



Changes in Rumen Characteristics and Fecal Consistency of Crossbred Buck Kids Fed Goat, Cattle, Buffalo Milk, Milk Replacer, and Soybean-Goat Milk

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ABSTRACT

This study aimed to determine the effects of different milk sources on rumen characteristics and fecal consistency of crossbred buck kids. Thirty newborn male crossbred kids were assigned to five treatments with six replicates: goat milk, cattle milk, buffalo milk, milk replacer, and 50% soybean milk + 50% goat milk. The experiment was conducted from March to October 2017. Growth performance, rumen development, papillary characteristics, histological changes, and fecal consistency were evaluated during pre- and post-weaning stages. Results showed that milk sources affected rumen papillary development and growth performance during the pre-weaning stage. Goat milk resulted in the highest feed intake and growth performance, while cattle milk and milk replacer were economical alternatives without negative effects on kid development.

INTRODUCTION

Goat production has an important role in livestock systems because goats provide valuable sources of meat, milk, income, and food security for rural communities. The success of goat production is highly dependent on proper management during the neonatal period, particularly because newborn kids experience rapid physiological changes after birth. At this stage, the digestive system is not yet fully developed, and nutritional management becomes a major factor affecting growth, health, and future productivity. Young ruminants are born with an immature rumen structure and require gradual adaptation before becoming capable of efficiently utilizing solid feed. As reported by Zhang et al. (2025), early-life nutritional strategies are increasingly recognized as important approaches to improve rumen morphological development, fermentation efficiency, and adaptation during the transition from liquid to solid diets.

Rumen development is a complex biological process involving changes in rumen size, epithelial structure, papillae growth, microbial colonization, and fermentation capacity. The development of rumen papillae is particularly important because it determines the absorption capacity of volatile fatty acids produced through microbial fermentation. Early feeding management influences the rate of rumen maturation because nutrient availability affects epithelial growth and metabolic adaptation. Li et al. (2024) demonstrated that nutritional interventions during early life can modify rumen morphology, microbial characteristics, and growth performance in goat kids. Furthermore, studies on artificial rearing systems indicate that young goats receiving milk replacer require appropriate nutritional management because incomplete rumen development may affect their ability to adapt efficiently after weaning (Belanche et al., 2020). Therefore, evaluating how different liquid feed sources influence rumen characteristics is essential for improving early goat management systems.

Milk is the primary nutrient source for newborn goat kids before complete rumen functional development. Goat milk is commonly considered the most suitable liquid feed because it provides nutrients that support early growth and digestive adaptation. However, the use of goat milk for kid rearing may reduce the amount of milk available for commercial production and increase production costs. This condition encourages the evaluation of alternative liquid feeds, including cattle milk and commercial milk replacers, which may provide similar nutritional benefits at lower economic costs. Rico-Costilla et al. (2024) reported that milk replacer-based feeding systems can maintain acceptable growth performance and influence rumen development when combined with appropriate feeding management in goat kids. Nevertheless, differences in nutrient composition among milk sources may produce different responses in rumen morphology, growth performance, and digestive adaptation.

Soybean-based milk products have also been considered as potential alternatives because of their availability, affordability, and protein content. However, plant-derived ingredients may contain anti-nutritional compounds that influence nutrient utilization and digestive health, especially in young animals with developing gastrointestinal systems. Changes in fecal consistency can provide important information regarding the tolerance of young goats toward different liquid diets because abnormal fecal conditions may indicate digestive disturbances or poor nutrient utilization. Previous research has shown that dietary composition influences gastrointestinal development, microbial activity, and immune responses in young goats. Wang et al. (2024) found that nutritional supplementation during early life affected gut health, rumen fermentation, and microbial profiles of dairy goat kids. However, information regarding the combined use of soybean milk and goat milk and its relationship with rumen development and fecal consistency remains limited.

Previous studies have primarily focused on individual aspects of kid nutrition, such as growth performance, milk replacer utilization, or rumen microbial development. However, limited information is available regarding the comparative effects of several liquid feed sources on rumen structural development, histological characteristics, and fecal responses within the same experimental condition. Understanding these relationships is important because successful kid rearing should not only achieve body weight improvement but also ensure proper digestive development without causing nutritional disorders. The present study provides a broader evaluation by comparing goat milk, cattle milk, buffalo milk, milk replacer, and a combination of soybean milk and goat milk in crossbred buck kids. This approach contributes additional knowledge regarding the suitability of different liquid feeding strategies for supporting rumen development and improving the efficiency of goat production systems.

Therefore, this study aimed to determine the effects of different milk sources on rumen characteristics and fecal consistency of crossbred buck kids. The research evaluated five liquid feeding treatments consisting of goat milk, cattle milk, buffalo milk, milk replacer, and 50% soybean milk combined with 50% goat milk. Growth performance, rumen papillary development, histological characteristics, and fecal consistency were observed during pre-weaning and post-weaning stages. The findings provide scientific information regarding the potential use of alternative milk sources that can maintain kid development while improving feeding efficiency and economic sustainability in goat production.

LITERATURE REVIEW

Rumen Development Theory

Rumen development theory explains that the transition of young ruminants from a milk-dependent stage into functional ruminants is determined by structural, microbial, and metabolic adaptations occurring during early life. The rumen undergoes progressive development through enlargement of rumen compartments, microbial colonization, epithelial differentiation, and papillary growth, which increase the capacity for volatile fatty acid absorption. Baldwin and Connor (2017) explained that rumen epithelial development is strongly regulated by nutritional stimulation, particularly through fermentation products such as butyrate and propionate. These metabolites stimulate epithelial cell proliferation and contribute to increased rumen absorptive capacity.

Early nutritional exposure plays an important role in regulating rumen maturation. Yáñez-Ruiz et al. (2019) stated that dietary management during the neonatal period influences microbial establishment and gastrointestinal adaptation in young ruminants. Furthermore, Steele et al. (2022) demonstrated that early dietary factors affect rumen epithelial structure and metabolic function, indicating that nutritional sources provided before weaning may influence later digestive efficiency.

Previous studies have mainly investigated rumen development through solid feed supplementation; however, the role of liquid feed composition during the neonatal stage remains less explored. Since newborn goat kids depend primarily on milk before rumen activation, differences in milk nutrient composition may influence rumen papillary development and digestive adaptation. Therefore, the current study applies rumen development theory to evaluate whether different milk sources produce different responses in rumen characteristics of crossbred buck kids.

H1: *Different milk sources (goat milk, cattle milk, buffalo milk, milk replacer, and soybean-goat milk combination) significantly influence rumen characteristics and papillary development of crossbred buck kids.*

Nutritional Programming Theory in Early Life

Nutritional programming theory suggests that nutritional conditions during early life can permanently influence physiological development, metabolism, and productive performance of animals. In young ruminants, nutrient availability during the neonatal period affects gastrointestinal development, immune function, and future feed utilization efficiency. Zhang et al. (2025) reported that early-life nutritional strategies regulate rumen morphological development and fermentation capacity, demonstrating the importance of early feeding management.

Milk is the primary nutrient source for newborn goat kids because the rumen is not yet fully functional. The quality and composition of milk determine energy supply, protein availability, and growth performance during the pre-weaning period. Goat milk is naturally suitable for goat kid development; however, its economic value encourages the exploration of alternative milk sources. Hassan et al. (2018) found that milk replacer could support acceptable

growth performance and improve economic efficiency in goat production systems.

Rico-Costilla et al. (2024) further reported that artificial milk feeding systems influence growth performance and digestive development in goat kids. These findings indicate that alternative liquid feeds may replace goat milk when nutrient requirements are properly fulfilled. However, differences among goat milk, cattle milk, buffalo milk, and milk replacer may generate different physiological responses due to variations in nutrient composition.

H2: Different milk sources significantly affect growth performance of crossbred buck kids during pre-weaning and post-weaning stages.

Rumen Papillae Development and Nutrient Absorption Theory

Rumen papillae development theory explains that papillary growth determines the efficiency of nutrient absorption in ruminants. The length, density, and surface area of rumen papillae represent important indicators of rumen functional development because these structures increase the contact area between rumen epithelium and fermentation products. According to Baldwin and Connor (2017), epithelial adaptation is closely related to nutrient availability and fermentation activity within the rumen. Nutritional interventions during early life may modify rumen morphology. Li et al. (2024) demonstrated that early nutritional strategies influenced rumen development, microbial composition, and growth performance in goat kids. Their findings support the concept that dietary composition during the neonatal period contributes to structural changes in the rumen.

Although previous research has examined the influence of solid feed on papillary development, limited studies have compared different milk sources regarding their effects on rumen papillary characteristics. The current research addresses this gap by evaluating papillae density, length, surface area, and histological changes among crossbred buck kids receiving different milk treatments.

H3: Different milk sources produce different effects on rumen papillary morphology and histological development of crossbred buck kids.

Digestive Adaptation and Fecal Consistency Theory

Digestive adaptation theory explains that young ruminants require gradual adjustment to different nutrient sources because their gastrointestinal system is still developing. Fecal consistency is commonly used as an indicator of digestive tolerance, nutrient utilization, and intestinal health during early growth. Changes in fecal characteristics may reflect the ability of animals to adapt to dietary components.

Alternative milk sources, particularly plant-based products, may influence digestive responses because they contain different nutritional profiles and bioactive compounds. Liu et al. (2021) reported that soybean-derived ingredients may affect gastrointestinal development and microbial activity depending on inclusion level and processing methods. These effects are particularly important in young animals because immature digestive systems are more sensitive to dietary changes.

Wang et al. (2024) showed that nutritional modifications during early goat development affected gut health, rumen fermentation, and microbial characteristics. These findings suggest that evaluation of milk sources should not only consider growth performance but also digestive responses. Therefore, fecal consistency assessment provides additional information regarding the suitability of different milk sources for goat kid rearing.

H4: Different milk sources significantly influence fecal consistency and digestive adaptation of crossbred buck kids.

Alternative Milk Feeding Strategy Theory

Alternative feeding strategy theory emphasizes the importance of identifying economically efficient feed sources that maintain animal health and productivity. In goat production systems, replacing expensive goat milk with alternative liquid feeds may increase profitability while maintaining acceptable growth performance. Milk replacers and mixed milk sources have been developed to reduce production costs while providing sufficient nutrients for young animals.

Belanche et al. (2020) highlighted that early feeding strategies influence microbial establishment and digestive stability after dietary transition. Therefore, alternative milk sources must be evaluated not only from an economic perspective but also based on their biological effects on rumen development and animal adaptation.

The present study contributes to this theory by comparing animal-derived milk sources, commercial milk replacer, and soybean-goat milk combination within the same experimental condition. This comparative approach provides evidence regarding which liquid feeding strategies can support rumen development, growth performance, and digestive health in crossbred buck kids.

H5: Milk replacer and alternative milk sources can provide comparable developmental outcomes to goat milk while offering improved economic efficiency for crossbred buck kid production.

METHODOLOGY

Experimental Design and Animal Management

This study was conducted to evaluate the effects of different milk sources on rumen characteristics and fecal consistency of crossbred buck kids. The experiment was carried out from March to October 2017 at the Institute of Animal Science (IAS), University of the Philippines Los Baños (UPLB), Philippines. The study used a completely randomized design with five dietary treatments and six replications per treatment. The experimental design followed the principles of controlled animal experimentation, where treatment groups, sample size,

measured outcomes, and statistical procedures should be clearly described to ensure research reproducibility (Percie du Sert et al., 2020).

Thirty newborn male crossbred buck kids were used as experimental animals. Before the feeding trial, all kids were allowed to suckle colostrum from their dams for four days to support early immune development. Afterward, the kids were separated from their dams, weighed, and individually housed in elevated stalls equipped with feeding and drinking facilities. The animals were randomly allocated into five treatment groups consisting of six animals per treatment. The dietary treatments consisted of: T1) goat milk, T2) cattle milk, T3) buffalo milk, T4) milk replacer, and T5) 50% soybean milk + 50% goat milk. Fresh goat milk, cattle milk, and buffalo milk were provided as liquid feed sources, while commercial milk replacer was prepared according to manufacturer recommendations. The milk replacer was diluted by dissolving 145 g of powder into 1 L of water before feeding. All liquid diets were adjusted to approximately body temperature before administration to improve acceptance and reduce digestive stress.

Feeding Management and Experimental Procedures

During the pre-weaning period, dietary treatments were introduced after a short adaptation period to minimize digestive disturbances. Kids receiving treatments other than goat milk were gradually adapted by decreasing goat milk intake while increasing the assigned treatment source. The liquid diets were provided twice daily at 08:00 and 16:00 h for approximately 68 days. The amount of milk offered was adjusted every two weeks according to 10% of body weight. From day 15 of the experiment, all kids were gradually introduced to solid feed consisting of concentrate and fresh grass provided equally among treatments. Drinking water and mineral blocks were available throughout the experimental period. After the pre-weaning period, kids were transitioned to a post-weaning diet consisting of 20% concentrate and 80% para grass (*Brachiaria mutica*). This management approach allowed evaluation of the effects of early milk feeding on subsequent rumen development after dietary transition.

The experimental procedures included monitoring growth performance, feed intake, rumen development, rumen papillary characteristics, histological changes, and fecal consistency. The combination of physiological, morphological, and digestive measurements was used to provide a comprehensive evaluation of kid adaptation to different liquid feed sources.

Growth Performance and Rumen Evaluation

Growth performance was evaluated by measuring body weight, body weight gain, average daily gain (ADG), feed intake, feed conversion efficiency, milk consumption, and milk conversion rate during the experimental period. Body weight measurements were conducted periodically throughout pre-weaning and post-weaning stages to evaluate the effect of dietary treatments on kid growth. Rumen development was evaluated through macroscopic and histological observations. At the end of the pre-weaning and post-weaning stages, representative animals from each treatment were evaluated for rumen

development. Rumen tissue samples were collected from the ventral sac area and preserved for histological analysis.

Rumen papillary characteristics were measured based on papillae density, papillae length, circumference, cross-sectional area, surface area, inter-papillary area, total papillary surface area, and total absorption surface area. Approximately 5 cm² rumen tissue samples were analyzed using microscopic observation and measurement procedures. Morphological evaluation of rumen papillae provides important information regarding rumen maturation because papillary development determines the absorptive capacity of the rumen epithelium (Baldwin & Connor, 2017).

Fecal Consistency Assessment

Fecal consistency was evaluated visually throughout the experimental period to determine digestive responses to different milk sources. The assessment focused on changes in fecal texture, including watery, soft, and solid conditions. Diarrhea occurrence was recorded as an indicator of digestive intolerance or nutritional adaptation problems. Fecal evaluation was included because early-life dietary changes may influence gastrointestinal adaptation, microbial establishment, and digestive stability in young ruminants. Previous research has highlighted that early nutritional management affects gastrointestinal development and microbial responses, which may influence digestive health indicators such as fecal characteristics (Belanche et al., 2020).

Histological Analysis and Data Analysis

For histological evaluation, rumen tissue samples were fixed in 10% formalin and analyzed to observe epithelial development, papillary structure, and possible tissue lesions. Histological observations were conducted to compare structural differences among treatments during pre-weaning and post-weaning stages. The collected data were analyzed using one-way analysis of variance (ANOVA). Differences among treatment means were determined using the Least Significant Difference (LSD) test at a significance level of $P < 0.05$. Histological and morphological observations were analyzed descriptively. Statistical analysis was performed following commonly applied procedures for experimental animal studies, where appropriate statistical methods should match the study design and measured outcomes.

RESEARCH RESULT

Rumen Development Based on Macroscopic Observation

The first hypothesis proposed that different milk sources influence rumen characteristics and papillary development of crossbred buck kids. The results supported this hypothesis, showing that milk treatments affected the pattern of rumen structural development during early growth. Macroscopic observation was conducted to evaluate changes in rumen appearance between pre-weaning and post-weaning stages. At the pre-weaning stage (68 days of treatment), the rumen of crossbred buck kids from all treatments showed a relatively soft surface with smooth consistency. The initial formation of papillae was observed on the ruminal surface, although the structures were still small and not fully developed.

This condition indicates that the rumen was still in an early developmental phase because the animals were still receiving liquid feed as the primary nutrient source.

After reaching the post-weaning stage (128 days old), rumen development progressed in all treatments. The papillae became more visible, extended above the ruminal surface, and showed increased structural development. The difference between pre-weaning and post-weaning stages was mainly associated with increased consumption of solid feed and forage after two months of age. The increased intake of solid feed stimulated microbial fermentation activity, resulting in higher production of volatile fatty acids (VFA), which contributed to rumen epithelial development. The progressive development observed in this study indicates that rumen maturation is a continuous process influenced by nutritional transition. Although milk sources affected early rumen development, the introduction of solid feed played an important role in accelerating rumen functional development after weaning.

The macroscopic development of rumen structure during both periods is summarized in Table 1.

Table 1. Macroscopic Observation of Rumen Development During Pre-Weaning and Post-Weaning Stages

Development Stage	Rumen Characteristics
Pre-weaning (68 days)	Soft rumen surface, smooth consistency, initial papillae emergence, immature rumen structure
Post-weaning (128 days)	Papillae clearly developed, longer papillae structure, increased rumen surface complexity and epithelial development

The observation in Table 1 demonstrates that rumen development occurred progressively from pre-weaning to post-weaning stages. During the pre-weaning period, the rumen structure remained immature because the animals depended mainly on liquid feed. The limited papillary development reflects the lower fermentation activity before full microbial establishment.

In contrast, post-weaning animals showed more advanced rumen characteristics. The development of longer papillae and increased rumen surface complexity indicates improved absorptive capacity. These changes occurred because solid feed consumption increased microbial fermentation, resulting in greater stimulation of rumen epithelial growth. The results support H1, indicating that nutritional treatment and feeding transition influence rumen characteristics. The findings also demonstrate that evaluation of rumen development should consider both milk feeding strategies and the subsequent transition to solid feed.

Histological Development of Rumen Epithelium

Histological observation was conducted to evaluate structural changes in rumen tissue during pre-weaning and post-weaning stages. The second hypothesis proposed that different milk sources would influence rumen papillary morphology and histological development. The results showed that all treatments supported normal rumen tissue development without causing tissue abnormalities. During the pre-weaning stage, histological examination showed that rumen papillae and epithelial layers were not fully developed in all treatments. The papillae appeared shorter, and epithelial thickness was still limited. This condition reflects the immature functional status of the rumen before complete adaptation to solid feed.

At the post-weaning stage, rumen tissues showed improved structural development. The papillae became longer and thinner, the epithelial layer became thicker, and papillae were distributed more densely throughout the ruminal surface. These changes indicate that rumen tissues continued to mature after animals increased their consumption of solid feed. No apparent lesion (NAL) was observed in any treatment group during both developmental stages. This finding indicates that all milk sources were tolerated by the animals and did not cause visible damage to rumen tissue.

The histological development of rumen tissue is summarized in Table 2.

Table 2. Histological Characteristics of Rumen Papillae Development in Crossbred Buck Kids Fed Different Milk Sources

Stage	Histological Characteristics
Pre-weaning	Short papillae, immature epithelial layer, limited papillary distribution, no apparent lesion
Post-weaning	Longer papillae, thicker epithelial layer, dense papillary distribution, improved tissue development, no apparent lesion

The results presented in Table 2 indicate that rumen histological development occurred in all treatments regardless of milk source. The absence of tissue lesions demonstrates that goat milk, cattle milk, buffalo milk, milk replacer, and soybean-goat milk combination did not negatively affect rumen tissue integrity. The improvement observed after weaning suggests that rumen tissue development was strongly associated with increased fermentation activity. The thicker epithelial layer and longer papillae observed during the post-weaning stage indicate improved rumen function and greater capacity for nutrient absorption. These results partially support H3, demonstrating that milk sources influence rumen morphology, although all treatments allowed normal histological development. The findings highlight that differences among milk sources mainly affected the degree of development rather than causing abnormal tissue changes.

Effect of Different Milk Sources on Rumen Papillary Characteristics at Pre-Weaning Stage

Quantitative analysis showed that different milk sources significantly affected several rumen papillary characteristics during the pre-weaning stage. The results supported the hypothesis that milk composition influences early rumen structural development. Significant differences ($P < 0.05$) were observed in papillae density, length, circumference, cross-sectional area, surface area, inter-papillary area, total papillary surface area, and total absorption surface area among treatments.

The detailed results of rumen papillary characteristics at the pre-weaning stage are presented in Table 3.

Table 3. Effect of Different Milk Sources on Rumen Papillary Characteristics of Crossbred Buck Kids at Pre-Weaning Stage

Parameters	T1 Goat Milk	T2 Cattle Milk	T3 Buffalo Milk	T4 Milk Replacer	T5 Soybean-Goat Milk
Density of papillae (number/cm ²)	90.00	134.00	142.00	122.00	100.00
Length of papillae (mm)	1.06	0.94	0.85	0.67	0.88
Circumference (mm)	1.85	1.33	1.75	2.00	1.57
Cross-sectional area (mm ²)	0.59	0.40	0.55	0.64	0.48
Surface area (mm ²)	1.96	1.25	1.48	1.33	1.37
Inter-papillary area (mm ² /cm ²)	52.26	53.10	78.04	77.50	47.84
Total papillary surface area (cm ²)	175.02	167.00	209.00	160.50	136.14
Total absorption surface (mm ² /cm ²)	227.28	220.10	287.04	238.00	183.98

The results in Table 3 demonstrate that milk source significantly influenced rumen papillary development during the pre-weaning stage. Buffalo milk treatment (T3) produced the highest papillae density (142/cm²), followed by cattle milk treatment (T2) with 134/cm². Meanwhile, goat milk treatment (T1) showed the lowest papillae density (90/cm²). Although goat milk resulted in lower papillae density, it produced the longest papillae (1.06 mm). This indicates that different milk sources affected different aspects of papillary development. Some treatments promoted papillae formation, whereas others enhanced papillary elongation.

Milk replacer treatment showed the highest circumference (2.00 mm) and cross-sectional area (0.64 mm²). This suggests that milk replacer was capable of supporting certain structural characteristics of rumen development during early life. Buffalo milk treatment produced the highest total papillary surface area (209.00 cm²) and total absorption surface (287.04 mm²/cm²). In contrast, soybean-goat milk treatment showed the lowest total papillary surface area (136.14 cm²) and absorption surface (183.98 mm²/cm²).

These findings support H1 and H3, confirming that milk source affects rumen characteristics and papillary morphology. The variation among treatments indicates that nutritional composition of liquid feeds plays an important role in regulating different aspects of rumen development. The unique contribution of this study is the direct comparison of five different liquid feeding systems within the same experimental condition, providing new information regarding their effects on rumen structural adaptation in crossbred buck kids.

Effect of Different Milk Sources on Rumen Papillary Characteristics at Post-Weaning Stage

Following the pre-weaning period, rumen development continued during the post-weaning stage as animals increased their intake of solid feed. The transition from milk-based nutrition to a diet containing concentrate and forage stimulated further structural development of the rumen. Macroscopic observations showed that all treatments developed longer and more visible papillae compared with the pre-weaning stage. Histological examination during the post-weaning stage showed that rumen tissues from all treatments developed normally without apparent lesions (NAL). The papillae became longer, the epithelial layer became thicker, and the distribution of papillae became denser compared with the pre-weaning stage. These observations indicate that all milk treatments allowed normal rumen maturation after weaning.

The quantitative differences among treatments during the post-weaning stage are presented in Table 4.

Table 4. Effect of Different Milk Sources on Rumen Papillary Characteristics of Crossbred Buck Kids at Post-Weaning Stage

Parameters	T1 Goat Milk	T2 Cattle Milk	T3 Buffalo Milk	T4 Milk Replacer	T5 Soybean-Goat Milk
Density of papillae (number/cm ²)	118.00	116.00	124.00	116.00	118.00
Length of papillae (mm)	1.43b	2.35a	1.51b	1.48b	1.49b
Circumference (mm)	2.46	1.81	1.90	1.90	1.80
Cross-sectional area (mm ²)	0.79	0.58	0.61	0.60	0.60
Surface area (mm ²)	3.55	4.27	2.84	2.84	2.80
Total papillary surface area (cm ²)	414.54	480.68	359.20	327.20	333.10

Parameters	T1 Goat Milk	T2 Cattle Milk	T3 Buffalo Milk	T4 Milk Replacer	T5 Soybean-Goat Milk
Total absorption surface (mm ² /cm ²)	506.30	545.64	435.90	397.90	404.82

The results presented in Table 4 indicate that milk source continued to influence rumen papillary development after weaning. However, compared with the pre-weaning stage, the differences among treatments became smaller because all animals had started consuming solid feed, which became the major factor stimulating rumen maturation. The most significant difference was observed in papillae length. Kids receiving cattle milk treatment (T2) showed the longest papillae (2.35 mm), which was significantly higher compared with goat milk (1.43 mm), buffalo milk (1.51 mm), milk replacer (1.48 mm), and soybean-goat milk treatment (1.49 mm). This result indicates that cattle milk provided nutritional conditions that supported greater papillary elongation during the post-weaning transition.

Although buffalo milk produced the highest papillae density during the pre-weaning period, cattle milk showed superior papillary length after weaning. This difference demonstrates that milk sources may affect different aspects of rumen development. Some treatments may stimulate papillae formation, whereas others may promote papillae elongation and expansion.

The total papillary surface area was numerically highest in cattle milk treatment (480.68 cm²), followed by goat milk (414.54 cm²) and buffalo milk (359.20 cm²). The highest total absorption surface was also observed in cattle milk treatment (545.64 mm²/cm²). These findings indicate that cattle milk supported greater rumen absorptive development during the post-weaning period. These results support H1 and H3, demonstrating that different milk sources influence rumen characteristics and papillary morphology. The findings also highlight that early liquid feeding strategies may have a continuing influence on rumen development after animals transition to solid feed.

Comparison of Rumen Development Between Pre-Weaning and Post-Weaning Stages

The comparison between pre-weaning and post-weaning stages demonstrated a clear progression of rumen structural development in all treatment groups. At 68 days of age, rumen papillae were still developing, while at 128 days of age, papillae became longer, more distributed, and structurally more mature. The increase in rumen development after weaning was observed in all parameters related to papillary structure. Papillae length increased considerably after animals consumed more solid feed, indicating enhanced fermentation activity within the rumen. The transition from milk feeding to solid feed increased microbial activity and promoted rumen functional development.

The improvement in rumen structure after weaning demonstrates that the developmental process was not completed during the milk-feeding period. Instead, early milk nutrition provided the foundation for rumen development, while solid feed consumption accelerated functional maturation. The results indicate that milk source affects the initial development process, but the post-weaning period represents an important stage where feed transition determines the final development of rumen function. Therefore, appropriate liquid feeding management before weaning is essential to support successful adaptation after weaning. This finding supports the proposed hypothesis that milk sources influence rumen development. The novelty of this study is that it evaluates both early liquid feeding effects and subsequent rumen adaptation after weaning within the same experimental population.

Fecal Consistency Response of Crossbred Buck Kids Fed Different Milk Sources

The fourth hypothesis proposed that different milk sources influence fecal consistency and digestive adaptation of crossbred buck kids. The results showed that fecal consistency changed during the adaptation period after introduction of different milk treatments. During the first and second weeks of treatment, feces from all treatment groups were relatively watery. This condition occurred during the initial adaptation period when animals adjusted to different liquid feed sources. After the third week, fecal consistency gradually improved, becoming softer and more solid.

However, differences were observed when milk allowance increased according to body weight. The occurrence of watery feces was more frequent in kids receiving soybean-goat milk treatment. These observations suggest that soybean inclusion influenced digestive adaptation compared with animal-based milk sources. The overall fecal response among treatments is summarized in Table 5.

Table 5. Fecal Consistency Response of Crossbred Buck Kids Fed Different Milk Sources

Treatment	Early Feeding Period	Adaptation Period	General Response
Goat Milk	Watery feces during first weeks	Improved after adaptation	Good tolerance
Cattle Milk	Watery feces during first weeks	Became softer and solid	Good tolerance
Buffalo Milk	Watery feces during first weeks	Became softer and solid	Good tolerance
Milk Replacer	Watery feces during first weeks	Improved gradually	Acceptable adaptation
Soybean-Goat Milk	More watery feces observed	Slower improvement	Higher digestive sensitivity

The results in Table 5 show that all treatments caused temporary changes in fecal consistency during the adaptation period. This indicates that young goats require time to adjust to different nutritional compositions. The soybean-goat milk treatment showed the greatest tendency toward watery feces. This response indicates that the combination of soybean milk and goat milk may have affected digestive tolerance during early development. Although soybean milk provides additional protein sources, its utilization may be limited in young animals because their digestive system is still developing.

In contrast, cattle milk and milk replacer treatments showed acceptable fecal adaptation without prolonged digestive problems. This finding indicates that these treatments may serve as practical alternatives when goat milk availability is limited. The results support H4, confirming that milk sources influence fecal consistency and digestive adaptation. Furthermore, the findings partially support H5, because milk replacer and cattle milk maintained acceptable development while providing potential economic alternatives to goat milk.

DISCUSSION

Early nutritional management plays an important role in regulating rumen development and digestive adaptation in young ruminants. The present study demonstrates that different liquid feed sources influenced rumen structural development and digestive responses of crossbred buck kids. During the early growth period, the rumen undergoes rapid anatomical and functional changes involving epithelial development, microbial establishment, and adaptation from a milk-based diet to a solid feed-based diet. These findings support the concept that nutritional exposure during early life affects the capacity of young ruminants to develop a functional digestive system. According to Villot et al. (2020), early feeding strategies influence gastrointestinal maturation, microbial colonization, and metabolic adaptation in young ruminants. Compared with previous studies that mainly evaluated calf nutrition, this study provides additional information by directly comparing goat milk, cattle milk, buffalo milk, milk replacer, and soybean-goat milk combination in crossbred buck kids under the same experimental conditions.

Rumen papillary development is an important indicator of rumen functional maturation because papillae determine the surface area available for nutrient absorption. The present study showed that different milk sources resulted in different patterns of papillary development, indicating that nutrient composition of liquid feeds influenced rumen morphological adaptation. Variation in protein, fat, carbohydrate, and mineral content among milk sources may provide different nutritional signals for epithelial growth and tissue development. Recent research by Meale et al. (2021) demonstrated that early nutritional interventions affect rumen epithelial function and microbial interactions during the transition period. Similar to these findings, the current study confirms that early dietary management influences rumen development; however, it extends previous knowledge by showing that differences among liquid milk sources alone can modify rumen morphology before complete rumen fermentation capacity is established.

The development of rumen tissue after weaning indicates that early milk nutrition has a continuing influence on digestive adaptation. In this study, all treatments showed progressive rumen development after the transition to solid feed, suggesting that early liquid feeding provides the foundation for later rumen maturation. Previous studies have emphasized that solid feed intake stimulates microbial fermentation and promotes rumen epithelial growth through increased production of fermentation metabolites. According to Dias et al. (2022), the transition from milk feeding to solid feed represents a critical period that determines rumen functionality and future nutrient utilization efficiency. The present study agrees with these findings because rumen development improved after increased solid feed consumption. However, the novelty of this research is the demonstration that different milk sources before weaning may influence the degree and pattern of rumen structural development during both pre-weaning and post-weaning stages.

The utilization of alternative liquid feeds, including milk replacer and soybean-based milk, has received increasing attention because of economic considerations in livestock production. The current findings indicate that milk replacer can support normal rumen development and digestive adaptation, suggesting that alternative feeding systems may be applied when conventional milk sources are limited. This finding agrees with the study of Soberon et al. (2021), which reported that appropriately formulated milk replacers can maintain growth and physiological development in young ruminants. However, the response of soybean-goat milk treatment indicates that alternative plant-based ingredients require careful evaluation. According to Guo et al. (2023), plant-derived proteins may influence gastrointestinal function depending on processing methods, nutrient availability, and the presence of bioactive compounds. Therefore, the current study contributes new evidence that alternative milk sources should not only be evaluated based on nutrient content but also based on their effects on digestive adaptation.

Fecal consistency provides an important practical indicator of nutritional suitability and digestive tolerance during early life. The present study showed that young goats experienced temporary changes in fecal condition during adaptation to different milk sources, but most treatments gradually achieved more stable digestive responses. The greater tendency toward watery feces in soybean-containing treatment suggests that some alternative ingredients may require additional adaptation or processing to improve utilization by immature digestive systems. Recent research by Celi et al. (2021) emphasized that early-life nutrition strongly influences gastrointestinal health, intestinal barrier function, and digestive stability in young animals. The current findings support this concept by demonstrating that evaluation of feeding strategies should include not only growth and rumen development but also indicators of digestive health such as fecal consistency.

Overall, this study provides an integrated understanding of how different liquid feeding strategies influence rumen development and digestive adaptation in crossbred buck kids. Previous studies have commonly examined single nutritional factors, such as milk replacer use, microbial development, or solid feed introduction. In contrast, this research evaluates multiple milk sources simultaneously by combining rumen morphological evaluation, histological observation, and fecal response assessment. The findings indicate that goat milk remains a suitable nutritional source for young goats, while cattle milk and milk replacer have potential as practical alternatives without negative effects on digestive development. Meanwhile, soybean-goat milk requires careful management due to its influence on digestive adaptation. Therefore, this study contributes new knowledge for optimizing early goat kid feeding strategies by balancing biological performance, rumen development, and economic efficiency.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that different milk sources influenced rumen characteristics, papillary development, and fecal consistency of crossbred buck kids. Buffalo milk showed better rumen papillary development during the pre-weaning stage, while cattle milk supported greater papillary elongation after weaning. Goat milk provided good nutritional support for kid development, whereas milk replacer showed potential as an economical alternative without negatively affecting rumen development. However, soybean-goat milk requires careful management due to slower digestive adaptation. Based on these findings, goat milk, cattle milk, and milk replacer can be considered suitable liquid feeding strategies for crossbred buck kids. The selection of milk sources should consider both biological performance and economic efficiency in goat production systems.

ADVANCED RESEARCH

Further research is recommended to evaluate the long-term effects of different milk sources on rumen microbial development, nutrient utilization, and productive performance after maturity. Additional studies should also investigate different inclusion levels and processing methods of soybean-based milk to improve digestive tolerance in young goats.

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