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Lactoferrin – The protective component of goat colostrum and milk

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Abstract: Lactoferrin (LF) is an important bioactive component of colostrum, is critical for the development of immunity in the newborns, and it is an important component of the mammary gland defence system. LF is also an important biomolecule in terms of promoting and restoring the human health. The aim of our study was to monitor the dynamics of changes in lactoferrin concentration in goat milk at varying stages of lactation and its correlation with selected components and physicochemical parameters. Colostrum (n = 24) and milk (n = 120) samples were obtained from 12 goats by hand milking. Lactoferrin was determined using reversed-phase high-performance liquid chromatography with an ion-pairing reagent equipped with a Photodiode Array Detector. The LF concentration in colostrum ranged from 206 mg/l to 1 228 mg/l, and showed a statistically significant decrease in concentration ($P < 0.05$) over the colostral period. Significant correlation coefficients ($P < 0.001$) were found between crude protein and LF (r = 0.896), lactose and LF (r = –0.754), as well as between non-fat solids and LF (r = 0.853). The LF content in milk ranged within a relatively wide range of 94 mg/l to 1 115 mg/l although the values were highly variable (vx = 57.0%). Significant correlations were found between fat content and LF in milk (r = 0.429, $P < 0.001$), crude protein and LF (r = 0.376), non-fat solids and LF (r = 0.361), somatic cell count (SCC) and LF (r = 0.330), as well as log SCC and LF (r = 0.348, $P < 0.01$).

Keywords: bioactive protein; lactation stage; physicochemical parameters; small ruminants

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The mammary gland defence system is an extremely well-developed, complex and highly effective barrier against pathogens as it integrates both innate and acquired immune responses. The immune system of the ruminant mammary gland has a number of functions, the most important of which include protecting the mammary gland from infection, eliminating the existing infection and restoring the normal tissue function. The main components of innate (non-specific) resistance include a number of cellular and humoral mechanisms that ensure protection of the mammary gland against infection (Sordillo 2018). Substances with antimicrobial effects found in milk – such as lactoferrin (LF), lysozyme and the lactoperoxidase-thiocyanate-hydrogen peroxide system – are among the most important contributors to innate resistance (Rainard and Riollet 2006).

LF is a cationic iron-binding glycoprotein found in exocrine gland secretions. LF found in colostrum and milk is synthesised by secretory cells of the mammary gland and is also present in secondary granules of neutrophils. Its antibacterial function including bacteriostatic and bactericidal activity against both Gram-negative and Gram-positive bacteria is one of the key protective properties of LF. Apart from LF, peptides derived from LF also show bactericidal effects. LF also has antiviral, antifungal and antiparasitic activity. LF promotes the proliferation, differentiation and activation of immune cells, thereby enhancing the immune response. It also acts as an anti-inflammatory factor (Giansanti et al. 2016).

Colostrum is formed in the mammary gland before and immediately after birth. According to the literature, true colostrum is produced in goats during the first 24 h after parturition. The transformation of colostrum into mature milk occurs gradually from day 2 to day 5 after parturition, and the mammary secretion over this period is considered transitional milk. The transition of colostrum to mature milk is completed on day 5 (Sanchez-Macias et al. 2014), with a maximum of 5–7 days postpartum (Raimondo et al. 2024). Colostrum is a rich source of bioactive components – immunoglobulins, cellular active molecules, enzymes, LF, lysozyme, cytokines, growth factors and hormones. These components stimulate and influence the immune system, and modulate the development of many other organ systems of newborn kids (Mondeshka et al. 2022). LF is among the bioactive components that are present in elevated concentrations in native colostrum 72 h after birth, with their levels decreasing over time. Colostrum composition depends on a number of factors including genetic factors, breed, lactation number, environmental stress, dry period length, animal health status, milk yield, season, diet, etc. (Kumar et al. 2016; Mehra et al. 2021).

According to the literature, the concentration of LF in goat milk varies between 20 and 200 μg/ml (Mehra et al. 2021). Studies have shown that the concentration of LF in goat milk is influenced by a number of factors: breed (Rachman et al. 2015; Agradi et al. 2023), stage of lactation (Rachman et al. 2015; Wang et al. 2018; Raimondo et al. 2024; Segura et al. 2024), season (Segura et al. 2024) and the health of the mammary gland (Segura et al. 2024). LF concentration increases during the inflammatory response, and so LF could also be used as a marker of mastitis (Giagu et al. 2022).

The aim of our study was to *i*) monitor the dynamics of LF concentration changes in goat colostrum and mature milk, *ii*) examine the correlation of LF concentration with selected components and physicochemical parameters of both colostrum (such as fat, crude protein, lactose monohydrate, total solids, non-fat solids, pH, electrical conductivity, freezing point, somatic cell count) and milk (fat, crude protein, lactose monohydrate, total solids, non-fat solids, somatic cell count).

MATERIAL AND METHODS

Material

Colostrum (n = 24) and mature milk (n = 120) samples were taken from a selected group of 12 goats from a small farm in the Brno-City district of the South Moravian Region in the Czech Republic. Colostrum and milk samples were obtained by hand milking. The animals came from breeds traditionally reared in the Czech Republic – brown short-haired goat and white short-haired goat, as well as their crossbreds. Parturitions occurred between February and the beginning of April. Samples were taken during the colostral period (day 2 and day 5 after parturition), on day 15 and day 30 after parturition and then every month until the end of lactation. After milking, samples were cooled, transported at 4–6 °C to the laboratory, and stored in a refrigerator at 4–6 °C until further analysis.

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Methods

Determination of the constituents and physicochemical parameters of colostrum. The analyses were performed in an accredited testing laboratory in Rapotín (Czech Republic). Goat colostrum was analysed for its major components as follows: fat content (F, %), crude protein content (CP, %), lactose monohydrate concentration (L, %) and non-fat solids content (SNF, %), which were determined using a Milko-Scan 133 B infrared spectroscope (Foss Electric, Hilleröd, Denmark) and a DairySpec FT analyser (Bentley Instruments, Chaska, Minnesota, USA). Two analytical methods were used to increase the reliability of the results. The results for each analyte were determined as the arithmetic mean of the two methods. Milko-Scan 133 B uses a specific optical selective filter technology (sample and reference for each milk component) in the mid-infrared (MIR) region of the spectrum. DairySpec FT operates over the whole spectrum in the mid-IR region and is equipped with a Michelson interferometer and Fourier transform (MIR-FT). Total solids content was determined on the DairySpec FT analyser (Bentley Instruments, Chaska, Minnesota, USA).

Somatic cell counts (SCC, $\times 10^3$ cells/ml) in colostrum were determined by fluoro-opto-electrolyte flow cytometry (staining of cell nuclei with ethidium bromide) using a Somacount 300 counter (Bentley Instruments, Chaska, Minnesota, USA).

The colostrum freezing point (FP, °C) was determined by the direct reference method on a CryoStar automatic cryoscope (Funke-Gerber, Berlin, Germany).

Electrical conductivity (EC, mS/cm) was measured using a Hanna Instruments HI5321-02 conductivity meter (Woonsocket, USA, Romania) while pH was measured using a VWR pHenomenal 1100L pH meter (Darmstadt, Germany).

Determination of milk constituents. The analyses were performed at the Milk Analysis Laboratory Brno (Czech Republic) – an accredited testing laboratory (The Czech-Moravian Breeders' Association, 1312.2 accredited by the Czech Accreditation Institute according to EN ISO/IEC 17025:2017).

Goat milk composition was monitored on the calibrated and controlled infrared milk analyser CombiFoss FT+ (Foss Analytical A/S, Hilleröd, Denmark) using the MIR-FT method, following the relevant standard operating procedures.

CombiFoss FT+ (Foss, Hilleröd, Denmark) with flow cytometry (FC) was used for determining the SCC in goat milk, with reference samples as controls being analysed using the direct microscopic method for SCC determination according to the relevant standard operating procedures.

Determination of LF in colostrum and milk. LF in colostrum and milk samples was determined by reversed-phase high-performance liquid chromatography (RP-HPLC) with ion-pairing reagent. The sample preparation prior to the actual determination involved centrifugation (Hermle Z 326 K centrifuge; Hermle Labortechnik, Germany) followed by mechanical removal of the fat fraction. The centrifuged milk/colostrum was precipitated using 10% acetic acid with continuous pH control (Hanna pH Meter PH211; Hanna Instruments, Romania). The precipitated sample was centrifuged (EBA 20 Hettich Centrifuge; Hettich, Germany) and the separated whey was filtered through a nylon membrane filter (0.22 µm) into chromatographic vials. HPLC was performed on an Alliance 2695 liquid chromatograph fitted with a Photodiode Array Detector 2996 (Waters, USA) and a Poroshell 300SB-C8 column, 2.1 × 75 mm, 5 µm (Agilent Technologies, USA). The mobile phase comprised water, acetonitrile and trifluoroacetic acid. The gradient elution was used at a flow rate of 1.0 ml/min and a column temperature of 50 °C. The analytes were detected at 205 nm. The limit of detection for lactoferrin was 1.5 mg/l. Empower v2 build 2154 Software (Waters, USA) was used for data acquisition and analysis and for running the liquid chromatograph. Quantification of lactoferrin was done using an external bovine milk lactoferrin standard (Sigma Aldrich, USA) using a calibration curve in the range of 11–1 129 mg/l.

Statistical evaluation. We used Microsoft Excel v2013 (Microsoft Corporation, USA) to evaluate the basic statistical characteristics of colostrum and milk parameters and their relationships based on linear regression and correlation analysis. As the normal frequency distribution of data for some milk indicators, especially SCC (Hanus et al. 2017) and lactoferrin, in goats is usually missing, particularly in individual milk samples, we logarithmically transformed these values to a decimal base ($\log_{10}$) for data normalisation and higher statistical yield-for hypothesis testing.

Multifactorial analysis of variance was performed with milk indicators of goat colostrum and (separated) milk. Packages in R (R Core Team 1997) were used as follows: linear model for ANOVA,

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EMMEANS for post hoc analysis, means and the General Linear Model procedures. This was carried out using a linear model with fixed effects and with random effect according to the following formula:

$$Y_{ijklm} = \mu + CLO_i + BR_j + MB_k + OS_l + e_{ijklm} \quad (1)$$

where:

Y – investigated milk indicator;
μ – general mean;
CLO_i – class of lactation number for i from 1 to 2;
BR_j – breed for j from 1 to 3;
MB_k – month of birth for k from 1 to 2;
OS_l – order of sampling (lactation stage) for l from 1 to 2 (colostrum) and from 1 to 10 (milk);
e_{ijklm} – random effect.

RESULTS AND DISCUSSION

Monitoring the dynamics of lactoferrin concentration changes in goat milk as a function of lactation stage

LF concentration in the colostral period. LF concentrations in all analysed colostrum samples ranged widely from 206.10 mg/l to 1 227.90 mg/l, with a mean LF concentration of 680.6 ± 277.3 mg/l in samples collected on the second day after delivery. On the fifth day after delivery, there was a statistically significant ($P < 0.05$) decrease to 441.1 ± 234.5 mg/l (see Figure 1). Figure 2 represents the wide variability of LF content in colostrum on the second day after parturition. Mean LF concentrations in colostrum samples in our study are higher compared to the values reported in some studies (Hiss et al. 2008; Rachman et al. 2015; Harjanti et al. 2017; Wang et al. 2018) while they are lower at the same time than those reported by others (Agradi et al. 2023; Raimondo et al. 2024).

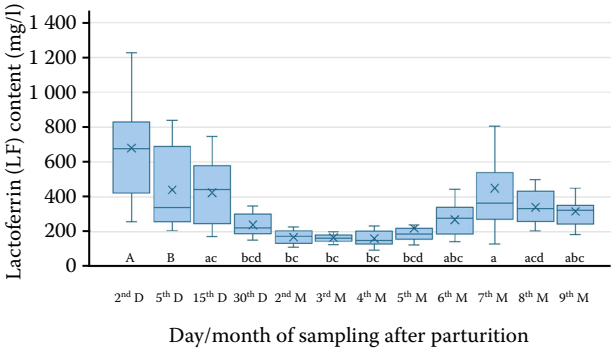

Figure 1. Dynamics of lactoferrin content in goat colostrum and milk during lactation

[A,B]Different capital letters below the boxes mark statistically significant differences ($P < 0.05$) in LF content between colostrum collection dates; [a–d]Different lower case letters below the boxes mark statistically significant differences ($P < 0.05$) in LF content between milk collection dates

D on the x-axis indicates day, M indicates month; the area of the blue boxes shows the spread between the first and third quartile; crosses in each box indicate mean values; the horizontal line inside the box indicates the median; the error bars show the minimum and maximum values

Table 1 shows the results of the multivariate analysis of variance for lactoferrin content in goat colostrum. A linear analysis of the variance model with fixed effects that included lactation number class, breed, month of birth, and order of collection (lactation stage) showed a determination of 35% for LF and colostrum. Logarithmic transformation of LF values increased the determination of the model to 36%. The effect of lactation stage was statistically significant only for colostrum ($P = 0.033\,36$), whereas the other effects for LF were not significant ($P > 0.05$).

Rachman et al. (2015) compared the LF concentration in the colostrum of three goat breeds (Peranakan Etawah, Jawarandu, Peranakan Etawah crossbreds and Saanen goats). Samples were collected between day 1 and day 8 postpartum. They found the highest mean LF values in samples collected on day 1 and day 2 postpartum, with a statistically significant decrease on day 3 (68–69%, $P < 0.05$). On day 2, the mean LF concentration was 154.82 ± 53.92 mg/l in Peranakan Etawah goats, 205.83 ± 32.30 mg/l in Jawarandu goats and 204.83 ± 32.30 mg/l in crossbred goats. On the fifth

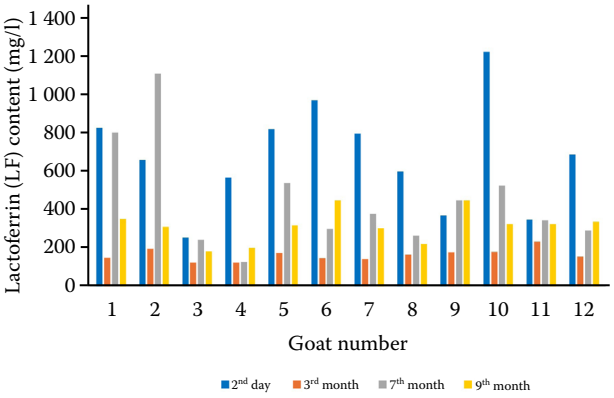

Figure 2. Variability of LF content in individual colostrum and milk samples at selected collection dates (for the highest and lowest average values during lactation)

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Table 1. Results of the multifactorial analysis of variance for lactoferrin content in goat colostrum and milk

Material, LMD/Effect	DF	Sum Sq	Mean Sq	*F* test value	Probability
Colostrum, 35% (LF)					
CLO	1	39 228	39 228	0.605 1	0.446 73
BR	2	236 225	118 112	1.822	0.190 29
MB	1	8 574	8 574	0.132 3	0.720 33
OS	1	344 090	344 090	5.307 9	**0.033 36**
RES	18	1 166 857	64 825	–	–
Milk, 41%					
CLO	1	383	383	0.023 3	0.878 9
BR	2	25 150	12 575	0.764 6	0.468 1
MB	1	2 830	2 830	0.172	0.679 1
OS	9	1 194 413	132 713	8.069 1	**4.95E-09**
RES	106	1 743 385	16 447	–	–
Colostrum, 36%, (log LF)					
CLO	1	0.005 13	0.005 13	0.118 7	0.734 46
BR	2	0.164 06	0.082 03	1.896 4	0.178 91
MB	1	0.0140 3	0.0140 3	0.324 3	0.576 05
OS	1	0.248 19	0.248 19	5.737 9	**0.027 69**
RES	18	0.778 58	0.043 25	–	–
Milk, 51%, (log LF)					
CLO	1	0.008 26	0.008 26	0.348 2	0.556 4
BR	2	0.047 37	0.023 69	0.997 9	0.372 1
MB	1	0.004 15	0.008 26	0.174 7	0.676 8
OS	9	2.530 29	0.281 14	11.845 3	**9.7E-13**
RES	106	2.515 86	0.023 73	–	–

Bold font indicates significant influence

BR = breed; CLO = class of lactation number; DF = degrees of freedom; LF = lactoferrin; LMD = linear model determination (in %); log LF = logarithm of the LF value at decadic ($\log_{10}$) base; MB = month of birth; Mean Sq = mean square; OS = order of sampling (lactation stage); RES = residuals; Sum Sq = sum of squares

day, the highest LF level was 48.45 ± 12.60 mg/l in the colostrum of Jawarandu goats. They concluded that both lactation stage and breed significantly affected the LF concentration ($P < 0.05$).

In another study, Hiss et al. (2008) determined LF concentrations in the colostrum of 19 goats of two breeds: German Improved Fawn and German Improved White. The average LF concentration in colostrum was 387 ± 69 mg/l, i.e. lower than our findings.

Harjanti et al. (2017) reported the LF concentration of 317.3 mg/l in the colostrum of Etawah crossbred goats on the first day after parturition, which decreased to 190.5 mg/l on the second day. They attribute this decrease to a marked reduction in the protein fraction in the colostrum, with the highest LF concentrations recorded on the first day of the colostral period.

Another study carried out in China investigated the variability of LF concentrations in the milk of Xinong Saanen goats. The average LF concentration in the colostrum was 222.6 ± 41.57 mg/l. The study confirmed a statistically significant effect ($P < 0.001$) of lactation stage on LF concentration (Wang et al. 2018).

Raimondo et al. (2024) described changes in the protein fraction of colostrum and mature milk in 11 healthy Saanen goats up to 30 days postpartum. They used the SDS-PAGE (sodium dodecyl sulfate polyacrylamide gel electrophoresis) for determining LF. LF concentrations were significantly influenced by the colostral phase with the

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highest concentration (4 180.0 ± 2 770.0 mg/l) 0–12 h postpartum. They recorded a significant decrease ($P \leq 0.05$) to 1 800.0 ± 1 070.0 mg/l as early as 12–24 h after delivery, when the concentration further decreased to 1 330.0 ± 800.0 mg/l on day 2 and 1 120.0 ± 340.0 mg/l on day 5. The authors concluded that LF plays an important role in the mammary gland immunity, and the LF concentration is associated with a higher susceptibility to intramammary infections during this period.

Agradi et al. (2023) observed differences in colostrum LF content in 4 goat breeds (Camosciata delle Alpi, Frisa, Lariana, Orobica). They found the highest content in the Frisa breed (1 781.3 ± 892.6 mg/l) while it was lower in the Camosciata delle Alpi and Lariana breeds (763.1 ± 357.9 and 1 148.0 ± 858.6 mg/l). They also confirmed a statistically significant effect ($P < 0.001$) of breed on the LF concentration in colostrum. Higher LF concentrations were found in traditional local breeds. Among other things, they attribute this to the adaptation of local breeds to local conditions, which is necessary for the growth and survival of the young in the postnatal period. In line with our observations, Agradi et al. (2023) also found that LF concentrations varied considerably in individual samples. In the Camosciata breed the values varied between 435.68 and 1 920.03 mg/l, between 345.35 and 3 232.93 mg/l in the Frisa breed, between 327.94 and 3 321.82 mg/l in the Lariana breed and between 425.56 and 2 759.11 mg/l in the Orobica breed.

According to Segura et al. (2024), the highest colostrum LF concentration in Murciano-Granadina goats was recorded on the first day after parturition (582 mg/l), which then gradually decreased to 425 mg/l (second day) and 334 mg/l (third day). The lowest LF concentration was measured on day 4 postpartum (295 mg/l). The LF concentration decreased by 29% within the first 24 h, and by up to 50% within 96 h after parturition. Segura et al. (2024) demonstrated the influence of season and lactation stage on the colostrum LF concentration, as it was significantly higher ($P < 0.05$) in the spring season. We could not assess the effect of season in our study as all births took place in the spring.

Our results confirmed that colostrum is a rich source of LF, its concentration being highest in the first days after delivery (up to 72 h), but it then decreases and stabilises to the physiological value typical of mature milk.

LF concentration in mature milk. Figure 1 shows LF concentration changes in mature milk during lactation (from day 15 to the end of lactation). The average LF content in mature milk was 275.72 ± 157.22 mg/l, similar to the colostral period, with a high variability (vx = 57.0%), ranging between 94.20 and 1 114.50 mg/l. Within one month (between day 15 and 30) of lactation, there was a statistically significant ($P < 0.05$) decrease in concentration. After the second month of lactation, LF concentrations showed no statistically significant differences ($P > 0.05$). From the fifth to the seventh month of lactation, there was an increase in LF content, reaching a maximum concentration in mature milk 7 months after parturition (450.42 ± 286.80 mg/l, $P < 0.05$), after which LF concentrations decreased again, but the difference was not statistically significant ($P > 0.05$). In the gradual increase in lactoferrin concentration from the 4th month of the lactation period, the hormonal effects of further pregnancy and the preparation of the mammary gland for this period can be seen. As the error bars in Figure 1 indicate a wide variability of LF content within the collection date, Figure 2 presents the LF concentrations on selected milk collection dates (months 3, 7 and 9) in samples collected from individual goats.

The results of the multivariate analysis of variance for LF content in goat milk presented in Table 1 show that the linear model with included fixed effects [lactation number class, breed, month of parturition and order of collection (stage of lactation)] had a 41% determination for LF and milk, which is better than that for colostrum. Logarithmic transformation of LF values significantly increased the statistical yield of the analysis of variance and the coefficient of determination of the linear model to 51%. The effect of lactation stage was highly statistically significant for milk ($P < 0.000\,1$), whereas the other effects were not significant ($P > 0.05$).

In contrast to our results, Raimondo et al. (2024) found higher levels of LF (630.0 ± 160.0 mg/l and 730.0 ± 340.0 mg/l) in mature milk of Saanen goats on day 15 and day 30 postpartum, but the differences were not statistically significant ($P > 0.05$).

Hiss et al. (2008) reported much lower concentrations of LF in goat milk. They observed that goat milk LF concentrations reached only 20% of the initial amount (62 ± 25 mg/l) in the week after the colostral period. By week 32 postpartum, LF concentrations ranged from 10 mg/l to 28 mg/l. The concentration increased 3.2-fold in late lacta-

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tion (around week 33 postpartum) reaching 107 ± 19 mg/l. They concluded that LF plays an important role in the mammary protection in late lactation. The results showed that lactation stage and lactation number had a significant effect ($P < 0.05$ and $P < 0.01$, respectively) on LF concentration.

The effect of lactation stage was also confirmed by our results. LF concentrations on day 15 postpartum were significantly ($P < 0.05$) different from those on day 30 postpartum, and from the concentration in samples collected 2, 3, and 4 months postpartum ($P < 0.001$), as well as 5 and 11 months postpartum ($P < 0.01$).

Wang et al. (2018) focused on the variability of LF concentration in milk of Xinong Saanen goats. They observed statistically significant correlations between LF content and CP, LF and L, as well as LF and SNF, but they saw no correlation between LF content and F or LF content and CP. Their results further showed that LF concentration in goat milk varied between 34.61 and 51.94 mg/l. LF concentration was 51.94 mg/l one week after parturition and it gradually decreased until the 11th week postpartum. It increased slightly in the 15th week postpartum (40.64 mg/l) and it continued to increase until the 23rd week reaching 41.28 mg/l, after which concentrations decreased again until the 31st week postpartum (35.44 mg/l). We also observed similar changes during lactation in our study (Figure 1). LF concentrations first decreased until about week 16 and then increased until about week 28, followed by a slight decrease until the end of lactation. However, the absolute LF concentrations in our study were higher than those reported by Wang et al. (2018).

Chen et al. (2004) investigated the milk of high, standard and low quality using the methylene blue test (MBRT). They found that the mean LF concentration was significantly lower ($P < 0.05$) in high-quality milk (167 ± 49 mg/ml) than in standard-quality milk (218 ± 77 mg/l) or low-quality milk (304 ± 87 mg/l). They consider a LF concentration of 20–200 mg/l to be the physiological value in a pooled sample of goat milk during lactation.

The differences in LF concentrations and their variability in mature lactating milk (Figure 1) are in line with the findings of previous studies that LF concentrations in mature milk vary widely depending on a number of factors. One such factor is the health of the mammary gland. The level of LF in milk increases rapidly when the mammary gland is infected (Chen et al. 2004; Segura et al. 2024); thus, LF concentrations may indirectly indicate the existence of an intramammary infection and can serve as an indicator of mastitis (Giagu et al. 2022). This is particularly important in the context of apocrine milk secretion in goats, which reduces the indicator function of somatic cell count in mastitis milk compared to cow's milk secretion. Nonetheless, no threshold goat milk LF concentration to confirm mastitis has been proposed so far.

Monitoring the correlation of LF concentration with selected components and physicochemical parameters of milk and colostrum

Components/parameters of colostrum, their changes during the colostral period and correlation with LF. The concentration of selected colostrum components and the results of physicochemical parameters are summmarised in Table 2. Comparing the values from days 2 and 5 of lactation showed that the concentrations of CP, SNF, TS and SCC showed a decrease, while other components (F and L concentration) showed an increase. Highly significant ($P < 0.001$) correlations were found between colostrum LF content and the content of CP, L and SNF as can be seen in Figure 3A–C. The statistical significance of the correlations of all the determined parameters of goat colostrum is summarised in Table 3. The correlations of selected colostrum parameters (Table 3) and LF show that these relationships are influenced by physiological changes in colostrum composition that are characteristic of the colostral period.

Crude protein (CP) content. CP content on days 2 and 5 postpartum was 7.77 and 5.37%, respectively, and this decrease was highly significant ($P < 0.001$; Table 2). The decrease in CP in the colostral period is consistent with results from other studies (Arguello et al. 2006; Rachman et al. 2015; Raimondo et al. 2024).

Our results showed that CP content was significantly correlated with SNF content ($r = 0.985$, $P < 0.001$), L content ($r = –0.718$, $P < 0.001$) and LF content ($r = 0.896$, $P < 0.001$). On the other hand, FP, SCC and log SCC were not correlated with CP content.

Segura et al. (2024) also found very close, statistically significant correlations between CP and LF ($P < 0.001$, $r = 0.705$) and between CP and other

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Table 2. Basic statistical parameters of the observed components and physicochemical parameters of colostrum

Parameter/ term of sampling		F (%)	CP (%)	L (%)	SNF (%)	TS (%)	pH	EC (mS/cm)	FP (°C)	SCC (×10^3 cells/ml)	log SCC
Day 2	x	6.84	7.77	4.12	12.42	21.06	6.60	4.30	–0.563 0	893.17	2.45
	SD	1.38	1.64	0.42	1.24	2.07	0.06	0.31	0.012	831.33	0.87
Day 5	x	7.12	5.37	4.38	10.42	18.91	6.64	4.50	–0.556 2	845.25	2.66
	SD	1.54	1.23	0.42	0.95	1.92	0.07	0.46	0.010	873.38	0.53
Total	x	6.98	6.57	4.25	11.42	19.99	6.62	4.40	–0.559 6	869.21	2.55
	SD	1.47	1.88	0.44	1.49	2.27	0.07	0.40	0.012	852.95	0.73
	min	4.28	4.02	3.50	9.37	15.19	6.51	3.80	–0.578 1	17	1.23
	max	9.57	10.74	4.93	14.68	23.91	6.84	5.11	–0.532 6	2 857	3.46

CP = crude protein; EC = electrical conductivity; F = fat; FP = freezing point; L = lactose monohydrate; log SCC = logarithm of somatic cell count; max = maximum; min = minimum; pH = active acidity; SCC = somatic cell count; SD = standard deviation; SNF = non-fat solids; TS = total solids; x = arithmetic mean

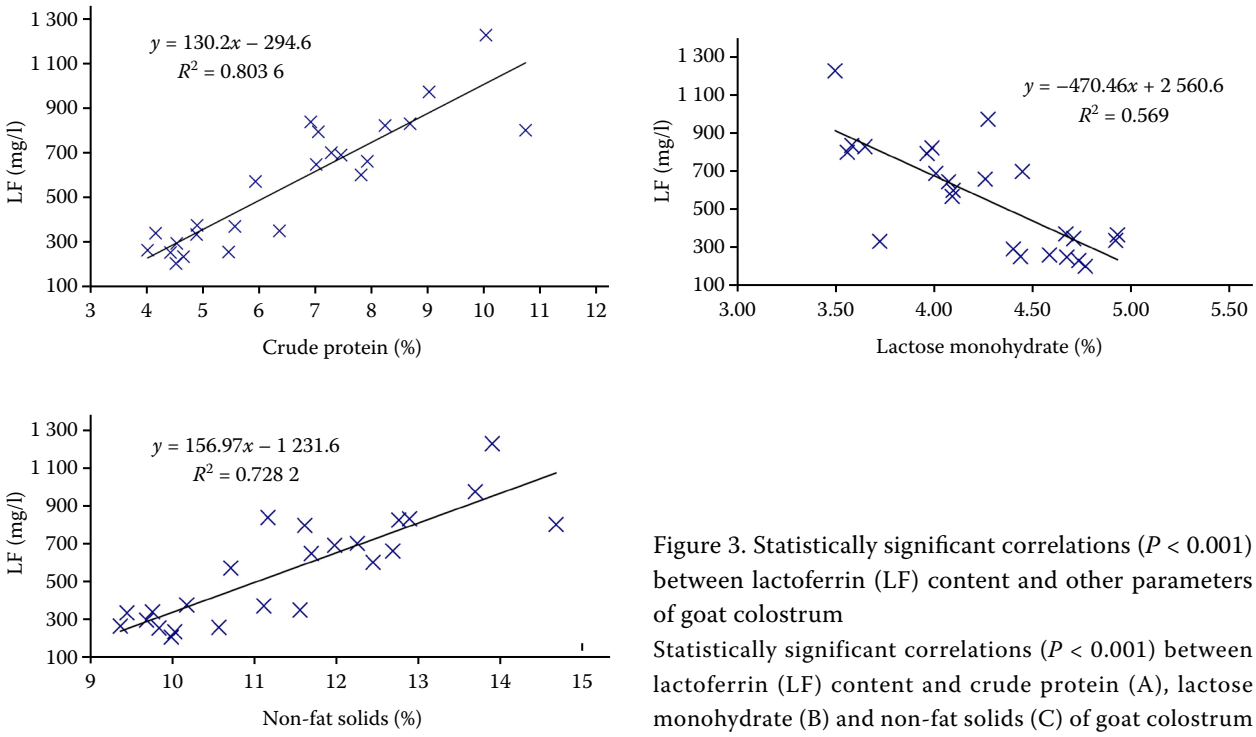

Figure 3. Statistically significant correlations ($P < 0.001$) between lactoferrin (LF) content and other parameters of goat colostrum

Statistically significant correlations ($P < 0.001$) between lactoferrin (LF) content and crude protein (A), lactose monohydrate (B) and non-fat solids (C) of goat colostrum

colostrum components: SNF ($r = 0.983$, $P < 0.001$), L ($r = –0.835$, $P < 0.001$), Brix ($r = 0.934$, $P < 0.001$).

The very close and statistically significant correlation between CP and LF is likely due to physiological changes in proteins typical of the colostral period. CP content in the colostrum is influenced by the high whey protein content, mainly made up of immunoglobulins, but also other proteins. Whey proteins account for 80% of the protein in the first 24 h after parturition, after which their content decreases; on day 5 postpartum they comprise only 30% (Raimondo et al. 2024).

Lactose content (L). As shown in Table 2, the L concentration showed an increasing trend, which is in line with the literature (Hadjipanayiotou 1995; Arguello et al. 2006; Moreno-Indias et al. 2012; Sanchez-Macias et al. 2014). Hadjipanayiotou (1995) monitored changes in colostrum L concentration and saw the greatest increase on day 2 postpartum, with a more gradual increase later on.

We observed a statistically significant correlation of L with SNF content ($r = –0.587$, $P < 0.01$), LF ($r = –0.754$, $P < 0.001$), SCC ($r = –0.419$, $P < 0.05$). These correlations indicate that L correlates with

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Table 3. Correlation coefficients of linear regression relationships between goat colostrum parameters

	CP	L	SNF	LF	pH	EC	FP	SCC
F	–0.014 (ns)	–0.481*	–0.133 (ns)	0.087 (ns)	–0.207 (ns)	–0.392 (ns)	0.045 (ns)	0.429*
CP	–	–0.718***	0.985***	0.896***	–0.425*	–0.166 (ns)	–0.314 (ns)	0.157 (ns)
L	–	–	–0.587**	–0.754***	0.291 (ns)	–0.020 (ns)	0.061 (ns)	–0.419*
SNF	–	–	–	0.853***	–0.430*	–0.205 (ns)	–0.354 (ns)	0.088 (ns)
LF	–	–	–	–	–0.196 (ns)	–0.106 (ns)	0.197 (ns)	0.255 (ns)
pH	–	–	–	–	–	0.263 (ns)	0.601**	0.340 (ns)
EC	–	–	–	–	–	–	–0.092 (ns)	–0.010 (ns)
FP	–	–	–	–	–	–		–0.381 (ns)

Significant at *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; not significant (ns) at $P > 0.05$

CP = crude protein; EC = electrical conductivity; F = fat; FP = freezing point; L = lactose monohydrate; LF = lactoferrin; pH = active acidity; SCC = somatic cell count; SNF = non-fat solids; TS = total solids

some milk parameters due to changes that occur physiologically in the colostral period. A negative statistically significant correlation ($r = –0.571$, $P < 0.001$) was also reported between L and LF in colostrum by Segura et al. (2024).

Total solids (TS) and non-fat solids (SNF). Our data show that both TS and SNF content decreased between day 2 and day 5 (Table 2). The same trend was also observed by Sanchez-Macias et al. (2014), Rachman et al. (2015) and Harjanti et al. (2017).

Our statistical analysis showed significant positive correlations of SNF with LF content ($r = 0.853$, $P < 0.001$), as well as significant negative correlations with pH ($r = –0.430$, $P < 0.05$). Similarly, Segura et al. (2024) found significant positive correlations between SNF and LF ($r = 0.688$, $P < 0.001$).

Fat content (F). In our measurements the average colostrum F content was 6.98 ± 1.47% (Table 2), with F content varying considerably (4.28–9.57%). Although there was a slight increase in the average colostrum F content between day 2 and day 5 postpartum, these differences were not statistically significant ($P < 0.05$). Hadjipanayiotou (1995), on the other hand, reported that F content was highest on the first day of lactation, after which it decreased. Also, Rachman et al. (2015) found that F contents decreased from day 1 to day 8 of lactation, except in the Peranakan Etawah breed, where F content increased to 16.79 ± 4.02% on day 6. Their results showed that breed and day of lactation significantly influenced F content ($P < 0.05$). Colostrum F content was highest on day 2 of lactation in the Jawarandu breed (16.75 ± 4.38%) and lowest in the Peranakan Etawah breed (13.17 ± 1.44%).

In our results, there were significant negative correlations between F and L ($r = –0.481$, $P < 0.05$) and positive correlations between F and SCC ($r = 0.429$, $P < 0.05$; see Table 3). The negative correlations of F and L correspond to changes in these components during the colostral period, when there is a decrease in F and an increase in L. Just like F, SCC was also reported to decrease (Mehra et al. 2021).

Somatic cell count (SCC). SCC values in colostrum and goat milk are higher compared to bovine milk, which is due to different mechanism of milk secretion (apocrine versus merocrine). Apocrine secretion is characterised by a high number of cytoplasmic particles in the milk. Neutrophilic leukocytes predominate in goat milk from healthy mammary glands, accounting for 45–75% of the somatic cells in the milk. SCC is influenced by numerous infectious and non-infectious factors; one significant factor is the health of the mammary gland (infectious factor). Breed, lactation number, lactation stage, yield, milking frequency, milk fraction, oestrus, and stress are among the non-infectious factors. These non-infectious factors have been reported to explain up to 48% of the SCC variance (Jimenez-Granado et al. 2014). Therefore, the high variability of SCC values in goat colostrum and milk is not surprising.

The mean somatic cell count in our colostrum samples was 869.21 ± 852.95 × 10^3 cells/ml, log SCC 2.55 ± 0.73. The differences in the mean SCC on days 2 and 5 postpartum were not statistically significant ($P > 0.05$; see Table 2). The statistical analysis showed a high variability of SCC in individual colostrum samples (vx = 98.1%). Higher SCC in the colostral period has been reported previously

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in several publications, e.g. by Hiss et al. (2008), Moreno-Indias et al. (2012), Sanchez-Macias et al. (2014) and Segura et al. (2024).

The SCC values in Table 2 also show a decrease over the colostral period, which is consistent with the results from Segura et al. (2024). They found the highest SCCs on day 1 and 2 postpartum in the colostrum of Murciano-Granadina goats. They also showed a statistically significant effect of season ($P < 0.001$) and day of lactation ($P < 0.001$) on colostrum SCC. The highest SCC was found in colostrum samples taken in spring and winter (4 462 and 3 796 × 10^3 cells/ml). High SCC values in the colostral period were also reported by Sanchez-Macias et al. (2014). The mean SCC in the colostrum of Majorera goats was 4 624 and 1 433 × 10^3 cells/ml on day 2 and day 5 postpartum, respectively. Moreno-Indias et al. (2012) focused on colostrum SCC along with the determination of basic parameters. Colostrum samples were obtained from 20 Majorera goats at hourly intervals up to 10 h after parturition. SCC values ranged from 4 200 to 5 800 × 10^3 cells/ml. Hiss et al. (2008) found the mean SCC of 1 109 ± 643 × 10^3 cells/ml in the colostrum obtained from 19 goats. We found no statistically significant correlations between SCC and LF in colostrum.

pH and electrical conductivity (EC). The mean pH of colostrum was 6.62 ± 0.07, with an increase apparent in the samples collected over the colostral period; the differences in the pH values of samples collected on day 2 and day 5 were statistically significant ($P < 0.01$). A similar trend of gradually increasing values from day 1 to day 6 was reported by Chen et al. (2018). Changes in colostrum pH were also observed by Sanchez-Macias et al. (2014), although, in contrast to our result, the difference in pH between day 2 and day 5 postpartum (6.68 and 6.65) was not statistically significant ($P < 0.05$). Rachman et al. (2015) found a decrease in pH values during the colostral period in Jawarandu goats. They showed a statistically significant effect of breed on the pH value of goat colostrum ($P < 0.05$); however, the differences in pH values on day 2 and day 5 were not statistically significant ($P > 0.05$).

Arguello et al. (2006) showed that the trend in pH values was significantly ($P < 0.01$) influenced by the day of lactation, whereas the lactation number had no statistically significant effect ($P > 0.05$). Colostrum had a lower pH after delivery than at 132 h postpartum.

We measured the mean colostrum EC of 4.40 ± 0.40 mS/cm, and found that the differences in the values on day 2 and day 5 postpartum were not statistically significant ($P > 0.05$). The EC increased slightly, which is in agreement with previous results from Arguello et al. (2006). In contrast to our measurements, Arguello et al. (2006) showed a statistically significant effect of time after delivery on EC ($P < 0.01$); colostrum after delivery showed EC values of 3.33 mS/cm to 3.79 mS/cm and 132 h after delivery the value was higher (4.34 mS/cm to 4.88 mS/cm).

Freezing point (FP). The mean FP of colostrum was –0.559 6 ± 0.012 °C (Table 2). No significant correlations were found between FP and other colostrum parameters in the present study. The literature sources do not provide any FP values for goat colostrum. Literature records of goat milk FP have been scarce: Mehra et al. (2021) reported –0.540 °C to –0.573 °C, while Raynal-Ljutovac et al. (2007) recorded a value of –0.537 °C to –0.576 °C.

Components/parameters of mature milk, their changes during lactation and correlation with LF. A summary of the concentrations of selected components in mature milk and the selected physicochemical parameters are given in Table 4. We found statistically significant ($P < 0.01$) correlations between the LF content in mature milk and the contents of F, CP, L, SNF and SCC, which can be seen in Figure 4A–E. The statistical significance of these correlations in goat milk is summarised in Table 5.

Crude protein (CP) content. The average CP content in mature milk was 4.07 ± 2.00 g/100 g. From the end of the colostral period, the concentration decreased over the first 5 months of lactation. From the 6th month onward, CP concentration gradually increased until the end of lactation. The CP content in individual samples varied from 2.23 g/100 g (minimum) to 13.32 g/100 g (maximum; see Table 4).

Raimondo et al. (2024) confirmed that the protein composition of goat milk varies with the stage of lactation and shows characteristic features that are influenced by the dynamic changes in protein composition and concentration during the transition from colostrum to mature milk. In contrast to the results of Hadjipanayiotou (1995) who reported that CP content in early lactation remained relatively stable from day 3 to day 11 postpartum, whereas in the present study the found that CP content was stable only from month 2 to month 6 postpartum.

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Table 4. Content of essential constituents of mature goat milk during lactation (mean ± SD)

Parameter/term of sampling	F (g/100 g)	CP (g/100 g)	L (g/100 g)	SNF (g/100 g)	TS (g/100 g)	SCC (×10^3 cells/ml)	log SCC
15th day	6.71 ± 1.87	5.08 ± 1.86	4.19 ± 0.70	10.22 ± 1.48	19.50 ± 1.86	1 220.17 ± 1 274.60	2.68 ± 0.74
30th day	4.90 ± 1.29	3.84 ± 1.53	4.69 ± 0.95	9.28 ± 0.88	17.61 ± 1.68	595.42 ± 713.68	2.46 ± 0.55
2nd month	3.65 ± 0.66	3.11 ± 0.22	4.45 ± 0.25	8.37 ± 0.26	16.73 ± 3.00	569.08 ± 281.52	2.66 ± 0.36
3rd month	2.52 ± 0.79	3.15 ± 0.28	4.20 ± 0.27	8.75 ± 0.33	14.18 ± 1.86	2 387.75 ± 4 589.12	2.98 ± 0.52
4th month	2.07 ± 0.87	2.96 ± 0.34	4.14 ± 0.11	8.24 ± 0.35	11.96 ± 0.86	2 117.00 ± 3 939.81	2.75 ± 0.72
5th month	2.37 ± 0.67	2.89 ± 0.21	4.15 ± 0.21	8.17 ± 0.31	10.62 ± 0.79	2 693.08 ± 2 124.15	3.27 ± 0.41
6th month	2.72 ± 0.60	3.28 ± 0.56	4.18 ± 0.20	8.58 ± 0.67	9.93 ± 1.06	3 150.17 ± 2 546.84	3.33 ± 0.43
7th month	3.72 ± 0.70	3.96 ± 1.32	4.07 ± 0.24	9.13 ± 1.27	10.16 ± 0.72	5 699.42 ± 5 983.56	3.49 ± 0.52
8th month	3.99 ± 1.59	5.7 ± 2.35	4.05 ± 0.88	10.84 ± 1.59	10.92 ± 1.04	7 298.67 ± 9 978.83	3.17 ± 1.00
9th month	5.71 ± 1.48	6.7 ± 3.27	3.58 ± 1.39	11.20 ± 2.12	12.33 ± 1.23	6 017.67 ± 8 918.85	2.92 ± 1.21
Total	3.84 ± 1.85	4.07 ± 2.00	4.17 ± 0.72	9.28 ± 1.53	13.39 ± 3.61	3 172 ± 5 614.70	2.97 ± 0.77

CP = crude protein; F = fat; L = lactose monohydrate; log SCC = logarithm of somatic cell count; SCC = somatic cell count; SNF = non-fat solids; TS = total solids

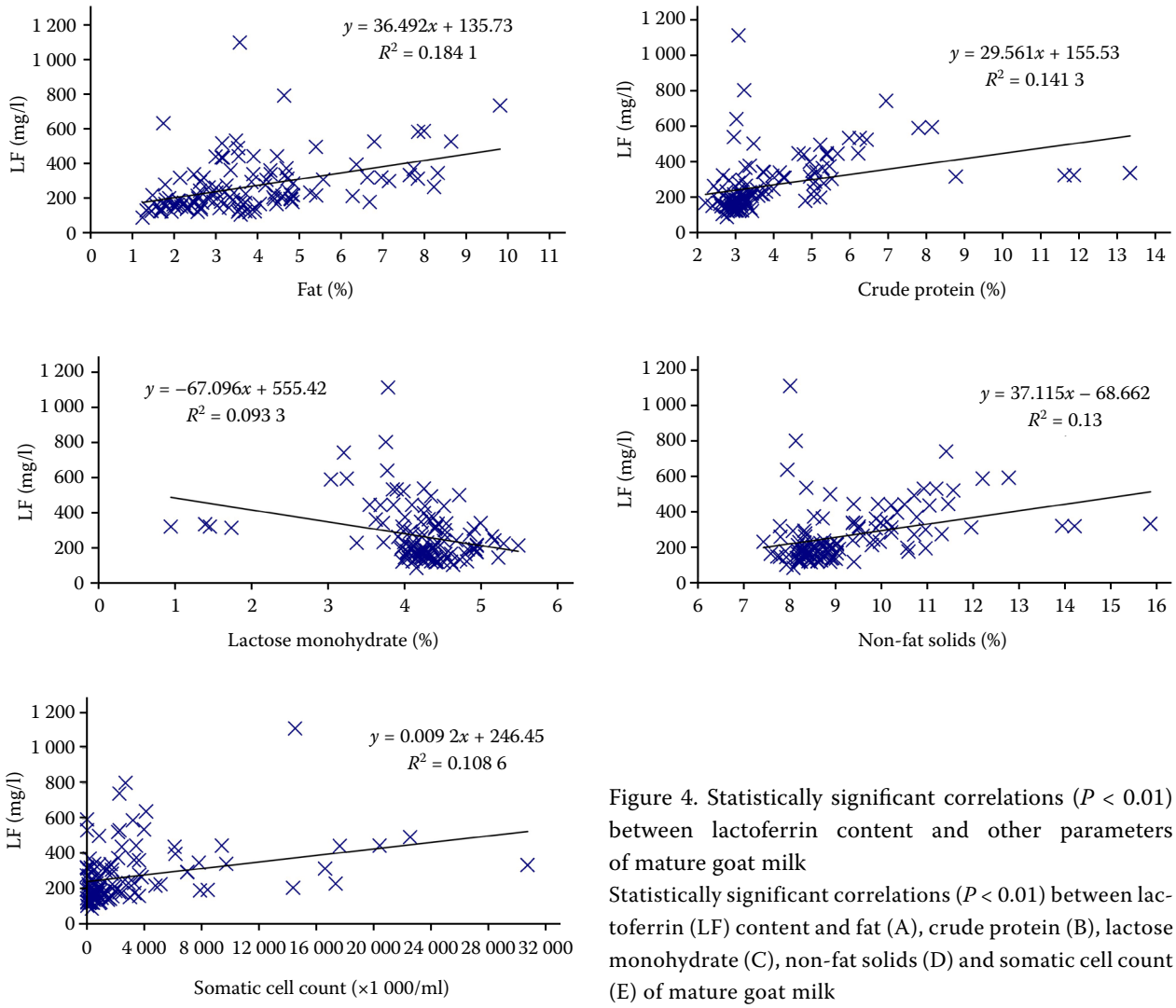

Figure 4. Statistically significant correlations ($P < 0.01$) between lactoferrin content and other parameters of mature goat milk

Statistically significant correlations ($P < 0.01$) between lactoferrin (LF) content and fat (A), crude protein (B), lactose monohydrate (C), non-fat solids (D) and somatic cell count (E) of mature goat milk

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Table 5. Correlation coefficients of linear regression relationships between goat milk components

	CP	L	SNF	SCC	Log SCC	LF	Log LF
F	0.640***	–0.308**	0.643***	0.193 (ns)	–0.020 (ns)	0.429***	0.503***
CP	–	–0.761***	0.968***	0.464***	–0.000 (ns)	0.376**	0.465***
L	–	–	–0.601***	–0.425***	–0.129 (ns)	–0.305**	–0.327**
SNF	–	–	–	0.424***	–0.039 (ns)	0.361**	0.461***
SCC	–	–	–	–	–	0.330**	0.364**
Log SCC	–	–	–	–	–	0.312**	0.348**

Significant at *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; not significant (ns) at $P > 0.05$

CP = crude protein; F = fat; L = lactose monohydrate; LF = lactoferrin; SCC = somatic cell count; SNF = non-fat solids; TS = total solids

According to Chen et al. (2018), the stage of lactation influences CP content in the milk of Laoshan goats. They saw a sudden decrease in CP content on day 255 of lactation, followed by an increase in values late in lactation, but there was no statistically significant difference ($P < 0.05$) between values measured on days 255 and 285. In our study, CP concentration also showed a slight increase at the end of lactation (from the 6th month postpartum).

We found that CP content in mature milk was significantly correlated with L content ($r = –0.761$, $P < 0.001$), SNF content ($r = 0.968$, $P < 0.001$), SCC ($r = 0.464$, $P < 0.001$) and with LF content ($r = 0.376$, $P < 0.05$). Wang et al. (2018) have also observed a positive correlation between LF and protein in goat milk ($r = 0.157$, $P = 0.004$).

Total solids (TS) and non-fat solids (SNF). The average TS and SNF concentrations from day 15 of lactation to the end of lactation are shown in Table 4. The average TS content in mature milk was 13.39 ± 3.61 g/100 g, and the SNF content was 9.28 ± 1.53 g/100 g. TS contents varied considerably as seen by the minimum (9.93 g/100 g) and maximum (19.50 g/100 g) values. TS and SNF concentrations decreased from the end of the colostral period, with the lowest values for TS and SNF recorded at months 6 and 5 postpartum, respectively, after which they increased gradually until the end of lactation. The variability in the content of mature milk, even if it is accompanied by completely similar trends of change, was confirmed by other studies (Sanchez-Macias et al. 2014; Chen et al. 2018; Wang et al. 2018). Rachman et al. (2015) found that the difference in SNF content is influenced by genetic factors and diet management (feed intake, feed quality and feed type). Statistical evaluation of our results revealed significant correlations between SNF and SCC ($r = 0.424$, $P < 0.001$), LF ($r = 0.361$, $P < 0.01$). A positive, statistically significant correlation between LF and SNF ($r = 0.216$, $P < 0.01$) was also reported by Wang et al. (2018).

Lactose content (L). The mean L content of mature milk samples was 4.17 ± 0.72 g/100 g. During lactation, the L content of mature milk fluctuated between 3.58 and 4.69 g/100 g. The highest L concentration was on day 30 postpartum, followed by a decrease until the end of lactation. The lowest value was measured at the end of the study period, i.e. 9 months postpartum (3.58 g/100 g). Similarly, Chen et al. (2018) reported the lowest value of L (3.57 ± 0.20%) in milk of Laoshan goats late in lactation (day 255). The maximum (4.62%) in their study was measured on day 15 of lactation, followed by a decrease in the values to day 255, after which, unlike what we see in our results, there was an increase followed by another decrease.

Higher concentrations of L were measured in the milk from Majorera goats. On day 15 of lactation, the average L concentration was 5.10%, while the concentration increased gradually up to 5.48 and 5.44% on day 60 and 90 of lactation, respectively (Sanchez-Macias et al. 2014). According to Wang et al. (2018), the highest L concentration was at week 3 of lactation (4.49 ± 0.33%) and the lowest at week 31 of lactation (3.88 ± 0.31%).

Our analyses revealed significant correlations between L and SNF ($r = –0.601$, $P < 0.001$), SCC ($r = –0.425$, $P < 0.001$), LF ($r = –0.327$, $P < 0.01$; see Table 4). On the other hand, Wang et al. (2018) found a positive correlation between L and LF ($r = 0.186$, $P = 0.001$) in goat milk.

Fat content (F). From the analyses of individual samples in our study, it is evident that F is a variable component of milk (vx = 48.2%). In individual

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samples of mature milk, the F content varied from 1.23 g/100 g to 9.79 g/100 g. Mature goat milk contained 3.84 ± 1.85 g/100 g fat on average, with the highest value in mature milk (6.71 ± 1.87 g/100 g) recorded on day 15 of lactation. The value subsequently decreased until the end of month 4 when it reached the lowest F value we measured (2.07 ± 0.87 g/100 g). F content then increased until the end of lactation. The average F content in mature goat milk is consistent with the values reported for goat milk (3.8%) in a review article by Kumar et al. (2016). Higher values (6.40 g/100 g) in early lactation (the first 11 days of lactation) were also reported by Hadjipanayitou (1995). Lipids are the main component of goat milk, and, according to Mehra et al. (2021), they play a vital role in regulating the body temperature and providing energy to the body. The average F content can vary over a range as wide as 2.46% to 7.76%.

Our analyses showed statistically significant positive correlations between F and CP (r = 0.640, P < 0.001), SNF (r = 0.643, P < 0.01), LF (r = 0.429, P < 0.001) and a significant negative correlation between F and L (r = –0.308, P < 0.01).

Somatic cell count (SCC) and log SCC. Somatic cell count (SCC) is an important indicator of the mammary gland health and, at the same time, it is an important determinant of hygiene in bovine milk. Unlike in bovine milk, SCC in goat milk cannot be reliably used in the diagnosis of mastitis as goat milk naturally contains a higher number of SCs and there are a number of non-infectious factors that significantly affect SCC. However, the mammary gland infection in goats is also an important contributor to increased SCC (Paape et al. 2001).

Due to different mechanism of secretion in goats and the high variability of SCC even in healthy animals, opinions regarding the threshold values for SCC in goat milk are not consistent. Unlike in bovine milk, no threshold value has currently been set in the EU for SCC in goat milk. In an extensive review, Jimenez-Granado et al. (2014) reported that in some countries national or regional thresholds have been defined for SCC in bulk milk samples in an effort to assess the quality of goat milk purchases. For example, in the USA and in France, the SCC threshold for goat milk is 1 000 × 10^3 cells/ml (Jimenez-Granado et al. 2014). Raynal-Ljutovac et al. (2007) reported that in Italy premium pricing can be applied to milk if the SCC is below 1 300 × 10^3 cells/ml, and conversely a price discount may be necessary for SCC above 1 800 × 10^3 cells/ml.

We analysed a total of 120 individual goat milk samples obtained from 12 goats at monthly intervals from day 15 to the end of lactation. The arithmetic mean SCC was 3 172 ± 5 614 × 10^3 cells/ml, log SCC 2.96 ± 0.76 (Table 4). The SCC values in the individual samples varied widely (vx = 177%). As can be seen in Table 4, SCC decreased until the end of the 2nd month of lactation before increasing (3rd month and later). There were no significant changes in SCC from then on until 6 months postpartum, when we saw an increase from the end of the 7th month to the end of lactation. These results confirmed that physiologically, there is an upward trend of SCC in dairy goats as lactation progresses (Rota et al. 1993; Hiss et al. 2008; Jimenez-Granado et al. 2014). In our study, the lowest SCC value (569 ± 281 × 10^3 cells/ml) was recorded in samples collected 2 months postpartum, which is consistent with the finding that the SCC values are usually minimum at the time of peak milk production due to the dilution effect, as reported by Rota et al. (1993), who recorded the lowest SCC value (580 × 10^3 cells/ml) at 5–6 weeks of lactation. Sanchez-Macias et al. (2014) found the lowest SCC value (458 × 10^3 cells/ml) on day 60 among the samples of mature milk collected in the first 90 days postpartum. Hiss et al. (2008) reported increasing SCC values as lactation progressed: SCC value was 486 ± 111 × 10^3 cells/ml at week 5 of lactation, 1 030 ± 187 × 10^3 cells/ml at week 31, and 4 295 ± 954 × 10^3 cells/ml at week 43. In our study, the mean SCC at 9 months postpartum was 6 017 ± 9 315 × 10^3 cells/ml.

High variability in goat milk SCC was widely cited in the published literature (Rota et al. 1993; Hiss et al. 2008; Hanus et al. 2017; Podhorecka et al. 2021; Desidera et al. 2025). Paape et al. (2001) reported that the average SCC in milk of healthy goats ranged from 270 to 2 000 × 10^3 cells/ml (geometric mean 672 × 10^3 cells/ml; arithmetic mean 675 × 10^3 cells/ml). In milk from goats with the mammary gland infection, SCC is significantly higher – between 659 and 4 213 × 10^3 cells/ml (geometric mean 1 641 × 10^3 cells/ml; arithmetic mean 2 076 × 10^3 cells/ml).

Desidera et al. (2025) analysed 360 individual milk samples taken from 40 lactating goats. The mean SCC was 852 × 10^3 cells/ml (geometric mean 287 × 10^3 cells/ml; median 317 × 10^3 cells/ml). Hanus et al. (2017) focused on the prediction and quantification of milk yield loss in goats based

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on SCC. They examined a total of 1 173 individual milk samples over a 2-year period. The arithmetic mean of SCC was 1 400 × 10^3 cells/ml but it was highly variable (128%) – something we see in our study as well. Podhorecka et al. (2021) examined 34 individual goat milk samples collected during the summer (August). The arithmetic mean of SCC in milk from goats on their second lactation was 1 456 × 10^3 cells/ml, and 1 338 × 10^3 cells/ml in milk from the third lactation. Rota et al. (1993) collected milk samples from 100 Verata goats over a 210-day lactation. The arithmetic mean of SCC was 1 920 × 10^3 cells/ml, and the SCC was significantly affected ($P < 0.05$) by lactation number and tended to increase from the first to the fourth lactation.

Some studies have focused on SCC changes and their effect on the technological properties of goat milk. Desidera et al. (2025) focused on several key factors affecting milk quality and its coagulation properties. They reported that the SCC levels above 2 million cells per ml significantly affected milk curdling, slowed the curdling process, and reduced the curd strength – all factors critical for cheese production. In their opinion, monitoring SCC and physiological changes during lactation is essential to ensure optimal milk quality and improve curdling, which ultimately leads to higher cheese yields and higher quality of the final product.

A study by Podhorecka et al. (2021) showed that milk with high SCC without proven mammary gland pathogens also showed altered technological properties. The first changes in the milk composition were observed at SCC values as low as 600 × 10^3 cells/ml.

We found statistically significant positive correlations between SCC and LF ($r = 0.330$, $P < 0.01$) and log LF ($r = 0.364$, $P < 0.01$). Similarly, we also found statistically significant correlations between log SCC and LF ($r = 0.312$, $P < 0.01$) and log LF ($r = 0.348$, $P < 0.01$). The correlations between SCC and LF show that the concentration of LF in milk increases with increasing SC numbers. Hiss et al. (2008) reported that milk with SCC > 430 × 10^3 cells/ml has the significantly higher LF content ($P < 0.05$) than milk with SCC < 430 × 10^3 cells/ml.

Chen et al. (2004) investigated changes in SCC and LF in milk from mastitic goats. The average SCC in milk from healthy goats was 300–400 × 10^3 cells/ml. In milk from goats with *S. aureus*-infected mammary glands, the SCC was 3 000 × 10^3 cells/ml after 24 h and 4 000 × 10^3 cells/ml after 48–72 hours. The difference between healthy and mastitic SCC was statistically significant ($P < 0.05$). In mastitic milk, there was a marked increase in LF content from the initial 10–30 mg/l to 1 000 mg/l after 72 hours. The mean LF content in mastitic milk after 72 h (587 ± 120 mg/l) was significantly higher ($P < 0.05$). These results further showed that the SCC increase occurred after 24 h, whereas the increase in LF occurred only after 48 h of the mammary gland infection. These results confirm the high correlation between LF and SCC concentrations at 48 h and 72 h ($r = 0.973$ and $r = 0.891$, respectively).

We also found positive, statistically significant correlations between SCC and LF, confirming that LF concentration increases with increasing SCC.

CONCLUSION

This study builds on our previous work that dealt with the content of lactoferrin in relation to other milk parameters in the context of possible early detection of mastitis in dairy cattle. Since the lactoferrin content is influenced by, among other factors, mammalian species, breed, individuality, lactation stage and health status (rise of somatic cells), this study focused on verifying and describing the effect of these factors on the lactoferrin content in non-bovine milk (goat's milk) in the context of other important parameters of goat's milk. From the results of the present study, it can be summarised that the individuality of the animal is an extremely important factor influencing the content of goat lactoferrin.

Other important findings resulting from the analyses of correlation relationships of lactoferrin and other important parameters in goat's milk clearly indicate the fact that, like in the case of cow's milk, the concentration of LF is also reflected in the health of the mammary glands and thus in the quality of the milk produced. These findings are of fundamental importance for the potential use of lactoferrin concentration for the detection of the mammary gland disease (mastitis) in the context of the fact that in small ruminants the somatic cell count criterion has limited informative power. Finally, due to the high degree of homology between goat and human LF, the results highlight the nutritional importance of goat colostrum, especially for human consumption.

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Conflict of interest

The authors declare no conflict of interest.

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