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Integrating Udder Morphology, Somatic Cell Count and Infrared Thermography to Assess Udder Health in Dairy Goats

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Simple Summary

Understanding udder health is essential for producing high-quality milk and supporting animal welfare in dairy goats. This study examined the relationships among udder conformation, somatic cell count, bacteriological findings, and udder surface temperature in a herd of clinically healthy Saanen goats. Udder and teat characteristics were evaluated, milk samples were collected, and udder surface temperature was measured using an infrared thermal camera. The results showed variation in udder shape, particularly in teat placement. Some udder traits, including stronger fore udder attachment, shorter teats, and a more cylindrical teat shape, which is more suitable for machine milking than funnel-shaped teats, were associated with lower somatic cell counts. Bacteria associated with udder health disorders were detected in a considerable proportion of half-udder milk samples, mainly involving opportunistic bacteria. Udder halves with positive bacteriological findings showed slightly higher surface temperatures than bacteriologically negative udder halves, but udder temperature did not differ clearly among somatic cell count categories. These results suggest that udder conformation assessment, bacteriological examination, somatic cell count, and infrared thermography may provide complementary information on udder health in dairy goats. However, infrared thermography should be considered a supportive monitoring tool rather than a stand-alone diagnostic method, and its results should be interpreted under standardized environmental conditions, including ambient temperature, humidity, airflow, animal positioning, and image acquisition settings.

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Abstract

Maintaining udder health and milk quality is important in dairy goat production; however, the interpretation of somatic cell count (SCC) in goats is complicated by physiological and non-infectious factors. This study evaluated the associations among udder and teat morphological traits, SCC, bacteriological status, and udder surface temperature in clinically healthy Saanen dairy goats. Udder conformation was assessed using a linear scoring system in multiparous goats (n = 70). Composite milk samples were collected at three lactation stages for SCC and milk quality analysis, whereas separate half-udder milk samples were used for bacteriological examination. Udder surface temperature was measured using infrared thermography (IRT) at the final sampling time point. Stepwise multiple regression

analysis was applied to identify udder and teat traits associated with log-transformed SCC. The results showed considerable variation in udder conformation, with the greatest deviations observed for teat placement. Fore udder attachment, udder cleft, teat length, and teat form were significantly associated with SCC, with stronger attachment, a more distinct udder cleft, shorter teats, and a more cylindrical teat shape being associated with lower SCC. Bacteriological examination detected mastitis-associated bacteria in 45.0% of half-udder samples, mainly coagulase-negative *Staphylococcus* spp. and *Corynebacterium* spp., while the proportion of obligate udder pathogens was highest in the >2,000,000 cells/mL SCC category. Bacteriologically positive udder halves showed slightly higher surface temperatures than bacteriologically negative udder halves ($p < 0.05$), whereas no significant differences in udder surface temperature were observed among SCC categories. These findings suggest that udder morphology is associated with SCC and may be useful in phenotypic udder health assessment. IRT may provide complementary information on bacteriological status under standardized conditions, but its diagnostic value in dairy goats requires further validation in larger, longitudinal studies.

Keywords: dairy goat; udder morphology; somatic cell count; infrared thermography; mastitis

1. Introduction

In recent decades, dairy goat production has become a rapidly developing sector of livestock farming, driven by increasing demand for goat milk and goat milk products [1]. In this context, raw milk quality is important not only for farm profitability but also for food safety, processing suitability, and consumer acceptance. Key milk quality parameters include milk fat, protein, lactose, somatic cell count (SCC), and total bacterial count, because these traits influence technological properties such as coagulation, cheese yield, shelf life, and the hygienic quality of dairy products [2–4].

Udder health is a central determinant of milk quality in dairy goats. Mastitis, particularly subclinical mastitis, may reduce milk yield and alter milk composition without visible clinical signs, thereby creating diagnostic and economic challenges in routine herd management [5–7]. In dairy cows, SCC is widely used as a routine reference indicator of subclinical mastitis and milk quality. In goats, however, SCC interpretation is more complex because physiological factors, including apocrine milk secretion, stage of lactation, parity, stress, milking interval, and environmental conditions, can contribute to naturally higher SCC values even in the absence of bacteriologically confirmed infection [6–8]. In goats free of bacteriologically confirmed intramammary infection, milk SCC has been reported to range from 270×10^3 to 2000×10^3 cells/mL [9]. Thresholds used to detect intramammary infections in goats are commonly reported between 500×10^3 and 1000×10^3 cells/mL, although proposed cut-off values may vary among studies [10–13]. Therefore, SCC remains a useful but not fully specific indicator of udder health in dairy goats.

Caprine mastitis is most commonly associated with opportunistic pathogens, including coagulase-negative *Staphylococcus* spp. and *Corynebacterium* spp., whereas major pathogens such as *Staphylococcus aureus*, *Streptococcus uberis*, *Streptococcus dysgalactiae*, *Escherichia coli*, and *Trueperella pyogenes* occur less frequently but may have greater clinical and economic consequences [6,14–16]. Because subclinical infections can occur without visible udder abnormalities or abnormal milk appearance, early detection usually requires the combined interpretation of clinical observation, SCC, bacteriological culture, and complementary indicators.

In addition to management and health-related factors, udder and teat morphology are important determinants of milking efficiency, udder hygiene, and susceptibility to

udder health disorders in dairy goats [16,17]. Linear udder scoring systems in goats are conceptually similar to those used in dairy cattle, but goat-specific evaluation is required because udder shape, teat orientation, and machine milking interactions differ between species. Traits such as udder attachment, udder cleft, udder depth, teat placement, teat length, and teat form influence cluster attachment, vacuum distribution, teat-end stress, milk flow dynamics, and the risk of environmental contamination during milking [16–21].

Previous studies have shown that several udder and teat traits are associated with SCC in dairy goats [20–23]. Stronger udder attachment, a more clearly defined udder cleft, and more favourable teat dimensions may reduce mechanical stress and improve milking unit alignment, whereas poorly positioned or excessively long and funnel-shaped teats may increase the likelihood of incomplete milking, liner slip, teat-end irritation, and bacterial entry through the teat canal [18–20,24]. Udder and teat morphological traits also show moderate-to-high heritability in several populations, indicating that they may be relevant for selection; however, phenotypic associations should be interpreted cautiously when no genetic analysis is performed [25–28].

Infrared thermography (IRT) has become an increasingly used non-invasive tool for assessing physiological and pathological processes in animals, including heat stress, metabolic disorders, and inflammatory conditions [29–37]. During mammary inflammation, local changes in blood flow, vascular permeability, and tissue metabolism may increase udder surface temperature [38–40]. Nevertheless, udder surface temperature is also affected by species-specific thermoregulation and udder vascularization, as well as ambient temperature, humidity, airflow, housing conditions, milking time, udder contamination, and image acquisition settings [35–37,41]. These factors are particularly important when interpreting small temperature differences in clinically healthy animals.

Although IRT has been widely investigated for mastitis-related applications in dairy cattle [39–43], fewer studies have evaluated its use in dairy goats [38,41]. In goats, the diagnostic value of IRT may differ from that observed in cattle because SCC values are physiologically more variable and subclinical udder health disorders may not always produce marked thermal changes. Consequently, the sensitivity of IRT may be limited in subclinical conditions, where inflammatory responses are mild and changes in udder surface temperature may be small or inconsistent [6–9,41,44]. Therefore, IRT should be considered primarily as a complementary monitoring approach for early or subclinical udder health changes rather than as a stand-alone diagnostic test for clinical mastitis.

Despite the available literature on udder morphology, SCC, bacteriological status, and thermographic assessment, limited information is available on the integrated evaluation of these indicators in dairy goats under practical farm conditions. In particular, the combined relationship among udder and teat conformation, SCC, pathogen presence, and udder surface temperature remains insufficiently clarified. Such an integrated approach may improve the interpretation of udder health status in dairy goats, especially because SCC alone may be influenced by both infectious and non-infectious factors.

Based on these considerations, the aim of this study was to investigate the relationships between udder and teat morphological traits and SCC in dairy Saanen goats. A further aim was to evaluate whether udder surface temperature measured by IRT differs according to bacteriological status and SCC category ($<500 \times 10^3$ cells/mL; 500–1000×10^3 cells/mL; 1000–2000×10^3 cells/mL; and $>2000 \times 10^3$ cells/mL). By integrating udder conformation scoring, SCC, bacteriological examination, and thermographic assessment, this study aimed to provide a more comprehensive evaluation of udder health indicators in dairy goats under practical farm conditions.

2. Materials and Methods

2.1. Ethical Approval

This study was conducted in accordance with the institutional guidelines of the Hungarian University of Agriculture and Life Sciences (MATE). This investigation was approved by the Institutional Animal Welfare Committee of MATE Szent István Campus (approval number: MATE-MKK-2020/22).

2.2. Farm, Animals, Housing and Management

This study was conducted at a commercial goat farm in Pest County, Hungary. The investigated animals (n = 70) were multiparous Saanen dairy goats that kidded in March and were milked from 2–3 days after kidding. Goats were of mixed parity (2–6, with fifth and sixth parities combined for statistical analysis) but were in the same lactation stage. Only clinically healthy animals were included in this study. Clinical udder health was assessed by visual inspection and palpation of the udder before sampling. Animals showing swelling, heat, redness, pain, or abnormal milk secretion were not included. No abnormalities in milk appearance were observed after discarding the first streams of milk. No California Mastitis Test or additional veterinary examination was performed, as none of the animals showed clinical signs of mastitis.

Animals were housed in a deep-litter barn and fed ad libitum alfalfa hay (NEL: 4.74 MJ/kg DM; crude protein: 183 g/kg DM), supplemented with a commercial dairy goat concentrate (NEL: 7.1 MJ/kg DM; crude protein: 180 g/kg DM) at 350 g/animal/day plus barley (NEL: 8.4 MJ/kg DM; crude protein: 118 g/kg DM) at 800 g/animal/day. Milking was performed twice daily in a Milkplan 2 × 12 milking parlour (vacuum: 48 kPa; pulsation ratio: 60:40; pulsation rate: 90 min^{-1}).

2.3. Udder and Teat Conformation Scoring

The udder conformation of goats was scored prior to afternoon milking at DIM 56 using a 1–9 linear scoring scale based on the guidelines of the International Committee for Animal Recording (ICAR) [45]. The following traits were assessed: udder depth, fore udder attachment, udder suspension/central ligament, rear udder width, rear udder height, teat placement in rear view, teat placement in side view, teat length, and teat shape.

All udder and teat traits were evaluated by one trained evaluator using the same scoring criteria throughout this study. The evaluator was familiar with the ICAR linear scoring system for dairy goats. Scoring was performed before milking to minimize the influence of udder emptying on udder conformation traits. When uncertainty occurred during scoring, the final score was assigned after repeated visual inspection of the trait. This approach was applied to reduce within-herd scoring inconsistency.

2.4. Milk Sample Collection and Handling

Milk samples were collected on three occasions during evening milking, corresponding to early, mid, and late lactation stages (DIM 56, 118, and 196). Before sample collection, the first streams of milk were discarded. Composite milk samples were collected from both udder halves into sterile 50 mL containers without preservatives for milk composition and SCC analyses. In addition, separate 10 mL aseptic milk samples were collected from each udder half without preservatives for bacteriological examination.

Before bacteriological sampling, teat ends were cleaned and disinfected with disinfectant wipes. Milk samples were then collected into sterile tubes while avoiding contact with the teat end or external surfaces. All samples were immediately placed in an insulated box containing cooling blocks and transported to the laboratory within a maximum of 3 h after collection. Samples were kept refrigerated during transport.

After arrival at the laboratory, milk samples intended for milk composition, SCC, and bacteriological analyses were stored at 4 °C and analysed within 24 h.

2.5. Milk Composition, SCC and Bacteriological Analysis

Milk samples were analysed for milk fat, protein, lactose, and somatic cell count. Milk composition was determined using a LactoScope™ analyser (Delta Instruments Ltd., Drachten, The Netherlands). Somatic cell count was measured using a fluorescence-based optoelectronic instrument (Bentley FCM; ÁT Ltd., Gödöllő, Hungary).

Composite 50 mL milk samples were used for milk composition and SCC analyses, whereas separate 10 mL milk samples collected from the left and right udder halves were used for bacteriological examination. Bacteriological analysis targeted mastitis-associated bacteria, including coagulase-negative *Staphylococcus* spp. (CNS), *Corynebacterium* spp., *Staphylococcus aureus*, *Streptococcus uberis*, *Streptococcus dysgalactiae*, *Escherichia coli*, and *Trueperella pyogenes*. For interpretation, coagulase-negative *Staphylococcus* spp. and *Corynebacterium* spp. were classified as opportunistic/facultative udder pathogens, whereas *Staphylococcus aureus*, *Streptococcus uberis*, *Streptococcus dysgalactiae*, *Escherichia coli*, and *Trueperella pyogenes* were classified as major udder pathogens because these bacteria are more consistently associated with clinically relevant intramammary infections and inflammatory responses in small ruminants [6,14–16].

For bacteriological culture, 0.1 mL of milk was inoculated onto Columbia esculin blood agar (Biolab Inc., Budapest, Hungary) supplemented with 5% sheep blood and 0.5% esculin. Plates were incubated aerobically at 37 °C for 48 h. Bacterial isolates were identified using standard microbiological procedures, including Gram staining, colony morphology, haemolytic activity, and other phenotypic characteristics, in accordance with the guidelines of the National Mastitis Council [46].

Samples were considered bacteriologically positive when growth of mastitis-associated bacterial colonies was detected. Samples with growth of more than two morphologically distinct colony types without a predominant mastitis-associated pathogen were considered contaminated and were excluded from bacteriological interpretation. When two mastitis-associated bacterial species were detected together, the sample was classified as a mixed infection and interpreted separately where appropriate.

2.6. Infrared Thermography

Udder surface temperature was evaluated on the last day of milk sample collection (DIM 196), before evening milking, in the closed milking parlour. Measurements were performed before milking in order to minimize the influence of milking-related changes in udder blood flow and surface temperature. Direct sunlight was avoided during image acquisition. Although airflow was not quantitatively measured, no detectable air movement was observed in the milking parlour during thermographic recording.

Ambient temperature and relative humidity in the milking parlour were recorded using a commercial thermo-hygrometer (Kerbl, Buchbach, Germany). During thermographic measurements, ambient temperature was 24 °C and relative humidity was 58%.

Thermal images were obtained using a Uni-T Pro thermal imager (UTi260A, Uni-Trend Technology Co., Dongguan, China). Images were captured separately from the left and right udder halves from the rear aspect of the udder at a distance of approximately 0.75 m. During image acquisition, a constant distance, perpendicular camera position, and similar animal positioning were maintained to improve measurement consistency.

For image evaluation, the central area of each udder half was selected as the region of interest (ROI). The mean surface temperature within the ROI was recorded separately for the left and right udder halves, and the mean udder surface temperature was calculated

for each animal. Areas visibly contaminated with dirt, bedding material, or milk residues were avoided during ROI selection where possible. Thermographic images were evaluated using the camera's built-in analysis software. The emissivity setting was set to 0.98, which is commonly used for biological tissues. No additional image post-processing was applied.

Because thermographic measurements were performed at a single time point, corresponding to DIM 196, the results were interpreted as cross-sectional surface temperature measurements rather than longitudinal thermographic monitoring.

2.7. Somatic Cell Count Categories

Goats were classified into four SCC categories based on the mean individual SCC value calculated from the three sampling occasions (DIM 56, 118, and 196):

1. <500,000 cells/mL (n = 24);
2. 500,000–1,000,000 cells/mL (n = 21);
3. 1,000,000–2,000,000 cells/mL (n = 15);
4. 2,000,000 cells/mL (n = 10).

These categories were selected to reflect the wide physiological variability in SCC in dairy goats and the threshold ranges commonly used in previous studies for interpreting possible intramammary infection in this species. In dairy goats, SCC is influenced not only by intramammary infection but also by physiological and management-related factors, including apocrine milk secretion, stage of lactation, parity, stress, milking interval, and environmental conditions [6–8]. Moreover, SCC values in bacteriologically negative goats may reach relatively high levels, and previously proposed thresholds for detecting intramammary infection in goats commonly range between 500×10^3 and 1000×10^3 cells/mL, although higher SCC values have also been reported in non-infected animals [9–13]. Therefore, the SCC categories used in the present study were applied for comparative interpretation rather than as definitive diagnostic thresholds for mastitis.

2.8. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA). The individual goat was considered the experimental unit for analyses involving udder morphology and somatic cell count (SCC). For analyses involving udder surface temperature, the left and right udder halves were evaluated separately when appropriate, and the mean udder surface temperature was also calculated for each animal.

Descriptive statistics were calculated for all continuous variables and are presented as mean ± standard deviation (SD). The normality of the data, and where applicable the normality of model residuals, was assessed using the Kolmogorov–Smirnov test. Homogeneity of variances was evaluated using Levene's test. SCC did not follow a normal distribution; therefore, SCC values were log10-transformed before parametric analyses. The transformed SCC values were used in the regression analyses.

The effects of parity and litter size on udder and teat traits were evaluated using a two-way analysis of variance (ANOVA). Parity and litter size were included as fixed effects. The interaction between parity and litter size was initially tested but was not significant; therefore, only the main effects are presented in the final model. The statistical model was as follows:

$$Yijk = \mu + Pi + Lj + eijk$$

where Yijk is the observed value of the examined udder or teat trait, μ is the overall mean, Pi is the fixed effect of parity (2, 3, 4, and 5 + 6 parities), Lj is the fixed effect of litter size (single, twin, and triplet kidding), and eijk is the random residual error. When significant differences were detected by ANOVA, Tukey's post hoc test was applied for pairwise comparisons.

Differences in udder surface temperature between bacteriologically negative and positive samples were evaluated using the independent-samples Student's t-test when the assumptions of normality and homogeneity of variance were met. If these assumptions were not fulfilled, the Mann–Whitney U test was applied. Differences in udder surface temperature among SCC categories were evaluated using one-way ANOVA followed by Tukey's post hoc test for normally distributed data, or by the Kruskal–Wallis test for non-normally distributed data.

Differences in the proportions of bacteriologically negative samples and obligate udder pathogens among SCC categories were evaluated using Pearson's chi-square test. When expected cell counts were low, Fisher's exact test was applied. Pairwise comparisons between SCC categories were performed where appropriate, and different superscript letters in the table indicate statistically significant differences at $p < 0.05$.

The relationships between udder and teat morphological traits and SCC were evaluated using multiple linear regression analysis with a stepwise variable selection procedure. The dependent variable was log10-transformed SCC, while the candidate explanatory variables were the udder and teat traits assessed by linear scoring. Stepwise regression was used because the analysis aimed to identify the subset of udder and teat traits most strongly associated with SCC from several potentially interrelated morphological variables. Variables were entered into and removed from the model according to the default probability-of-F criteria in SPSS (entry: $p < 0.05$; removal: $p > 0.10$). Model fit was assessed using R, R^2, adjusted R^2, the standard error of the estimate, the F-statistic, and the corresponding *p*-value.

For all statistical analyses, differences were considered statistically significant at $p < 0.05$.

3. Results

3.1. Descriptive Statistics of Udder and Teat Traits

The investigated udder and teat traits are summarized in Table 1. The evaluated traits showed moderate variability within the examined Saanen goat herd ($n = 70$). The highest mean scores were recorded for rear udder width (6.23 ± 1.58) and central ligament (6.21 ± 1.66), whereas lower mean scores were observed for teat placement in rear view (3.10 ± 1.23) and teat placement in side view (3.74 ± 1.19). The results obtained with the 1–9 ICAR linear scoring scale used in this study indicate that teat placement showed greater deviation from the upper end of the scoring range than the other udder traits.

Table 1. Results of udder scoring in the examined herd ($n = 70$).

Trait	Mean ± SD	Range
Udder depth	4.60 ± 1.07	3–8
Fore udder attachment	4.13 ± 1.28	1–8
Central ligament	6.21 ± 1.66	2–9
Rear udder width	6.23 ± 1.58	3–9
Rear udder height	5.70 ± 1.65	3–8
Teat placement, rear view	3.10 ± 1.23	1–7
Teat placement, side view	3.74 ± 1.19	1–8
Teat length	5.94 ± 1.47	3–9
Teat form	4.00 ± 1.68	1–8
Somatic cell count, $\times 10^3$ cells/mL	997.12 ± 902.85	12–7813

The average somatic cell count (SCC) was 997.12 ± 902.85 × 10^3 cells/mL, with a wide range from 12 to 7813 × 10^3 cells/mL. This indicates substantial variability among animals; however, SCC values in dairy goats should be interpreted cautiously because they may be influenced by both infectious and non-infectious factors.

3.2. Effects of Parity and Litter Size on Udder and Teat Traits

The effects of parity and litter size on udder and teat traits are presented in Table 2. Neither parity nor litter size had a statistically significant effect on any of the evaluated udder or teat traits ($p > 0.05$). Although minor numerical differences were observed among groups, these differences were not statistically supported.

Table 2. Effect of parity and litter size on udder and teat parameters.

Factor	*n*	Udder Depth	Fore Udder Attachment	Central Ligament	Rear Udder Width	Rear Udder Height	Teat Placement Rear View	Teat Placement Side View	Teat Length	Teat Form
Parity										
2	36	4.68 ± 0.21	3.96 ± 0.24	6.34 ± 0.34	6.38 ± 0.30	5.30 ± 0.32	3.11 ± 0.25	3.69 ± 0.24	6.24 ± 0.27	3.66 ± 0.32
3	14	5.13 ± 0.29	4.46 ± 0.33	6.28 ± 0.43	6.92 ± 0.43	6.25 ± 0.45	3.24 ± 0.35	4.30 ± 0.33	6.48 ± 0.38	4.22 ± 0.46
4	10	4.19 ± 0.37	3.96 ± 0.41	6.06 ± 0.53	6.68 ± 0.53	5.18 ± 0.56	3.07 ± 0.44	3.43 ± 0.41	5.02 ± 0.48	4.96 ± 0.57
5 + 6	10	4.31 ± 0.35	4.11 ± 0.39	5.69 ± 0.50	5.57 ± 0.50	5.46 ± 0.53	3.08 ± 0.42	3.66 ± 0.39	4.75 ± 0.45	4.43 ± 0.54
p-value		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Litter size										
1	30	4.75 ± 0.21	3.88 ± 0.24	6.06 ± 0.35	5.97 ± 0.31	5.91 ± 0.33	3.12 ± 0.26	3.79 ± 0.24	6.06 ± 0.28	3.86 ± 0.33
2	30	4.32 ± 0.21	4.28 ± 0.24	6.17 ± 0.34	6.18 ± 0.31	5.73 ± 0.33	3.00 ± 0.25	3.63 ± 0.24	5.38 ± 0.28	4.44 ± 0.33
3	10	4.67 ± 0.34	4.20 ± 0.39	6.04 ± 0.56	7.01 ± 0.50	5.00 ± 0.53	3.24 ± 0.41	3.89 ± 0.39	5.43 ± 0.45	4.65 ± 0.54
p-value		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S.: not significant.

3.3. Relationship Between Udder Morphology and Somatic Cell Count

The results of the stepwise multiple regression analysis are shown in Table 3. All generated models were statistically significant ($p < 0.001$). The coefficient of determination increased from 0.23 in Model 1 to 0.39 in Model 4, indicating that the final model explained 39% of the variation in log-transformed SCC.

Table 3. Results of the multifactorial regression analysis of relationships between somatic cell count and udder and teat traits.

Model	Variables Included in the Model	R	R^2	Adjusted R^2	Standard Error of the Estimate	F	*p*-Value
1	Teat form	0.48	0.23	0.22	0.31	19.96	<0.001
2	Teat form; fore udder attachment	0.55	0.31	0.29	0.30	14.75	<0.001
3	Teat form; fore udder attachment; teat length	0.59	0.35	0.32	0.29	11.84	<0.001
4	Teat form; fore udder attachment; teat length; udder cleft	0.62	0.39	0.35	0.28	10.36	<0.001

The regression coefficients of the examined traits are presented in Table 4. Teat form showed a significant negative association with log SCC in all models ($p < 0.001$). In the final model, fore udder attachment, teat length, teat form, and udder cleft were negatively

associated with log SCC. For example, a one-unit increase in teat form score was associated with an approximately 0.39-unit decrease in log SCC in Model 4.

Table 4. Regression coefficients for the associations between udder traits and somatic cell count.

Model	Parameter	Coefficient	Error of the Coefficient	Standardized Coefficient	*t*-Value	*p*-Value
1	Constant	6.45	0.14	—	46.81	<0.001
1	Teat form	−0.36	0.08	−0.48	−4.47	<0.001
2	Constant	6.77	0.17	—	39.37	<0.001
2	Teat form	−0.34	0.08	−0.46	−4.54	<0.001
2	Fore udder attachment	−0.20	0.07	−0.28	−2.78	<0.001
3	Constant	7.07	0.22	—	31.75	<0.001
3	Teat form	−0.41	0.08	−0.55	−5.11	<0.001
3	Fore udder attachment	−0.18	0.07	−0.25	−2.53	<0.05
3	Teat length	−0.17	0.08	−0.23	−2.12	<0.05
4	Constant	7.38	0.25	—	29.09	<0.001
4	Teat form	−0.39	0.08	−0.53	−4.92	<0.001
4	Fore udder attachment	−0.17	0.07	−0.23	−2.35	<0.05
4	Teat length	−0.17	0.08	−0.24	−2.22	<0.05
4	Udder cleft	−0.13	0.06	−0.20	−2.05	<0.05

3.4. Distribution of Bacteriological Findings

The prevalence of bacteriological findings in the milk samples is presented in Table 5. Of the 420 half-udder milk samples, 231 samples (55.0%) were bacteriologically negative, whereas 189 samples (45.0%) were bacteriologically positive. Among the positive samples, facultative udder pathogens accounted for 86.2%, while obligate udder pathogens accounted for 13.8%.

Table 5. Percentage distribution and numbers of udder pathogen bacteria species in goat milk.

Udder Pathogens	Ratio in Positive Samples, %	Ratio in Total Samples, %	*n*
Total negative samples	—	55.0	231
Total positive samples	100.0	45.0	189
Facultative udder pathogens	86.2	38.8	163
Coagulase-negative *Staphylococcus* spp.	54.0	24.2	102
Corynebacterium spp.	7.9	3.6	15
Coagulase-negative *Staphylococcus* spp. and *Corynebacterium* spp. together	24.3	11.0	46
Obligate udder pathogens	13.8	6.2	26
Staphylococcus aureus	3.7	1.7	7
Streptococcus dysgalactiae	1.1	0.5	2
Streptococcus uberis	5.3	2.4	10
Escherichia coli	1.6	0.7	3
Trueperella pyogenes	2.1	1.0	4

Coagulase-negative *Staphylococcus* spp. were the most frequently detected isolates, representing 54.0% of positive samples and 24.2% of all samples. *Corynebacterium* spp. were detected in 7.9% of positive samples, while the combined occurrence of coagulase-negative *Staphylococcus* spp. and *Corynebacterium* spp. represented 24.3% of positive samples. Among obligate pathogens, *Staphylococcus aureus*, *Streptococcus dysgalactiae*, *Streptococcus uberis*, *Escherichia coli*, and *Trueperella* pyogenes were detected at lower frequencies. The bacterial isolates were grouped according to their commonly recognized epidemiological and clinical relevance in caprine mastitis, distinguishing opportunistic/facultative pathogens from major udder pathogens.

3.5. Bacteriological Findings According to Somatic Cell Count Categories

Goats were classified into four SCC categories according to their mean individual SCC values across the three sampling occasions: <500,000; 500,000–1,000,000; 1,000,000–2,000,000; and >2,000,000 cells/mL. Within these animal-level SCC categories, the distribution of bacteriological findings was evaluated using the half-udder milk samples collected during this study. The relationship between SCC category and bacteriological status is shown in Table 6.

Table 6. Distribution of bacteriological findings in half-udder milk samples according to animal-level SCC categories based on mean SCC values across three sampling occasions.

Somatic Cell Count Category	*n*	Ratio of Negative Samples, %	Ratio of Obligate Udder Pathogens, %
<500,000 cells/mL	24	60.4 [b]	2.8
500,000–1,000,000 cells/mL	21	53.2	4.8
1,000,000–2,000,000 cells/mL	15	51.1	5.6
>2,000,000 cells/mL	10	46.7 [a]	13.3
Total	70	54.3	5.5

Note: *n* = number of goats in each SCC category. Different superscript letters within a column indicate significant differences between SCC categories ($p < 0.05$).

The proportion of bacteriologically negative half-udder samples decreased from 60.4% in goats belonging to the lowest SCC category to 46.7% in goats belonging to the highest SCC category. In contrast, the proportion of obligate udder pathogens increased from 2.8% in the lowest SCC category to 13.3% in the >2,000,000 cells/mL category. Because the highest SCC category contained the smallest number of animals ($n = 10$), this pattern should be interpreted cautiously.

3.6. Udder Surface Temperature According to Bacteriological Status

For the comparison with thermographic data, bacteriological status was evaluated using the half-udder milk samples collected at the same sampling time point as infrared thermography, corresponding to DIM 196. Udder surface temperature according to bacteriological status is presented in Table 7. Bacteriologically positive samples were associated with higher udder surface temperatures than bacteriologically negative samples. The mean left udder surface temperature was 36.86 ± 0.47 °C in negative samples and 37.16 ± 0.58 °C in positive samples ($p < 0.05$). The corresponding values for the right udder surface temperature were 36.98 ± 0.56 °C and 37.28 ± 0.45 °C, respectively ($p < 0.05$). When both udder halves were evaluated together, the mean udder surface temperature was 36.92 ± 0.52 °C in negative samples and 37.21 ± 0.53 °C in positive samples ($p < 0.01$).

Table 7. Udder surface temperature according to bacteriological status.

Bacteriological Status	*n*	Left Udder Surface Temperature, °C	*n*	Right Udder Surface Temperature, °C	*n*	Mean Udder Surface Temperature, °C
Negative sample	32	36.86 ± 0.47	38	36.98 ± 0.56	70	36.92 ± 0.52
Positive sample	38	37.16 ± 0.58	32	37.28 ± 0.45	70	37.21 ± 0.53
p-value		<0.05		<0.05		<0.01

3.7. Udder Surface Temperature According to Somatic Cell Count Categories

The relationship between udder surface temperature and SCC categories is shown in Table 8. Mean udder surface temperature ranged from 37.01 to 37.16 °C across the four SCC categories. The highest mean value was observed in the 500,000–1,000,000 cells/mL category (37.16 ± 0.41 °C), while the lowest mean value was recorded in the >2,000,000 cells/mL category (37.01 ± 0.52 °C). However, these differences were not statistically significant ($p > 0.05$).

Table 8. Udder surface temperature according to somatic cell count categories.

Somatic Cell Count Category	*n*	Udder Surface Temperature, °C	SD
<500,000 cells/mL	24	37.15	0.55
500,000–1,000,000 cells/mL	21	37.16	0.41
1,000,000–2,000,000 cells/mL	15	37.09	0.67
>2,000,000 cells/mL	10	37.01	0.52

Note: No significant difference was observed among SCC categories ($p > 0.05$).

4. Discussion

The examined herd deviated most markedly from the optimal score in teat placement, with a mean value of 3.1, which is considerably lower than the optimal value of 9. This conformation is disadvantageous for machine milking, as teats positioned close to the hind limbs may complicate udder preparation, correct cluster attachment, and stable milking unit alignment, thereby increasing the risk of liner slip, teat-end stress, milk residues, and environmental contamination [16,47]. Such mechanical and hygienic effects may contribute to increased susceptibility to udder health disorders, particularly under intensive milking conditions. Similarly, relatively low scores were observed for fore udder attachment and udder height, while udder suspension and udder base width also remained below optimal values. Strong udder attachment and suspension are essential not only for milking efficiency but also for maintaining udder integrity, reducing mechanical load on the mammary gland, and limiting excessive movement of the udder during milking; for instance, Mellado et al. (2008) [48] reported a substantially lower reproductive risk in animals with well-supported udders.

In contrast, udder depth was generally within a favourable range, although variability was present within the herd. Teat orientation was predominantly forward-pointing rather than vertical, which is less desirable from both functional and hygienic perspectives. Forward-oriented or poorly positioned teats may alter the distribution of milking vacuum, reduce the stability of the teat cup, and increase local tissue stress at the teat end [41]. These effects may impair teat canal integrity and facilitate bacterial entry, especially when combined with incomplete milking or environmental contamination. Teat length and

shape approached optimal values; however, the tendency towards longer and more funnel-shaped teats may represent a disadvantage, as such conformations have been associated with elevated somatic cell count (SCC) and impaired udder health [24]. The moderate heritability of teat traits [25,27,28] further indicates that these traits may be relevant for long-term selection objectives. However, because the present study did not include genetic analyses, breeding-related implications should be interpreted cautiously. Moreover, recent findings confirm that udder and teat morphometry are closely linked to milk production efficiency and udder health status, reinforcing their importance as phenotypic selection criteria [20,23].

Overall, the observed heterogeneity in udder traits suggests that phenotypic variation exists within the studied population. This variation may be useful for identifying animals with more favourable udder conformation under practical herd conditions. However, the present results should be interpreted as phenotypic associations rather than direct evidence of genetic improvement potential. Targeted attention to favourable udder conformation could therefore support udder health monitoring and milking management, while further genetic studies would be required to confirm its value in breeding programs.

Parity and litter size had no significant effect on udder traits in the present study. This finding is in agreement with recent studies indicating that udder morphology in goats is relatively stable across parities under uniform management conditions [17]. It is likely that the major structural changes occur primarily during early lactations, while subsequent variation is limited, particularly when suckling duration is short. Nevertheless, parity-related effects may differ among breeds, management systems, and lactation stages, and the relatively limited number of animals in some parity groups should be considered when interpreting these findings.

A moderate but significant association was identified between udder conformation traits and SCC, with combined traits explaining up to 39% of SCC variability. This supports the concept that udder health is a multifactorial trait influenced by the interaction of several anatomical, physiological, environmental, and management-related factors [19,21,22]. Nevertheless, the moderate explanatory power also indicates that non-morphological factors—such as hygiene, management practices, stage of lactation, stress, milking interval, environmental conditions, thermoregulatory responses, and individual immune response—play a substantial role in determining SCC levels [14]. Therefore, SCC should not be interpreted as the result of udder morphology alone, particularly in dairy goats, where physiological variation in SCC is considerable.

Among the evaluated traits, teat form showed a consistent and strong negative association with SCC, suggesting that more favourable teat morphology—particularly conformations better suited for machine milking—is associated with lower SCC values. This is consistent with earlier findings linking unfavourable teat shapes to increased SCC and higher susceptibility to mastitis [24]. From a biological perspective, teat shape may influence teat cup fit, milking vacuum distribution, teat-end compression, and the risk of milking-induced trauma [47,49]. Repeated mechanical stress may compromise teat canal integrity and increase local inflammatory susceptibility, thereby facilitating bacterial penetration or enhancing the inflammatory response of the mammary gland. In addition, the negative associations observed for fore udder attachment and udder cleft indicate that improved structural support may reduce udder movement during milking, improve milk flow dynamics, and reduce pathogen exposure, thereby contributing to better udder health.

Udder pathogens were detected in 45% of the examined samples, with coagulase-negative Staphylococcus spp. and Corynebacterium spp. being the most prevalent isolates. This finding is consistent with previous studies indicating that subclinical mastitis in dairy goats is predominantly associated with opportunistic pathogens [5,14,50]. However, the

high proportion of bacteriologically positive samples should be interpreted cautiously because all animals were clinically healthy. In such cases, bacteriological positivity may reflect true subclinical intramammary infection, opportunistic colonization, or, in some cases, contamination during sample collection. This distinction is particularly important for opportunistic bacteria, which may be present without causing evident clinical disease. Compared with earlier findings, a slightly higher prevalence was observed, which may reflect herd-specific environmental or management conditions. The association between these pathogens and elevated SCC has been widely documented, as CNS infections are known to increase SCC without always causing clinical symptoms [9,15,51].

The increasing proportion of pathogenic bacteria with higher SCC categories supports the relationship between SCC and udder health. However, the presence of bacteriologically negative samples even at elevated SCC levels highlights an important limitation of SCC as a diagnostic tool in goats. Unlike in dairy cattle, SCC in goats is influenced by physiological factors such as apocrine milk secretion, which can result in inherently higher baseline values [4,8,52]. Previous studies indicate that, in clinically healthy goats, somatic cell counts in milk are generally below 1,000,000 cells/mL [53]. Recent studies further emphasize that SCC reflects both infectious and non-infectious processes, reinforcing the need for integrated diagnostic approaches combining microbiological and physiological indicators [6]. Somatic cell count (SCC) reflects the udder's immunological response to intramammary infection (IMI) and may serve as an indicator of mastitis in goats; however, its diagnostic value remains debated and is less widely applied than in dairy cows. Although IMI generally elevates SCC in goat milk, elevated values may also occur in bacteriologically negative samples [54,55]. Such values may reflect physiological inflammation, stress-related immune activation, lactation-stage effects, milking-related tissue reactions, or other non-infectious mammary gland responses.

The observed temperature differences between bacteriologically positive and negative udder halves were statistically significant but relatively small, approximately 0.2–0.3 °C. These differences may be consistent with physiological mechanisms associated with inflammation, including increased local blood flow, vascular permeability, and metabolic activity. These findings are in agreement with previous studies demonstrating the potential of infrared thermography (IRT) for detecting mastitis-related changes [39,44]. However, the biological and practical relevance of such small differences should be interpreted cautiously, because statistically significant temperature differences do not necessarily indicate sufficient diagnostic accuracy under practical farm conditions [42]. Because only clinically healthy animals were included and clinical mastitis cases were not evaluated, the present results do not demonstrate the diagnostic accuracy of IRT for mastitis detection. Rather, they suggest that IRT may provide complementary information on udder surface temperature differences associated with bacteriological status under standardized measurement conditions.

Species-specific thermoregulation and udder vascularization may also influence thermographic findings in dairy goats. Udder surface temperature is affected not only by inflammatory processes but also by ambient temperature, humidity, airflow, milking time, udder contamination, animal positioning, and image acquisition settings [42,56]. These factors are particularly relevant when the observed differences are small. Therefore, the interpretation of IRT data requires strict standardization of measurement conditions and careful consideration of environmental effects. In the present study, thermographic measurements were performed under controlled parlour conditions as far as possible; however, the lack of repeated measurements limits the assessment of temporal repeatability.

In contrast, no significant differences in udder surface temperature were observed across SCC categories. This finding is important because it suggests that SCC and udder

surface temperature may reflect partly different biological processes. SCC is influenced by both infectious and non-infectious factors, whereas IRT reflects surface heat patterns that may be affected by local vascular and thermoregulatory responses. Therefore, the absence of clear temperature differences among SCC categories may indicate that elevated SCC in goats does not always correspond to measurable changes in udder surface temperature. This supports the need for combined interpretation of SCC, bacteriological results, udder morphology, and thermographic data rather than reliance on a single indicator.

From a practical perspective, the results emphasize the importance of considering udder and teat morphology in dairy goat herd management. Traits such as teat form, udder attachment, and udder cleft appear particularly relevant for udder health monitoring because they may influence milking efficiency, teat-end condition, and SCC. In addition, the integration of IRT into routine herd monitoring may offer a rapid and non-invasive supplementary tool for identifying animals or udder halves requiring closer examination. However, practical implementation requires further validation, including standardized measurement protocols, repeatability assessment, environmental correction, cost–benefit evaluation, and the establishment of biologically meaningful threshold values. Therefore, IRT should currently be considered a complementary monitoring tool rather than a stand-alone diagnostic method [57].

Despite these findings, certain limitations should be considered. The relatively moderate sample size and the use of a single herd may limit the generalizability of the results to other breeds, populations, or management systems. Furthermore, thermographic measurements were conducted at a single time point, which may not capture temporal variation in udder temperature across lactation stages or changing environmental conditions. The absence of clinical mastitis cases also limits conclusions regarding the diagnostic performance of IRT for detecting clinically apparent disease. In addition, although udder morphology was assessed using a standardized scoring system, some degree of subjectivity in conformation scoring cannot be fully excluded. Environmental factors affecting IRT were recorded only partly, and residual effects of humidity, airflow, udder contamination, or animal positioning may have influenced the measured surface temperatures. Finally, the observational design does not allow causal relationships to be established between udder morphology, SCC, bacteriological status, and udder surface temperature. Future studies should therefore include larger and more diverse populations, repeated thermographic measurements, longitudinal designs, clinical mastitis cases, and the integration of SCC, bacteriological, morphological, and thermographic data into predictive models to improve early detection and management of udder health disorders in dairy goats.

5. Conclusions

The present study showed that udder and teat morphology are associated with somatic cell count in clinically healthy dairy goats. Among the evaluated traits, teat form, fore udder attachment, teat length, and udder cleft showed significant negative associations with SCC, suggesting that more favourable udder conformation may be related to lower SCC values. These findings support the practical relevance of udder morphology assessment as a complementary component of udder health monitoring in dairy goat herds. Bacteriological examination revealed that a considerable proportion of milk samples from clinically healthy goats contained mastitis-associated bacteria, mainly facultative pathogens. The proportion of obligate udder pathogens was higher in goats belonging to the highest SCC category; however, SCC values should be interpreted cautiously in dairy goats because they are influenced by both infectious and non-infectious factors. Infrared thermography detected slightly higher udder surface temperatures in bacteriologically positive udder halves than in bacteriologically negative udder halves. However, the observed temperature

differences were small, and udder surface temperature did not differ significantly among SCC categories. Therefore, infrared thermography should be considered a supportive monitoring tool rather than a stand-alone diagnostic method for mastitis detection in dairy goats. Overall, the combined evaluation of udder morphology, SCC, bacteriological status, and udder surface temperature may provide a more comprehensive approach to assessing udder health in dairy goats. Further studies involving larger populations, multiple herds, repeated thermographic measurements, clinical mastitis cases, and detailed environmental monitoring are needed to confirm the practical applicability of infrared thermography and to refine its use under farm conditions.

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Abbreviations

The following abbreviations are used in this manuscript:

SCC	Somatic cell count
IRT	Infrared thermography
DM	Dry matter
DIM	Days in milk
ICAR	International Committee for Animal Recording
CNS	Coagulase-negative Staphylococci

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