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COMPARATIVE PHYSICOCHEMICAL AND MINERAL CHARACTERIZATION OF COW, GOAT AND SHEEP MILK: IMPLICATIONS FOR NUTRITIONAL QUALITY

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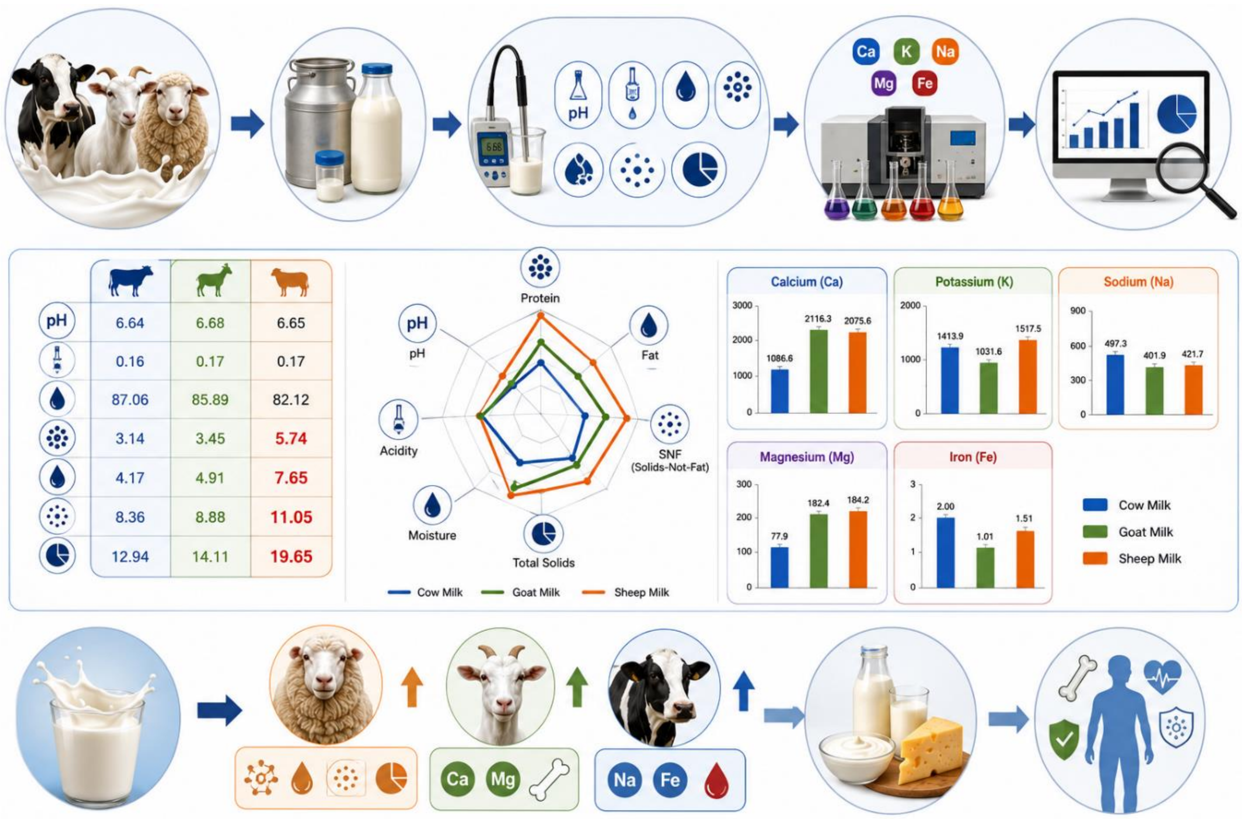
Abstract



Milk from diverse animal sources exhibits difference in their nutritional and industrial value due to variations in their composition. The current research trial was carried out to compare the physicochemical and mineral content of cow, goat and sheep milk under the same analytical conditions. Raw milk samples were procured from the dairy farm of University of Agriculture, Faisalabad and subjected to various physicochemical analysis including pH, titratable acidity, moisture, protein, fat, solids-not-fat (SNF), total solids (TS) by following the standard protocols of AOAC. Whereas selected minerals i.e. Calcium (Ca), Potassium (K), Sodium (Na), Magnesium (Mg) and Iron (Fe) concentrations were measured using Atomic Absorption Spectrophotometry (AAS). Significant compositional differences ($p < 0.05$) were observed in milk species. Sheep milk displayed the highest protein (5.74 ± 0.22%), fat (7.65 ± 0.31%), SNF (11.05 ± 0.44%) and total solids (19.65 ± 0.72%) contents, whereas cow milk had the highest moisture level (87.06 ± 3.48%). Considering mineral content, goat milk showed the highest Ca concentration (2116.3 ± 11.25 mg/L), while sheep milk contained the highest K (1517.5 ± 25.38 mg/L) and Mg (184.2 ± 15.04 mg/L) levels. Cow milk exhibited the highest Na (497.3 ± 58.33 mg/L) and Fe (2.00 ± 0.26 mg/L) concentrations. There were no significant differences between the pH of the milk species. The finding explains that the sheep milk has a more concentrated nutrient profile rich in protein, fat, total solids and mineral contents while the goat milk is rich in calcium. The results of these studies can be further processed for nutritional evaluations, development of dairy products and utilization of small ruminant milk in value added dairy applications.

1. Introduction

Milk is considered one of the most nutrient-dense foods in the human diet, providing a wide range of essential nutrients that are necessary for growth, development and health (Elrefaey and Eissa, 2025). It provides high-quality proteins, carbohydrates, fats, vitamins, and minerals in a highly bioavailable form, making it an important component of a balanced diet. Beyond its nutritional value, milk contains numerous bioactive compounds that influence physiological processes, including nutrient digestion and absorption, metabolic regulation, immune function, and protection against disease (Kumar et al., 2025; Wang et al., 2026). Owing to its nutritional richness and health-promoting properties, milk and dairy products are integral components of dietary patterns in many cultures and are consistently recommended in national and international dietary guidelines (Park et al., 2007; Flis et al., 2025). Cow and buffalo milk are the major sources of milk production in the world, but goat milk and sheep milk have gained increasing attention because of their unique composition and nutritional benefits (Pal et al., 2026). They are also more digestible and nutritious due to their higher levels of short-chain and medium-chain fatty acids, lower fat globule size, and higher protein content. Consequently, goat milk and sheep milk are gaining recognition as natural functional foods that can offer health benefits (Panta et al., 2021; Ahmad et al., 2025). With the growing demand for milk and milk products and their significance in human nutrition, much research work has been undertaken to assess milk quality and composition. Fat, protein, solids-not-fat (SNF), acidity, pH and moisture are important milk quality and processing parameters (Meena et al., 2023).

These parameters should be accurately determined for dairy product development, quality control, breed evaluation (Lewis, 2022). These parameters not only reflect nutritional content but are also key in assessing the technological characteristics of milk for cheese, yogurt or butter production. Examples include pH, which is associated with milk freshness and microbiological condition, influences casein micelle stability, and influences coagulation during cheese development (Bansal and Veena, 2024) and total solids content which affects overall yield and processing efficiency of cheese (Akshit et al., 2024). The fat fraction also differs significantly among species and breeds and affects the sensory properties, fatty acid profile, and the formation of fat globule membrane structures, which in turn affects digestibility and technological performance (Ponnampalam et al., 2024). Likewise, the protein content (casein/whey ratio, and ratio of the different casein fractions) determines the firmness of the curd, the coagulation time of the rennet, and the bioavailability of peptides formed during digestion (Ren, 2024).

Although goat and sheep milk is nutritionally and commercially important, comparative physicochemical studies performed under standardized analytical conditions are still limited but practically essential for the industries to optimize milk processing parameters, establish species-specific milk quality criteria and distinguish milk categories for consumers with special nutritional needs and requirements. Accordingly, the present study was designed to conduct a comprehensive physicochemical analysis of cow, goat and sheep milk, comparing key parameters including pH, titratable acidity, total solids, SNF, fat, protein content and mineral composition with the objective of establishing a comparative compositional profile for these species under comparable conditions.

1. Material and Methods

The proposed study was conducted at the National Institute of Food Science and Technology, Faculty of Food, Nutrition and Home Sciences, University of Agriculture, Faisalabad.

2.1. Procurement of raw materials/chemicals

Cow, goat and sheep milk were sourced from the Dairy Farm, University of Agriculture Faisalabad, Pakistan, while chemicals used in the study were obtained from Sigma-Aldrich (St. Louis, MO, USA) and Fisher Scientific (CHEMTREC®, USA).

2.2. Physicochemical analysis of milk

The physical and chemical characteristics of the milk including pH, acidity, protein, fat, solid not fat (SNF), total solids, and moisture, were examined to ensure the milk was suitable before cheese production.

2.2.1. pH

The pH of milk sample was measured directly from the electronic digital pH meter (Hanna, HI-99161) after calibration using a pH 4 and pH 7 buffer solution.

2.2.2. Acidity

The AOAC (2012) Method No. 947.05 was used to assess the acidity of all three milk samples. 2-3 drops of phenolphthalein indicator were added to a beaker containing 10 mL of milk. After that, the sample was titrated with 0.1 N NaOH until a light pink color appeared. Using the following formula, the volume of NaOH consumed was calculated from the difference between the initial and final burette readings in order to ascertain the sample's acidity:

$$\text{Volume of Sodium hydroxide (NaOH) used} = \text{final volume} - \text{initial volume}$$
$$\text{Acidity \%} = (\text{vol of NaOH used} \times 0.009 / \text{ volume of milk used}) \times 100$$

2.2.3. Moisture content

The moisture content of the milk samples was determined using method no. 930.15 according to the AOAC (2012) guidelines. By subtracting the weight of the dry sample from the weight of the wet sample, as indicated by the following equation:

$$\text{Moisture (\%)} = \frac{\text{Weight of wet sample} - \text{Weight of dried sample}}{\text{Weight of sample}} \times 100$$

2.2.4. Protein content

Protein content was determined using the Kjeldahl method (AOAC, 2012; Method No. 930.29) with a Kjeltec System (D-40599, Behr Labor Technik GmbH, Germany). A 10 mL milk sample was digested with two catalyst tablets (5 g K_2SO_4 and 0.005 g selenium) and 20 mL nitrogen-free H_2SO_4. The mixture was then heated at 230°C, and then at 430°C till a clear solution was achieved. The sample was then digested and distilled using 40% NaOH, and the released ammonia was trapped in 4% boric acid. The distillate was titrated with 0.1 N N free H_2SO_4 until it turned pink. The nitrogen content was then determined and protein content was calculated using the formula:

$$\text{Nitrogen (\%)} = \frac{\text{Volume of 0.1 N sulphuric acid} \times 0.0014 \times \text{volume of dilution (250 mL)}}{\text{Sample weight} \times \text{Volume of distillation sample taken (10 mL)}} \times 100$$

$$\text{Crude protein content (\%)} = \text{\% Nitrogen} \times 6.25$$

2.2.5. Fat content

The fat content was measured by the Gerber method (Marshall 1993). In brief, 10.94 mL of milk was poured into a butyrometer that contained 10 mL of sulfuric acid and then amyl alcohol was added. Contents were well mixed and the butyrometer was placed in a water bath, heated to 65°C, for 5 min. Then subjected to centrifugation at 1100 rpm for 5 min and put back in the water bath for 5 min at 65°C. The fat percentage was read directly from the calibrated neck of the butyrometer.

2.2.6. Solid-not-fat content

The solid-not-fat (SNF) contents were calculated according to David (1977) using a Lactometer. The Lactometer reading (LR) was noted from the meter and SNF was calculated

2.2.7. Total solids

Total solids (TS) were measured using the method outlined in AOAC 925.23 (2012). A crucible containing a weighed sample was dried at 105±3°C using a hot air oven. The total solids were determined using the weight of the dried sample.

$$\text{Total solids (\%)} = \frac{\text{Weight of dried sample (g)}}{\text{Weight of samples}} \times 100$$

2.3. Mineral Composition

After the wet acid digestion, the mineral composition of the milk samples was determined. Briefly, 5 mL of each milk sample was placed in a digestion flask and added to nitric acid perchloric acid solution. Samples were digested till a clear digest was received. The digested samples were then cooled and filtered and diluted to a known volume with deionized water. The concentrations of calcium (Ca), magnesium (Mg), iron (Fe), sodium (Na) and potassium (K) were carried out in an Atomic Absorption Spectrophotometer (AAS) based on the method of AOAC (2012). All mineral concentration was expressed as mg/L of milk.

2.4. Statistical Analysis

The data analysis was conducted utilizing statistical software Minitab 20, LLC, State College, Pennsylvania, USA. To check for variations in response at the significance level of $\alpha = 0.05$, a one-way ANOVA was employed. The mean ± standard deviation of the mean is used to present the data throughout the study.

2. Results

The composition of milk is a crucial factor that impacts the quality of the milk and products. The milk samples were subjected to several compositional analyses to evaluate their nutritional profile and they were also compared with cow milk. Significant variations were observed in the physicochemical composition of all milk samples.

3.1. pH

The pH values of cow, goat, and sheep milk were relatively similar, with cow milk at 6.64 ± 0.29, goat milk at 6.66 ± 0.31 and sheep milk slightly higher at 6.68 ± 0.33 (Table 1). The pH values represent the acidity of the milk and may impact on the flavor, stability and microbial development. Sheep milk has a higher pH indicating a more alkaline environment, probably because of the higher buffering capacity of their milk because of the higher protein and mineral content.

3.2. Acidity

The acidity level of the milk samples varied significantly between the species, with sheep milk having the highest acidity level at 0.17 ± 0.006%, followed by cow milk at 0.13 ± 0.003% and goat milk at 0.11 ± 0.005%. The lactic acid content in the milk is an important parameter that affects the shelf life and taste of milk. Sheep milk's increased acidity likely stems from its increased lactic acid content, which can be attributed to specific metabolic pathways and microbial interactions during lactation (Terzioğlu et al., 2023).

3.3. Moisture Content

Cow milk (87.06 ± 3.48%) had the highest moisture content followed by goat milk (85.87 ± 3.21%) and comparatively less moisture content was observed in sheep milk (80.35 ± 2.41%). The lower moisture content of sheep milk and the corresponding higher total solids content, indicates that the sheep milk could yield more dense and concentrated dairy products.

3.4.Protein Content

Protein percentage of the milk was different among the species with sheep milk having the highest amount (5.74 ± 0.22%), goat milk (3.61 ± 0.13%) and cow milk (3.56 ± 0.14%). Sheep milk may have more protein as a result of the genetics of sheep that yield milk that contains more casein and whey protein, making it more nutritious. It can enhance the hardness and quality of cheeses, increase dairy products nutritional value (Moatsou and Sakkas, 2019).

3.5. Fat Content

There was also significant variation in fat content, with the highest being sheep milk (7.65 ± 0.31%), followed by goat milk (4.17 ± 0.16%) and cow milk (4.91 ± 0.19%).

3.6. Solids Not Fat (SNF)

Solids Not Fat (SNF) content was highest in sheep milk (11.05 ± 0.44%), followed by cow milk (8.56 ± 0.34%) and goat milk (8.23 ± 0.30%). Sheep milk has a higher content of SNF, indicating a higher nutrient density, including more essential minerals and vitamins, that can improve the nutritional value of milk products (Terzioğlu et al., 2023).

3.7. Total Solids

Sheep milk (19.65 ± 0.72%) exhibited higher total solids content in comparison to cow milk (13.61 ± 0.49%) and goat milk (14.13 ± 0.56%). The higher protein, fat and SNF content of sheep milk results in higher total solids content, which is desirable for the yield and quality of dairy products.

Table 1. Mean values of physicochemical analysis of milk

Parameters	**Cow**	**Goat**	**Sheep**
pH	6.64 ± 0.29a	6.66 ± 0.31a	6.68 ± 0.33a
Acidity (%)	0.13 ± 0.003b	0.11 ± 0.005c	0.17 ± 0.006a
Moisture (%)	87.06 ± 3.48a	85.87 ± 3.21a	80.35 ± 2.41b
Protein (%)	3.56 ± 0.14b	3.61 ± 0.13b	5.74 ± 0.22a
Fat (%)	4.17 ± 0.16c	4.91 ± 0.19b	7.65 ± 0.31a
SNF (%)	8.56 ± 0.34b	8.23 ± 0.30b	11.05 ± 0.44a
TS (%)	13.61 ± 0.49b	14.13 ± 0.56b	19.65 ± 0.72a

Values are expressed as mean values ± standard deviation (n = 3)
SNF= Solid not fat
TS= Total solids

3.8. Mineral composition

The mineral content of cow, goat and sheep milk is shown in Figure 1. Major differences ($p<0.05$) were found between the milk species for most minerals analyzed. Calcium concentration was significantly highest in goat milk (2116.3 ± 11.25 mg/L), followed by sheep milk (2075.6 ± 10.45 mg/L) while cow milk had the lowest calcium level (1086.6 ± 80.05 mg/L). The concentration of potassium was found to be different among the milk species; the sheep milk showed a highest potassium concentration (1517.5 ± 25.38 mg/L) followed by cow milk (1413.9 ± 75.04 mg/L) and goat milk (1031.6 ± 37.55 mg/L). On the other hand, cow milk had the highest sodium level (497.3 ± 58.33 mg/L), then sheep milk (421.7 ± 7.50 mg/L), and finally goat milk (401.9 ± 8.30 mg/L). While sodium is essential for fluid balance and for the correct functioning of the nerves, too much sodium generally isn't desirable, and that is why the relatively low sodium content of goat milk and sheep milk is thought to be an advantage in terms of nutrition. Magnesium concentrations were significantly higher in sheep milk (184.2 ± 15.04 mg/L) and goat milk (182.4 ± 17.13 mg/L) than in cow milk (77.9 ± 8.97 mg/L). All milk samples contained low levels of iron. However, cow milk exhibited the highest iron content (2.00 ± 0.26 mg/L), followed by sheep milk (1.51 ± 0.21 mg/L) and goat milk (1.01 ± 0.28 mg/L). Although these differences exist, milk is not considered to be a significant iron food in the diet. Sheep and goat milk generally had higher levels of some of the nutritionally significant minerals than cow milk and in particular had higher levels of calcium and magnesium. The results showed that milk produced by small ruminants could be a better source of minerals and can be used as a good alternative to the cow milk particularly for those who want to relish mineral rich dairy products.

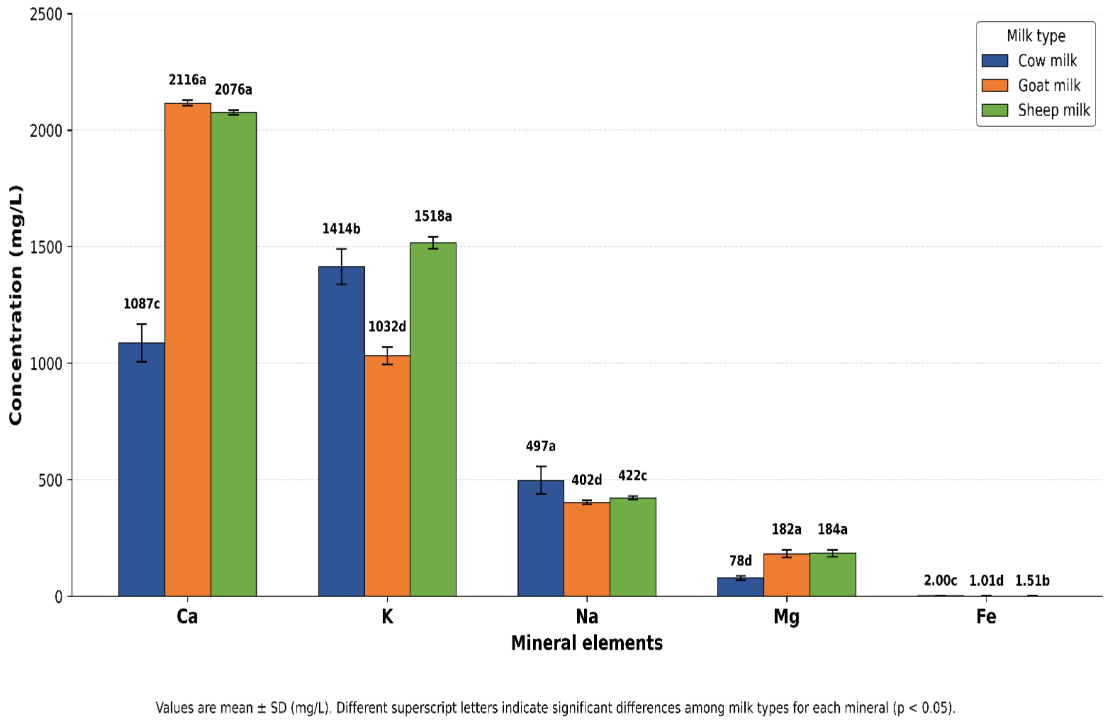


Figure 1. Comparison of the mineral composition of cow, goat and sheep milk. Values represent mean ± SD (mg/L). Different letters indicate significant differences among milk species ($p < 0.05$).

3. Discussion

The physicochemical parameters of milk are the most critical factor for the manufacturing of various dairy products. The pH values of milk species of the present study are consistent with the results of Tan et al. (2020), who observed the pH of cow milk and goat milk to be 6.59 and 6.34, respectively, while studying the quality parameters of cow and goat milk. Goat milk had a slightly higher fat content (4.51%) than cow milk (3.33%), and goat milk exhibited a higher TS value (13.88%) than cow milk (11.65%). Kasapidou et al. (2021) also studied the quality parameters of sheep milk and observed that values for pH (6.68-6.70), fat (6.40-6.63%), protein (5.39-5.53%) and TS (17.39-17.59%) of sheep milk are in the range of the current study findings. A slight variation in pH and titratable acidity of goat milk was observed compared to that of Zakaria et al. (2020). The titratable acidity and pH of raw, pasteurized (LTLT) and commercial (HTST) goat milk samples obtained in the current study ranged 0.16-0.17% and 6.50-6.53 respectively. The protein content of goat milk was 3.26-3.43% and fat content ranged from 1.34% to 2.75%. Variations can be due to differences in environmental conditions, diet, and lactation stages.

The current study is in line with the study of Kučević et al. (2016), who reported that the protein content of goat milk ranged from 2.79% to 3.76 %. The results are also in accordance with the outcomes of Pappa et al. (2021), who characterized sheep and goat dairy chains in Northwestern Greece. The pH ranged from 6.41-6.79 for sheep milk and 6.6-6.83 for goat milk. The fat level was observed to be 5.07–7.33% and 4.59-6.95% for sheep milk and goat milk, respectively. In comparison, the protein content was reported as 4.73–6.08% for sheep milk and 3.18-3.62% for goat milk. The compositional variations in cow, goat and sheep milk discovered in this study have implications for the nutritional content and processing qualities of milk produced by different animal species. Sheep milk, especially, possesses more protein, fat, and total solids which is desirable for high nutrient dense and quality dairy product production.

The present results demonstrate that there are significant differences between the physicochemical and mineral content of cow, goat and sheep milk. Compared with goat milk, sheep milk exhibited higher levels of protein, fat, SNF, total solids, calcium, magnesium and potassium, suggesting that it contains higher nutrient concentration, and thus is more suitable for value-added dairy products like cheese and fermented milk. These findings were also observed by Salhi et al. (2025), who reported higher fat and acidity contents for sheep milk, and higher calcium and magnesium contents for goat and sheep milk compared to other ruminant milks. They also found differences between the species in the physicochemical and mineral parameters of their study. Goat and sheep milk are higher in calcium and magnesium, which could relate to the higher concentrations of casein and mineral binding protein in these types of milk. The potential interaction of goat milk casein with metal ions also gives a clue to its role in the availability of minerals and functional properties in milk, as recently revealed (Ma et al., 2024).

Conclusion

The outcomes of the present study demonstrates that the physicochemical and mineral profile of cow, goat and sheep milk is very different because protein, fat, total solids and some essential minerals were found to be more abundant in sheep milk while the goat milk had good digestion rate and better mineral bioavailability with favorable nutritional characteristics, which could be beneficial to health. The significance of these results is that small ruminant milk is nutritious and can be used for the production of functional dairy foods. The effect of breed, feeding system, stage of lactation and environmental factors on goat and sheep milk composition and the health benefits of goat and sheep milk consumption should be investigated further. This research can help develop new value-added dairy products and nutrition strategies to enhance human health and wellbeing.

Conflict of Interest: The authors declare no conflict of interest.

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