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RESEARCH ARTICLE

Variations in the Mineral Profiles of the Micellar and Water-Soluble Fractions of Goat Milk between the First and Second Lactations

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Abstract

A. A. Lechuga-Arana, R. Rosiles-Martínez, A. J. Gutierrez-Chavez, N. Ghavipanje, and E. Vargas-Bello-Pérez. 2025. Variations in the Mineral Profiles of the Micellar and Water-Soluble Fractions of Goat Milk between the First and Second Lactations. Int. J. Agric. Nat. Resour. 11-27. The objective of this study was to determine the variations in the mineral profile of the micellar and water-soluble fractions of goat milk between the first and second lactations. Twenty Saanen dairy goats in their first (n=10) or second lactation (n=10) were randomly selected for this trial. Milk samples were obtained monthly from all the animals for seven months. The concentrations of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), phosphorous (P), iron (Fe), copper (Cu), zinc (Zn), selenium (Se), nickel (Ni), cadmium (Cd), and arsenic (As) in both the water-soluble and micellar fractions were analyzed. Na, Mg, Zn, K, and As were positively correlated with both total milk production and lactation days in the first-lactation dairy goats (r>0.9; $p<0.05$). For the second-lactation goats, Ca, Se, and P had negative correlation coefficients with days in lactation (r<-0.75; $p<0.05$). Overall, the mineral contents in the micellar and water-soluble fractions of first- and second-lactation goats varied throughout lactation. The concentrations of essential elements in the milk of goats from the first and second births did not significantly differ. The distribution of essential and toxic minerals in the micellar and aqueous fractions found in goat milk is important for identifying the fraction with the highest percentage of recorded concentration of a particular mineral, especially toxic ones. For example, the content of arsenic in goat milk was above the international standard allowed for drinking water (10 µg L^{-1}), which is important for monitoring the quality and safety of goat milk.

Keywords: Goat, milk, lactation curve, micellar, heavy metals.

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Highlights

- Potassium was the main mineral distributed in the water-soluble fraction in goat's milk.
- Monitoring mineral content is goat's milk is important to detect toxic elements such as arsenic.
- Monitoring the stage of lactation where some minerals are relatively high is important for milk processing.

Introduction

Dairy goats account for 2.2% of total annual global milk production worldwide, contributing approximately 18.7 million tons of milk per year (Hammam et al., 2022). The unique nutritional and functional properties of goat milk, including increased digestibility, high protein content, buffering capacity, alkalinity, and minerals, have attracted significant attention (Nayik et al., 2022; Singh et al., 2021). The mineral composition of goat milk could indicate that it is a nutrient-rich food (Tripathi et al., 1999; Biadała & Konieczny, 2018; Pan et al., 2024). Several studies have focused on exploring the mineral elements in milk from various species. For example, Denholm et al. (2019) analyzed mineral elements (including Ca, Mg, K, P, and Zn) in cow milk using inductively coupled plasma–mass spectrometry. Moreover, the concentrations of 11 mineral elements, including Fe, Cu, and Zn, in goat milk are also well established (Liu et al., 2019). Astolfi et al. (2020) compared the concentrations of 41 elements in milk from goats, donkeys, and cows. Although the mineral composition of milk has been well studied, there is very little information regarding the distribution of minerals between the soluble and colloidal phases of goat milk compared with cow and buffalo milk. Therefore, the study of mineral bioavailability in goat milk allows evaluation of the influence of its composition on the mineral content of dairy products, given that in Mexico, milk is used mainly for making cheese and sweets (De la Fuente et al., 1997; Ducoing, 2011).

Essential mineral element concentrations should remain within narrow limits to safeguard tissue functionality, structure, and overall animal health and productivity. Consuming an insufficient, imbalanced, or overly concentrated mineral ratio causes shifts in their form and/or concentration in tissues and fluids, possibly affecting production parameters. Susceptibility to deficiency or toxicity in goats differs with diet, sex, stage of lactation, and genetics (Nayik et al., 2022; Underwood & Suttle, 2003).

Among the essential mineral elements for livestock are some with potentially toxic properties, such as iron (Fe), zinc (Zn), selenium (Se), and copper (Cu) (Underwood & Suttle, 2003; Astolfi et al., 2020). However, other heavy metals [mercury (Hg), arsenic (As), lead (Pb), or cadmium (Cd)] do not fulfill a known physiological function but are incorporated into the food chain. These metals are potentially toxic and bioaccumulative in milk and dairy products (Li et al., 2005). Thus, it is worth noting the potential risk that the various products of animal origin come from fed cattle and are in contaminated regions, including goats, so periodic monitoring of the concentrations of different toxic metals in milk and food is considered necessary (Crout et al., 2004).

This study aimed to assess the variation in the content of mineral elements in the micellar and water-soluble fractions of milk during the first and second lactations of Saanen goats. Additionally, the following objectives were pursued: 1) determine the relationship of the lactation curve of Saanen goats with the mineral concentration, and 2) determine the distribution of the essential mineral elements, namely, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), phosphorous (P), iron (Fe), copper (Cu), zinc (Zn), and selenium (Se), as well as the toxic mineral elements, namely, nickel (Ni), cadmium (Cd), and arsenic (As), in the micellar and water-soluble portions in the first- and second-lactation goat milk. The results of this study not only help us understand the relationship between mineral bioavailability and lactation but also help us make nutritional adjustments on the basis of the state and level of production.

Materials and methods

Study site

The study was carried out in the "Puente Colorado" goat milk production unit, Apaseo el Grande, Guanajuato, Mexico (located at 1,767 meters above sea level, with a temperate-dry climate). The milk production system was intensive and incorporated mechanical milking. The unit keeps individual production records as well as reproductive parameters. In total, 20 Saanen dairy goats in their first (n=10) or second lactation (n=10) were randomly selected for this trial. All the animals were fed a diet with an 84:16 forage (corn silage and alfalfa hay)-to-concentrate ratio. The chemical composition of the diet for lactating goats based on dry matter (DM) was 18.5% protein, 3.5% fat, 9.0% ash, and 52% nitrogen-free extract. Animal studies were carried out according to the Animal Care and Use Committee protocols from Facultad de Medicina Veterinaria y Zootecnia of Universidad Nacional Autónoma de México (thesis ID 97142052).

Sampling and laboratory analysis

The sampling started in March 2011 and ended in September 2011, resulting in seven monthly samples for each first-lactation goat. For the second-lactation goats, the sampling ended in November 2011, resulting in a nine monthly samples for each goat. Only the afternoon milking (at 15:00 h) was sampled because of the farm's logistical restrictions. Monthly individual milk samples (30 mL $goat^{-1}$) were collected into sterile 50 mL centrifuge tubes and kept frozen (-20 °C) until analysis. Similarly, a monthly sample of the diets was taken from the animals in production (30 g), and 50 mL of drinking water in sterile polypropylene bottles was also harvested for analysis. The contents of the minerals in the micellar and water-soluble fractions of the monthly milk samples from each goat were analyzed.

The mineral contents of the milk samples were analyzed as follows: 2 mL of raw milk was combined with 8 mL of HPLC-grade methanol (1:4 ratio) and centrifuged at 3500 rpm for 15 min to ensure proper protein sedimentation. Supernatants containing water-soluble components were separated into separate vials, while residual micelles remaining at the bottom of the original tubes were dried overnight at 30 °C for accurate mass measurement. After drying, the micelle weights were determined via mass differences. Following this stage, the micelles undergo acid hydrolysis with 2 mL of nitric acid (Baker® ACS) and heat until complete evaporation ensues (Hernandez, 2011). The samples were subsequently cooled and graduated to 16 mL with demineralized water. All the samples were filtered with filter paper (Whatman® No. 1).

The essential mineral elements were analyzed as follows: Na and K by atomic emission; Ca, Mg, Fe, Cu and Zn by atomic absorption with a flame; Se by a hydride generator; and P by colorimetry. The concentrations of the toxic mineral elements Cd and Ni were analyzed via flame atomic absorption spectroscopy, and As was analyzed via a hydride generator.

For mineral determination in the diet, 1 g per dried sample was ground into 1 mm particles, followed by incineration at 450 °C for 5 h. An ash suspension was obtained after adding hydrochloric acid diluted with distilled water. Additionally, measurements of the minerals in the water were carried out directly.

Adjusting the lactation curves

For the prediction of lactation curves, individual milk records (kg) within each group (n=10) were used.

The Wood gamma model (Wood, 1967) was used to describe the lactation curves:

$$Yt = at ^ b e ^ (- ct)$$

where:

Yt = milk yield on day t; t = day of lactation; e = base of natural logarithms; and a (initial milk yield after delivery), b (slope of the curve before peak), and c (slope of the curve after peak).

The model was fitted to test-day milk yield records using the NLIN procedure of SAS (SAS Institute Inc.). Using the model estimators, the following parameters were calculated: 1) day of production peak (Tmax), with the expression b/(- 1 * c); 2) the maximum milk yield to the peak (Ymax), with the expression a [b/(- 1 * c)] b * (1/b); and 3) persistence (s), with the expression (b + 1) * - ln (-1 * c) + ln (b + 1).

Analysis of the mineral concentration adjusted to the lactation curve

After determining the mineral percentages within milk fractions, we calculated changing mineral concentrations considering the lactation curve. By multiplying the mineral concentration (µg mL^{-1} or ng mL^{-1}) by the daily milk yield (kg), we generated an average mineral concentration adjusted for milk output per sampling timeframe. Comparisons of modified mineral concentration trends with predicted lactation curves revealed patterns consistent with dairy production fluctuations. The results of the Kolmogorov–Smirnov and Bartlett tests confirmed a Gaussian distribution and homoscedasticity, satisfying the prerequisites for parametric analysis. Repeated-measures ANOVA, followed by Bonferroni's post hoc comparative test, was used to evaluate average mineral concentrations relative to curve lactation stages. T tests were used to compare mineral element concentrations during lactation with those during the initial and final stages. All figures and statistical evaluations were performed using the Prism 5.03 software, and the data are presented as the mean values ± SEMs unless otherwise stated. Statistical significance was set at $p<0.05$. In this study, no time or interaction effects were found between sampling time and mineral concentration; therefore, those data are not reported.

Results

Characteristics of the first and second lactations of goats

On the basis of these results, the Wood Gamma Model was used to estimate the daily milk production of first- and second-lactation goats, with lactation periods of 175 and 279 days, respectively; the second-lactation goats had a significantly greater production of milk (Fig. S1). Quantitative analysis of milk yield revealed different initial productions (parameter a; first: 0.53 vs. second: 1.47) and curve slopes before the peak (parameter b; first: 0.521 vs. second: 0.32) (Table S1).

Mineral content in milk fractions, diet, and water

For both groups, K was present in greater proportions in the water-soluble fraction, whereas Fe and Cu were not detected in any fraction. The remaining essential mineral elements were mainly distributed in the micellar fraction. With respect to the toxic mineral elements, only As was detected, which was distributed in the micellar fraction (Table 1). Additionally, the mineral contents of the feedstuffs and drinking water of Saanen dairy goats, as well as an estimation of total mineral intake, are provided in Table S2 and Table S3, respectively.

Essential minerals in milk

The Na concentration (µg mL^{-1}) was greater in the first-lactation group than in the second-lactation group, peaking after 100 days of lactation (Fig. S2). During the first lactation, sodium increased gradually after the peak of lactation ($p<0.05$). However, during the second lactation, the sodium concentration did not change ($p>0.05$). The Ca concentration (µg mL^{-1}) showed greater variation in the first lactation than in the second lactation, where consistent concentrations were recorded

Table 1. Percentage of mineral distribution between the micellar and water-soluble fractions of milk from first- and second-lactation goats.

Mineral elements (%)		First-lactation goats		Second-lactation goats	
		Fraction			
		Micellar	water-soluble	Micellar	water-soluble
Essential	Na	74.0 *	26.0	73.1	26.9
	K	44.0	56.0 *	37.7	62.3
	Ca	99.7 *	0.3	99.8	0.2
	Mg	86.6 *	13.4	86.0	14.0
	Fe	ND	ND	ND	ND
	Cu	ND	ND	ND	ND
	Zn	100 *	0	100	0
	Se	100 *	0	100	0
	P	86.0 *	14.0	87.5	12.5
Toxic	Ni	ND	ND	ND	ND
	Cd	ND	ND	ND	ND
	As	100 *	0	100	0

*Indicates the fraction with the highest percentage concentration of each mineral. ND. Not detected

in each sampling (Fig. S3). The maximum level of Ca was observed at the peak of lactation for both groups and was greater in second-lactation goats, and the Ca level decreased gradually as lactation progressed ($p<0.05$). There was a steady increase in the Mg concentration as lactation progressed in first-lactation goats (Fig. S4). Additionally, Mg levels after the lactation peak were significantly higher in first-lactation goats than in second-lactation goats ($p<0.05$). The Zn concentrations ranged from 3–60 μg mL^{-1} for both groups throughout lactation (Fig. S5). Zn levels gradually decreased as lactation progressed in the second-lactation goats, whereas an increasing trend was observed in the first lactation goats ($p<0.05$) (Fig. S5). Among all the essential minerals, Se presented the lowest concentrations in both groups (50 to 400 ng mL^{-1}) (Fig. S6). After the lactation peak, the Se level was greater in the first-lactation goats ($p<0.05$). The concentration of P in milk did not significantly differ between first- and second-lactation goats. The adjusted P content showed a similar behavior to that of the adjusted milk yield curve (Fig. S7). K had the highest concentration of water-soluble minerals, which increased in both groups as lactation progressed ($p<0.05$) (Fig. S8).

Toxic mineral elements in milk

Arsenic was the sole toxic mineral detected in the micellar fraction, exhibiting a notable increase as lactation progressed in primiparous goats ($p<0.05$), whereas the second-lactation group presented a decreasing trend (Fig. S9).

Changes in mineral concentration during the first and second lactation

The correlations between the adjusted mineral concentration and milk production duration during the lactation period are shown in Table 2. In particular, Na, Mg, Zn, K, and As were positively correlated with first-lactation goats ($r>0.9$; $p<0.05$). However, for the second-lactation goats, the results revealed a negative correlation for Ca, Se, and P ($r<-0.75$; $p<0.05$). No significant differences in mineral content were found between the first and second lactations (Table 3).

Table 2. Pearson linear correlation coefficients (r) of mineral concentration a long of lactation period.

Minerals		Lactation	
		First	Second
Essential	Na	0.95*	-0.63
	Ca	-0.16	-0.87 *
	Mg	0.95*	-0.10
	Zn	0.89 *	-0.70
	Se	0.46	-0.92 *
	P	0.57	-0.76 *
	K	0.91*	0.29
Toxic	As	0.80 *	-0.62

* indicates a significant correlation coefficient at the $p<0.05$.

Table 3. Mean ± SE of the highest mineral concentration (µg/mL) in the milk of first- and second-lactation goats.

Minerals	Lactation		*p* value
	First	Second	
Sodium	1770 ± 100.2	1750 ± 61.2	NS
Calcium	2525 ± 94.33	2625 ± 51.0	NS
Magnesium	679 ± 39.62	673 ± 22.82	NS
Zinc	19 ± 1.61	14 ± 0.4	NS
Selenium	0.210 ± 0.017	0.182 ± 0.018	NS
Phosphorous	4089 ± 218.3	3882 ± 141.9	NS
Potassium*	5956 ± 231.8	5922 ± 194.9	NS
Arsenic	0.182 ± 0.028	0.186 ± 0.015	NS

NS. Not significant (p > 0.05); *Water soluble fraction

Discussion

Characteristics of the first and second lactations of goats

Lactation curve characteristics in dairy cattle provide useful information about milk production traits, which can assist farmers in making informed decisions regarding nutrition and production management (León et al., 2012). Our results showed that the lactation peak for both first- and second-lactation goats occurred in the 10th and 9th weeks, respectively. Additionally, lactation persistence was greater in first-lactation goats (7.9 days) than in second-lactation goats. This coincides with the findings of Majid et al. (1994), who noted that Saanen goats typically reach the production peak between the 8th and 12th weeks postpartum. Similarly, goats reportedly reach a production peak 45 days postpartum on average (Kala & Prakash, 1990). Our results are also in line with those of previous reports showing that primiparous goats have lower initial production and a lower peak but greater persistence than multiparous goats do (Menéndez-Buxadera et al., 2010; León et al., 2012).

Mineral content in milk fractions

Minerals represent the smallest fraction of milk (8–9 g L^{-1}) and are composed of cations (Ca^{2+}, Mg^{2+}, $Na^{+,}$ and K^{+}) and anions (PO_4-3, $C_6H_8O_{7,}$ and Cl^{-}) (Gaucheron, 2005). Determining minerals in milk holds relevance, as the mineral fraction substantially influences casein micelle structure and stability (Pan et al., 2024).

In the case of milk, the concentration of some minerals is dependent on the absorption rate and serum or plasma levels, so the addition of mineral supplements to the diet favors their passage into milk (Goff, 2018). Furthermore, there are certain circumstances, such as those related to physiology (pregnancy) and metabolism (acidosis or lactation), where the mobilization of significant amounts of mineral elements within the organism can be observed (Gulson et al., 1998). In addition, the concentration of minerals, especially some metals, can be related to the protein content of milk (Allen & Miller, 1981). Importantly, trace minerals are important components of a wide variety of enzymatic and transport metal complexes in organisms (Smart et al., 1981; Lönnerdal, 2000), which can be regulated by molecular and ionic processes and even through the effects of some toxic elements (Ballatori, 2002).

The results of this study revealed that mineral elements, except for K, were detected mainly in the micellar portion of goat milk. It is widely recognized (Gaucheron, 2005) that milk comprises colloidal particles formed by a complex interplay between proteins and calcium phosphate, which are commonly referred to as casein micelles. Additionally, minerals are distributed differently between the water-soluble and micellar fractions of milk (Gaucheron, 2005). Hence, increasing the casein content in milk throughout lactation may lead to variations in the concentrations of various minerals linked to the micellar component of milk (Aganga et al., 2002). It has been well established (De la Fuente, 1997) that the casein micelles in goat milk possess higher amounts of Ca and P than those in cow milk. Therefore, it is not surprising that in the present study, we observed a greater share of these minerals in the goat milk micellar fraction, which is also in line with the findings of Pan et al. (2024).

Different methodologies (centrifugation, filtration, and HPLC to induce protein precipitation) for isolating milk fractions may contribute to inconsistent findings among studies examining minerals in milk fractions (De la Fuente et al., 1997). De la Fuente et al. (1997) reported that most of the Zn (87.5%) was found in the micellar fraction of goat milk; however, in this study, all the Zn contents were detected in the micellar fraction, which agreed with the findings of Pan et al. (2024), who reported that Zn was mainly distributed in the micellar fraction of goat milk, whereas Cimmino et al. (2023) reported that casein is the main binding agent for Zn in sheep and goat milk. Singh et al. (2021) reported that the Se distribution in milk is tied to the aqueous part rather than the fat fraction of milk. Gaucheron (2005) reported that K and Na are distributed in the water-soluble fraction of milk, explaining the greater presence of these elements in the aqueous phase of goat milk in the present study. De la Fuente et al. (1997) reported that the percentages of calcium, magnesium, and phosphorus in the soluble phase of goat milk were 33%, 66%, and 39%, respectively, which are higher than those reported in this investigation. Toxic mineral elements such as aluminum, lead, and cadmium can bind lipids and casein, promoting acidity, obstructing curdling, and causing "mineralization" of casein micelles (Ziarati et al., 2018).

Essential and toxic mineral elements in milk

The mineral content in goat milk may vary due to management practices, lactation stage, environmental conditions, genetics, and health status (Aganga et al., 2002; Nayik et al., 2022). Additionally, analytical method sensitivities play a main role in mineral determination (De la Fuente et al., 1997). In the present study, the lack of significant differences in mineral element contents between first- and second-lactation goats suggests that the variations in mineral content reported in previous studies could have arisen from the numerous aforementioned sources, which requires careful interpretation when conclusions are drawn. There is little information about the concentrations of As in milk and dairy products, and deeper exploration is needed. Data on the distribution of As in milk fractions are also scarce, with existing reports indicating As elimination in milk (Ziarati et al., 2018). It has also been reported that the content of As in different tissues and body fluids is directly related to the level of ingestion (Ziarati et al., 2018). Arsenic is a mineral widely distributed in the underground layer that is released into the environment naturally and by human activity. Since 2010, arsenic contamination in drinking water has been one of the major global public health concerns of the WHO (World Health Organization) due to the large number of people exposed worldwide and the association of arsenic with serious diseases (Fisher et al., 2017). Although the international limit is 10 $\mu g\ L^{-1}$ (Flanagan et al., 2012), in Mexico, authorities limit the amount of arsenic in drinking water to 25 $\mu g\ L^{-1}$ (NOM-127-SSA1-2021). In the Mexican states of Chihuahua, Coahuila, Durango, and Sonora, the arsenic concentrations exceed both of these limits, with arsenic concentrations ranging from 7 to 600 $\mu g\ L^{-1}$; nine other states, namely, Aguascalientes, Guanajuato, Jalisco, Morelos, Oaxaca, Puebla, San Luis Potosi, Hidalgo, and Zacatecas, continue to report arsenic concentrations above the current Mexican maximum contaminant limit for drinking water (Armienta & Segovia, 2008; Bundschuh et al., 2012). The quality of drinking water is important since the ingestion of water with such high arsenic concentrations can seriously affect animal and human health. Ismail et al. (2019) reported that normal levels of As in goat milk range between 2.10 and 3.40 mg L^{-1}, which are higher than those reported in the present study for both lactation groups. Pérez-Carrera and Fernández-Cirelli (2005) reported that the concentration of As in cow milk ranged from 0.0028 to 0.0105 $\mu g\ g^{-1}$. Additionally, the As concentrations in Danish farms ranged from 0.00025 to 0.23 $\mu g\ g^{-1}$, which is lower than the findings of the present study. Animals can tolerate low levels of tissue arsenic (<0.5 ppm) (el Bahri & Romdane, 1991). Estimates of arsenic requirements (25–50 $\mu g\ kg^{-1}$/DM) are well below those found in commercial rations or forage, and notably, the safety margin between the beneficial and toxic doses is very narrow (Underwood & Suttle, 2003). As previously mentioned, Fe, Cu, Ni, and Cd were not detected in our study, which is due to the sensitivity of the equipment used for detection.

Changes in mineral concentration throughout lactation

Pan et al. (2024) reported that the concentration of minerals in goat milk increases significantly from the first to the fourth lactation. Similarly, Aganga et al. (2002) reported that the content of minerals in milk varies between primiparous and multiparous goats. Similarly, Güzeler et al. (2010) reported that the mineral content (including Ca, P, K, and Mg) of milk from Saanen×Kilis dairy goats varied throughout lactation. The variations in the mineral content of goat milk across and between lactations are affected by multiple factors, leading to conflicting results in the literature; for example, Boroš and Herian (1989) reported increases in P, K, Na, Ca, and Mg as lactation progressed. However, Simos et al. (1991) reported that Ca levels gradually decreased during lactation, whereas the levels of other elements, such as Na, P, and K, increased. This finding coincides with our results, where a peak in Ca occurred at the 7th and 11th weeks postpartum in first- and second-lactation goats, followed by a gradual decrease until the end of lactation. The observed changes in Ca levels align with previous studies (Pan et al., 2024), highlighting the importance of Ca content fluctuations throughout lactation. Like our data, Antunac et al. (2001) reported significantly higher Ca and P levels at the beginning of lactation than in the middle third of lactation. Likewise, Pan et al. (2024) reported that Ca and P levels are higher in early lactation than at the end of lactation. The relatively constant Ca concentration in goat milk is essentially because casein levels are genetically governed and remain unaffected by diet (Nayik et al., 2022). It is well known that minerals penetrate milk easily when blood or plasma concentrations are high (Gaucheron, 2005). High-producing goats often experience a decrease in Ca and Mg at the start of lactation but recover by the middle of lactation (Mbassa, 1991). Boros and Herian

(1988) reported diminished levels of P at the onset of lactation, followed by a 3.4% increase near the end of lactation. While concentrations of Mg and Zn are typically associated with minor fluctuations in goat milk, the Se content closely tracks its dietary intake (Nayik et al., 2022).

Conclusions

The results revealed that the concentrations of minerals in the micellar and water-soluble fractions of first- and second-lactation goats varied throughout lactation; however, no significant differences were found between the two groups. Essential minerals, including Na, Ca, Mg, Zn, Se, and P, were found in the micellar fraction, while K was mainly distributed in the water-soluble fraction of goat milk. The partitioning of mineral elements in milk fractions remained unaffected by lactation. Among the toxic minerals, only As was detected in the micellar fraction of milk from both groups, making it an important bioindicator for monitoring the toxic minerals in goat milk. Further investigations are needed to clarify the underlying mechanisms and implications behind the distribution patterns of mineral elements across milk fractions. Overall, the results from this study are useful for identifying the stage of lactation where solids are relatively high for milk processing or for identifying the lactation stage where heavy metals are present at relatively high concentrations.

Conflicts of interest

The authors declare no conflicts of interest for this article.

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Supplementary material

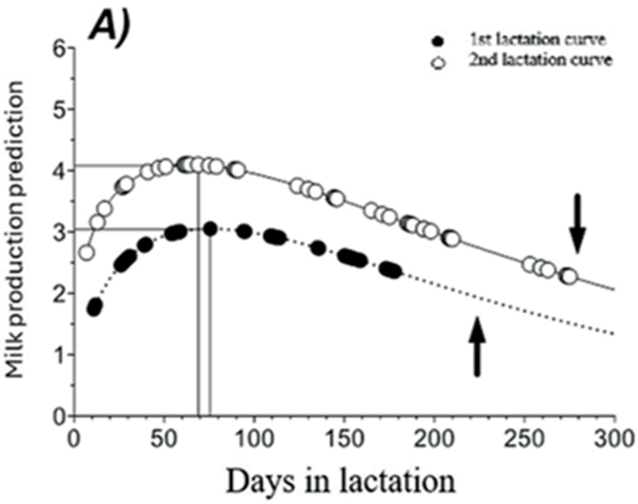


Figure S1. Lactation curves of the first and second lactating goats. The straight lines that cut the x and y axes indicate the day of peak production and maximum yield (Kg), respectively. The arrow indicates the drying time of lactating goats.

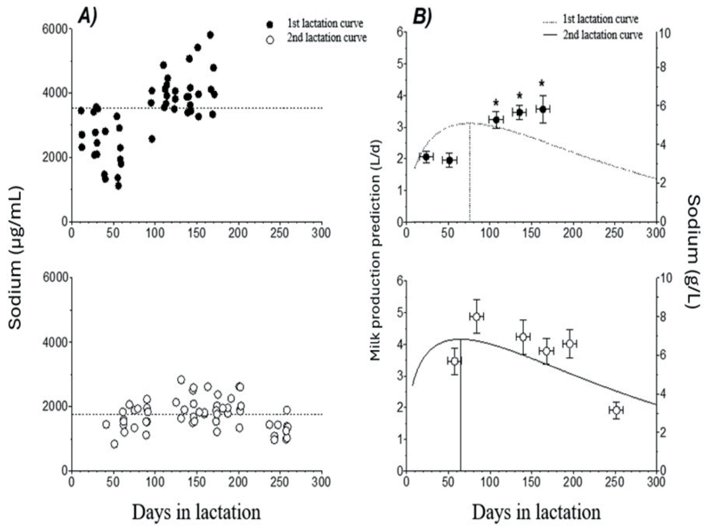


Figure S2. Scatter plots of sodium concentration (A) and average value of adjusted sodium concentration for total milk production during each sampling period (B).

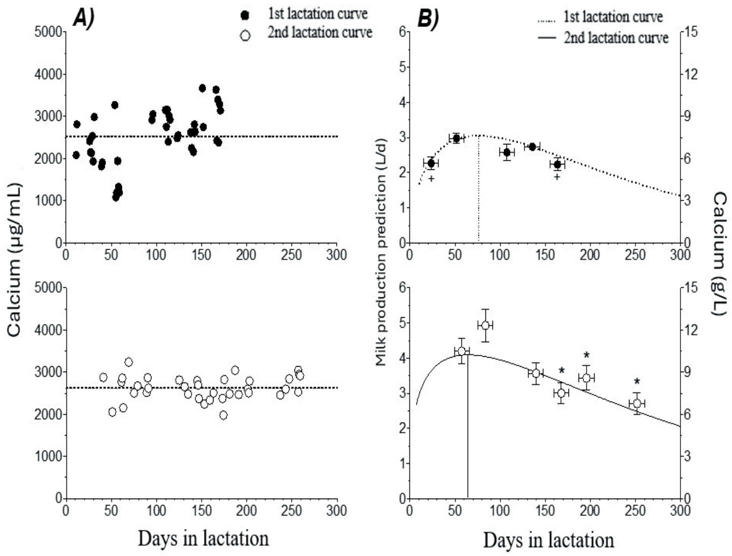
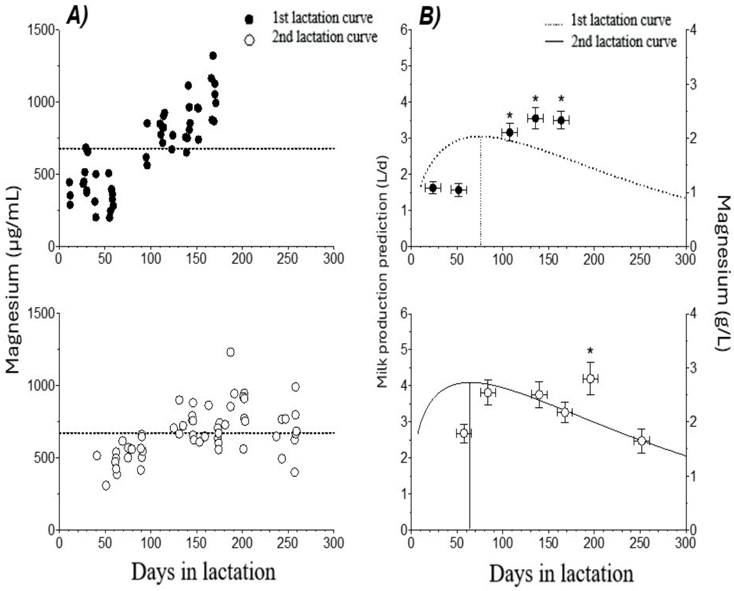


Figure S3. Scatter plots of calcium concentration (A) and average value of adjusted calcium concentration for total milk production during each sampling period (B).



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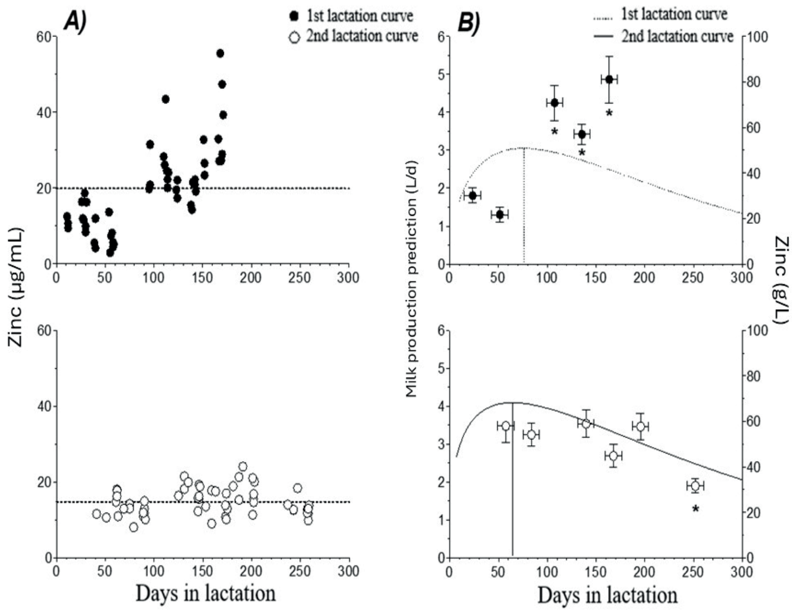

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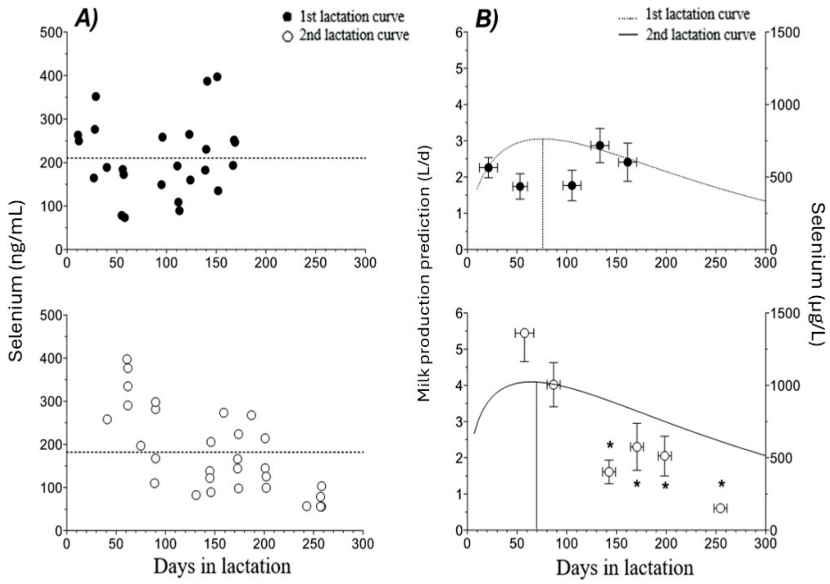

Figure S6. Scatter plots of selenium concentration (A) and average value of adjusted selenium concentration for total milk production during each sampling period (B).

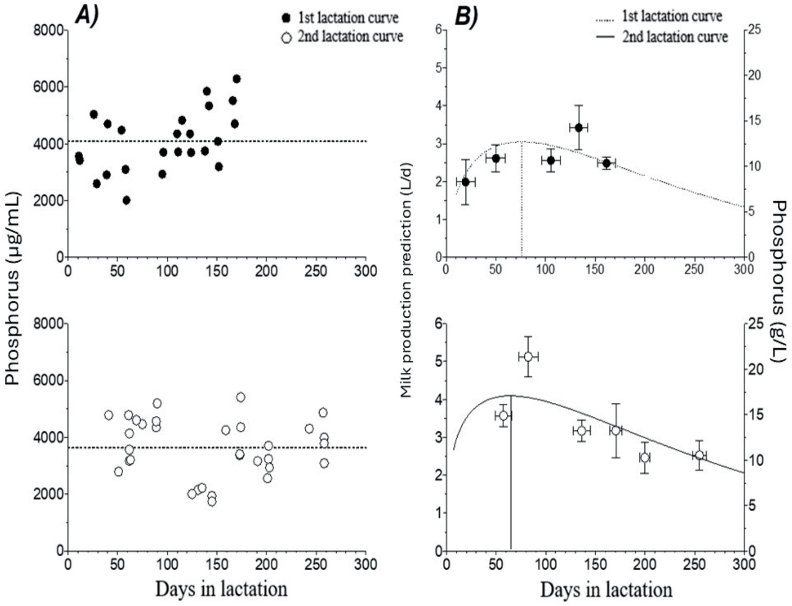

Figure S7. Scatter plots of phosphorous concentration (A) and average value of adjusted phosphorous concentration for total milk production during each sampling period (B).

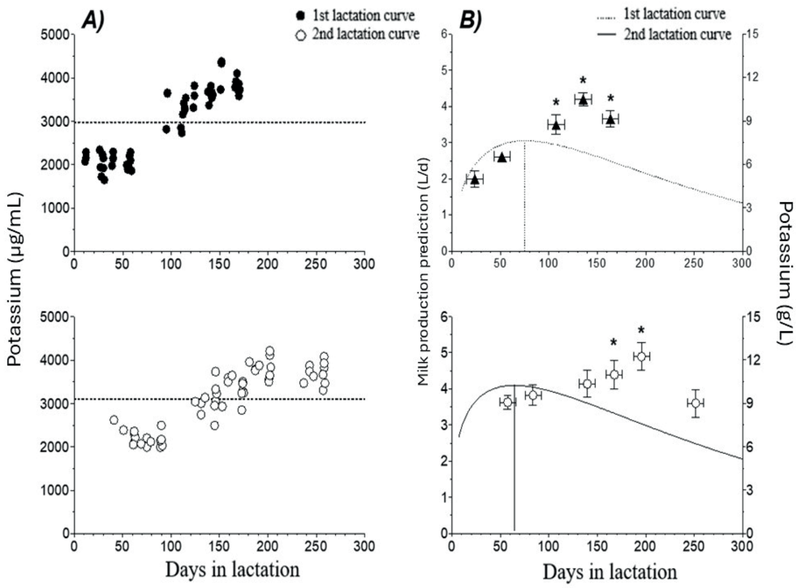

Figure S8. Scatter plots of potassium concentration (A) and average value of adjusted potassium concentration for total milk production during each sampling period (B).

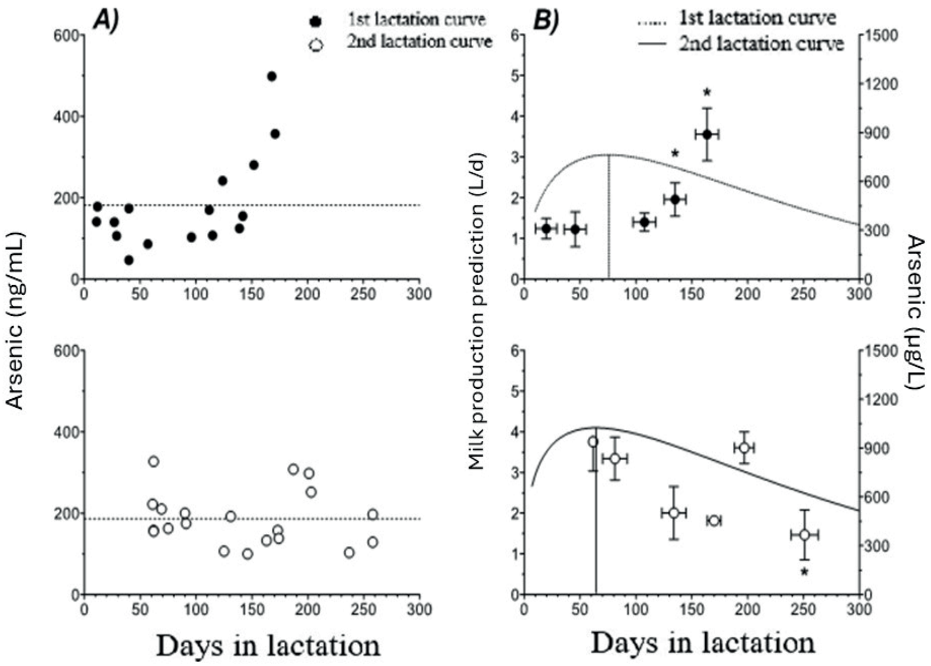

Figure S9. Scatter plots of Arsenic concentration (A) and average value of adjusted Arsenic concentration for total milk production during each sampling period (B).

Table S1. Characteristics (parameters ± S.E.) of the Wood gamma model for the prediction of the lactation curve in first and second lactation Saanen dairy goats.

Parameter	lactation	
	First	Second
a (initial milk yield)	0.53 ± 0.31	1.47 ± 0.31
b (slope of the curve before peak)	0.521 ± 0.10	0.32 ± 0.09
c (slope of the curve after peak)	-0.0069 ± 0.0014	-0.005 ± 0.001

Table S2. Mineral concentration of feedstuffs and drinking water of Saanen dairy goats.

Item	Minerals								
	Na	K	Mg	Ca	P	Se	As	Cd	Ni
Feedstuff (µg/g/DM)									
Corn silage	182 ± 52	3583 ± 1962	651 ± 285	357 ± 219	94 ± 139	0.064 ± 0.013	0.061	ND	ND
Alfalfa hay	1863 ± 279	17817 ± 3400	1099 ± 77	2093 ± 72	723 ± 313	0.049 ± 0.023	0.23 ± 0.17	ND	ND
Commercial concentrate*	1983 ± 891	10002 ± 1039	1169 ± 38	1843 ± 381	2449 ± 476	0.110 ± 0.067	1.11 ± 1.05	ND	ND
Water (µg/mL)	208 ± 41	18 ± 7	6 ± 2	ND	ND	ND	0.027 ± 0.008	ND	ND

ND=Not detected; DM= dry matter; *Supreme Dairy Goat Feed™ (www.ugrgg.com)

Table S3. Estimation of the total mineral intake (mg d-1) of Saanen goats.

Minerals (mg)	Diet	Water	Total
Sodium	4,801.1	2,496	7,297.1
Magnesium	3,157.9	72.0	3,229.9
Potassium	40,971.7	216.0	41,187.7
Selenium	0.0276	N.D.	0.0276
Arsenic	1.19	0.324	1.514
Calcium	5,225.6	ND	5,225.6
Phosphorous	3,010.9	ND	3,010.9

ND=Not detected; mg d-1= milligrams per day