



## Dairy Goat Farming at Different Altitudes in Indonesia: Implications for Feeding Practices, Milk Quality, and Manure Management

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### ABSTRACT

Due to its rich nutritional profile, goat milk is increasingly recognized as a viable alternative to cow's milk for human consumption. However, variation between dairy farming systems at different altitudes is unknown. This study aimed to compare dairy goat farm performances across three altitudinal zones in West Sumatra, Indonesia. Data were collected from three representative farms located at high (F1), mid (F2), and low (F3) altitude. Structured interviews were conducted to capture feeding, milking, and manure management practices. Samples of milk, feed, and manure were collected for laboratory analysis. Results indicate that the daily dry matter intake (DMI) ranging from 1.6 to 3.7 kg per animal. Average milk production was 1.10 kg head<sup>-1</sup> day<sup>-1</sup> in F1, 0.65 kg head<sup>-1</sup> day<sup>-1</sup> in F2, and 0.83 kg head<sup>-1</sup> day<sup>-1</sup> in F3. Goat milk on farm F3 exhibited significantly higher somatic cell counts and lower milk fat content compared with F1 and F2 ( $P < 0.05$ ). In contrast, F2 showed significantly higher milk protein, SNF, and lactose concentrations ( $P < 0.05$ ). Heat stress assessment indicated severe stress in goats at F1 and F2, while F3 experienced extreme heat stress. In conclusion, altitude influenced thermal stress levels in dairy goats, whereas farm management practices were important for determining milk yield and milk quality.

**Keywords:** Environment, milk goat, smallholder farms, sustainability, tropical livestock system

### ABSTRAK

Susu kambing memiliki kandungan nutrient yang bermanfaat untuk manusia. Penelitian ini bertujuan untuk membandingkan sistem produksi ternak kambing perah pada tiga zona ketinggian yang berbeda di Sumatra Barat, Indonesia. Data dikumpulkan dari tiga peternakan yang berada pada ketinggian yang berbeda : dataran tinggi (F1), dataran sedang (F2), dan dataran rendah (F3). Wawancara terstruktur dilakukan untuk memperoleh informasi mengenai manajemen pemberian pakan, pemerahan, dan pengelolaan kotoran ternak. Sampel susu, pakan, dan kotoran dikumpulkan untuk analisis laboratorium. Hasil penelitian menunjukkan bahwa konsumsi bahan kering harian berkisar antara 1,6 hingga 3,7 kg per ekor. Rata-rata produksi susu tercatat sebesar 1,10 kg ekor<sup>-1</sup> hari<sup>-1</sup> pada F1, 0,65 kg ekor<sup>-1</sup> hari<sup>-1</sup> pada F2, dan 0,83 kg ekor<sup>-1</sup> hari<sup>-1</sup> pada F3. Susu kambing pada peternakan F3 menunjukkan jumlah sel somatik yang signifikan lebih tinggi dan kandungan lemak susu yang lebih rendah dibandingkan dengan F1 dan F2 ( $P < 0,05$ ). Sebaliknya, F2 memiliki kandungan protein, solid non-fat (SNF), dan laktosa yang signifikan lebih tinggi ( $P < 0,05$ ). Penilaian stres panas menunjukkan bahwa kambing pada F1 dan F2 mengalami tingkat stres cukup berat, sedangkan pada F3 mengalami stres panas yang berat. Secara keseluruhan, ketinggian lokasi memengaruhi tingkat stres termal pada kambing perah, dan sistem manajemen berperan penting dalam menentukan produksi dan kualitas susu.

**Kata kunci:** Lingkungan, kambing perah, keberlanjutan, peternakan takyat, sistem produksi tropis

## INTRODUCTION

Dairy goat milk is increasingly recognized as a viable alternative to cow's milk for human consumption. As the global population continues to grow and demand for animal-source foods increases, diversifying milk production systems has become essential to ensure food and nutrition security. In this context, goat milk production has shown a steady global increase, rising from approximately 15.9 million tons in 2013 to 20.8 million tons in 2023. Asia accounts for the largest share of global goat milk production (56.3%), followed by Africa (23.6%), Europe (15.7%), and the Americas (4.4%). India is currently the world's leading producer, with an annual production of about 6.1 million tons of goat milk (FAO, 2025).

In Indonesia, the government is actively promoting the expansion of national milk production to reduce dependence on imports and improve population nutrition. This effort aligns with the Nutritious Meal Program (NMP), which aims to enhance child nutrition and educational performance, thereby supporting long-term human development and economic growth. Within this framework, dairy goat farming is expected to play an increasingly important role, particularly in regions where dairy cattle production faces constraints related to land availability, climate, and capital investment. National statistics indicate a positive trend in goat milk production over the past five years (2017–2023), with current production reaching approximately 0.3 million tons annually, reflecting growing interest in dairy goat development among smallholder farmers (Indonesian Statistic Bureau, 2024).

The increasing interest in goat milk is closely linked to its nutritional and functional properties. Goat milk contains balanced proportions of carbohydrates, proteins, fats, and essential macro- and micronutrients (Dos Santos *et al.* 2023; Verma *et al.* 2025). Compared with cow's milk, goat milk is generally more digestible, has lower allergenicity, contains a higher proportion of short-chain fatty acids, and features smaller fat globules, which enhance fat digestion and absorption (Getaneh *et al.* 2016; Prosser, 2021). These characteristics make goat milk particularly suitable for children, elderly individuals, and people with certain digestive or metabolic conditions (ALKaisy *et al.* 2023; Verma *et al.* 2025), and thus relevant to the objectives of national nutrition programs such as the NMP. In addition, dairy goat farming can contribute to the resilience of smallholder and marginalized communities in rural areas, by providing regular income opportunities and employment, especially in marginal or upland areas where cattle-based dairy systems may be economically less viable (Navarrete-Molina *et al.* 2024; Mutunga *et al.* 2023).

From an environmental perspective, dairy goat production is often considered to produce lower pressure than conventional dairy cattle systems. Small ruminants are estimated to contribute approximately 6.5% of global livestock-related greenhouse gas emissions, lower than the dairy cattle which contribute to 20% of global emissions. Emissions from dairy goat systems primarily originate from methane (CH<sub>4</sub>) produced during enteric fermentation,

methane and nitrous oxide (N<sub>2</sub>O) from manure management, and carbon dioxide (CO<sub>2</sub>) and N<sub>2</sub>O associated with feed production, processing, and transportation (Gerber, 2013; Horrillo *et al.* 2024). Understanding how farm management practices influence these emission sources is essential for developing more sustainable livestock systems.

Despite the growing potential of dairy goats, research on dairy goat farming systems in tropical regions remains limited. Comprehensive studies are rare that examine how different farming systems, shaped by environmental conditions such as altitude, affect feeding practices, milk production, and animal health. Therefore, this study aims to compare dairy goat farming systems across different altitudinal zones in Indonesia, focusing on feeding practices, milk production, and manure management. The findings are expected to provide practical insights to support the sustainable development of dairy goat farming under diverse agroecological conditions.

## MATERIALS AND METHODS

### Data Collection

The study was conducted in West Sumatra Province, Sumatra Island, Indonesia, from February to May 2024. This region is recognized as one of the main centres of dairy goat production on Sumatra Island. Three smallholder dairy goat farms located at different altitudinal zones were selected for this study.

The first farm (F1), representing the high-altitude system, was in the Bukittinggi area, Agam District (0°19'16" S, 100°25'39" E), at an elevation of approximately 990 m above sea level (m a.s.l.), and had 19 lactating goats. The second farm (F2), representing the mid-altitude system, was situated in the Payakumbuh area, Agam District (0°13'57" S, 100°37'43" E), at an elevation of approximately 510 m a.s.l., with 26 lactating goats. The third farm (F3), representing the low-altitude system, was in Padang City, Padang District (0°54'39" S, 100°22'20" E), at an elevation of approximately 10 m a.s.l., and had 24 lactating goats. The breed of dairy goats is dominated by Saannen and Peranakan Etawah (PE) which are commonly found in Indonesian dairy goat system.

An in-depth interview was conducted with each dairy goat farmer to obtain detailed information on their farming practices. The interviews covered daily milk production, feeding practices, and manure management strategies. Information on feed types, quantities, and feed sources was also collected. Manure management practices were inquired to understand how manure was handled, stored, and utilized within each farm.

Milk, feed, and manure samples were collected for laboratory analysis. During the morning milking session, a 50 mL milk sample was collected aseptically from the udder of every lactating goat. For milk analysis we collected 69 milk samples from all farms. Milk quality parameters, including fat, lactose, protein, and solids-not-fat (SNF) were analysed using a Lactoscan milk analyser. To further assess milk hygienic quality and udder health, Total Plate Count (TPC) and Somatic Cell Count (SCC) were determined. TPC was analysed using milk samples from individual goats,

while SCC was measured separately for milk obtained from each udder dairy goat. All milk samples were secured in the cooling box and immediately freeze before further analysis. Representative fresh feed samples (250 g per feed type) were collected from each farm and analysed for dry matter (DM), ash, nitrogen (N), carbon (C), and phosphorus (P) contents following standard analytical procedures described by AOAC. Fresh faecal samples (200 g) were collected from each farm and composited into duplicate samples. The faecal samples were analysed for total solids, N, C, and P using standard laboratory methods.

Microclimatic conditions within the goat housing areas were assessed by measuring ambient temperature and relative humidity using a digital hygrometer. Thermoregulatory responses for each individual lactating goats were evaluated through measurements of rectal temperature and heart rate. Rectal temperature was measured using a digital thermometer inserted into the rectum, while heart rate was determined using a stethoscope by counting beats over a one-minute period. Both microclimatic variables and physiological measurements were recorded twice daily, in the morning (08:00–09:00) and in the afternoon (15:00–16:00), to capture diurnal variations (Zahra *et al.* 2025). This study was conducted under field conditions without experimental manipulation. Measurements of rectal temperature and heart rate were non-invasive and performed in accordance with standard animal welfare practices. According to institutional guidelines, formal animal ethics approval was not required. Informed consent was obtained from all participating farmers prior to data collection.

#### Data Analysis

The farm interview, feed and faeces composition from the three dairy goat farms were summarized using descriptive statistics. For SCC and TPC, the minimum, maximum, mean, median, and interquartile range were calculated. Milk quality parameters were summarized as mean values. Comparisons of SCC, TPC, milk quality traits, and thermoregulatory responses among the three farms were

performed using the non-parametric Kruskal–Wallis test. When significant differences between farms were detected, Dunn’s post hoc test was used for pairwise comparison. All statistical analysis is performed using R studio. Ambient temperature and relative humidity measured in the goat houses were used to calculate the Temperature–Humidity Index (THI) to assess heat stress levels in dairy goats. The THI was calculated using the following equation (Eq. 1):

$$THI = T - (0.31 - 0.31 \times RH/100) \times (T - 14.4) \quad (1)$$

Where  $T$  is ambient temperature ( $^{\circ}\text{C}$ ) and  $RH$  is relative humidity (%). THI values were interpreted according to Marai *et al.* 2001), where values  $< 22.2$  indicate no heat stress, 22.2 to  $< 23.3$  indicate moderate heat stress, 23.3 to  $< 25.6$  indicate severe heat stress, and values  $\geq 25.6$  indicate extreme heat stress.

## RESULTS AND DISCUSSION

### Feeding Systems

The farming systems across the three altitudinal zones revealed distinct patterns in dairy goat feed management. Across all farms, two main feed components were identified: green forage and solid concentrate (Figure 1). Green forage, supplied either as fresh grass or silage, constituted the dominant proportion of the diet in all three dairy goat systems. In contrast the concentrate, typically purchased from local feed manufacturers, represented a smaller proportion of the total ration. Notably, the proportion of concentrate in the diet was higher in the mid-altitude farm (F2) compared with the high-altitude (F1) and low-altitude (F3) farms. This feeding strategy resulted in a relatively higher protein intake in F2, which may partly explain differences observed in milk composition among the farming systems. These findings indicate that, while forage-based feeding systems predominate across altitudes, variations in concentrate supplementation reflect differences in management intensity and resource availability.

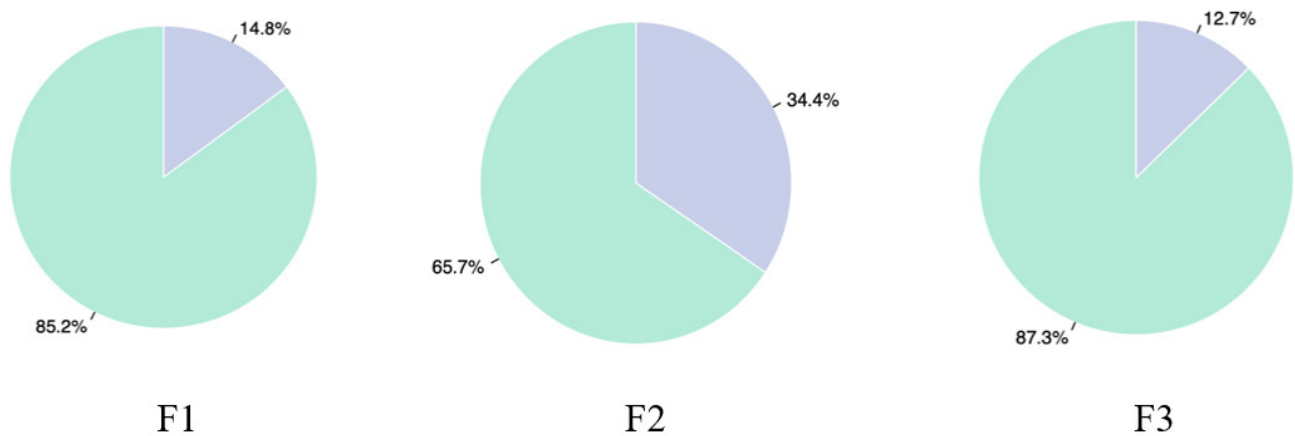


Figure 1. Proportion of feed types in different dairy goat farming systems across altitudinal zones (F1 = high-altitude system, F2 = mid-altitude system, F3= low-altitude system). Green colours represent green forage including fresh grass and silage, and purple colours indicate concentrate feed

Table 1. Dairy goat feeding content of collected samples at different dairy goat systems

	Feed type	DM (%)	Ash (%)	N-Total (%)	C-Organic (%)	Phosphor (%)
F1	Grass	19.1±0.001	17.7±0.31	2.9±0.09	32.5±0.10	0.3±0.003
	Tofu Waste	11.6±0.01	3.3±0.001	4.2±0.04	38.9±0.20	0.5±0.002
F2	Grass	21.2±0.07	12.1±0.20	2.7±0.07	23.9±0.05	0.3±0.003
	Mixed concentrate	11.1±0.01	5.5±0.03	4.2±0.06	31.3±0.15	0.4±0.003
F3	Grass	22.6±0.004	9.1±0.17	2.4±0.04	35.3±0.35	0.3±0.002
	Concentrate	28.1±0.02	9.1±0.05	3.8±0.17	29.7±0.06	0.6±0.006
	Silage	41.8±0.01	8.1±0.003	3.4±0.04	38.4±0.14	0.4±0.002
	Pellet	22.7±0.003	8.5±0.01	3.9±0.04	30.6±0.14	0.7±0.002

F1 = high-altitude system, F2 = mid-altitude system, F3= low-altitude system

Table 1 presents the nutrient composition of feed used in the different dairy goat farming systems. The dry matter (DM) content of forage varied across farms, largely because the grass was sourced from native or wild vegetation, which typically exhibits greater variability in nutrient composition. The reliance on native grass reflects common smallholder practices, as limited land availability often restricts the cultivation of improved forage species.

In F1, each lactating goat fed an average of 7 kg of fresh grass and 2 kg of tofu by-product per day, resulting in a total dry matter intake (DMI) of 1.6 kg per animal per day, with nitrogen intake (NI) of 48.7 g and phosphor intake (PI) of 4.7 g. In F2, the daily ration consisted of approximately 10 kg of fresh grass and 10 kg of mixed concentrate per animal, yielding a total DMI of 3.2 kg, NI of 105.2 g and PI of 10.1 g per animal per day. The mixed concentrate being feed to the animal was a combination of majority locally available by-products such as tofu waste, beer waste and small portion of concentrate powder. In F3, lactating goats received 5 kg of fresh grass, 5 kg of silage, 1.5 kg of concentrate, and 0.2 kg of pelleted feed per day, resulting in the highest intake levels, with a total DMI of 3.7 kg, NI of 115 g, and PI of 14.5 g per animal per day.

Feeding management practices differed across dairy goat farming systems at different altitudes, resulting in variation in nutrient intake and milk production. In the present study, F1 had DMI levels that aligned with recommended requirements, whereas F2 and F3 farms supplied diets exceeding suggested intake levels. Nutrient requirements of dairy goats vary according to lactation stage, body weight, and milk yield, and guidelines from the USDA recommend a DMI range of approximately 1.21 to 2.65 kg day<sup>-1</sup> for goats in early lactation (Kirkham *et al.* 2025; USDA, 2022).

Despite higher feed and nutrient inputs in F2 and F3, milk yield did not increase proportionally, suggesting inefficiencies in nutrient utilization which can affect milk production, fertility, and health (Fu *et al.* 2025; Marcos *et al.* 2020). This imbalance between nutrient intake and productive output may lead not only to economic losses for farmers but also to increased nutrient excretion, which can contribute to environmental risks such as nitrogen and phosphorus loading and eutrophication of surrounding water bodies (Zahra *et al.* 2024; Biagini & Lazzaroni, 2018). These findings highlight the importance of aligning

feed quantity and quality with animal requirements rather than maximizing feed inputs.

The predominance of native or wild grasses across all farming systems further contributes to variability in dietary nutrient supply, as such forages typically exhibit inconsistent nutritional quality. Limited land availability for cultivated forage production constrains farmers' ability to improve feed consistency and quality. The dry matter content of purchased concentrate feeds in F2 and F3 was relatively low due to the inclusion of moist agro-industrial by-products, such as tofu waste and beer waste. While these by-products can serve as cost-effective feed resources, their high moisture content may dilute dietary nutrient density and complicate ration balancing if not carefully managed (Lee *et al.* 2018).

### Milk Production and Quality

Feeding management not only influences milk yield and composition but also plays an important role in maintaining udder health in dairy goats by supporting immunity and ensuring adequate micronutrient supply (Zigo *et al.* 2021). Imbalances between nutrient intake and productive output, particularly excessive protein and energy supply, can impair metabolic efficiency and immune function, potentially increasing susceptibility to intramammary infections (Marcos *et al.* 2020; Sitaesmi *et al.* 2023). In addition, higher nutrient intake is often associated with increased nitrogen excretion, which may elevate microbial loads in the housing environment and increase the risk of udder contamination during milking. Therefore, differences in feeding strategies across farming systems are likely to contribute, directly or indirectly, to variations in somatic cell count (SCC), an established indicator of udder health and milk quality (Onjai-uea *et al.* 2024).

Table 2 summarizes the descriptive statistics of SCC across the three farming systems. Median SCC values differed significantly among farms ( $p < 0.05$ ), with the highest median observed in F3, indicating a higher central tendency compared with F1 and F2. In addition, SCC variability was greater in F2 and F3 than in F1, as reflected by wider ranges, suggesting more heterogeneous udder health conditions in the mid- and low-altitude systems.

Elevated SCC levels are commonly associated with reduced milk yield and alterations in milk composition, as mammary infections can damage epithelial cells,

Tabel 2. Somatic cell count (cells/mL) at different dairy goat systems

	F1	F2	F3
n	18	24	12
	------(cells/mL)-----		
Minimum	40 x 10 <sup>3</sup>	40 x 10 <sup>3</sup>	40 x 10 <sup>3</sup>
Q1	120 x 10 <sup>3</sup>	40 x 10 <sup>3</sup>	130 x 10 <sup>3</sup>
Median	160 x 10 <sup>3</sup> ab	80 x 10 <sup>3</sup> a	260 x 10 <sup>3</sup> b
Mean	240 x 10 <sup>3</sup>	610 x 10 <sup>3</sup>	810 x 10 <sup>3</sup>
Q3	230 x 10 <sup>3</sup>	270 x 10 <sup>3</sup>	1.000 x 10 <sup>3</sup>
Maximum	880 x 10 <sup>3</sup>	5.400 x 10 <sup>3</sup>	4.160 x 10 <sup>3</sup>
Standard deviation	220 x 10 <sup>3</sup>	1.350 x 10 <sup>3</sup>	1.060 x 10 <sup>3</sup>
IQR	110 x 10 <sup>3</sup>	230 x 10 <sup>3</sup>	870 x 10 <sup>3</sup>
Range	840 x 10 <sup>3</sup>	5.360 x 10 <sup>3</sup>	4.120 x 10 <sup>3</sup>
IQR ratio	130 x 10 <sup>3</sup>	40 x 10 <sup>3</sup>	210 x 10 <sup>3</sup>

F1 = high-altitude system, F2 = mid-altitude system, F3= low-altitude system. a,bSuperscripts in the same row with different letters indicate significant differences (p<0.05).

Table 3. Total plate count (CFU/ml) at different dairy goat systems

	F1	F2	F3
n	9	11	10
	------(Log CFU/mL)-----		
Minimum	2.3 x 10 <sup>4</sup>	8.0 x 10 <sup>3</sup>	0.1 x 10 <sup>3</sup>
Q1	3.0 x 10 <sup>4</sup>	2.0 x 10 <sup>5</sup>	0.1 x 10 <sup>5</sup>
Median	7.0 x 10 <sup>4</sup>	4.5 x 10 <sup>5</sup>	1.0 x 10 <sup>5</sup>
Mean	1.2 x 10 <sup>6</sup>	2.0 x 10 <sup>6</sup>	4.4 x 10 <sup>6</sup>
Q3	2.1 x 10 <sup>6</sup>	2.5 x 10 <sup>6</sup>	7.7 x 10 <sup>6</sup>
Maximum	4.4 x 10 <sup>6</sup>	6.9 x 10 <sup>6</sup>	1.6 x 10 <sup>7</sup>
Standard deviation	1.7 x 10 <sup>6</sup>	2.8 x 10 <sup>6</sup>	6.3 x 10 <sup>6</sup>
IQR	2.1 x 10 <sup>6</sup>	2.3 x 10 <sup>6</sup>	7.6 x 10 <sup>6</sup>
Range	4.4 x 10 <sup>6</sup>	6.9 x 10 <sup>6</sup>	1.6 x 10 <sup>7</sup>
IQR ratio	5.0 x 10 <sup>5</sup>	0.3 x 10 <sup>6</sup>	4.7 x 10 <sup>5</sup>

F1 = high-altitude system, F2 = mid-altitude system, F3= low-altitude system

impair milk synthesis, and increase the leakage of blood-derived components into milk (Borneman & Ingham, 2014). Previous studies have reported that SCC values in uninfected dairy goats typically range from 270 to 2,000 × 10<sup>3</sup> cells mL<sup>-1</sup>, whereas infected goats often exhibit higher values, ranging from 659 to 4,213 × 10<sup>3</sup> cells mL<sup>-1</sup> (Paape *et al.* 2001). In general, F1 exhibited consistently lower SCC values compared with the F2 and F3 systems. The SCC values ranged from 240 to 810 × 10<sup>3</sup> cells mL<sup>-1</sup> for most sampled animals, which falls within the range commonly reported for uninfected dairy goats. However, isolated high SCC values were also detected, with a maximum value of 5,400 × 10<sup>3</sup> cells mL<sup>-1</sup> observed in F2 and 4,160 × 10<sup>3</sup> cells mL<sup>-1</sup> observed in F3, indicating the presence of individual goats with a high likelihood of intramammary infection. This coexistence of low mean SCC values with an extreme observation reflects the heterogeneous health status typically observed in smallholder dairy goat herds. Although mean SCC values suggest generally acceptable udder health at the farm level, the occurrence of high outliers underscores

the importance of individual animal monitoring to prevent subclinical mastitis and associated milk quality losses. Nevertheless, SCC levels in dairy goats are influenced by a range of non-infectious factors, including parity, stage of lactation, seasonal conditions, and milk yield (Desidera *et al.* 2025; Kaskous *et al.* 2022; Nudda *et al.* 2023; Paape *et al.* 2001). Due to the considerable overlap in SCC values between infected and uninfected animals, it is not possible to definitively attribute elevated SCC to infection status alone based on SCC measurements. Despite this limitation, SCC remains a practical and informative indicator of udder health under field conditions.

One of the foremost considerations is the analysis of subclinical mastitis conditions, which can significantly impact milk yield and quality (Dimitrov *et al.* 2018; Tibebe *et al.* 2025). Understanding the prevalence and management of this condition is vital for improving overall herd health and, consequently, milk production. The analysis of TPC can help to understand the subclinical mastitis conditions. Table 3 presents the descriptive statistics of total plate count

(TPC) across the three dairy goat farming systems. Median TPC values did not differ significantly among the systems ( $p > 0.05$ ). Nevertheless, F3 tended to exhibit a higher median TPC, indicating a greater central tendency compared with F1 F2 systems. In addition, TPC variability was greater in F2 and F3 than in F1, as reflected by their wider ranges, suggesting more heterogeneous hygienic conditions during milk production in the mid- and low-altitude farms.

Milking in all dairy goat farming systems was performed manually, with farmers hand-milking the goats under traditional management practices. Based on farmer interviews and production records, average daily milk yield was 1.10 kg head<sup>-1</sup> day<sup>-1</sup> in the high-altitude farm (F1), 0.65 kg head<sup>-1</sup> day<sup>-1</sup> in the mid-altitude farm (F2), and 0.83 kg head<sup>-1</sup> day<sup>-1</sup> in the low-altitude farm (F3). Figure 2 presents the milk quality parameters across the different dairy goat farming systems. Milk fat content differed significantly among the systems ( $P < 0.05$ ), with the low-altitude farm (F3) had a significantly lower fat content compared with the high- (F1) and mid-altitude (F2) farms. In contrast, milk lactose, protein, and solids-not-fat (SNF) contents were significantly higher in the mid-altitude farm (F2) than in F1 and F3 ( $P < 0.05$ ).

In the present study, goats in F2 and F3 farming systems, which exhibited SCC values, produced 44.5% and 8.13% less milk, respectively, compared with goats in the F1. This reduction in milk yield is consistent with previous findings, as (Šlyžius *et al.* 2023) reported that goats with elevated SCC ( $>1,000 \times 10^3$  cells mL<sup>-1</sup>) experienced decreases in milk production by 10%. The alteration in milk composition associated with elevated SCC were also observed (Barrón-Bravo *et al.* 2013). In this study, milk fat content in F3 was lower than that in F1, suggesting a negative association between SCC and milk fat concentration. This observation aligns with findings by (Šlyžius *et al.* 2023), showing that the higher SCC levels were associated

with tendencies toward reduced fat, protein, and lactose contents. In contrast, other studies have reported negative correlations between SCC and milk protein and total solids content (Podhorecká *et al.* 2021). An increase of SCC may reflect not only animal health status but also environmental hygiene conditions, which could be influenced by manure handling practices within dairy goat housing systems. Moreover, environmental temperature is a key ecological factor influencing bacterial growth. Lower temperatures reduce enzymatic activity and cellular metabolism, thereby slowing the biological reactions required for cell division. This results in an extended lag phase and a reduced bacterial growth rate; consequently, in cooler environments such as highland areas, Total Plate Count (TPC) values tend to be lower than those observed in warmer environments (De Silvestri *et al.* 2018).

### Housing and Manure Management System

In the F1 and F2 farming systems, dairy goats were housed in individual pens, whereas in the F3, goats were kept in colony pens containing approximately 20–30 animals. All farms used elevated (raised floor) housing systems, with floor heights ranging from 75 to 100 cm above ground level, to facilitate manure removal and improve hygiene. Roofing materials differed among systems: bamboo roofs were used in F1 and F2, while asbestos roofing was used in F3.

Microclimatic conditions within the housing systems are presented in Table 4. During the morning period, ambient temperatures ranged from 23.6 to 25.0 °C, relative humidity from 85 to 88%, and the Temperature–Humidity Index (THI) from 73.4 to 78.0. In the afternoon, temperatures increased to 26.9–27.5 °C, while relative humidity ranged from 75 to 88%, resulting in higher THI values of 77.3–79.6.

Based on THI classification, dairy goats in F1 and F2 experienced moderate heat stress during both morning and afternoon periods. In contrast, goats in the low-altitude system (F3) were exposed to extreme heat stress conditions,

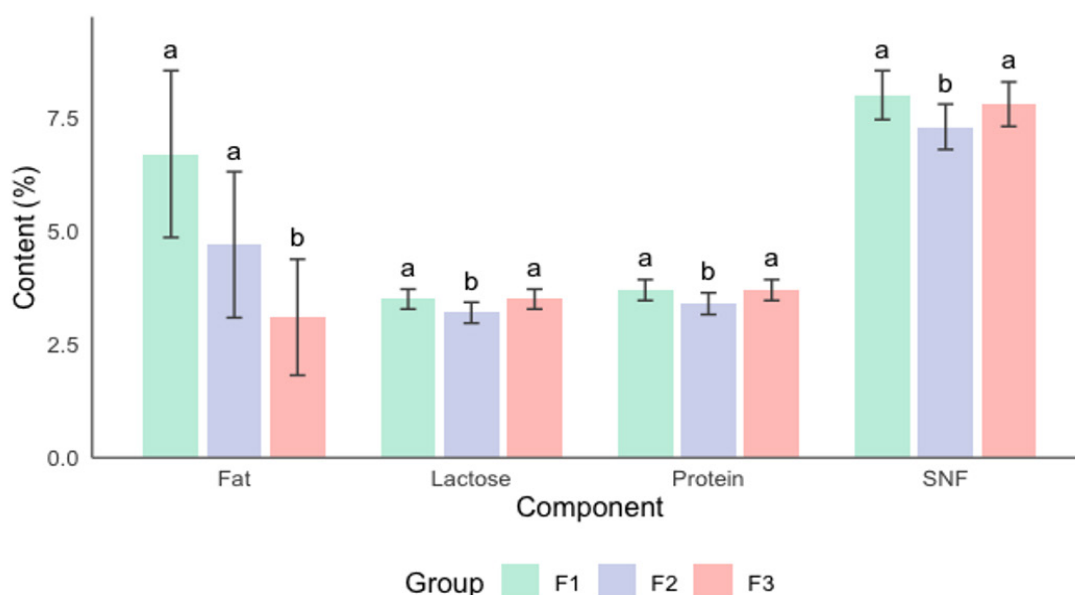


Figure 2. The milk quality parameters at different dairy goat systems. F1 = high-altitude system, F2 = mid-altitude system, F3= low-altitude system. Bars with different lowercase letters differ significantly ( $P < 0.05$ )

Table 4. Microclimate condition of the stable at different dairy goat systems

	Observation	Ambient temperature (°C)	Humidity (%)	THI	Stress level
F1	9	24.7	78	24	Severe
	15	25.3	75	24.5	Severe
F2	9	23.6	88	23.3	Severe
	15	26.5	71	25.4	Severe
F3	9	26.5	85	25.9	Extreme Severe
	15	26.8	85	26.2	Extreme Severe

Table 5. Faeces content of collected samples at different dairy goat systems

Farm	Parameters						
	Total solid (%)	Ash (%)	N-NH <sub>3</sub>	N-Total (%)	C-Organic (%)	Phosphor (%)	C/N ratio
F1	25.4±0.02	15.7±0.04	34.6±0.003	3.3±0.04	31.3±0.17	0.8±0.01	9:04:01
F2	29.6±0.02	11.2±0.20	17.9±0.003	3.1±0.04	33.6±0.001	0.6±0.01	10:08:01
F3	41.5±0.04	14.5±0.002	25.6±0.003	3.0±0.04	29.0±0.06	0.9±0.01	9:06:01

F1 = high-altitude system, F2 = mid-altitude system, F3= low-altitude system

particularly during the afternoon, indicating a less favourable microclimate for animal comfort and welfare.

Manure management is an important component of dairy goat farming systems and has indirectly link to hygiene and milk quality. In all observed farms, elevated (raised floor) housing was used, allowing faeces to fall through the slatted floors while urine drained downward, resulting in the mixing of faeces and urine beneath the housing structures. None of the studied farms were equipped with anaerobic digesters or other manure treatment systems. The nutrient composition of faecal matter from the different farming systems is presented in Table 5, providing an overview of manure characteristics under the existing management practices.

The F3 exhibited the highest total solids content in faeces, indicating lower moisture content compared with F1 and F2. The higher faecal total solids concentration observed in F3 is likely associated with the inclusion of silage in the diet. F1 exhibited the highest faecal ammoniacal nitrogen (N-NH<sub>3</sub>), suggesting excess nitrogen excretion and increased risk of ammonia losses. Across the three farming systems, the faecal carbon-to-nitrogen (C/N) ratio ranged from 9.4 to 10.8, reflecting a relatively high nitrogen concentration in the manure.

Manure management practices in the three dairy goat farming systems require substantial improvement. Currently, faeces and urine are mixed beneath the raised-floor housing, a practice that increases the potential for ammonia volatilization and subsequent nutrient losses from the system. Based on field observations, farmers typically collect faeces in sacks for later use by crop farmers; however, manure removal is not conducted accordingly. Consequently, manure frequently accumulates beneath the housing structures, which may adversely affect barn hygiene and animal health. Furthermore, lower total solids (TS) content, as observed in the high-altitude farm (F1), can create challenges for manure handling and transport due to its higher moisture content. In contrast, higher TS levels indicate greater nutrient concentration and improved

suitability for storage, transport, and subsequent utilization as organic fertilizer, thereby enhancing the potential value of manure as a resource.

However, this study did not perform correlation analyses to quantify relationships between altitude, management practices, and animal performance due to the limited sample size. Nevertheless, a consistent pattern was observed in which the high-altitude farming system (F1) tended to exhibit better feeding management, lower SCC and TPC, and superior milk quality compared with the mid- (F2) and low-altitude (F3) systems. Farms located at higher altitudes also experienced lower thermal stress, likely due to more favourable temperature and humidity conditions. Although these observations do not allow definitive conclusions regarding the direct effects of altitude on farm performance, overall milk yield, commonly used as an indicator of management success was higher in the high-altitude system. These findings suggest that agroecological conditions associated with altitude may interact with farm management practices to influence productivity, milk quality, and animal health in smallholder dairy goat systems.

Overall, the close interrelationship between animal health and manure management underscores the need for a holistic approach to dairy goat farming. Addressing both aspects simultaneously can enhance productivity while reducing environmental risks associated with nutrient losses and emissions. Such an integrated management strategy is essential for ensuring the long-term sustainability of dairy goat systems, particularly in meeting the growing demand for milk in an environmentally responsible and socially viable manner.

## CONCLUSION

This study shows that dairy goat farming systems across different altitudes differ in feeding practices, animal health, milk quality, and manure characteristics. The forage-based feeding dominated all systems, imbalances between nutrient intake and productive output were shown,

particularly in the mid- and low-altitude farms, indicating inefficient nutrient utilization. These inefficiencies were reflected in elevated nitrogen excretion, low faecal C/N ratios, and increased risks of environmental nutrient losses. Although altitude influences microclimatic conditions and animal stress levels, farm performance was largely shaped by management practices. Farms located at higher altitudes exhibited lower heat stress, better milk quality, and lower somatic cell counts; however, these outcomes were also associated with more effective feeding, housing, and hygiene management. The findings suggest that farmers operating under less favourable environmental conditions can improve productivity and animal health by adopting management strategies observed from high-altitude farms. Strengthening feeding management, housing hygiene, and manure handling is therefore essential for improving efficiency and sustainability in smallholder dairy goat farming systems.

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#### CONFLICT OF INTEREST

We declare that the research we have conducted does not contain any conflict of interest in any form, whether in the form of financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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