Research Article

Dynamics of Goat Milk Macronutrient Composition Across Lactation Stages: A Comprehensive Review and Meta-Analysis

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Abstract | Goat milk is becoming more popular because of its distinctive characteristics and possible health advantages, especially for lactose-intolerant people. Nonetheless, enhancing goat milk production throughout the lactational phase to achieve nutritional profiles remains challenging. The mammary glands of goats undergo physiological changes and hormonal variations throughout lactation, affecting milk composition. This research sought to review the impact of the lactation stage on goat milk's protein, lactose, and fat composition. We conducted a meta-analysis of current research to examine changes in milk composition throughout lactation. Our data indicate that the lactation stage influences milk composition, with elevated quantities of protein and fat seen in the latter stage. Conversely, lactose levels fluctuate, exhibiting elevated concentrations throughout the early and late phases. This information may assist farmers in enhancing milk production techniques and enable the food sector to create products designed for nutritional requirements.

Keywords | Milk composition, Farmers, Goat milk, Health benefit, Lactation stage, Dairy goat

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INTRODUCTION

Goats are among the first domesticated animals worldwide, sometimes termed the poor man's cow (Goura and Singh, 2025). The global dairy goat industry is rapidly evolving to meet the rising demands of a population exceeding one billion (Rai *et al*., 2022). Farmers and enthusiasts worldwide increasingly recognize dairy goats for their flexibility, resilience, and the nutritional benefits of their milk. These ruminants are very flexible and do well in various climates, eating a wide range of forages. They are essential for agricultural communities because they can survive in challenging conditions and still produce much milk (Becchi *et al*., 2025). Goat milk proteins provide superior nutritional and functional qualities, demonstrating increased digestibility, buffering capacity, and alkalinity relative to cow's milk proteins (Saikia *et al*., 2022). The distinctive properties of goat milk stem from its lipid content, primarily including butterfat (Getaneh *et al*., 2016). Goat milk has a somewhat lower lactose content compared to cow's milk. This essential nutrient facilitates the absorption of calcium, magnesium, and phosphorus (Jareda *et al*., 2023). Goat milk is a valuable natural source of oligosaccharides used in human nutrition and has a relatively high level of prebiotics compared to the milk of other ruminants (Verruck *et al*., 2019). Its abundant nutritional profile, including proteins, lipids, carbohydrates, vitamins, and minerals, renders it a significant component in gourmet food manufacturing, especially cheese manufacturing. The distinctive fatty acid composition enhances the flavour of the cheese. Additionally, these fatty acids' possible anti-cancer and anti-cholesterol effects render goat milk appropriate for medicinal uses (Mohsin *et al.*, 2019).

Despite differences in breed, parity, nutrition, and health, the stage of lactation primarily affects the quality and content of goat milk (Singh *et al.*, 2014). The mammary glands of goats undergo physiological changes and hormonal variations throughout lactation, affecting milk composition (Zamuner *et al.*, 2020). Recent research on goat milk has shown substantial biochemical changes throughout lactation, affecting its nutritional composition and functional characteristics (Qin *et al.*, 2021). Goat milk is abundant in immunoglobulins, growth factors, and bioactive peptides at the initial lactation phase, providing a crucial immunological defence for newborn kids (Liu *et al.*, 2021). As lactation advances, there is a progressive alteration in macronutrient composition, characterized by an increase in fat content, mostly medium-chain fatty acids, which are advantageous for energy metabolism and digestive function when used as an infant formula (Gallier *et al.*, 2020). Moreover, the concentration of bioactive substances such as oligosaccharides, essential for gut health and microbial equilibrium, also changes. Proteins, especially caseins, exhibit structural alterations influencing milk digestibility and cheese production capability (Gallo *et al.*, 2024). The mineral composition, particularly calcium and phosphorus, adjusts to satisfy the nutritional requirements of both infants and adults, increasing milk use in fortified dairy products (Prosser, 2021).

These biochemical alterations significantly impact dairy science, especially in enhancing goat milk processing methodologies, product compositions, and cheese ageing. The changing nutritional content during lactation underscores the need to focus on specific stages to optimize health benefits. Comprehending these dynamics facilitates the creation of customized dairy products that fully utilize goat milk's potential. This research uses data from contemporary literature to investigate the intricate relationship between the lactation stage and the three macro components of goat milk (protein, fat, and lactose) and to understand the timing of the milk collection to optimize its composition for specific dairy products, timing the lactation stages effectively is essential for farmers to produce dairy products with optimal quality and composition as the milk's nutrient profile changes throughout the lactation period. By clarifying these connections, valuable insights can be obtained that improve the quantity and quality of milk production. This information can enhance farming practices, improve milk processing techniques, and eventually provide consumers with a better goat milk product.

Macronutrient composition of goat milk

The schematic diagram illustrating the macronutrient composition of goat milk is presented in Figure 1.

Protein profile in goat milk

Goat milk primarily comprises 25% whey protein (WP), 70% casein, and 5% minor proteins (Chen *et al.*, 2019). While whey proteins make up a smaller portion of goat milk, they are recognized for their diverse health benefits and rapid digestion rate due to their quick passage through the stomach (Sun *et al.*, 2020). The main components of whey protein in goat milk are beta-lactoglobulin (β-LG) and alpha-lactalbumin (α- LA), while the caseins include αs1-casein, αs2-casein, β-casein, and κ-casein (Selvaggi *et al.*, 2014).

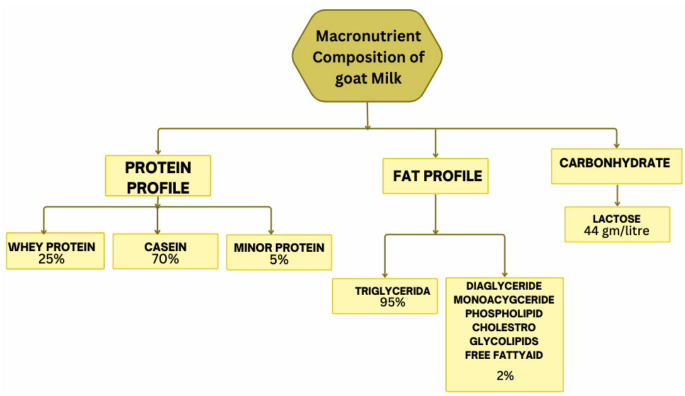

Figure 1: Schematic diagram of macronutrient composition in goat milk.

Whey protein

α-LA is a major whey protein in ruminant milk, characterised by its ability to bind calcium ions, and it is essential for milk production as it plays a crucial role in lactose synthesis and water transport within the mammary gland. α-LA is essential in amino acids, particularly lysine, cysteine, and tryptophan (Permyakov and Berliner, 2000; Selvaggi *et al.*, 2014).

β-LG is a small lipocalin family protein known for its ability to bind small molecules. While its specific function in milk is not fully understood, it is believed to contribute to the transport of retinol and fatty acids and provide essential amino acids to offspring (Flower, 1996).

Casein

αs1-casein and αs2-casein

Among the different casein proteins, αs1-casein is the most soluble in calcium. It is a highly phosphorylated protein that plays a crucial role in forming the structure of casein micelles, which are essential for cheese production (Farrell *et al.*, 2004). The CSN1S1 gene encodes for αs1-

casein. Despite variations in the mature protein sequences, the gene's signal sequence remains highly conserved across many mammalian species, indicating its rapid evolution. αs1-casein comprises 214 amino acids in each species (Masoodi and Shafi, 2010).

While αs2-casein is less studied due to its challenging isolation process, it is present in various mammalian milks. In some cases, it can constitute up to 29% of the total casein content. Notably, it is found in higher concentrations within larger casein micelles in goat milk. Whereas it was previously thought that goat milk lacked αs1-casein, subsequent research has identified multiple variants of this protein with varying expression levels. The polymorphism of αs1-casein has become a significant focus of study in goat milk research (Selvaggi *et al.*, 2014). The CSN1S2 gene, which encodes αs2-casein, has a highly conserved signal sequence essential for calcium phosphate transport. Notably, goat milk contains a higher proportion of αs2-casein, typically around 19%, compared to cow's milk, which has approximately 10% (Rahmatalla *et al.*, 2022).

β-casein is the most abundant protein in goat milk, accounting for up to 50% of the total casein content (Clark and García, 2017). The CNS2 gene encodes for β-casein, a primary source of essential amino acids that aid in mineral absorption, particularly important for infants. Additionally, peptides derived from β-casein during digestion exhibit antihypertensive and immune-boosting properties (Sadler and Smith, 2013).

κ-casein is a calcium-insensitive protein that forms a protective layer around the calcium-sensitive caseins (α-S1, α-S2, and β), stabilizing the micelles. The structure and stability of these micelles significantly influence milk's physical and technological properties (Glantz *et al.*, 2010). CNS3 is the gene that encodes for *k*-casein, and it constitutes approximately 20% of goat and sheep milk, while it makes up to only 12-14% of cow's milk (Molik *et al.*, 2012).

Minor proteins

Milk, in addition to its major proteins, also contains smaller amounts of various proteins like immunoglobulins, lactoferrin, ferritin, transferrin, protease-peptone, glycomacropeptides, calmodulin, lactoperoxidase, lysozyme, prolactin, folate-binding protein, and several growth factors. While the overall levels of these minor proteins are comparable between goat and cow milk, goat milk has a higher concentration of folate-binding protein, specifically 12 micrograms per milliliter compared to 8 micrograms per milliliter in cow's milk. Folate-binding protein is a glycoprotein containing about 22% carbohydrates. Lactoferrin, another glycoprotein, is present in all vertebrate milk and is the primary iron-binding protein in human and mare milk. At the same time, transferrin is more abundant in rat and rabbit milk. Goat milk also contains immunoglobulins like IgG, IgA, and IgM. Additionally, it has protease-peptones, a mixture of heat-stable, acid-soluble phosphoglycol proteins. Despite their low concentrations, these minor milk components can significantly impact metabolic, immunological, and physiological processes, contributing to the potential benefits of goat milk in nutritional products (Park *et al.*, 2007; Silanikove *et al.*, 2010).

Fat profile in goat milk

Goat milk contains 3.25-4.2% milk fat. The milk fat contains a complex mixture of lipids, mainly triglycerides, comprising about 98% of its total fat content. The remaining 2% is a mix of other lipids, such as diacylglycerides, monoacylglycerides, phospholipids, cholesterol, glycolipids, and free fatty acids. The triglycerides comprise over 400 fatty acids, each with distinct physical and biological characteristics (Djordjevic *et al.*, 2019). Biologically active lipids, like monounsaturated fatty acids (MUFAs) such as oleic acid (C18:1 n-9), and polyunsaturated fatty acids (PUFAs) like linoleic acid (LA; C18:2 n-6) and alpha-linolenic acid (ALA; C18:3 n-3), play crucial roles in the body. Longer-chain PUFAs with 20C, including docosahexaenoic acid (DHA; C20:5 n-3) and eicosapentaenoic acid (EPA; C22:6 n-3), are precursors to eicosanoids, which help regulate various bodily functions (Siegel and Ermilov, 2012). Goat milk fat is high in medium-chain fatty acids, particularly caproic, caprylic, and capric acids (6:0, C8:0, C10:0, respectively). The lauric to capric acid ratio is a key difference between goat and cow or sheep milk. Goat milk has a lower ratio (<0.5), while cow and sheep milk have a higher ratio (>1). This difference can be used to identify milk adulteration. The higher levels of these medium-chain fatty acids in goat milk are responsible for its unique aroma (Markiewicz-Kęszycka *et al.*, 2013). The Fatty acid composition of goat milk varies depending on the goat's breed and diet. However, some common fatty acids found in goat milk include Palmitic acid (C16:0, saturated fatty acid), Oleic acid (C18:1, monounsaturated fatty acids), Myristic acid (C14:0, saturated fatty acids), and Capric acid (C10:0, saturated fatty acids) (Sumarmono and Sulistyowati, 2015).

Carbohydrates in goat milk

Goat milk primarily contains lactose, a type of sugar composed of galactose and glucose. The average lactose content in goat milk is approximately 44 grams per litre (Martinez-Ferez *et al.*, 2006). Goat milk also contains small amounts of other carbohydrates like oligosaccharides, glycopeptides, glycoproteins, and nucleotides. Among these, milk oligosaccharides are particularly noteworthy. They possess prebiotic properties, meaning they nourish beneficial gut bacteria and have anti-infective qualities, making them valuable for human health (Lara-Villoslada *et al.*, 2006).

Milk yield and the lactations stage impact

Milk production and quality may fluctuate considerably owing to a complex interaction of variables, including the goat's physiology, nutrition, genetics, environment, dietary intake, and milking frequency (Mehra *et al*., 2021). A previous study revealed that the quantity of milk produced and its nutritional composition experience substantial variations throughout the various phases of lactation (Kalyankar *et al*., 2016). The lactation curve, which shows the trajectory of milk production over time, peaks at elevated output and then transitions into a more consistent production phase. This pattern significantly affects the total milk production of a goat during its lactation cycle (Auld *et al*., 2000). The lactation stage in dairy goats significantly affects milk output and its biochemical qualities (El-Tarabany *et al*., 2019). The lactation stage in dairy goats can be categorized into early (less than 80 days), mid (80-140 days), and late (over 140 days) (Ibrahim and Tajuddin, 2021).

Numerous studies have shown that dairy goats produce the highest milk during the mid-lactation phase. After this apex, the goat's physiology naturally prepares for the subsequent gestation and lactation cycle (Zailan and Yaakub, 2018; Ibrahim and Tajuddin, 2021). The decline in milk supply after its peak might be attributed to the inherent evolution of the lactation period. Several factors, including hormonal fluctuations, metabolic alterations, and the progressive exhaustion of energy reserves, contribute to this typical physiological phenomenon (Patbandha *et al*., 2015). However, study in 2020 discovered that milk production in Balkan goats grown under semi-extensive settings was minimal at the onset of lactation and progressively increased during the lactation cycle (Markovic *et al*., 2020). This indicates that the first phases of lactation may represent a time of adaptation for the goat's physiology as it initiates milk production.

Distinct biochemical and physiological changes mark each phase and influence milk production (Soares *et al*., 2018). Milk production generally reaches its peak early and diminishes as lactation advances, but the content of milk, including fat, protein, and lactose, varies correspondingly (Raheem *et al*., 2024). Understanding the influence of lactation on milk output and concentration is essential in the dairy sector. Recent research has shown the impact of several physiological variables on milk supply during lactation. A notable discovery is the hormonal modulation that fluctuates markedly throughout the phases of lactation. In early lactation, high levels of prolactin and oxytocin facilitate milk production to satisfy the kids' requirements (Nascimento *et al*., 2021). This time, milk production peaks owing to enhanced alveolar cell activity and increased nutrition transport from the bloodstream to the mammary glands. As lactation advances, milk production inherently diminishes owing to the involution process, during which the mammary gland loses its secretory capability (Dai *et al*., 2022).

Protein in goat milk and the lactation stage impact

Goat milk proteins have three primary categories: Casein, whey, and minor proteins. Casein, a slowly digesting protein, creates a gel-like structure upon precipitation. This makes it optimal for cheesemaking. Due to their superior solubility, the body swiftly metabolizes whey proteins, such as lactoglobulin, lactalbumin, immunoglobulins, and lactoferrin. The body cannot synthesize essential amino acids, which serve as the fundamental components of proteins and are abundant in these proteins. Minor proteins, like lysozyme, lactoperoxidase, and serum albumin, exist in limited quantities but fulfill critical functions in the body. Lysozyme has antibacterial capabilities, while lactoperoxidase and serum albumin have roles in immune system regulation (Park *et al*., 2007; Hejtmánková *et al*., 2012; Horáčková *et al*., 2014). Studies on Alpine and Saanen goats have shown a substantial relationship between the lactation phase and milk protein levels. Analysis indicated that the protein concentration peaked during the late lactation phase and was at its nadir in the mid-stage (Table 1). This indicates that the nutritional profile of goat milk might fluctuate significantly throughout the lactation cycle (Antunac *et al*., 2001). Research in India regarding indigenous goat breeds revealed a similar pattern, indicating that protein levels were minimal at the onset of lactation and progressively increased during the lactation period (Bhosale *et al*., 2009). This indicates that the augmentation of protein content during lactation is a prevalent trait of goat milk, irrespective of breed or geographic region. The study results of corroborate earlier studies, demonstrating a substantial link between the lactation stage and protein concentration in goat milk (Strzałkowska *et al*., 2009). As lactation advances, protein concentrations often rise.

On the other hand, other studies suggested that goat milk generally exhibits elevated protein concentrations during the initial phases of lactation, which gradually decrease as the lactation period progresses (Mestawet *et al*., 2012; Ibnelbachyr *et al*., 2015; Ibrahim and Tajuddin, 2021). This pattern diverges from the prevalent tendency of rising protein levels during lactation, underscoring the possible heterogeneity in protein content across various goat breeds or communities. Nonetheless, research on Baladi goats conducted by El-Tarabany *et al*. (2018) indicated an alternative result, showing no significant differences in protein levels across the several phases of lactation. This disagreement underscores the possible impact of breed-specific features and several environmental variables on the correlation between the lactation stage and milk protein concentration.

Table 1: Summary analysis of milk composition during the lactation stages.

Milk production/ Nutrient composition	Lactation stages			References
	Early stage	Mid-stage	Late stage	
Milk Production	Lowest	Peak	Low	(Ibrahim and Tajuddin, 2021; Zailan and Yaakub, 2018).
	Lowest	Low	Peak	(Markovic *et al*., 2020)
Protein	Low	Lowest	Peak	(Antunac *et al*., 2001; Bhosale *et al*., 2009)
	Peak	Low	Lowest	(Ibnelbachyr *et al*., 2015; Ibrahim and Tajuddin, 2021; Mestawet *et al*., 2012)
Fat	Low	Peak	Peak	(Bhosale *et al*., 2009)
	Stable	Low	Peak	(Antunac *et al*., 2001)
	Lowest	Peak	Low	(Ibrahim and Tajuddin, 2021)
	Does not affect		Low	(El-Tarabany *et al*., 2018).
Lactose	………	Lowest	Peak	(Strzałkowska *et al*., 2009).
	Peak	Low	Lowest	(Antunac *et al*., 200; Bhosale *et al*., 2009; El-Tarabany *et al*., 2018)
	Peak	Peak	Low	(Ibrahim and Tajuddin, 2021)

Fat in goat milk and lactation stage impact

Goat milk fat has unique properties that make it easier to assimilate than cow milk fat. The fat globules in goat milk are much smaller, enhancing their disintegration and assimilation inside the digestive tract. Furthermore, goat milk contains a higher proportion of short- and medium-chain fatty acids, which the body absorbs and utilizes more effectively than long-chain fatty acids. The interplay of these characteristics enhances the digestibility of goat milk fat, making it a preferable choice for people with digestive sensitivities or those in pursuit of a more readily digested dairy product (Yurchenko *et al*., 2018).

Goat milk fat is a medical therapy for individuals with diverse health issues who recognize the beneficial effects. Due to its substantial nutritional content, goat milk fat has been examined for its potential function in combating malnutrition. Moreover, goat milk fat has shown potential in regulating cholesterol levels due to its distinctive fatty acid composition that may facilitate healthy cholesterol metabolism (Kumar *et al*., 2014; Yadav *et al*., 2015). Although goat milk fat provides overall advantages, its concentration might fluctuate over the lactational cycle as shown in Table 1.

Numerous studies have examined the correlation between fat content and the stage of lactation, uncovering some consistent patterns (Bhosale *et al*., 2009), indicate that the lactation stage significantly affects the fat content in goat milk, noting that it is at its nadir during the first phases of lactation and undergoes a considerable rise as the lactation cycle advances. Likewise, (Antunac *et al*., 2001; Strzałkowska *et al*., 2009) identified a distinct trend in the fat content of goat milk during the lactation cycle. The fat content remained rather stable throughout the first lactation phase, decreased in the middle period, and peaked in the last phase. This pattern suggests that while the general tendency is a rise in fat content over time, oscillations may occur within the lactation cycle (Ibrahim and Tajuddin, 2021) documented an alternative trend in fat content that was minimal during early lactation, peaked at mid-lactation, and decreased toward the conclusion of lactation. Differences in physiological and metabolic parameters during the lactation cycle may account for this divergence. Conversely, discovered that the lactation stage may not substantially influence the lipid content of goat milk (El-Tarabany *et al*., 2018). This discovery, however, challenges the prevailing view that the lactation stage is a major determinant affecting milk fat content.

Lactose in goat milk and lactation stage impact

Lactose, a disaccharide formed from glucose and galactose, represents a substantial fraction of the carbohydrate content in milk. Goat milk has a comparatively lower percentage of lactose than cow milk (Park *et al*., 2007). The reduced lactose content makes it a potentially appropriate substitute for people with lactose sensitivity. Lactose in milk is essential for calcium absorption in the intestines, which is especially important for bone mineralization in newborn (Yoganandi *et al*., 2014; Mehra *et al*., 2021).

Strzalkowska and co-workers identified the maximum lactose concentration during the late phases of lactation, while mid-lactation had the lowest levels relative to early lactation (Strzałkowska *et al*., 2009). This result indicates that the lactose content of goat milk may fluctuate significantly throughout various stages of the lactation cycle (Table 1). Other researchers identified a unique pattern in the lactose concentration of goat milk, diverging from earlier research (Antunac *et al*., 2001; Bhosale *et al*., 2009; El-Tarabany *et al*., 2018). The first phases of lactation showed the highest lactose levels, which steadily declined as the lactation cycle progressed. This inconsistency suggests that variables such as breed, environmental circumstances, and individual differences among goats may affect the correlation between lactation stage and lactose concentration in goat milk, making it not uniformly reliable. Research conducted in Malaysia on Saanen goats indicated that the lactose concentration in their milk peaked during the early to mid-lactation period and markedly decreased towards the end of lactation (Ibrahim and Tajuddin, 2021). Subsequently, their examination of Saanen goats corroborated the observation that lactose concentration reaches its highest content during early to mid-lactation and then declines toward the conclusion of the lactation period (Manuelian *et al*., 2020). These data underscore the possible heterogeneity in lactose levels across various lactation phases and goat breeds.

Additional variables impacting milk output and nutrient

In addition to the lactation stage, other variables can influence goat milk yield and composition (Figure 2). This section briefly explores the impact of breed, seasons, parity, and feeding practices on milk production and nutrient content.

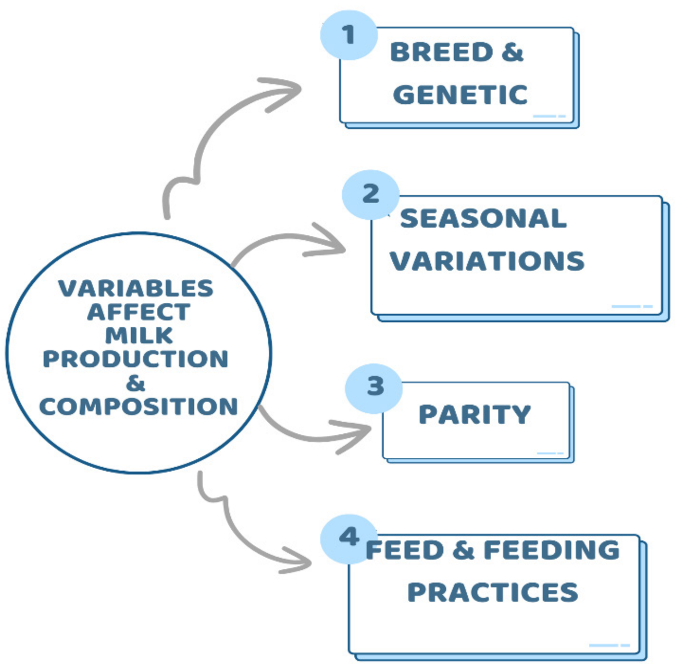

Figure 2: Schematic presentations of key components involved in the production and composition of goat milk.

Breed and genetic factors

Genetics significantly influence goat milk production, with each breed possessing unique genetic attributes that shape their performance in specific ways. Milk components, including protein, fat, and lactose content, vary among goats due to their breed and the specific genetic loci that control milk production traits (Bhumure, 2021). European dairy goat breeds, specifically bred for milk production, generally produce significantly more milk than native goats without similar selective breeding. This difference persists even when we factor in the higher concentration of solids (like protein and fat) typically found in the milk of native goats (Miller and Lu, 2019). Adamu and Sciences (2021) demonstrates that breed significantly influences daily milk production, with Saanen goats consistently producing the most milk, followed by Toggenburg and British Alpine (Teissier *et al*., 2024) revealed substantial differences in milk composition across various indigenous goat breeds. These findings highlight the significant impact of breed and genetics on milk quantity and quality. Genetics significantly influences milk production efficiency, with research demonstrating that selective breeding may improve the sustainability of milk output throughout the lactation stages.

Seasonal variations

Seasonal variations can significantly impact goat milk production. While some researchers believe that wet and dry seasons substantially influence milk yield, others hold differing opinions on the matter (Adamu and Sciences 2021). According to (Scano and Caboni, 2022), milk yield and composition peaked from March to August but dropped significantly from September to November. Heat stress, a common challenge during certain seasons, can significantly impact milk production in heat-sensitive breeds like Saanen. High temperatures can significantly reduce their milk yield and quality, making them vulnerable to the detrimental effects of hot weather on their milk production (Kljajevic *et al*., 2018).

Parity

The influence of parity (the number of times a goat has given birth) on milk production and quality has not been extensively studied. However, research suggests that goats with multiple births tend to produce more milk, likely due to the development of larger mammary glands with more milk-producing alveoli (Kalita *et al*., 2025). Goats with twins often yield more milk than those with a single birth throughout lactation. Nevertheless, the milk from single-offspring goats often has elevated fat, protein, and lactose levels, indicating a more nutrient-dense composition (Ralević *et al*., 2021).

Feeds and feeding practices

Looking at goats' pasture and indoor housing systems side by side shows that the feeding system does not change the milk's fat, protein, and lactose content, but it does change how much milk the goats produce (Currò *et al*., 2019). Substandard feeding methods, including insufficient nutrient consumption or imbalanced meals, may result in diminished milk output and impaired health. Permitting goats to graze at an early period increases milk fat content, while indoor systems using concentrated meals augment milk protein levels. Modifying the nutritional mix of forages and concentrations in goat feed successfully alters the fat-to-protein ratio in goat milk (Zucali *et al*., 2020). Studies indicate that dietary supplements might somewhat alleviate the variation in milk yield and composition. Animals with elevated energy and protein consumption throughout the post-partum period may maintain superior milk output compared to those with insufficient diets (Dai *et al*., 2022).

CONCLUSION AND RECOMMENDATIONS

The lactation phase significantly influences milk production and content, with early lactation producing large quantities and late lactation providing nutrient-rich milk. Recent discoveries about the biochemical and physiological processes influencing these alterations provide significant insights into enhancing dairy production and nutrition.

This study underscores the considerable influence of the lactation phase on the protein, fat, and lactose content of goat milk, with notable variations seen throughout lactation. Protein and fat concentrations often rise during the latter stages of lactation, although lactose content displays inconsistent patterns, peaking in both the early and late periods in certain studies. These results highlight the importance of timing milk collection to enhance nutritional quality, particularly for products like cheese that need elevated fat and protein levels. The heterogeneity of lactose concentrations across various breeds and phases of lactation hampers the standardization of nutritional profiles.

The lactation phase influences milk output and composition, directly impacting dairy production and human nutrition. Dairy farmers may use an understanding of lactation stages to enhance feeding tactics, oversee herd health, and modify milking schedules to guarantee optimal production and quality. Milk obtained during the peak lactation phase, characterized by elevated lactose content and volume, is optimal for fluid milk production. In contrast, subsequent phases, enriched in fats and proteins, are more appropriate for cheese and butter production. The dynamic changing composition of milk throughout lactation can be used to create functional dairy products tailored to specific health requirements.

Subsequent studies must concentrate on breed-specific investigations to identify the optimal lactation phases for enhancing milk production and nutritional quality. Examining the genetic and environmental determinants affecting lactation-related variations, especially lactose content, will improve the capacity to customize goat milk production for individual dietary requirements. Furthermore, precision agricultural technology, like real-time milk composition monitoring, might empower farmers to enhance feeding practices and milking schedules, improving the quality and quantity of milk. An in-depth investigation of the physiological factors influencing changes in milk composition during lactation will enhance dairy management techniques and product innovation.

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NOVELTY STATEMENT

The article presents a comprehensive synthesis of current data on how lactation phases affect the macronutrient content of goat milk, providing insights for optimising milk quality for certain dairy products. Unlike prior studies on milk composition, this study focuses on the biochemical changes during lactation and their significance for dairy science, notably in cheese production and functional food formulation. This work extends our understanding of milk collection time by examining the dynamic alterations in protein, fat, and lactose concentration during lactation. This study bridges the gap between dairy farming methods and the milk processing industry by making evidence-based suggestions for optimising goat milk composition for commercial.

AUTHOR'S CONTRIBUTION

YA: Write the original Manuscript, conceptualization, and writing review and editing. BB: Writing review and editing. NS: Supervision, funding acquisition. All authors authorised the final version of the manuscript.

Generative AI and AI-assisted technology statement

This manuscript was designed, analyzed, and written without the support of any generative AI or AI-assisted technology. Only regular grammar and language correction tools were used to enhance readability.

Conflict of interest

The authors have declared no conflict of interest.

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