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Feeding Strategies for Improving Growth Performance in Goats

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Abstract Improving goat growth performance is a key objective in modern livestock production, directly influencing economic efficiency and product quality. This study systematically explores feeding strategies that enhance growth performance in goats by integrating nutritional management, feeding practices, genetic improvement, health control, and environmental regulation. The research analyzes critical growth indicators such as weight gain, feed conversion efficiency, and immune status, and evaluates the effects of optimized diet formulation, including balanced roughage-to-concentrate ratios and functional feed additives. In addition, different feeding systems and management approaches are compared to identify optimal practices. The role of genetic selection and marker-assisted breeding in improving growth traits is also discussed. A case study is presented to demonstrate the practical application and effectiveness of these strategies under farm conditions. The findings provide a comprehensive framework for improving goat production efficiency and offer valuable insights for sustainable and scientific goat farming.

Keywords Goat growth performance; Feeding strategies; Nutritional management; Feed efficiency; Genetic improvement

1 Introduction

Feeding management is a central lever for improving productivity and profitability in modern goat production systems. Goats contribute substantially to food security and rural livelihoods by supplying meat, milk, and high-value by-products in both intensive and smallholder settings, particularly in tropical and subtropical regions where they are often better adapted than larger ruminants to heat, poor-quality forages, and feed scarcity (Teixeira et al., 2024). However, suboptimal nutrition and poorly designed feeding programs remain major constraints to realizing the genetic growth potential of goats, leading to low average daily gains, delayed market age, and reduced reproductive efficiency. Recent work in replacement breeder goats has shown that relatively modest adjustments in diet composition and quantity—such as increasing total daily feed allowance and rebalancing roughage–concentrate ratios—can substantially enhance body weight gain, body condition score, and overall growth performance under smallholder conditions (Ghani et al., 2017). At the same time, climate change and rising temperatures are intensifying heat stress, altering nutrient requirements and increasing maintenance costs for thermoregulation, which makes context-specific feeding strategies even more critical for sustaining growth in hot environments. Against this background, evidence-based feeding strategies tailored to production goals, production systems, and environmental constraints are essential for improving growth performance in goats.

Goat growth performance is shaped by a wide array of interacting nutritional, managerial, and environmental factors. At the most fundamental level, growth depends on meeting energy and protein requirements that vary with genotype, physiological state, body weight, and ambient temperature. Under- or over-feeding energy markedly alters average daily gain, carcass yield, and the allometric development of muscle and internal organs in growing dairy goats, with restricted feeding decreasing growth rate, carcass meat yield, and visceral development in a weight-stage-dependent manner (Huang et al., 2024). Beyond total nutrient supply, the feeding system and diet structure strongly influence performance. Comparative assessments of stall feeding, pasture grazing, and grazing plus supplementation in small ruminants show that finishing kids and lambs solely on pasture typically reduces average daily gain and carcass yield, whereas supplemented grazing or intensive stall-feeding can match or exceed growth and carcass traits of confined systems when rations are appropriately balanced. Within intensive systems, diet form and ingredient selection are important: pelleted or hydroponic-fodder-based rations can increase intake, nutrient digestibility, and weight gain compared with conventional roughage-based diets, while manipulated starch degradability and non-forage fiber sources can improve feed efficiency and lean tissue deposition by enhancing post-ruminal starch digestion and nutrient utilization. Feed additives and specific supplements, including live yeast (*Saccharomyces cerevisiae*), mulberry leaves, and fermented roughages, have been shown to stimulate average daily gain and feed efficiency by modulating rumen fermentation, antioxidant capacity, immune status, and gut microbiota, particularly under thermal stress. In young goats, early-life feeding strategies that support rumen development—through appropriate liquid feeding, concentrate and roughage management, and functional additives—have lasting benefits on growth and health after weaning (Abdelsattar et al., 2025). Collectively, these findings highlight that growth performance in goats depends not only on nutrient level but also on feeding frequency, physical form of the diet, forage combinations, and the inclusion of targeted functional ingredients.

Building on this growing body of evidence, the present study on “Feeding Strategies for Improving Growth Performance in Goats” aims to systematically evaluate and integrate practical dietary interventions that can be implemented in commercial and smallholder contexts. The specific objectives are to: (i) summarize and compare the effects of different feeding systems (extensive grazing, semi-intensive, and intensive stall-feeding) and ration structures on growth rate, feed efficiency, and carcass-related traits in goats; (ii) assess how key ration design variables—such as energy and protein density, forage–concentrate ratio, starch degradability, forage species combinations, and physical form of the diet—modulate nutrient intake, rumen function, and growth outcomes; (iii) review and, where possible, quantify the contribution of selected nutritional strategies and feed additives (e.g., yeast, hydroponic fodder, functional forages, and plant-based supplements) to improving growth performance under heat stress and other challenging conditions; and (iv) identify feeding strategies that are both biologically effective and economically feasible across diverse production environments, with particular attention to hot climates and resource-limited systems. By integrating controlled trials, meta-analyses, and recent updates on nutrient requirements, the study seeks to provide a framework for designing context-appropriate feeding programs that enhance average daily gain, shorten finishing time, and improve overall productivity in goat enterprises. Ultimately, this work is intended to support producers, nutritionists, and policymakers in adopting feeding strategies that align improved growth performance with sustainability and resilience in goat production systems.

2 Evaluation System of Goat Growth Performance

A comprehensive evaluation system for goat growth performance integrates productive, nutritional, and health–immune indicators to assess feeding strategies effectively. Key productive traits, such as body weight and average daily gain, reflect growth capacity, while nutritional efficiency indicators like feed conversion ratio and digestibility measure how well feed is utilized. Health and immune parameters, including antioxidant status and blood indices, ensure that growth improvements do not compromise animal welfare. This integrated framework enables comparison of feeding systems, diet composition, and management practices, while also providing mechanistic insights through metabolic and rumen-related measurements, supporting the optimization of sustainable goat production.

2.1 Growth rate and body weight gain indicators

Growth rate and body weight gain are primary outcomes for evaluating feeding strategies in goats, because they integrate nutrient intake, metabolic status, and environmental conditions over time. On-farm evaluations and experimental trials typically record live weight at standardized ages (e.g. birth, 3, 6, 9, and 12 months) and compute period-specific ADG to describe growth trajectories and identify sensitive phases. For example, Arsi-Bale kids reached mean weights of 2.0, 7.6, 13.0 and 19.3 kg at birth, 3, 6 and 12 months, respectively, with corresponding daily gains between 40 and 125 g depending on age, agroecology and sex (Guyo et al., 2023). Crossbred Boer × Central Highland goats showed birth to yearling weights from 2.52 to 20.5 kg, with phase-specific gains of 31–80 g/day that were strongly influenced by Boer blood level, birth type and season (Tesema et al., 2021). Such data provide a baseline against which nutritional interventions can be judged.

Controlled feeding trials use ADG and final body weight to quantify the response to diet formulation, feeding level, feed form or supplementation. Raising Saanen dairy kids at 40, 70 or 100% of ad libitum intake produced a linear decline in ADG as feed level decreased, accompanied by lower shrunk and empty body weights, hot carcass weight and tissue yields at slaughter (Huang et al., 2024). Under thermal stress, Boer goats given fermented Pennisetum giganteum feed achieved higher ADG (48.2 g vs. lower in controls) and carcass weight while consuming less feed, illustrating how diet quality can counter environmental constraints on growth. Similar improvements in final weight and ADG have been reported when diets were supplemented with garlic skin, cecropin, or optimized concentrate levels, confirming that body weight gain indicators are sensitive tools for discriminating among feeding strategies.

2.2 Feed conversion efficiency and nutrient utilization

Feed conversion efficiency expresses how effectively goats transform feed into live weight and is central to evaluating and comparing feeding strategies economically and environmentally. FCR or feed-to-gain ratios are usually calculated as total feed intake per unit of weight gain over a defined period, while related indices such as Kleiber ratios (growth rate relative to metabolic weight) capture efficiency across growth stages. Meta-analysis of *Saccharomyces cerevisiae* supplementation in growing goats showed that yeast preparations increased ADG while having smaller overall effects on dry matter intake and FCR, indicating potential efficiency gains from altered rumen fermentation and health status (Ogbuewu and Mbajiorgu, 2023). In intensive systems, concentrate feeding frequency changed daily feed intake and ADG in Sirohi kids, but did not markedly alter FCR, suggesting that higher intake and gain can occur without proportional improvements in conversion.

Nutrient utilization is evaluated by measuring intake and apparent digestibility of dry matter and key nutrients, as well as rumen fermentation characteristics. Young Kacang goats fed diets with increasing energy density (TDN 70.0%-73.3%) showed higher intakes of organic matter, crude protein and metabolizable energy and achieved better ADG and feed efficiency at the highest energy level, even though dry matter intake and most digestibilities remained high and similar across treatments (Tahuk et al., 2024). Under heat stress, goats receiving fermented Pennisetum feed had reduced average daily feed intake yet improved F:G ratio, accompanied by enhanced antioxidant and immune status, suggesting more efficient nutrient use under challenging conditions (Figure 1) (Qiu et al., 2023). Functional additives such as garlic skin or cecropin have been linked to higher volatile fatty acid production and favorable shifts in acetate-to-propionate ratios, which support more efficient energy capture from fiber and starch, reinforcing the value of combining FCR with nutrient and rumen measurements when assessing feeding interventions.

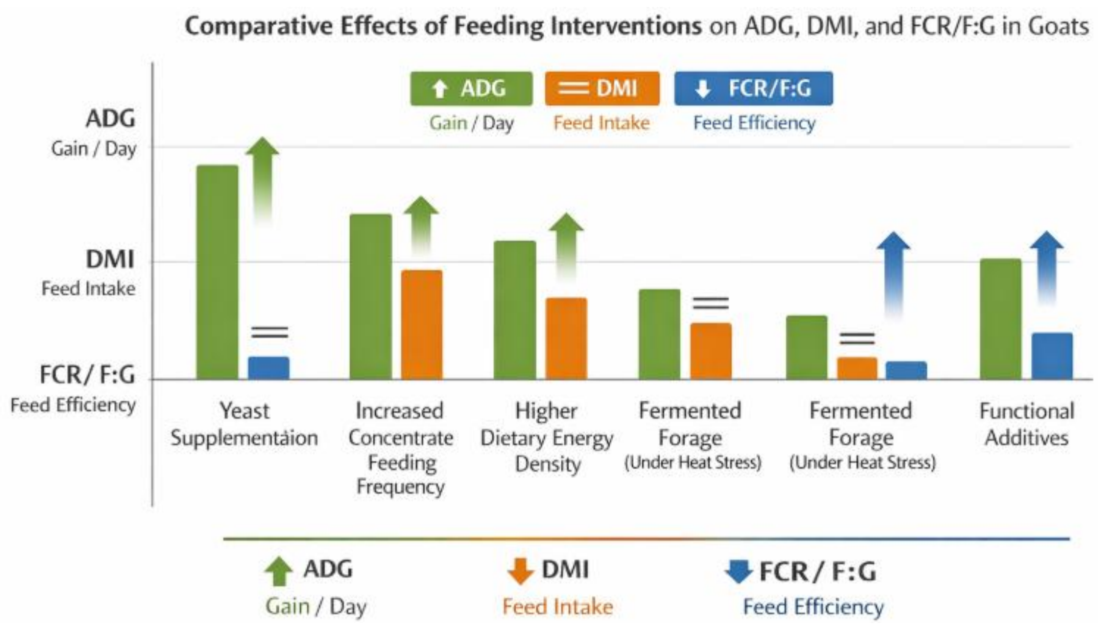

Figure 1 Comparative effects of feeding interventions on average daily gain, dry matter intake, and feed conversion efficiency in goats. The figure summarizes the relative responses of goats to yeast supplementation, concentrate feeding frequency, dietary energy density, fermented forage, and selected functional additives (Adopted from Qiu et al., 2023)

2.3 Health status and immune performance indicators

Health and immune indicators are essential components of goat growth evaluation systems, because rapid gains achieved at the expense of resilience can undermine long-term productivity. Hematological variables such as hemoglobin, packed cell volume, and leukocyte counts, together with rectal temperature and clinical observations, provide a basic assessment of health across management systems. In Beetal kids compared under stall-fed and free-range grazing conditions, stall-fed animals displayed better overall growth and health profiles, while free-range kids often showed higher antioxidant enzyme activities, reflecting differing oxidative challenges and adaptive responses (Bhinder et al., 2024). Comparisons of free-range, semi-intensive and fully barn-kept Thai native goats revealed that continuous confinement led to weight loss, elevated red and white blood cell counts, increased neutrophil-to-lymphocyte ratio, cortisol, and higher gastrointestinal parasite egg counts, highlighting how management and associated feeding patterns can induce physiological stress despite controlled nutrition (So-In, 2023).

At a finer level, immune and oxidative stress biomarkers are widely used in feeding trials to link diet composition to health-related performance. Supplementing goat diets with garlic skin enhanced serum activities of superoxide dismutase, glutathione peroxidase and catalase, reduced malondialdehyde, and elevated IgA and IgG, alongside increased anti-inflammatory cytokines (IL-4, IL-10) and reduced pro-inflammatory cytokines (IL-1β, IL-6, TNF-α) (Zhou and Shen, 2025). Cecropin supplementation similarly increased antioxidant enzyme activities, improved immunoglobulin levels, and shifted rumen fermentation and microbiota composition, coinciding with better growth and lower feed-to-gain ratio. Meta-analytic evidence for yeast additives also points to higher blood glucose, white blood cell counts and ruminal propionate and total VFA, indicating combined metabolic and immune modulation (Ogbuewu and Mbajiorgu, 2023). Together, these findings support incorporating antioxidant status, immunoglobulins, cytokine profiles and selected hematological traits into growth performance evaluation, ensuring that feeding strategies promote both productivity and robust immune function.

3 Nutritional Requirements and Diet Formulation for Goats

Nutritional requirements of goats vary with age, physiological stage, and environmental conditions, making precise feeding management essential for optimal growth. During rapid growth, energy and protein demands increase significantly, requiring adjustments in nutrient density and intake. Higher energy and protein levels generally promote better weight gain and feed efficiency, while environmental stress, such as heat, can shift nutrient use toward maintenance rather than growth. Modern feeding standards emphasize stage-specific nutrient supply, considering body weight and growth status. Mineral needs, particularly calcium and phosphorus, rise moderately with body weight, allowing for more accurate and efficient diet formulation in growing goats.

3.1 Nutritional characteristics at different growth stages

Nutritional priorities shift markedly from pre-weaning to post-weaning, finishing, and pregnancy, and feeding strategies must track these changes. Early-life goats transition from liquid to solid feeds while the rumen is still developing, so diets must support both tissue growth and rumen maturation. Energy and protein restriction in weaned kids has been shown to impair antioxidant capacity of gastrointestinal tissues, underscoring the sensitivity of this stage to nutritional insults (Abdelsattar et al., 2025). Later, during the main growth period (roughly 4-8 months), goats respond strongly to dietary energy and protein density: increasing ME concentration and CP level enhances average daily gain up to an optimum, beyond which performance may plateau or decline (Lu and Potchoiba, 1990).

Physiological state also modifies nutritional characteristics and efficiency of nutrient use. In hot environments, goats show altered requirements for sodium, potassium and phosphorus relative to widely used feeding systems, likely reflecting adaptive mechanisms to cope with heat stress and associated water and electrolyte challenges (Teixeira et al., 2024). During pregnancy, energy and protein requirements for the conceptus rise, but recent work indicates that the efficiency of ME utilization for pregnancy actually increases as gestation advances, even though absolute mineral accretion requirements grow with fetal size. Under-nutrition at critical gestational windows can compromise offspring gastrointestinal development: feed restriction in early gestation reduced small-intestinal mass, length, and villus height:crypt depth ratio in newborn kids, suggesting long-term consequences for nutrient absorption and growth potential (Figure 2) (Santos et al., 2023).

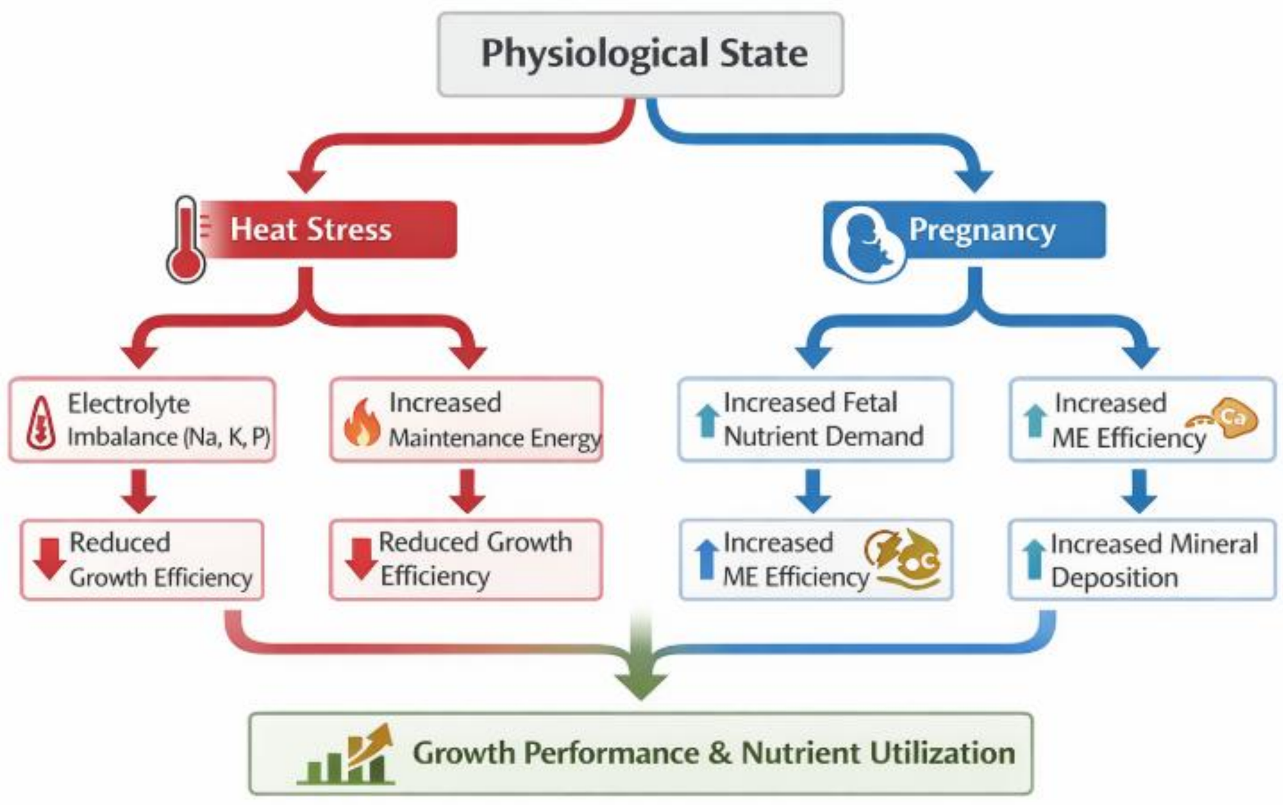

Figure 2 Effects of maternal undernutrition on gastrointestinal development in offspring goats. The diagram compares intestinal morphology under normal and restricted nutritional conditions, highlighting differences in intestinal size and villus structure (Adopted from Santos et al. 2023)

3.2 Scientific ratio of roughage and concentrate feed

Balancing roughage and concentrate is fundamental to maintaining rumen health while supplying adequate energy and protein for growth. Concentrate supplementation consistently improves dry matter intake, nutrient digestibility and growth when goats are otherwise dependent on low-quality forages or grazing alone. In Jamunapari does under semi-intensive conditions, increasing concentrate from 150 to 300 g/day alongside roughage significantly improved intake of digestible crude protein and total digestible nutrients, as well as digestibility of dry matter and crude protein (Shoshe et al., 2021). Similarly, in Barbari kids fed pulse-straw diets, raising concentrate mix to 2.1% of body weight enhanced weight gain, total VFA production and nitrogen retention, indicating more efficient nutrient utilization in finisher goats (Dutta et al., 2025).

However, excessively high concentrate and low forage can compromise rumen function, welfare, and long-term health. Rumen development in young kids benefits from higher roughage proportions: in early-weaned Balady kids, a 70:30 concentrate:roughage diet increased total volatile fatty acids, ammonia nitrogen and ciliate protozoa counts and was recommended as a high-roughage strategy for rumen development (Aziz et al., 2018). Forage-to-concentrate (F:C) ratio also affects behavior and stress; in goat kids, a 20:80 F:C diet produced superior growth but was associated with more stereotypic behaviors such as bar and bucket biting, while higher-forage diets elevated cortisol at extreme roughage levels, indicating the need to avoid both forage deficiency and excess under intensive systems (Tölü, 2025). Under comparable feeding regimes, altering concentrate:roughage ratios (3:7 vs. 5:5) changes fiber digestibility and rumen fermentation patterns, highlighting that optimal F:C ratios must be tailored to growth stage and production goals while maintaining rumen pH and microbial stability (Lin et al., 2023).

3.3 Application of functional additives

Functional additives, particularly probiotics and enzyme preparations, have emerged as effective tools to enhance growth performance and rumen efficiency in goats, especially in high-concentrate or stressful conditions. Supplementation with Bacillus subtilis and B. licheniformis, alone or combined with multi-enzyme complexes, has repeatedly improved average daily gain and final body weight in fattening goats relative to unsupplemented controls (Lu et al., 2025). These combinations can increase average daily feed intake and growth rate simultaneously, resulting in higher slaughter weights without adverse effects on serum biochemical or antioxidant indices (Lu et al., 2021). In weaned goats, complexes of Candida utilis, Bacillus coagulans, Lactobacillus acidophilus and multi-enzymes significantly increased end weight and ADG, while tending to improve digestibility of dry matter and crude fat, suggesting better exploitation of both fiber and non-fiber nutrients (Lu et al., 2022).

Beyond growth, functional additives modulate rumen fermentation, epithelial integrity, and immune status. Probiotic–enzyme combinations elevate total volatile fatty acids or specific branched-chain VFAs, improve rumen papilla morphology, and enrich fiber-degrading taxa such as Prevotellaceae and Fibrobacteres, thereby supporting more efficient fermentation of high-concentrate diets. In goats fed high-concentrate rations, probiotic supplementation increased concentrations of acetate, propionate, butyrate and total VFAs, while upregulating tight-junction proteins and anti-inflammatory cytokines (e.g., IL-10) and downregulating pro-inflammatory mediators, ultimately enhancing rumen barrier function and growth performance. Under heat stress, supplementation with *Saccharomyces cerevisiae* and Clostridium butyricum improved rumen pH, cellulolytic enzyme activities, volatile fatty acid concentrations, dry matter intake and ADG, indicating a protective effect on rumen function and productivity in challenging environments (Cai et al., 2021). Together, these findings support the targeted use of probiotics and enzymes as part of scientific diet formulation to improve growth, health and resilience in modern goat production systems (Barsila et al., 2025).

4 Optimization of Feeding and Management Practices

4.1 Comparison of intensive and grazing-combined systems

Intensive stall-feeding generally supports higher growth rates than continuous grazing, primarily through better control of nutrient supply and reduced energy expenditure on walking and thermoregulation. In Black Bengal does, daily live weight gain was significantly higher under stall feeding than under tethering, restricted grazing, or full-day grazing, even though all groups received the same level of concentrate supplementation (Moniruzzaman et al., 2002). Similar patterns were observed in Kanni Adu and Osmanabadi goats, where stall-fed or high-supplement groups achieved the greatest average daily gain and body size, while goats maintained on sole grazing showed markedly poorer performance (Jeyakumar, 2020; Da et al., 2021). These results indicate that intensive systems are particularly advantageous where high-quality forages or concentrates can be reliably supplied.

However, integrating grazing with strategic supplementation often narrows the performance gap with intensive systems while exploiting low-cost pasture resources. Reviews of small ruminant feeding systems show that kids and lambs grazing with concentrate supplementation can reach average daily gains and carcass yields comparable to or higher than those of stall-fed animals, especially when pastures are of good quality (Huang et al., 2023; Ke et al., 2023). Time-limited or restricted grazing with concentrate has also been proposed as a finishing strategy that maintains growth performance while reducing feed costs and improving some meat quality traits relative to purely indoor systems. In practical goat production, semi-intensive or grazing-combined systems thus represent a compromise, trading some control over intake for lower feed costs, more natural behavior, and potential product quality advantages.

4.2 Optimization of feeding regimes and frequency

Beyond system type, growth performance in goats is strongly influenced by the level of concentrate supplementation within a given diet. In intensively raised Barbari kids, increasing concentrate mix from 0.7% to 2.1% of body weight improved daily weight gain, dry matter intake, digestible crude protein, and total digestible nutrients, along with more favorable rumen fermentation and blood profiles (Dutta et al., 2025). Similar benefits of higher-quality or better-balanced forage-concentrate combinations were reported when guinea grass was mixed with protein-rich Indigofera, which produced the highest crude protein intake, total weight gain, and average daily gain among several forage legume mixtures. These findings support the principle that growth optimization requires both adequate energy density and sufficient rumen-degradable and bypass protein in the ration.

Feeding frequency is another key management lever for improving growth in goats. In Sirohi kids, offering a fixed amount of concentrate three times daily significantly increased total daily feed intake and average daily gain relative to once- or twice-daily feeding, with little effect on feed conversion ratio, suggesting improved utilization of nutrients rather than increased efficiency per se. Studies in Beetal kids and in goats receiving turmeric-supplemented diets likewise showed that more frequent or daily provision of the ration enhanced dry matter intake, weight gain, and body measurements compared with less frequent feeding schedules (Ahmad et al., 2014; Omotoso, 2022). Collectively, this evidence indicates that dividing the daily ration into multiple meals better matches the high metabolic rate and limited rumen capacity of young goats, stabilizing rumen conditions and supporting faster growth.

4.3 Water management and environmental control

Water availability and quality interact strongly with feed intake to determine growth performance in goats. Experiments with Nguni does showed that moderate water restriction (around 70%-80% of ad libitum) can temporarily coincide with peak dry matter intake and average daily gain, but more severe or prolonged restriction reduces gain and worsens gain-to-feed ratio, especially when combined with saline drinking water (Mpendulo et al., 2017). In related work, increasing the period of water deprivation from 0 to 48 hours led to higher compensatory water and feed intake after rehydration but significantly decreased average daily gain, final body weight, and body condition score, and increased parasite burden, underscoring the cumulative negative impact of hydric stress on productivity and health (Mpendulo et al., 2020). These results emphasize that any short-term adaptation to reduced water supply is quickly offset by losses in growth and condition when restriction is extended.

Environmental conditions, particularly heat and humidity, further modify water needs and growth responses. Under hot-humid tropical conditions, providing drinking water with pH as low as 3.8 did not adversely affect nutrient intake, water balance, or growth, and in some cases was associated with higher metabolizable energy use and daily gain compared with mildly acid water, suggesting considerable tolerance to naturally acidic sources where microbial safety is adequate (Ali et al., 2022). In tropical and semi-arid settings, higher temperature-humidity indices drive increased water intake, highlighting the importance of continuous access to clean water to maintain thermoregulation and feed intake (Mpendulo et al., 2017). From a systems perspective, integrating robust water supply, shade, and ventilation into intensive housing, and ensuring accessible watering points and microclimate refuges in grazing systems, is essential to protect growth performance as climate variability and heat stress intensify (Mugoti et al., 2025).

5 Genetic Factors and Breeding Improvement Strategies

5.1 Selection of superior breeds and utilization of hybrid vigor

Breed choice is a foundational decision for improving growth performance, because heritability estimates for body weights and average daily gain are generally moderate, allowing sustained response to selection in meat-type goats (Ofori and Hagan, 2020; Tesema et al., 2020). Crossbreeding indigenous does with specialized meat breeds such as Boer has been widely used to combine adaptation with superior growth, as shown in Boer × Central Highland goats where F_1 progeny raised semi-intensively achieved substantial gains from birth to yearling age under moderate inputs (Tesema et al., 2021). Within indigenous populations such as West African Dwarf goats, relatively high heritability for birth and weaning weights indicates that systematic selection among local animals can also deliver progress when crossbreeding options are limited.

Exploiting heterosis (hybrid vigor) can accelerate improvement, but the level of exotic blood must be carefully managed under low-input systems. In Boer × Central Highland goats, F_2 and F_3 generations did not outperform F_1 for growth and efficiency traits, and increasing Boer inheritance beyond 50% was considered uneconomical under minimal inputs, suggesting that much of the advantage lies in the first cross. Similar patterns have been reported for other crossbreeding schemes, where positive heterosis for birth and yearling weight and post-weaning growth was greatest in the initial crossbred generation before diminishing in later backcrosses (Prastowo et al., 2019; Chavala et al., 2023). These results support breeding strategies that prioritize robust F_1 or other limited-generation crosses, combined with improved nutrition and health, rather than indiscriminately increasing the proportion of specialized meat breeds.

5.2 Application of marker-assisted selection (MAS)

Marker-assisted selection (MAS) uses DNA markers associated with growth traits to enrich breeding populations for favorable alleles earlier and more accurately than phenotype-based selection alone. Genome-wide association studies (GWAS) in diverse goat populations have identified numerous single nucleotide polymorphisms (SNPs) linked to body weight, body length, height, chest circumference, and carcass traits, pointing to genes involved in skeletal growth, muscle development, and energy metabolism (Shangguan et al., 2024). In meat and dual-purpose goats, MAS for such loci can complement conventional selection indices built on estimated breeding values for weights and gains, allowing breeders to identify superior kids before full performance records are available (Moaeen-Ud-Din et al., 2022; Ncube et al., 2025).

Selection signature and candidate-gene studies provide further targets for MAS by revealing genomic regions under strong artificial or natural selection for growth. Whole-genome scans in indigenous and improved breeds have pinpointed genes related to body size, muscle accretion, and fat metabolism, including loci with functional variants such as an insertion–deletion polymorphism in PNLIPRP1 associated with enhanced early growth. Copy-number-variation and SNP-based GWAS in cashmere and meat goats have also highlighted growth-related genes involved in cell proliferation, differentiation, and key signaling pathways, suggesting that multi-marker panels could be assembled for routine MAS in breeding nuclei (Liu et al., 2025; Zhang et al., 2025). For smallholder systems, incorporating a limited set of well-validated markers into low-density genotyping tools offers a practical route to integrate genomics into growth-oriented selection programs.

5.3 Mechanisms of genetic improvement on growth performance

Genetic improvement of growth performance operates through both additive and non-additive effects on traits such as birth, weaning, and yearling weight, as well as average daily gain. Heritability estimates for these traits in crossbred and indigenous goats are typically low to moderate, implying that selection can steadily improve early growth and marketing weights when pedigree and performance records are available. Meta-analyses across small ruminants also indicate that efficiency and resilience traits have exploitable genetic variation, supporting selection for animals that maintain growth under variable environments without excessive increases in mature size or health problems (Mucha et al., 2022).

At the molecular level, growth is regulated by complex networks involving endocrine axes, structural proteins, and signaling pathways that govern muscle hypertrophy, bone growth, and nutrient use. Candidate-gene and genomic studies in goats highlight polymorphisms in growth hormone, insulin-like growth factor-1, myostatin, and multiple loci uncovered by GWAS that affect muscle growth, fat deposition, and carcass composition, thereby influencing overall growth efficiency (Shangguan et al., 2024; Ncube et al., 2025). Pathway analyses repeatedly implicate metabolic and MAPK signaling routes, along with genes affecting body size and lipid metabolism, indicating that selection on these genomic regions alters the balance between lean tissue accretion, maintenance requirements, and feed conversion (Guo et al., 2018; Zhang et al., 2025). Integrating this knowledge into breeding schemes—through indices that weigh growth, efficiency, and health, supported by genomic prediction—provides a mechanistic basis for designing goat populations with faster, more efficient growth adapted to specific feeding systems.

6 Health Management and Disease Prevention Measures

6.1 Effects of common diseases on growth performance

Infectious and parasitic diseases are major constraints on growth performance in goats, primarily by depressing feed intake, diverting nutrients to the immune response, and directly damaging target organs. Gastrointestinal nematodes (GIN) are among the most important, reducing live weight gain, carcass quality, milk yield, and reproductive performance, with particularly severe losses in resource-poor systems where control measures are limited (Rajesh et al., 2017). Meta-analysis indicates that increasing fecal egg counts in infected goats is associated with pronounced declines in average daily gain, dry matter intake, and packed cell volume, reflecting both undernutrition and anemia that undermine growth efficiency (Cei et al., 2018). Internal parasites also lower serum protein and albumin and induce oxidative stress, consistent with chronic malabsorption and inflammation that further compromise productive potential (Sarkar et al., 2024).

High burdens of GIN and other parasites are common in tropical and subtropical regions, where prevalence in goats often exceeds 80%-90% and mixed infections are the rule rather than the exception (Sontigun et al., 2025). On farms in the tropics, higher individual parasite loads correlate with lower body condition scores and hematocrit, demonstrating that even under relatively good nutrition, parasitism still contributes measurably to variation in growth and health (Ortíz-Domínguez et al., 2024). Similar disease-related growth penalties are observed with systemic infections such as trypanosomiasis, contagious caprine pleuropneumonia, and peste des petits ruminants, which cause anemia, respiratory compromise, fetal losses, and increased kid mortality, cumulatively depressing herd productivity and slowing genetic and nutritional gains (Challaton et al., 2023). In intensive settings, poorly managed housing can further predispose goats to parasitic and infectious disease, leading to weight loss accompanied by hematological signs of stress and elevated parasite egg counts.

6.2 Disease prevention and immunization programs

Effective disease prevention programs are essential to protect the benefits of improved feeding strategies on growth. Broad reviews of small-ruminant systems in sub-Saharan Africa conclude that infectious diseases, together with poor nutrition and genetics, are the main causes of low productivity, and emphasize that herd health plans must prioritize control of GIN, major viral diseases, and key bacterial infections (Kimeli et al., 2025). Strategic anthelmintic use, improved grazing management, and nutritional support all help reduce the clinical expression of parasitism and sustain growth, but rising anthelmintic resistance and knowledge gaps about parasite epidemiology often limit control in practice. Meta-analysis shows that better energy and protein supply improves resilience and resistance to GIN infection, mitigating the growth-depressing effects of worm burden and supporting the argument that parasite control and nutrition should be managed together (Cei et al., 2018).

Vaccination against major transboundary and respiratory diseases is a cornerstone of preventive programs and has direct implications for growth. A scoping review of preventive veterinary interventions in sub-Saharan Africa found that vaccination against priority diseases such as PPR, pasteurellosis, and contagious pleuropneumonia was generally both effective and profitable, reducing morbidity and mortality and improving returns on investment in feed and other inputs (Nuvey et al., 2022). At the herd level, implementing vaccination and basic biosecurity was associated with steep declines in respiratory disease incidence in semi-intensively managed goats, illustrating how targeted immunization can translate into healthier animals and better growth performance over time (Atlı et al., 2025). Even where some vaccines cause transient reductions in daily gain, as observed after foot-and-mouth disease vaccination in Korean native goats, the long-term protection against outbreaks and trade losses outweighs these short-term setbacks, especially when supportive management is used to buffer temporary performance dips (Jo et al., 2014).

6.3 Biosecurity and sanitation management

Biosecurity and sanitation measures reduce the introduction and spread of pathogens that erode growth performance, and they complement both feeding and vaccination strategies. Good herd health and biosecurity programs aim to maximize production while lowering the incidence of preventable diseases through practices such as pre-purchase testing, quarantine of new arrivals, and strict control of animal movement. Clean housing, appropriate stocking densities, and proper manure handling limit the buildup and transmission of gastrointestinal and ectoparasites, thereby decreasing chronic production losses associated with subclinical infection and improving the response to nutritional improvements (Fthenakis and Papadopoulos, 2017). In extensive and semi-intensive systems, lack of biosecurity, poor hygiene, and inadequate health management have been linked to high burdens of parasitism and lameness, culminating in reduced growth, reproduction, and increased mortality despite the apparent environmental adaptability of goats (Sejian et al., 2021).

Sanitation and general farm management also influence the prevalence of vector-borne and reproductive pathogens that indirectly affect growth by causing abortions, weak kids, and chronic debilitation. Studies in tropical dry-forest systems demonstrate that herds with poorer infrastructure and less structured sanitary management experience higher seroprevalence of agents such as Neospora caninum and bluetongue virus, whereas larger herds with better facilities show lower infection levels, underscoring the role of housing, vector control, and waste management in disease ecology (Gutiérrez et al., 2024). Regular monitoring for zoonotic and production-limiting parasites, prompt treatment of clinically affected animals, and avoidance of practices like spreading fresh feces on pastures all contribute to reduced environmental contamination and lower reinfection rates. Integrating these biosecurity and sanitation measures with tailored nutrition and vaccination creates a health-oriented production system in which goats can express their genetic growth potential more fully.

7 Environmental Factors Affecting Growth Performance

7.1 Regulation of temperature, humidity, and light conditions

Thermal environment is one of the main external factors modulating feed intake, energy use, and thus growth performance in goats. When temperature-humidity index (THI) rises above comfort thresholds, goats show increased respiratory rate, heart rate, and skin temperature, reflecting a higher energetic cost of thermoregulation that diverts nutrients away from growth (Figure 3) (Zhou et al., 2023). Experimental exposure to stepwise combinations of higher temperature and relative humidity demonstrated that, at THI ranges above about 75-80, goats reduce behaviors related to metabolism (feeding and rumination) and shift toward behaviors that enhance evaporative cooling, such as panting and increased water intake. Under hot, humid tropical conditions, rectal and skin temperatures, respiration rate, and lying time increase, while dry matter intake declines, confirming that prolonged heat load depresses nutrient intake and growth even in heat-adapted breeds (Ali et al., 2023).

Maintaining environmental conditions within the thermoneutral range, or at least limiting time above critical THI, is therefore essential to protect growth response to improved feeding. Reviews of heat stress in goats indicate that, beyond reduced intake, chronic high temperatures alter endocrine and immune function, leading to impaired metabolic efficiency and increased disease susceptibility that further constrain performance (Gadzama et al., 2025). Goats are resilient to heat compared with other ruminants, but their productivity and welfare still deteriorate markedly once ambient temperatures exceed about 38 °C, especially when combined with high humidity that limits evaporative cooling (Stavetska et al., 2025). Managing diurnal variation by exploiting cooler night or early morning periods for feeding and activity can help offset reductions in daytime intake and mitigate negative energy balance in hot environments (Danso et al., 2024).

Light conditions also interact with growth and product yield, particularly in cashmere goats, where controlled short-day photoperiods have been used to manipulate fiber growth. In Shanbei white cashmere goats, reducing daily light exposure to seven hours increased annual cashmere production by about one-third, demonstrating the strong photoperiodic control of secondary hair growth (Cui et al., 2023). However, the same short-photoperiod system increased concentrations of harmful gases such as ammonia in the barn, implying that without adequate ventilation, air quality and health may be compromised despite gains in fiber output. For meat-oriented systems, providing natural or artificial shade reduces solar radiation and contributes to lowering heat load, supporting higher feed intake and growth rates under hot conditions.

7.2 Housing design and ventilation management

Housing design strongly influences the microclimate experienced by goats and thus the extent to which heat stress erodes the benefits of improved nutrition. Studies comparing different housing systems during hot–humid seasons show that modified sheds can reduce respiration rate and improve thermal comfort relative to conventional housing or fully open environments, even when rectal temperature remains within a narrow range across systems (Singh et al., 2023). Cross-ventilated barns and shade structures are highlighted as core environmental modifications, lowering heat load by reducing solar gain and facilitating convective and evaporative heat loss, which in turn helps sustain intake and productivity in hot climates (Gadzama et al., 2025). In contrast, fully confined “barn” systems with high stocking density and limited movement have been associated with weight loss, elevated stress indicators, and higher parasitic egg counts, indicating that poorly designed intensive housing can impair growth despite controlled feeding.

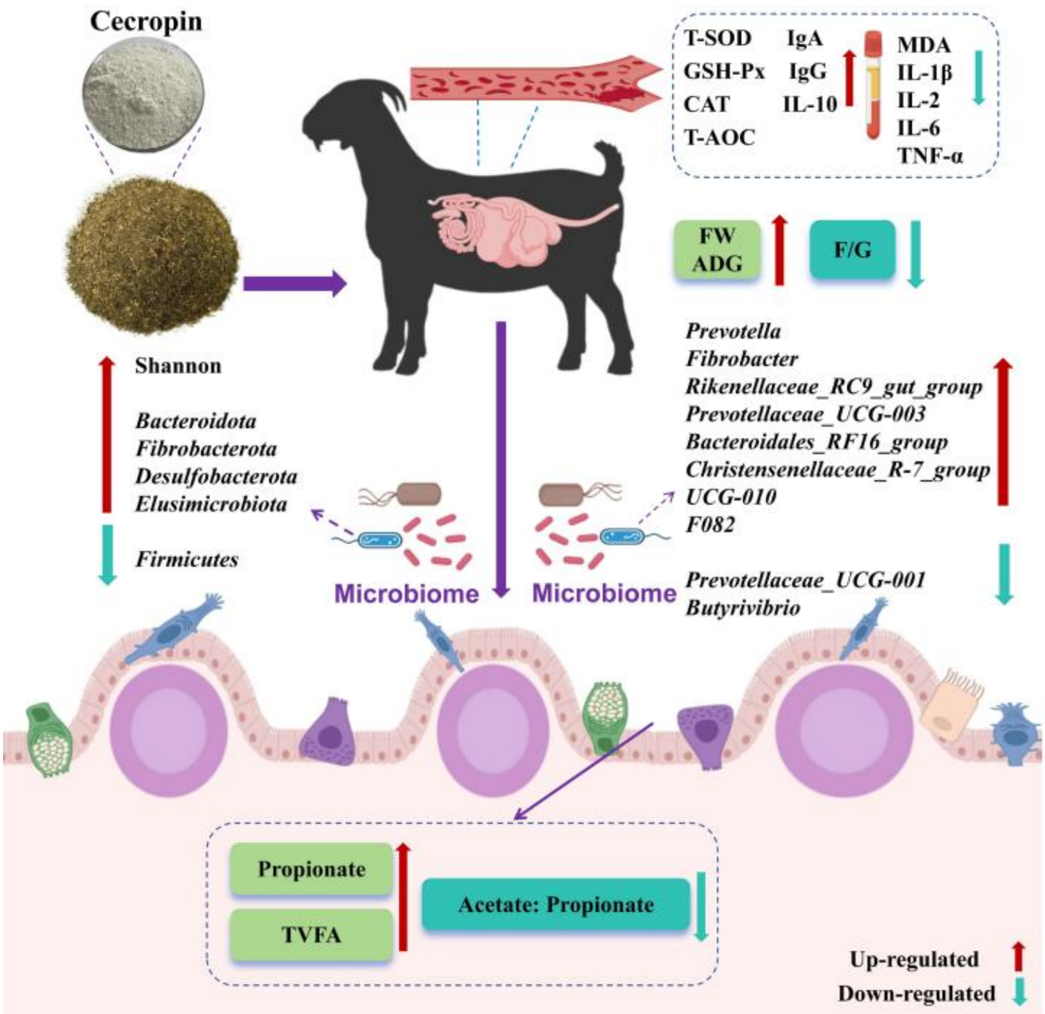

Figure 3 Mechanisms of the impact of dietary cecropin on the health of goats. T-SOD, total superoxide dismutase; GSH-Px, glutathione peroxidase; CAT, catalase; T-AOC, total antioxidant capacity; IgA, immunoglobulin A; IgG, immunoglobulin G; IL-10, interleukin-10; MDA, malondialdehyde; IL-1β, interleukin-1 beta; IL-2, interleukin-2; IL-6, interleukin-6; TNF-α, tumor necrosis factor-alpha; FW, final body weight; ADG, average daily gain; F/G, feed-to-gain ratio; TVFA, total volatile fatty acid (Adopted from Zhou et al., 2023)

Ventilation management is equally critical for maintaining both temperature-humidity balance and air quality. A review of the relationship between thermal environment and energy metabolism in goats emphasizes that, once ambient conditions exceed adaptive thresholds, respiratory frequency, evaporative heat loss, and rectal temperature rise sharply, underscoring the need for designs that promote airflow and heat dissipation (Lima et al., 2022). Monitoring temperature and humidity in real time, and adjusting wall openings or mechanical ventilation accordingly, allows farmers to keep THI below levels that trigger declines in metabolic behaviors and disruptions in endocrine status (Zhou et al., 2023). In dairy goat barns, Internet-of-Things monitoring of gases showed that building structure and the management of openings, together with litter replacement frequency, significantly affect concentrations of ammonia and carbon dioxide, and low winter THI even raised concerns about cold stress when openings were over-managed (Celozzi et al., 2025). These findings suggest that housing design and ventilation should be tuned seasonally to avoid both heat and cold stress, ensuring that feed resources are converted efficiently into growth.

7.3 Stress factors and mitigation strategies

Environmental, nutritional, and handling stressors interact to shape growth performance by altering behavior, physiology, and immune competence. Heat stress is often the dominant physical stressor in tropical and subtropical regions, where goats display behavioral adaptations such as shade seeking, nocturnal grazing, and reduced daytime feeding; while these responses help maintain homeothermy, they also decrease feeding efficiency and growth if not compensated by management. Under experimental hot environments, goats exhibit elevated rectal and skin temperatures, higher respiration rate, and reduced blood glucose, alongside lower dry matter intake but increased digestibility, indicating both a physiological strain and a metabolic adjustment that may not fully protect growth over longer periods (Ali et al., 2023). Reviews of climate change and goat production emphasize that high temperatures impair immune and endocrine systems, depressing growth, reproductive capacity, and product quality, which collectively lowers herd-level productivity unless mitigated by adapted management (Stavetska et al., 2025).

A variety of mitigation strategies can buffer goats against environmental and management-related stress, thereby preserving growth responses to improved feeding. Environmental strategies include providing shade, optimizing housing orientation, and installing cooling systems or misting where feasible, which have been shown to reduce heat load and lower key stress indicators such as respiratory rate and rectal temperature. Nutritional and rumen-oriented interventions, such as feeding antioxidants or specific probiotics, can also enhance resilience; for example, prophylactic supplementation with Clostridium butyricum and *Saccharomyces cerevisiae* before a heat-stress period improved average daily gain and feed efficiency by supporting rumen fermentation and antioxidant status under high THI (Xue et al., 2022). At the same time, good handling practices that minimize psychological and pre-slaughter stress are important, because goats are particularly susceptible to management-related stress during transport and lairage, which can depress performance and meat quality even when on-farm feeding is optimal (Kumar et al., 2022). Combining environmental control, targeted feeding strategies, and low-stress handling provides a comprehensive approach to mitigating stress and securing growth performance in modern goat systems.

8 Case Study: Analysis of Typical Feeding Strategies on Goat Growth Performance

8.1 Case of diet optimization in a large-scale farm

Diet optimization in commercial goat operations typically focuses on balancing local roughage resources with strategic concentrate supplementation to maximize average daily gain (ADG) and feed efficiency. An intensive trial with 32 Barbari male kids showed that increasing concentrate mix from 0.7% to 2.1% of body weight on a pulse-straw basal diet significantly improved weight gain, nutrient digestibility, rumen volatile fatty acid production, and nitrogen retention, providing a clear framework for intensive meat-oriented farms using crop residues as the main roughage (Dutta et al., 2025). In practice, such a strategy allows large farms to convert low-value chickpea straw and similar by-products into higher-value meat while maintaining acceptable health indicators, as reflected in improved blood glucose and hemoglobin profiles under higher concentrate inclusion.

On-farm diet optimization for replacement females illustrates how modifying existing rations can enhance future herd productivity in semi-commercial settings. In a Malaysian smallholder but fully intensive system, 4-month-old Boer-cross replacement does fed a reformulated ration based on NRC recommendations, using the same local forages and agro-industrial by-products as the farmer's original diet but at higher quantity and better nutrient balance, achieved markedly higher final body weight and ADG than goats on the routine feeding program (Ghani et al., 2017). After seven months, treated goats reached about 39 kg versus 32 kg in controls, and a higher proportion achieved a body condition score ≥3, demonstrating how technically guided ration formulation within existing feed resources can lift growth performance and readiness for breeding in a quasi-large-scale scenario.

8.2 Comparative analysis of growth performance under different feeding systems

Comparisons among feeding systems consistently show that intensive or supplemented systems support higher growth rates than unsupplemented grazing, though at the cost of greater input use. A review of feeding systems in sheep and goats concluded that kids and lambs finished on pasture alone have lower ADG and carcass yield than those finished in stalls or on pasture plus concentrate, while supplemented grazing animals often achieve performance comparable to, or better than, fully stall-fed counterparts (Ke et al., 2023). These patterns reflect both increased energy and protein density and more stable nutrient supply, underscoring why semi-intensive systems with targeted supplementation are often recommended for improving growth while retaining some grazing-based advantages (Huang et al., 2023).

Field comparisons confirm these general trends under smallholder conditions. In Assam local goats, kids reared intensively with ad libitum concentrate and fodder exhibited significantly higher final body weights and superior feed conversion efficiency compared with contemporaries managed extensively with traditional grazing and browsing, with divergence in body weight becoming highly significant from the third week onward (Hoque et al., 2020). Similarly, work on Osmanabadi goats comparing traditional grazing with various stall-feeding plus supplementation methods found that systems combining grazing with stall feeding achieved the best overall body growth and chest girth development, suggesting that integrating controlled feeding with natural browsing can yield both biological and economic benefits over purely extensive methods (Da et al., 2021).

8.3 Evaluation of technical interventions (Additives/Management Measures)

Feed additives and formulation technologies offer additional leverage to enhance growth performance beyond basal ration design. A meta-analysis of *Saccharomyces cerevisiae* supplementation in growing goats found that dietary yeast consistently increased ADG while only modestly affecting dry-matter intake and feed conversion ratio, and also elevated blood glucose, white blood cell counts, and ruminal propionate and total volatile fatty acids, indicating improved rumen fermentation and health status (Ogbuewu and Mbajiorgu, 2023). Similarly, a factorial trial with neem leaf and polyethylene glycol showed that adding 6% neem leaf plus 15% PEG to the concentrate raised feed intake, nutrient digestibility, ADG, and propionic acid concentration while reducing ruminal methanogens and protozoa, suggesting that certain plant-based additives can simultaneously enhance growth and modulate the rumen microbiome in a favorable direction (Taethaisong et al., 2023).

Management-type technical interventions, such as pelleting and optimizing concentrate level, can also markedly improve growth efficiency in commercial settings. A comparative on-farm study in Bangladesh demonstrated that a complete pelleted feed (40% roughage, 60% concentrate) under stall feeding produced substantially higher daily weight gain and lower feed conversion ratio and cost per kilogram gain than conventional semi-intensive feeding without pellets, implying strong economic incentives for pelleting where infrastructure allows (Ahmed et al., 2020). Likewise, trials in India and Iraq indicate that intermediate concentrate levels around 2%-3% of body weight, whether in mash or pelleted form, often yield superior growth and feed efficiency compared with lower or higher levels, helping define practical targets for intensive fattening systems (Al-Ani, 2024; Dutta et al., 2025). Together, these technical interventions—microbial and plant additives, precision in concentrate level, and physical processing of feeds—provide a toolkit for fine-tuning feeding strategies to maximize growth performance in goats under diverse production environments.

9 Conclusion and Prospects

Research on feeding strategies for goats consistently demonstrates that growth performance is highly responsive to both nutrient density and ration structure. Optimally balanced diets that match energy and protein to physiological stage, breed, and production objectives improve average daily gain, feed conversion ratio, and carcass traits. Appropriate use of high-quality forages, combined with concentrates formulated to support rumen health, underpins efficient growth while reducing digestive upsets. Strategic supplementation with minerals and vitamins further supports skeletal development, immune competence, and overall robustness, especially in intensive or semi-intensive systems. Studies comparing different management systems indicate that integrating good nutrition with appropriate housing, health programs, and environmental control yields additive benefits for growth. Intensive and semi-intensive systems, when properly managed, enable more precise feed allocation and better control of environmental stressors, leading to more uniform growth rates. Genetic improvement and targeted breeding add another layer of enhancement by improving feed efficiency, growth potential, and resilience, particularly when combined with modern tools such as marker-assisted selection. Overall, the literature converges on the view that growth in goats is maximized when feeding strategies are designed holistically, aligning diet formulation, management, health, genetics, and environment.

Despite substantial progress, existing studies on feeding strategies for goats exhibit several methodological and contextual limitations. Many experiments are short-term and focus on immediate growth responses rather than lifetime performance, carcass quality, or long-term health outcomes. Sample sizes are often modest, and experimental conditions may not reflect the diversity of real-world production systems, especially in smallholder or resource-limited settings. Furthermore, results generated in one breed or cross are commonly extrapolated to others without rigorously accounting for genetic and physiological differences. This reduces the generalizability of reported feeding recommendations. There is also a lack of standardized protocols for evaluating growth performance and feed efficiency, complicating comparisons across studies and meta-analyses. Economic assessments, including cost–benefit analyses of feed interventions, are frequently underdeveloped or omitted, limiting the practical applicability for farmers and advisors. Environmental dimensions, such as greenhouse gas emissions, nutrient excretion, and resource use efficiency, are not consistently integrated into feeding trials. Finally, interactions among nutrition, disease dynamics, housing design, and climate-related stress are often studied in isolation, leaving important knowledge gaps on how combined interventions influence growth and sustainability.

Future research on feeding strategies for goats is likely to move toward more integrated, systems-based approaches that address productivity, animal welfare, economic viability, and environmental impact simultaneously. There is a growing need for long-term, multi-site trials that examine how diet formulation, feeding frequency, and management practices perform across different breeds, climates, and production scales. Precision nutrition, supported by digital tools and sensor technologies, offers promising avenues for tailoring diets to individual animals or groups based on real-time assessment of growth, health, and behavior. These approaches could help optimize feed use efficiency while reducing waste and environmental footprints. Another important trend is the incorporation of genomic and molecular tools into nutrition research, enabling better understanding of how genetic variation shapes responses to different diets. This will support breeding programs that explicitly select for traits such as feed efficiency, resilience to nutritional stress, and adaptability to alternative or locally available feed resources. Research on functional feeds, including plant bioactives, probiotics, and other additives, should increasingly focus on their combined effects with management and environmental interventions rather than in isolation. Ultimately, development of context-specific, evidence-based feeding guidelines that consider local feed availability, climate risks, and market demands will be essential for translating scientific advances into practical gains in goat growth performance worldwide.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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