships between milk pH and cheese-making traits found in this study can be explained by the positive correlations of pH with milk fat, protein,

Table 2. Effects of lactose (LSM and *F*-values of contrasts) on nutrient recovery (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of individual milk samples (560 goats, 1,120 total observations)

Item	Lactose, % (range per class) ¹										Contrast, <i>F</i> -value		
	<4.32	4.32–4.45	4.46–4.58	4.59–4.73	4.74–4.86	4.87–4.99	>4.99	Linear	Quadratic	Cubic			
Number of samples	120	116	188	258	208	128	102						
Nutrient recovery, %													
%REC _{FAT}	82.6	80.5	80.1	80.6	80.2	79.5	79.6	2.5	1.0	1.3			
%REC _{PROTEIN}	82.7	83.1	81.3	81.4	81.3	81.2	79.4	24.6***	0.9	3.9*			
%REC _{SOLIDS}	59.5	58.5	56.7	56.5	55.0	54.3	51.2	57.0***	2.2	4.0*			
%REC _{ENERGY}	69.4	68.5	66.3	66.5	65.8	65.0	62.4	29.5***	0.3	4.6*			
Cheese yield, %													
%CY _{CURD}	16.3	16.1	16.0	16.0	15.7	15.9	14.7	4.5*	1.7	2.5			
%CY _{SOLIDS}	8.43	8.45	7.96	7.98	7.69	7.44	6.70	35.9***	5.8*	2.9			
%CY _{WATER}	8.16	7.86	8.04	8.02	8.12	8.34	8.16	0.5	0.4	2.2			
Daily yield traits, kg/d													
dCY _{CURD}	0.286	0.278	0.277	0.282	0.284	0.291	0.290	0.1	0.3	0.3			
dCY _{SOLIDS}	0.145	0.144	0.135	0.136	0.134	0.135	0.128	1.6	0.1	0.2			
dCY _{WATER}	0.146	0.136	0.145	0.146	0.151	0.156	0.166	2.7	1.3	0.2			

¹Milk lactose content levels were classed on the basis of variable distribution: each class explains 0.5 SD of the variable; the fourth class is centered on the mean value; and the first and seventh classes represent the tails of the distribution.

²%REC_{PROTEIN} = percent protein recovery; %REC_{FAT} = percent fat recovery; %REC_{SOLIDS} = percent solids recovery; %REC_{ENERGY} = percent energy recovery. %CY_{CURD} = percent curd yield; %CY_{SOLIDS} = percent solids yield; %CY_{WATER} = percent water yield. dCY_{CURD} = curd yield; dCY_{SOLIDS} = solids yield; dCY_{WATER} = water yield.

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

and casein in goat milk, and by the higher acidification normally observed in milk samples closer to basicity after addition of rennet, compared with those with lower pH (Dejmek and Walstra, 2004).

In cows and sheep, high milk pH is positively related to high SCC (Pirisi et al., 2000; Batavani et al., 2007) and correlated with lower fat and casein concentrations, as well as with reduced ratios of casein to protein (Coulon et al., 2002). In goats, the relationship between milk pH and SCS is less clear, as a high SCC is not always a symptom of bacterial infection. However, it has been evidenced that high pH values are commonly recorded in milk produced in early lactation (<80 DIM) or from young goats (i.e., 1st or 2nd parity; Vacca et al., 2018b).

Effects of SCS

Goat milk SCS affected almost all the %REC traits (protein and solids at *P* < 0.001, and energy at *P* < 0.05), the 3 %CY traits at *P* < 0.001, and dCY_{SOLIDS} at *P* < 0.01 (Table 1). In particular, higher values of SCS were associated with a tendency toward a lower %REC_{PROTEIN} and higher %REC_{SOLIDS} (Table 4). The latter result was probably related to the increased water retained (%CY_{WATER}) and greater amount of lactose recovered in the curd. Because %CY_{SOLIDS} and %CY_{WATER} increased with higher numbers of somatic cells in milk, %CY_{CURD} produced from high-SCS samples was higher than those derived from milk with a lower SCC. Goat milk is normally characterized by a relatively high SCC, and milk samples with high SCS frequently contain a higher percentage of protein and casein than do those with low SCS (Barrón-Bravo et al., 2013). Moreover, the relationship between goat SCC and milk fat is still controversial: some authors have reported negative (Barrón-Bravo et al., 2013; Hanuš et al., 2017) and others positive relationship (Park and Humphrey, 1986; Ying et al., 2002), whereas Min et al. (2007) did not find any relationship. A previous study evidenced that in healthy goats, milk with high SCS is characterized by high fat, protein, and casein contents, slow coagulation time, and high rate of curd-firming (Stocco et al., 2019). The positive relationships between SCS and milk composition (Pazzola et al., 2019) could explain the higher %REC_{SOLIDS} obtained from milk samples with high SCS, whereas the negative relationship between SCS and %REC_{PROTEIN} could be explained by the remarkable proteolytic activity of some enzymes contained in somatic cells (i.e., cathepsins, plasmin; Kelly and McSweeney, 2003), as well as by the increased proportion of whey proteins. The increase of whey proteins in milk as a result of subclinical mastitis is caused by augmented proportions of blood protein

Table 3. Effects of milk pH (LSM and *F*-values of contrasts) on nutrient recovery (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of individual milk samples (560 goats, 1,120 total observations)

Item	pH (range per class ¹)										Contrast, <i>F</i> -value		
	<6.59	6.59–6.63	6.64–6.69	6.70–6.75	6.76–6.80	6.81–6.85	>6.85	Linear	Quadratic	Cubic			
Number of samples	120	96	238	260	196	106	104						
Nutrient recovery, ² %													
%REC _{FAT}	78.7	81.5	80.4	81.1	81.2	80.3	79.7	0.1	5.9*	0.6			
%REC _{PROTEIN}	80.7	80.5	81.5	81.4	82.1	82.2	81.8	10.7***	1.8	2.6			
%REC _{SOLIDS}	54.5	54.3	55.3	55.4	56.8	57.6	57.7	22.4***	0.4	1.9			
%REC _{ENERGY}	65.0	65.2	65.9	66.2	67.3	67.1	67.2	8.0**	0.5	0.8			
Cheese yield, %													
%CY _{CURD}	15.0	14.6	15.1	15.6	16.0	17.1	17.4	36.1***	1.7	2.5			
%CY _{SOLIDS}	7.53	7.18	7.54	7.60	8.10	8.30	8.41	58.5***	2.7	0.2			
%CY _{WATER}	7.28	7.36	7.72	7.98	8.29	8.87	9.20	27.5***	3.4	6.2*			
Daily yield traits, kg/d													
dCY _{CURD}	0.299	0.268	0.272	0.270	0.285	0.302	0.291	0.4	2.7	3.3			
dCY _{SOLIDS}	0.147	0.127	0.133	0.127	0.142	0.143	0.138	0.1	2.4	6.0*			
dCY _{WATER}	0.150	0.144	0.140	0.142	0.150	0.160	0.158	1.4	2.3	1.2			

¹Milk pH levels were classed on the basis of variable distribution: each class explains 0.5 SD of the variable; the fourth class is centered on the mean value; and the first and seventh classes represent the tails of the distribution.

²%REC_{PROTEIN} = percent protein recovery; %REC_{FAT} = percent fat recovery; %REC_{SOLIDS} = percent solids recovery; %REC_{ENERGY} = percent energy recovery. %CY_{CURD} = percent curd yield; %CY_{SOLIDS} = percent solids yield; %CY_{WATER} = percent water yield. dCY_{CURD} = curd yield; dCY_{SOLIDS} = solids yield; dCY_{WATER} = water yield.

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

Table 4. Effects of SCS [least squares means (LSM) and *F*-values of contrasts] on nutrient recovery (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of individual milk samples (560 goats, 1,120 total observations)

Item	SCS (range per class ¹)										Contrast, <i>F</i> -value		
	<3.15	3.15–4.12	4.13–5.11	5.12–6.11	6.12–7.10	7.11–8.08	>8.08	Linear	Quadratic	Cubic			
Number of samples	128	142	190	218	170	140	132						
Nutrient recovery, ² %													
%REC _{FAT}	79.0	80.9	80.7	80.5	80.9	80.6	80.4	0.8	2.4	0.8			
%REC _{PROTEIN}	82.4	81.9	81.8	82.1	81.3	80.8	80.2	29.4***	3.3	0.8			
%REC _{SOLIDS}	54.1	55.2	55.2	56.1	57.0	57.1	57.9	24.1***	1.9	0.9			
%REC _{ENERGY}	64.7	65.6	66.0	66.6	67.3	66.7	66.8	9.2**	3.5	0.1			
Cheese yield, %													
%CY _{CURD}	15.0	15.7	15.1	15.8	16.1	16.6	16.4	18.8***	0.0	0.9			
%CY _{SOLIDS}	7.35	7.42	7.58	7.84	8.17	8.18	8.10	10.0***	3.9*	0.1			
%CY _{WATER}	7.86	8.18	7.66	7.98	8.10	8.43	8.49	32.7***	1.5	4.6*			
Daily yield traits, kg/d													
dCY _{CURD}	0.280	0.274	0.272	0.293	0.306	0.286	0.276	0.4	1.4	3.6			
dCY _{SOLIDS}	0.132	0.126	0.134	0.143	0.151	0.139	0.132	1.8	4.7*	5.8*			
dCY _{WATER}	0.152	0.148	0.140	0.151	0.157	0.149	0.149	0.1	0.0	2.3			

¹Milk SCS levels were classed on the basis of variable distribution: each class explains 0.5 SD of the variable; the fourth class is centered on the mean value; and the first and seventh classes represent the tails of the distribution.

²%REC_{PROTEIN} = percent protein recovery; %REC_{FAT} = percent fat recovery; %REC_{SOLIDS} = percent solids recovery; %REC_{ENERGY} = percent energy recovery. %CY_{CURD} = percent curd yield; %CY_{SOLIDS} = percent solids yield; %CY_{WATER} = percent water yield. dCY_{CURD} = curd yield; dCY_{SOLIDS} = solids yield; dCY_{WATER} = water yield.

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

(i.e., albumin and immunoglobulins) and lactoferrin in the total protein content (Urech et al., 1999).

The positive relationship between SCS and %CY found in this study contrasts with the results of Leitner et al. (2004), who tested the effect of subclinical mastitis on goat milk used for cheese-making, but agrees with results obtained for sheep milk (Othmane et al., 2002). However, the majority of studies on goat milk do not find any effect of SCC on %CY. For example, in a study on the effects of 3 levels of goat milk SCC on cheese-making, Chen et al. (2010) observed no significant difference, either in %CY or in fat and protein recovery, among semi-soft cheeses. Rather, those authors report that, after ripening, total sensory and texture scores for cheeses made from milk with high SCC are lower than those made from milk with low and medium SCC. Galina et al. (1996) report no significant correlation between %CY and SCC for goat milk, with SCC ranging from 250,000 to more than 1,000,000 cells/mL. The same results were observed in comparisons of bulk milk with %CY obtained from 2 levels of milk SCC (<700,000 and >1,800,000 cells/mL; Morgan and Gaspard, 1999). Sánchez-Macías et al. (2013) concluded that SCC has a major effect on ripening, especially on lipolysis activity (i.e., increasing free fatty acids) and on casein proteolysis. Certainly, our results were very different from those reported for individual milk samples of dairy cows, in which high milk SCC is associated with evident and nonlinear decreases of %REC and %CY traits (Bobbo et al., 2016).

Effects of LBC

Total bacterial count is commonly used to monitor the hygiene of dairy goat flocks and the quality of milk used to produce cheese (Pirisi et al., 2007). In this study, compared with the other indirect indicators of udder health, LBC showed the least important effect on %REC and %CY traits. We observed a tendency for fat to be better recovered in curds made from milk characterized by high LBC at $P < 0.05$, whereas the opposite was observed for protein recovery at $P < 0.01$ (Table 5). A previous study indicated that milk samples characterized by high LBC are associated with increased levels of fat and protein in milk and a significant decrease in curd firmness traits (Stocco et al., 2019). The findings reported in the present study for the effects of LBC evidenced a decrease of daily CY traits, at $P < 0.01$ for curd and solids, and at $P < 0.05$ for water (Table 5). Given that dCY traits are calculated on the basis of daily milk yield of goats, this result is explained by the negative correlation between dMY and LBC. Indeed, a linear decrease of dMY from 2.08 to 1.63 kg/d was observed across classes of LBC,

Table 5. Effects of logarithmic bacterial count [LBC; least squares means (LSM) and *F*-values of contrasts] on nutrient recovery (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of individual milk samples (560 goats, 1,120 total observations)

Item	LBC (range per class ¹)							Contrast, <i>F</i> -value		
	<0.76	0.76–1.16	1.17–1.58	1.59–2.01	2.02–2.43	2.44–2.83	>2.83	Linear	Quadratic	Cubic
Number of samples	102	166	226	188	182	134	122			
Nutrient recovery, %										
%REC ² FAT	78.4	80.0	80.5	79.9	81.0	81.3	81.8	6.1*	0.2	0.8
%REC ² PROTEIN	82.3	81.9	81.8	81.4	80.8	81.2	80.9	8.4**	0.9	0.2
%REC ² SOLIDS	55.3	56.1	56.4	55.9	55.3	56.4	56.2	0.4	0.1	2.0
%REC ² ENERGY	65.3	66.5	66.7	66.2	66.0	66.2	67.1	0.9	0.0	3.9*
Cheese yield, %										
%CY ² CURD	15.5	15.8	16.1	16.0	15.2	15.8	16.3	0.5	0.1	6.0*
%CY ² SOLIDS	7.62	7.82	7.98	7.77	7.59	7.93	7.94	0.5	0.0	3.5
%CY ² WATER	7.82	7.99	8.06	8.23	7.99	8.23	8.38	2.9	0.0	1.0
Daily yield traits, kg/d										
dCY ² CURD	0.307	0.311	0.286	0.297	0.275	0.255	0.256	7.2**	0.2	0.3
dCY ² SOLIDS	0.147	0.151	0.139	0.141	0.134	0.125	0.122	7.6**	0.3	0.2
dCY ² WATER	0.159	0.162	0.148	0.157	0.148	0.138	0.134	4.7*	0.4	0.0

¹Milk LBC levels were classed on the basis of variable distribution: each class explains 0.5 SD of the variable; the fourth class is centered on the mean value; and the first and seventh classes represent the tails of the distribution.
²%REC²PROTEIN = percent protein recovery; %REC²FAT = percent fat recovery; %REC²SOLIDS = percent solids recovery; %REC²ENERGY = percent energy recovery. %CY²CURD = percent curd yield; %CY²SOLIDS = percent solids yield; %CY²WATER = percent water yield. dCY²CURD = curd yield; dCY²SOLIDS = solids yield; dCY²WATER = water yield.
* $P < 0.05$; ** $P < 0.01$.

correlating with losses of 50, 20, and 30 g per d, respectively, for %CY_{CURD}, %CY_{SOLIDS}, and %CY_{WATER} (data not shown).

Previous studies of milk TBC among healthy vs. infected goats indicate that infection status causes worsening of milk quality and decreases in dMY and %CY (Leitner et al., 2004). Some studies have associated IMI with decreases in milk yield (Leitner et al., 2004; Gelasakis et al., 2016), although other authors report no significant differences between infected and uninfected goats (Moroni et al., 2005; Min et al., 2007). When the association between pathogen-specific cases of subclinical mastitis and cheese-making traits in dairy cows were tested (Bobbo et al., 2017), IMI status did not affect %CY traits, but only %REC_{FAT} and %REC_{PROTEIN}. Besides the differences among species, the absence of the specific composition of the microflora in milk samples used in the present study did not allow clear attribution of the effects of different bacterial species on each cheese-making trait. However, it was clear that a high LBC in goat milk was detrimental to daily yields of both milk and cheese.

Effects of NaCl

Both composition and mineral balance of milk are affected by NaCl content, as salt levels are responsible for the osmotic pressure of milk (Huppertz and Fox, 2006). The physical (e.g., texture, protein solubility) and organoleptic (e.g., flavor) traits of cheese are also affected by levels of NaCl (Fox et al., 2000). Despite some studies reporting on the effects of NaCl on the quality and coagulation properties of bovine milk (Sbodio et al., 2006; Awad, 2007), none have investigated the effects on cheese-making traits of different concentrations of NaCl in goat milk.

In the present study, milk samples with high NaCl concentration were characterized by significant decreases of both %REC_{FAT}, at $P < 0.001$, and %REC_{PROTEIN}, at $P < 0.05$, and, as a consequence, lower values for recovery of total solids and energy in the curd (Table 6). These findings could be explained by the osmotic properties of NaCl in milk. When concentration of milk NaCl increases, other milk components (fat, proteins, minerals) decrease, and significant physicochemical modifications occur at the casein-structure level (Huppertz and Fox, 2006). In the present study, reduced %CY_{CURD} was mainly attributable to a decrease in %CY_{SOLIDS}, and not in %CY_{WATER}, which seemed not to be influenced by milk NaCl levels. These results are in agreement with previous findings about the effects of milk NaCl on coagulation, curd-firming, and syneresis of cow (Sbodio et al., 2006; Awad, 2007) and goat milk (Stocco et al., 2019), evincing that higher NaCl concen-

Table 6. Effects of NaCl content [least squares means (LSM) and *F*-values of contrasts] on nutrient recovery (%REC), cheese yield (%CY), and daily cheese yield (dCY) traits of individual milk samples (560 goats, 1,120 total observations)

Item	NaCl, mg/100 mL (range per class) ¹										Contrast, <i>F</i> -value		
	<184	184–209	210–235	236–262	263–288	289–315	>315	Linear	Quadratic	Cubic			
Number of samples	118	142	208	208	192	126	126						
Nutrient recovery, ² %													
%REC _{FAT}	82.8	82.5	81.5	80.0	79.6	79.6	77.0	15.3***	0.4	0.5			
%REC _{PROTEIN}	82.3	81.9	81.7	81.7	81.1	80.8	80.9	6.6*	0.1	0.2			
%REC _{SOLIDS}	58.8	57.5	56.8	55.7	55.0	54.1	53.8	29.8***	0.8	0.0			
%REC _{ENERGY}	69.3	68.1	67.2	66.2	65.6	63.9	63.5	30.5***	0.1	0.0			
Cheese yield, %													
%CY _{CURD}	16.8	16.6	16.3	15.7	15.6	15.1	14.5	19.2***	0.3	0.0			
%CY _{SOLIDS}	9.01	8.41	8.05	7.67	7.50	7.05	6.94	66.0***	3.5	0.3			
%CY _{WATER}	8.13	8.36	8.27	8.08	8.12	7.95	7.79	2.2	1.3	0.3			
Daily yield traits, kg/d													
dCY _{CURD}	0.271	0.280	0.295	0.304	0.275	0.289	0.273	0.0	2.5	0.2			
dCY _{SOLIDS}	0.142	0.140	0.143	0.146	0.129	0.129	0.129	2.2	0.7	0.9			
dCY _{WATER}	0.136	0.142	0.153	0.159	0.147	0.156	0.153	1.4	1.7	0.4			

¹Milk NaCl content levels were classed on the basis of variable distribution: each class explains 0.5 SD of the variable; the fourth class is centered on the mean value; and the first and seventh classes represent the tails of the distribution.

²%REC_{PROTEIN} = percent protein recovery; %REC_{FAT} = percent fat recovery; %REC_{SOLIDS} = percent solids recovery; %REC_{ENERGY} = percent energy recovery. %CY_{CURD} = percent curd yield; %CY_{SOLIDS} = percent solids yield; %CY_{WATER} = percent water yield. dCY_{CURD} = curd yield; dCY_{SOLIDS} = solids yield; dCY_{WATER} = water yield.

* $P < 0.05$; *** $P < 0.001$.

trations are associated with longer curd-firming time, lower curd firmness, and lower levels of syneresis.

CONCLUSIONS

Results of this study will improve knowledge about the effects of indirect udder health indicators in milk on the recovery of nutrients in the curd, cheese yield traits, and daily cheese yields of goats. High values of milk lactose were associated with decreased nutrients recovery and reduced %CY_{SOLIDS}. This finding could be attributable to the reduced fat and protein contents of milk samples rich in lactose. Unlike bovine milk, goat milk samples characterized by high values of pH were associated with higher recovery of nutrients in the curd and higher cheese yield traits. Also contrary to results of bovine studies, high SCS in goat milk was associated with greater recovery of solids and energy in the curd. This finding may be attributable to the greater recovery of lactose in the curd and the positive correlations between SCS and milk fat, protein, and casein. Among the effects investigated in the present study, LBC was the least important factor affecting cheese-making traits. The significant influence of NaCl on milk composition and coagulation explained the poorer recovery of all nutrients in the curd during cheese-making process. The significant changes in milk composition associated with increases in NaCl concentration probably led to lower values of cheese yield and cheese solids for milk samples characterized by high NaCl levels. Further studies are needed to investigate effects of indirect udder health predictors on cheese-making traits and efficiency in goat milk. As the indirect indicators in the present study exhibited high importance in the cheese-making process, such information could be used to adjust the milk-to-cheese economic value and milk payment systems.

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