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Effect of goat milk composition on cheesemaking traits and daily cheese production

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ABSTRACT

Cheese yield is strongly influenced by the composition of milk, especially fat and protein contents, and by the efficiency of the recovery of each milk component in the curd. The real effect of milk composition on cheesemaking ability of goat milk is still unknown. The aims of this study were to quantify the effects of milk composition; namely, fat, protein, and casein contents, on milk nutrient recovery in the curd, cheese yield, and average daily yield. Individual milk samples were collected from 560 goats of 6 different breeds. Each sample was analyzed in duplicate using the 9-laboratory milk cheesemaking assessment, a laboratory method that mimicked cheesemaking procedures, with milk heating, rennet addition, coagulation, curd cutting, and draining. Data were submitted to statistical analysis; results showed that the increase of milk fat content was associated with a large improvement of cheese yield because of the higher recovery of all milk nutrients in the curd, and thus a higher individual daily cheese yield. The increase of milk protein content affected the recovery of fat, total solids, and energy in the curd. Casein number, calculated as casein-to-protein ratio, did not affect protein recovery but strongly influenced the recovery of fat, showing a curvilinear pattern and the most favorable data for the intermediate values of casein number. In conclusion, increased fat and protein contents in the milk had an effect on cheese yield not only for the greater quantity of nutrients available but also for the improved efficiency of the recovery in the curd of all nutrients. These results are useful to improve knowledge on cheesemaking processes in the caprine dairy industry.

Key words: fat recovery, protein recovery, caprine cheese, casein number, cheese yield

INTRODUCTION

The main use of goat milk is cheesemaking (Boyazoglu and Morand-Fehr, 2001), and both cheese yield (**%CY**) and daily cheese yield (**dCY**) are the final economic target of many dairy goat farmers. In particular, the assessment or prediction of %CY and dCY of individual goats is an important topic in studies regarding the existence of a genetic basis for those traits (Othmane et al., 2002) and in crossbreeding programs. It is recognized that the breed has a large effect on bovine %CY traits (Verdier-Metz et al., 1995). In goat, %CY shows a large variability according to the breed and the individual animal (Vacca et al., 2018a); however, the large %CY variability among breeds and animals within the same breed is also attributable to the differences in milk yield and composition, mainly to fat and protein contents (Banks and Tamime, 1987; Kalantzopoulos, 1993; Verdier-Metz et al., 2001). In addition, the recovery of each milk component in the curd (**%REC**; Stocco et al., 2018a) is an important aspect to achieve overall efficiency of cheesemaking. Milk fat and protein contents are considered in formulas to predict cheese yield (Emmons and Modler, 2010). Those formulas often assume a constant %REC of fat and protein, because the predicted %CY is proportional to the amount of fat and protein available, and do not take into account the complex relationships between milk composition and cheesemaking efficiency.

In a study by Vacca et al. (2018a), the overall effect of breed on cheesemaking traits was split into direct effects of breed (independent from milk yield and composition) and indirect effects of breed (mediated by milk yield and composition). Those results show that a large proportion of the total breed variance is attributable to milk yield and composition, and prove that a deeper investigation about the real effect of milk composition on cheesemaking ability of goat milk is needed.

During recent decades, the replacement of local goat breeds with specialized breeds has led to an increase in total milk yield and a decrease in milk fat and protein contents and coagulation ability (Boyazoglu and Mo-

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rand-Fehr, 2001). Large differences have been observed among goat breeds in terms of milk composition (Sung et al., 1999; Goetsch et al., 2011; Lôbo et al., 2017), coagulation ability (Clark and Sherbon, 2000; Pazzola et al., 2018; Vacca et al., 2018b), and cheesemaking efficiency (Soryal et al., 2005). Milk composition significantly influences yield and sensory quality of cheese, and results from the literature regarding dairy cows cannot be adapted to goats. Large differences exist among species with regard to coagulation properties, curd firming and syneresis (Bittante et al., 2012), and, as a consequence, recovery of milk nutrients in the curd and cheese yield. Hence, it is important for goat farmers and the caprine cheese industry to understand the effect of milk components, in particular fat and protein, on cheesemaking ability. The available literature is mainly focused on the effect of milk composition on measured fresh cheese (Guo et al., 2004) or predicted fresh cheese (Zeng et al., 2007). Investigations of the effects of milk traits on TS and moisture retained in cheese, the efficiency of recovery of milk nutrients in the curd, and the average daily production of cheese per goat are still lacking.

For these reasons, the present research was carried out to quantify the effect of milk fat, protein, and casein number, calculated as casein-to-protein ratio, on (1) recovery of milk nutrients in the curd, (2) measured cheese yields, and (3) daily cheese yields per goat.

MATERIALS AND METHODS

Milk Sampling and Analyses

Five hundred and sixty 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) were sampled. All goats were milked twice a day in the morning (at about 0600 h) and afternoon (at about 1700 h). For the present study, goats were sampled once (1 sampling day for each farm) during afternoon milking for milk composition and cheesemaking analyses. This study is a part of a larger project on the comparison of milk and cheesemaking traits from the 6 goat breeds, which also describes farm characteristics (Vacca et al., 2018a). Briefly, farms were classified on the basis of type of management and flock size. Three management types were considered: traditional (extensive system with free grazing of natural pastures, seasonal milk production, family operated); intermediate (semi-extensive system, cultivated grasslands, and control of estrus and kidding season); and 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). With regard to flock size, farms were classified as small (<100 producing goats), medium-sized (100–200), and large (>200). With regard to breed, Saanen goats (n = 99) were characterized by parity at 3.3 ± 1.7 (means ± SD) and DIM at 109 ± 72; Camosciata delle Alpi goats (n = 98) were characterized by 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 Saanen and Camosciata delle Alpi, at 3.0 ± 1.4 and 129 ± 38 DIM; Maltese goats (n = 104) were characterized by parity at 3.8 ± 1.7, and DIM at 129 ± 49; and the Sarda (n = 86) and Sarda Primitiva (n = 84), local breeds from the island of Sardinia (Italy), had parity at 4.7 ± 2.0 and 5.1 ± 2.5, and DIM at 129 ± 36 and 124 ± 40 DIM, respectively.

Milk fat and protein were analyzed using a MilkoScan FT6000 milk analyzer (Foss Electric A/S, Hillerød, Denmark), calibrated according to FIL-IDF recommendations (ISO 9622:2013; ISO-IDF, 2013). Casein number was calculated as the casein-to-protein ratio and multiplied by 100. Daily milk yield (kg/d) was calculated as the sum of morning plus afternoon milking yields.

Individual Cheesemaking Procedure

The laboratory milk cheesemaking assessment (9-MilCA) procedure proposed by Cipolat-Gotet et al. (2016) was used to measure individual %CY and %REC traits. The laboratory cheesemaking assessment procedure was performed with 2 replicates per each animal (2 aliquots of 9 mL of the same milk sample), for a total of 1,120 observations. Each milk replicate was poured into a glass tube and inserted into the modified rack of the lactodynamograph instrument (Formagraph, Foss Italia S.P.A., Padova, Italy). Samples were heated to 35°C for 15 min and mixed with 0.2 mL of a rennet solution [Hansen Standard 215 (Pacovis Amrein AG, Bern, Switzerland), 80 ± 5% chymosin and 20 ± 5% pepsin; diluted to 1.2% (wt/vol) in distilled water; 0.0513 international milk clotting units/mL of milk]. The sample rack was transferred to the lactodynamograph for a 30-min test at 35°C. At the end of the analysis, coagulated milk samples were manually cut and moved to a heater at 55°C for the curd-cooking phase, which lasted 30 min. Fifteen minutes after the beginning of the cooking phase, each sample was subjected to a further manual cutting by the same operator. At the end of the cooking phase, each glass tube was removed from the sample rack and the curd was separated from the whey. Separation was performed at room temperature using a conical funnel containing a concave metallic net. The curd was gently pressed on the net by using a stainless steel spatula and drained on the net for 15 min. Whey was collected in the underlying plastic tube. The obtained curd and whey were weighed using a precision scale. Whey composition was assessed by using an infrared spectrophotometer (MilkoScan FT2, Foss Electric). The composition of the curd was calculated by subtracting the weight of the nutrient in the whey from the weight of the corresponding nutrient in the processed milk. The %CY traits were $\%CY_{CURD}$, $\%CY_{SOLIDS}$, and $\%CY_{WATER}$, calculated as the ratio of the weight (g) of fresh curd, curd DM, and water retained in curd, respectively, to the weight of the processed milk (g), and multiplied by 100. Daily cheese yields (dCY_{CURD}, dCY_{SOLIDS}, and dCY_{WATER}; kg/d) were calculated by multiplying the %CY ($\%CY_{CURD}$, $\%CY_{SOLIDS}$, and $\%CY_{WATER}$, respectively) by the daily milk yield of the individual animal. The %REC traits were $\%REC_{PROTEIN}$, $\%REC_{FAT}$, and $\%REC_{SOLIDS}$, calculated as the ratio of the weight (g) of the curd components (protein, fat, and DM, respectively) to the same component of processed milk (g) 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 megajoules per kilogram, and multiplied by 100.

Statistical Analysis

Data were analyzed using a MIXED procedure (version 9.4, SAS Institute Inc., Cary, NC), according to the model

$$Y_{efghijklmn} = \mu + DIM_e + Parity_f + Fat_g + Protein_h + Casein\ number_i + Farm_j + Breed_k + Animal_l + Glass\ Tube_m + e_{efghijklmn}, \quad [1]$$

where $Y_{efghijklmn}$ is the observed trait; μ is the overall intercept of the model; DIM_e is the fixed effect of the eth class of DIM [e = 1–4; 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 fth parity [f = 1–3; class 1: parity 1 and 2 (193 goats); class 2: parity 3 and 4 (205 goats); class 3: parity ≥5 (162 goats)]; Fat_g is the fixed effect of the gth class of fat percentage (g = 1–7; class 1: <2.77; class 2: 2.77–3.48; class 3: 3.49–4.21; class 4: 4.22–4.95; class 5: 4.96–5.68; class 6: 5.69–6.41; class 7: >6.41); $Protein_h$ is the fixed effect of the hth class of protein percentage (h = 1–7; class 1: <2.91; class 2: 2.91–3.17; class 3: 3.18–3.44; class 4: 3.45–3.72; class 5: 3.73–4.00; class 6: 4.01–4.27; class 7: >4.27); Casein $number_i$ is the fixed effect of the ith class of percentage casein number (i = 1–7; class 1: <74.0; class 2: 74.0–75.6; class 3: 75.7–77.3; class 4: 77.4–79.1; class 5: 79.2–80.8; class 6: 80.9–82.5; class 7: >82.5); $Farm_j$ is the random effect of the jth farm (j = 1–35); $Breed_k$ is the random effect of the kth breed (k = Saanen, Camosciata delle Alpi, Murciano-Granadina, Maltese, Sarda, and Sarda Primitiva); $Animal_l$ is the random effect of the lth animal (l = 1–1,120 observations, 2 replicates for each of the 560 goats); Glass $Tube_m$ is the fixed effect of the mth glass tube of the modified Formagraph instrument (m = 1 to 8); and $e_{efghijklmn}$ is the random residual ~ $N\left(0, \sigma_e^2\right)$, where σ_e^2 is the residual variance. Each of the 7 classes of fat, protein, and casein number was designed on the basis of distribution of the variables: each single class explained 0.5 standard deviations of the variable; the fourth was centered on the mean value and the first and the seventh represented the tails of the distribution. The division into classes was planned both to describe possible nonlinearity of the relationships of fat, protein, and casein number and to collect a sufficient number of observations in each class. All the fixed effects included in the model were tested using the variance of the animal as the error line. Casein content was not included in the model to avoid multicollinearity with protein content. In an exploratory analysis, daily milk yield was included in the model described above; because it was significant only for daily cheese productions, it was not considered in model [1].

Orthogonal polynomial contrasts (linear, quadratic, and cubic pattern) were estimated between least squares means of classes of fat, protein, and casein number. Pearson product-moment correlations were assessed between milk composition and cheesemaking traits.

RESULTS AND DISCUSSION

The effects of farm, breed, parity, and DIM were presented and discussed in detail in a previous paper (Vacca et al., 2018a), and results are only summarized in this section.

ANOVA

Descriptive statistics (mean and SD) of milk fat, protein, and casein number are reported in Table 1, together with Pearson product-moment correlation between these milk traits and %REC, %CY, and dCY.

The effects of the different milk traits affecting cheesemaking efficiency are often similar because those traits, mainly fat and protein, are correlated with each

Table 1. Descriptive statistics (mean and SD) and Pearson product-moment correlations between individual milk fat, protein, and casein numbers and nutrient recovery, cheese yield, and daily yield traits of goat milk samples

Item	Mean	SD	Fat, %	Protein, %	Casein number,[1] %
Mean			4.61	3.64	78
SD			1.47	0.60	2.95
Nutrient recovery, %					
Fat	80.86	5.84	0.38***	0.46***	0.33***
Protein	81.63	2.51	0.33***	0.16***	0.13*
DM	55.75	5.54	0.81***	0.69***	0.44***
Energy	66.40	5.49	0.74***	0.63***	0.45***
Cheese yield, %					
Curd	15.73	2.83	0.76***	0.60***	0.46***
DM	7.74	1.76	0.50***	0.78***	0.60***
Water	7.97	1.49	0.39***	0.35***	0.22***
Daily yield,[2] kg/d					
Curd	0.29	0.15	−0.27***	−0.40***	−0.30***
DM	0.14	0.07	−0.17***	−0.32***	−0.23***
Water	0.15	0.08	−0.35***	−0.45***	−0.34***

[1]Casein number = casein to protein ratio, multiplied by 100.

[2]Obtained by multiplying the cheese yield of curd, DM, and water by the daily milk yield of the individual animal.

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

other. In our study, the concurrent effects of all the major sources of variation (i.e., herds, breeds, parity, lactation stage, and milk composition) were included in the model to obtain a clearer picture of individual factors affecting cheesemaking efficiency. The ANOVA for %REC, %CY, and daily yield traits are summarized in Table 2. Among the random effects, the individual animal was the main factor explaining the variability for %REC (from 66–80%) and %CY traits (from 42.2–74.8%), whereas farm (from 37.7–40.5%) was the factor with the most important effect on dCY traits.

Contribution of Fat

High concentrations of milk fat (Table 3) were associated with higher recovery of nutrients in the curd (3.1, 3.8, 13.4, and 12.4% from the lowest to the highest class, respectively, for $\%REC_{FAT}$, $\%REC_{PROTEIN}$,

Table 2. The ANOVA for nutrients recovery, cheese yields, and daily yield traits of milk samples from individual goats (n = 1,120) of 6 breeds, with *F*-value and significance for fixed effects and the proportion of variance (in percentage) explained by random effects

	Fixed effects (*F*-value)						Random effects (% on total variance)			
Trait	DIM	Parity	Fat	Protein	Casein number[1]	Glass tube[2]	Farm	Breed	Animal	RMSE[3]
Nutrient recovery, %										
Fat	1.9	1.1	1.6	7.2***	4.6***	9.3***	13.9	12.4	73.3	0.4
Protein	2.5	7.3***	10.4***	1.6	0.9	1.4	9.2	7.4	80.0	0.5
DM	2.6*	2.0	70.5***	21.8***	4.1***	1.5	12.1	8.6	66.0	1.1
Energy	0.4	1.0	45.4***	8.5***	2.8*	1.5	9.6	13.8	72.0	0.8
Cheese yield, %										
Curd	0.3	1.6	36.6***	4.1***	1.5	0.7	13.7	5.9	61.8	0.9
DM	0.7	1.1	265.7***	43.7***	1.4	1.2	9.1	6.8	74.8	0.2
Water	0.4	0.8	5.2***	1.7	1.2	1.2	25.4	4.3	42.2	0.8
Daily yield,[4] kg/d										
Curd	1.9	3.0	5.5***	3.0**	1.5	1.0	38.5	23.6	35.9	0.0
DM	1.8	2.8	17.6***	2.2*	1.2	1.7	37.7	27.6	34.4	0.0
Water	2.1	3.5	2.0	3.3**	1.2	1.3	40.5	21.0	33.3	0.0

[1]Casein number = casein to protein ratio, multiplied by 100.

[2]Glass tube of the modified Formagraph instrument.

[3]RMSE = root means square error.

[4]Obtained by multiplying the cheese yield of curd, DM, and water by the daily milk yield of the individual animal.

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

%REC$_{SOLIDS}$, and %REC$_{ENERGY}$; data not shown in tables), higher %CY traits (6.5, 4.5, and 1.6%, respectively, for %CY$_{CURD}$, %CY$_{SOLIDS}$, and %CY$_{WATER}$; data not shown in tables), and higher dCY traits (0.12, 0.07, and 0.03 kg/d, respectively, for dCY$_{CURD}$, dCY$_{SOLIDS}$, and dCY$_{WATER}$; data not shown in tables). As expected, milk fat content was related to %CY$_{CURD}$. Indeed, fat is one of the main components of cheese and it is included in all formulas predicting cheese yield (Emmons and Modler, 2010). However, formulas to predict %CY, which are useful for bovine milk, are generally based on the linear relationships between milk composition and cheese yield. However, those formulas do not take into account the specificity of goat milk coagulation, curd firming and syneresis processes, interactions, and the possible nonlinearity of relationships among milk traits.

In a study on the relationship between %CY and goat milk composition, Guo et al. (2004) reported a strong relationship (r = 0.75) between the 2 traits and suggested that fat content could be used as a reliable predictor of %CY of Chevre fresh cheese. In addition, Zeng et al. (2007) found similar results (r = 0.81) in fresh goat cheese, but not in semihard and hard cheeses.

Results from Table 3 show that the positive effect of milk fat content on cheese yield also depended on the linear improvement of the fat recovery rate in the curd. No study on the effects of milk nutrient contents on their recovery rate in the curd and on related cheesemaking traits is available in the literature for goat milk. The explanation of this effect was attributable to milk coagulation and curd-firming processes. A previous paper by Stocco et al. (2018b), on the effect of milk fat, protein, and casein contents on coagulation ability of goat milk, showed that milk samples with high content of fat are characterized by better coagulation traits; namely, shorter coagulation time, higher curd-firming rate, and earlier attainment of maximum firmness of the curd.

More information is available on dairy cattle than on goats. In Cheddar cheese, Fenelon and Guinee (1999) found that the recovery of fat increased significantly from 80.84 to 89.48% when milk fat content increased from 0.54 to 2.00%, but it slightly decreased when milk fat was further increased to 3.30% (%REC$_{FAT}$ = 87.84%). In goats, %REC$_{FAT}$ increased linearly (Supplemental Figure S1; https://doi.org/10.3168/jds.2018-15397) across all classes of milk fat. The differences between the 2 species could be due to differences in the size of milk fat globules and the tendency of fat globules to aggregate into clusters (Guinee and McSweeney, 2006).

The higher milk fat content was also associated with higher values of recovery of milk protein, TS, energy, and water in curd (Table 3). In bovine milk, fat glob-

Table 3. Effect of fat (LSM and *F*-values of contrasts) on nutrients recovery, cheese yield, and daily yield traits of milk samples from individual goats (n = 1,120)

	Fat, %							Contrast, *F*-value, and significance		
Item	<2.77	2.77–3.48	3.49–4.21	4.22–4.95	4.96–5.68	5.69–6.41	>6.41	Linear	Quadratic	Cubic
Goats, no.	56	186	308	202	144	84	140			
Nutrient recovery, %										
Fat	78.64	79.64	79.75	80.39	79.52	80.84	81.70	4.0*	0.12	1.44
Protein	78.98	80.53	81.33	81.79	82.00	82.43	82.76	38.2***	7.2**	2.37
DM	48.90	51.89	54.28	56.01	57.52	59.78	62.26	384.3***	0.87	5.8*
Energy	59.43	62.77	64.64	66.89	67.34	69.81	71.87	217.9***	2.36	5.7*
Cheese yield, %										
Curd	13.00	13.93	14.50	15.42	16.69	17.69	19.52	201.0***	7.6**	0.8
DM	5.72	6.49	7.14	7.79	8.41	9.09	10.26	1,459.5***	10.3**	16.6***
Water	7.41	7.72	7.60	7.88	8.30	8.43	9.03	23.1***	2.48	0.24
Daily yield,[1] kg/d										
Curd	0.20	0.27	0.27	0.29	0.30	0.29	0.32	13.7***	5.4*	4.31
DM	0.09	0.12	0.13	0.15	0.15	0.14	0.16	30.5***	12.8***	4.7*
Water	0.12	0.15	0.14	0.15	0.15	0.14	0.15	2.43	2.72	3.57

[1]Obtained by multiplying the cheese yield of curd, DM, and water by the daily milk yield of the individual animal.

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

ules represent a physical limit for the contraction of the para-casein network, and they therefore reduce the extent of syneresis (Guinee and McSweeney, 2006). On the contrary, in goat milk, fat does not affect the extent of syneresis (Stocco et al., 2018b). In the present study, the comparison of samples from the lowest and the highest class of milk fat (Table 3) showed an increased $\%CY_{WATER}$ (from 7.41 to 9.03%) and an almost 2-fold increase of $\%CY_{SOLIDS}$ (from 5.72 to 10.26%). Given that this effect was also found for daily yield traits, it could be speculated that the positive contribution of fat to %CY was directly mediated by the fat content rather than by water.

The study by Fox et al. (2017), dealing with the processing of Cheddar cheese, elucidated the complex relationships among milk constituents in the bovine species. Fat, casein, and casein-to-fat ratio are the main traits affecting cheese yield, as caseins create the continuous para-casein network occluding fat and water but fat has limited ability in holding water. Hence, a high casein-to-fat ratio is associated with a higher percentage of moisture trapped in the casein network. Moisture contributes to cheese yield directly and indirectly because of dissolved solids (i.e., whey proteins and soluble milk salts).

Contribution of Protein

Milk samples from the lowest to the highest class of protein content (Table 4) showed an increased $\%REC_{FAT}$ (7.3%), $\%REC_{SOLIDS}$ (7.8%), and $\%REC_{ENERGY}$ (5.8%; data not shown in tables). The effect was also positive on all %CY traits (2.2, 1.9, and 0.9%, respectively, for $\%CY_{CURD}$, $\%CY_{SOLIDS}$, and $\%CY_{WATER}$; data not shown in tables). These results were expected because, similar to fat, milk protein is a major component of cheese and it is correlated with %CY traits (Guo et al., 2004; Zeng et al., 2007).

Different from fat, the effect of milk protein content on $\%REC_{PROTEIN}$ across classes of milk protein (Table 4) was not significant. It should be considered that the statistical model also included the effect of casein number, so the effect of total protein was corrected for the ratio between caseins and whey proteins, which was supposed to be one of the main factors affecting quality of milk protein.

Milk protein content significantly affected $\%REC_{FAT}$, $\%REC_{SOLIDS}$, and $\%REC_{ENERGY}$, with a linear trend (Supplemental Figure S2; https://doi.org/10.3168/jds.2018-15397). As previously reported for the contribution of fat, the significant linear association found between protein content and $\%REC_{FAT}$ (Table 4) is attributable to the network of casein entrapping milk fat, which is then recovered in the curd. It worth noting

Table 4. Effect of protein (LSM and *F*-values of contrasts) on nutrients recovery (%REC), cheese yields (%CY) daily yield traits of milk samples from individual goats (n = 1,120)

Item	Protein, %							Contrast, *F*-value, and significance		
	<2.91	2.91–3.17	3.18–3.44	3.45–3.72	3.73–4.00	4.01–4.27	>4.27	Linear	Quadratic	Cubic
Goats, no.	84	188	236	214	166	98	134			
Nutrient recovery, %										
Fat	75.93	77.83	80.66	79.36	81.18	82.28	83.23	24.4***	1.04	2.02
Protein	81.20	81.82	81.36	81.94	81.57	80.98	80.96	0.6	3.35	0.28
DM	51.63	53.39	54.77	56.45	57.05	57.92	59.42	122.0***	2.98	1.44
Energy	63.03	63.95	65.69	66.28	67.23	67.76	68.82	45.4***	1.1	0.18
Cheese yield, %										
Curd	14.91	15.10	15.56	15.71	16.15	16.24	17.08	19.2***	0.68	0.63
DM	6.97	7.22	7.51	7.86	8.10	8.34	8.89	235.5***	2.77	1.92
Water	7.67	7.77	8.00	7.95	8.13	8.26	8.60	7.0**	0.49	0.61
Daily yield,[1] kg/d										
Curd	0.32	0.29	0.31	0.28	0.25	0.25	0.24	11.0**	0.15	0.84
DM	0.14	0.14	0.15	0.14	0.12	0.13	0.12	3.75	0.2	1.15
Water	0.17	0.16	0.16	0.14	0.13	0.13	0.13	11.8***	0.97	1.33

[1]Obtained by multiplying the cheese yield of curd, DM, and water by the daily milk yield of the individual animal.

$^{**}P < 0.01$; $^{***}P < 0.001$.

that $\%REC_{FAT}$ was greatly improved by increasing milk protein content (*F*-value of linear contrast at 24.4, $P < 0.001$; Table 4) than by increasing milk fat content (*F*-value of linear contrast at 4.0, $P < 0.05$; Table 3). The effect of protein on $\%REC_{FAT}$ was expected to be favorable, especially in goats, because fat globules in goat milk are smaller than those in bovine (Michalski et al., 2003), and smaller globules appear to be better retained in thicker casein network.

Even if the higher $\%CY_{WATER}$ was associated with an augmented $\%CY_{CURD}$, the linear increase of $\%CY_{WATER}$ could be not considered a positive finding because an excess of water in the curd generally leads to a worsening of cheese quality during ripening, with a final depreciation of the product (Martin et al., 1997). Samples with high contents of both fat and protein showed a concurrent increase of $\%CY_{WATER}$ and, in particular, $\%CY_{SOLIDS}$ (Tables 3 and 4); however, the composition of curd changed with different values of moisture percentage for increasing classes of fat and protein. Indeed, if the ratio between $\%CY_{WATER}$ and $\%CY_{SOLIDS}$ was calculated, the value was almost steady from the lowest to the highest class of milk protein content (51.4–50.4, data not shown in tables), whereas it decreased from 57 for fat content <2.77% to 46.3 for fat content >6.41% (data not shown in tables).

Contribution of Casein Number

Casein number, calculated as the proportion of caseins to proteins, was expected to be an important predictor of $\%REC_{PROTEIN}$ because the major part of caseins is normally entrapped in the curd while whey proteins pass that barrier. In the present study, $\%REC_{PROTEIN}$ was not affected by casein number, with a approximately constant value across the different classes of casein number (Table 5). The difference between the values of $\%REC_{PROTEIN}$ and casein number (data not shown in tables) was positive for milk samples from the lowest class of casein number, 7.97, and slightly negative, −1.13, in those from the highest class. This would mean that part of whey proteins were entrapped in the curd in the first case and that some caseins were lost in the second case, as also suggested by the decrease of $\%REC_{SOLIDS}$ in milk samples with greater casein numbers (Table 5). The absence of an effect of casein number on $\%REC_{PROTEIN}$ confirmed the nonsignificant effect observed for protein content on the same trait (Table 4). In accordance with the present study, Zeng et al. (2007) report that a predictive formula including only milk protein is less effective (r = 0.73) than one including only fat (r = 0.81); if protein and fat are included together in the formula, no improvement is recorded (r = 0.81) and the regression coefficient for fat (5.72) is much larger than that for protein (0.29). Moreover, casein is characterized by a negative regression coefficient (−0.65), and the addition of casein does not further improve the accuracy of the predictive formula (r = 0.81) of semihard and hard goat cheeses (Zeng et al., 2007).

Casein number also influenced $\%REC_{FAT}$ and $\%REC_{ENERGY}$ with a curvilinear pattern (Table 5; Supplemental Figure S3; https://doi.org/10.3168/jds.2018-15397).

With regard to coagulation properties of goat milk, Stocco et al. (2018b) reported that high values of casein number (>82%) were associated with a general improvement of coagulation ability of goat milk, but no information is available about the effect of casein number on milk nutrient recovery in goat cheese. Some studies on bovine milk have clarified that, other than the ratio between caseins and whey proteins, the proportions among individual caseins and whey protein fractions also significantly affect both milk coagulation properties (Amalfitano et al., 2019) and cheesemaking efficiency traits (Cipolat-Gotet et al., 2018). Large breed differences in the proportions among individual protein fractions in goat milk have been demonstrated (Moatsou et al., 2008; Thomann et al., 2008), but their effects were only studied in relation to milk coagulation properties (Clark and Sherbon, 2000) and cheese yield (Damián et al., 2008). No information is available on the effects of breed on the recovery of milk nutrients in cheese, and that topic deserves further research for improving the knowledge on the complex relationships between goat milk composition and cheesemaking process.

CONCLUSIONS

The current study allowed us to quantify the effect of the major milk nutrients on nutrient recovery, cheese yield, and daily yield traits of goat milk. In particular, the increase of milk fat improved cheese yield, not only because fat is one of the most important components of cheese, but also because it positively affected its recovery rate and of protein, TS, and energy. Fat also caused a higher retention of water and solids in cheese. Milk protein improved the recovery of nutrients in the curd, particularly fat recovery, with a significant positive contribution to individual %CY and daily yield traits. Contrary to what we expected, casein number slightly affected the recovery rate of protein, whereas it affected to a greater degree the recovery of fat. In conclusion, the present study allowed for a better understanding of the role of fat, protein, and casein number of milk on the productivity and efficiency of dairy goats, but a better definition of cheesemaking efficiency could be

Table 5. Effect of casein number (LSM and *F*-values of contrasts) on nutrient recovery, cheese yields, and daily yield traits of milk samples from individual goats (n = 1,120)

Item	Casein number,[1] %							Contrast, *F*-value, and significance		
	<74.0	74.1–75.6	75.7–77.3	77.4–79.1	79.2–80.8	80.9–82.5	>82.5	Linear	Quadratic	Cubic
Goats, no.	110	120	206	260	168	140	116			
Nutrient recovery, %										
Fat	76.67	79.20	80.70	81.90	82.04	80.29	79.66	3.08	18.9***	0.09
Protein	81.97	81.87	81.13	81.21	81.23	81.06	81.37	1.18	1.94	0.02
DM	56.87	56.91	56.76	56.25	55.65	54.45	53.74	19.3***	5.6*	0.25
Energy	64.98	66.63	66.73	66.95	66.74	65.65	65.09	0.13	13.6***	0.95
Cheese yield, %										
Curd	15.30	16.07	15.77	16.19	15.98	15.69	15.75	0.11	3.14	1.04
DM	7.74	7.85	7.87	7.86	7.84	7.74	7.98	0.58	0.0	5.7*
Water	7.81	8.11	7.85	8.20	8.23	8.25	7.91	0.31	1.75	0.99
Daily yield,[2] kg/d										
Curd	0.28	0.32	0.28	0.28	0.27	0.26	0.26	1.6	0.49	1.92
DM	0.14	0.15	0.14	0.13	0.13	0.13	0.13	2.04	0.0	1.79
Water	0.15	0.16	0.14	0.15	0.14	0.14	0.14	0.94	0.18	0.37

[1]Casein number = casein to protein ratio, multiplied by 100.

[2]Obtained by multiplying the cheese yield of curd, DM, and water by the daily milk yield of the individual animal.

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

achieved in studies by including the effects of individual milk protein fractions and their genetic variants.

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