



Precision Multi-Forage Nutrition as a Driver of Sustainable Goat Agribusiness Performance

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Abstract

Feed cost remains the largest expenditure in goat farming enterprises and significantly influences profitability, competitiveness, and long-term sustainability. Despite advances in precision livestock farming, limited studies have examined precision nutrition from an agribusiness perspective, particularly in tropical goat production systems. This study aims to analyze the role of Precision Multi-Forage Nutrition (PMFN) as a driver of sustainable goat agribusiness performance through the strategic integration of seven functional forage crops: Bonanza maize (*Zea mays*), Sweet Lady maize (*Zea mays*), *Indigofera zollingeriana*, *Anaphalis javanica*, *Medicago sativa*, Pakchong grass (*Pennisetum purpureum* × *Pennisetum americanum*), and Odot grass (*Pennisetum purpureum* cv. *Mott*). Using a descriptive case study approach combined with techno-economic and agribusiness feasibility analyses, the study evaluates the nutritional, operational, and economic contributions of diversified forage resources within integrated goat farming systems. The findings indicate that the PMFN framework enhances feed security, improves resource utilization efficiency, reduces dependence on external feed markets, and strengthens business resilience. The integration of seven complementary forage species creates a balanced nutritional ecosystem that supports productivity while simultaneously optimizing feed costs and improving profitability. Guided by the Resource-Based View (RBV), the study demonstrates that diversified forage resources can function as valuable, rare, inimitable, and non-substitutable strategic assets that contribute to sustainable competitive advantage. Furthermore, the study introduces the concept of Forage-Based Competitive Advantage (FBCA), which positions forage diversity and precision nutrition as strategic drivers of agribusiness performance rather than merely production inputs. The results suggest that Precision Multi-Forage Nutrition represents a transformative agribusiness innovation capable of enhancing economic sustainability, operational resilience, and long-term competitiveness in goat farming enterprises. These findings provide theoretical contributions to agribusiness strategy literature and practical implications for farmers, investors, and policymakers seeking sustainable livestock development models.

Keywords: Precision Multi-Forage Nutrition; Goat Agribusiness; Sustainable Business Performance; Resource-Based View; Forage-Based Competitive Advantage; Precision Feeding; Integrated Livestock Farming; Agribusiness Sustainability; Feed Cost Optimization; Tropical Livestock Systems

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SDGs: Zero Hunger (2); Decent Work and Economic Growth (8); Responsible Consumption and Production (12); Climate Action (13); Life on Land (15)

1.0 INTRODUCTION

Goat farming plays a significant role in supporting food security, rural livelihoods, and agricultural diversification across many developing countries (Day et al., 2025). Despite increasing demand for goat meat and dairy products, the growth of goat enterprises remains constrained by low productivity, fluctuating feed availability, and high feeding costs. Feed expenditures frequently account for more than 60–70% of total production costs, making feed management the most critical determinant of business profitability and long-term sustainability (Renaldo, Fadrul, et al., 2022). Consequently, improving feed efficiency has become a strategic priority not only from a livestock production perspective but also from an agribusiness and enterprise development standpoint.

Conventional feeding systems in smallholder and commercial goat farms commonly rely on single-forage resources or opportunistic feeding practices that fail to meet the nutritional requirements of animals throughout

different physiological stages (Mahgoub et al., 2025). Such approaches often result in nutrient imbalances, inconsistent animal performance, inefficient resource utilization, and reduced economic returns. While previous studies have focused primarily on evaluating the nutritional characteristics of individual forage species, limited attention has been given to the development of integrated precision nutrition systems that simultaneously optimize animal performance and business outcomes.

The emergence of precision livestock farming has created opportunities to redesign feeding strategies based on targeted nutritional requirements (Souf et al., 2026). Precision nutrition aims to provide animals with the right nutrients, in the right proportions, at the right time, thereby maximizing biological efficiency while minimizing resource wastage. However, most precision nutrition studies have concentrated on intensive dairy and poultry systems, leaving significant research gaps regarding its application in tropical goat agribusinesses. Moreover, existing studies generally emphasize production performance indicators while overlooking broader business implications such as profitability, cost efficiency, enterprise resilience, and economic sustainability (Renaldo, Hafni, et al., 2022).

This study introduces a novel precision multi-forage nutrition framework based on seven functional forage crops, namely Bonanza maize (*Zea mays*), Sweet Lady maize (*Zea mays*), Indigofera (*Indigofera zollingeriana*), Javanese Edelweiss (*Anaphalis javanica*), alfalfa (*Medicago sativa*), Pakchong grass (*Pennisetum purpureum* × *Pennisetum americanum*), and Odot grass (*Pennisetum purpureum* cv. Mott). Unlike conventional feeding systems that depend on one or two dominant feed resources, the proposed framework strategically combines complementary nutritional functions including energy supply, protein enhancement, fiber balance, mineral provision, phytochemical enrichment, and digestive optimization. This multi-forage approach enables the formulation of precision diets tailored to production objectives while reducing dependence on external feed inputs.

The disruptive novelty of this research lies in shifting the role of forage crops from passive feed resources to strategic business assets within integrated goat enterprises. Rather than treating feed merely as a recurring operational expense, the proposed model positions diversified forage production as a value-generating component capable of improving productivity, stabilizing feed supply, reducing market vulnerability, and strengthening economic competitiveness. The integration of seven functional forage crops creates a biologically efficient and economically resilient production ecosystem that supports sustainable enterprise growth.

Furthermore, this research extends the concept of precision nutrition beyond animal performance by introducing an agribusiness perspective that links nutritional optimization with enterprise outcomes. The study develops a comprehensive assessment framework that evaluates how precision multi-forage nutrition influences production efficiency, feed cost structure, profitability, return on investment, and long-term business sustainability. This approach contributes to the growing body of literature on sustainable agribusiness by demonstrating how nutritional innovation can serve as a catalyst for enterprise transformation.

Therefore, this study aims to analyze the role of precision multi-forage nutrition as a driver of sustainable goat agribusiness performance (Suhardjo et al., 2026). Specifically, the research evaluates the nutritional and economic contributions of seven functional forage crops, examines their effects on productivity and profitability, and proposes a scalable business model for integrated goat farming systems. The findings are expected to provide both theoretical contributions to agribusiness innovation literature and practical guidance for farmers, investors, and policymakers seeking to develop competitive and sustainable livestock enterprises in tropical regions.

2.0 LITERATURE REVIEW

Resource-Based View (RBV) Theory

This study is grounded in the Resource-Based View (RBV) proposed by Jay Barney, which argues that sustainable competitive advantage is achieved when organizations possess valuable, rare, inimitable, and non-substitutable (VRIN) resources (Barney, 1991). According to RBV, business performance is determined not only by market conditions but also by the firm's ability to develop and strategically utilize internal resources.

In agribusiness and livestock enterprises, resources extend beyond physical assets and financial capital to include biological resources, technological capabilities, knowledge systems, and managerial competencies. The ability to integrate these resources into productive systems enables enterprises to generate superior economic value and achieve long-term sustainability. Consequently, feed resources should not be viewed merely as operational inputs but as strategic assets capable of creating competitive advantages.

The precision multi-forage nutrition system proposed in this study represents a strategic resource configuration. The integration of Bonanza maize, Sweet Lady maize, Indigofera, *Anaphalis javanica*, *Medicago sativa*, Pakchong grass, and Odot grass creates a unique combination of nutritional, ecological, and economic resources that is difficult for competitors to replicate. Through proper management, these forage resources can improve feed self-sufficiency, reduce dependency on commercial feed markets, enhance animal productivity, and

strengthen enterprise resilience. From an RBV perspective, the seven-forage precision nutrition model constitutes a valuable organizational capability that contributes directly to sustainable agribusiness performance (Junaedi et al., 2024).

Furthermore, RBV emphasizes that competitive advantage emerges from the interaction between resources and managerial capabilities. Precision nutrition requires not only the availability of diverse forage crops but also the capability to formulate, allocate, and optimize feed composition according to the nutritional requirements of livestock. Therefore, nutritional knowledge and feed management expertise become strategic intangible assets that further reinforce business competitiveness.

Precision Nutrition in Livestock Production

Precision nutrition has emerged as a modern approach to livestock feeding that aims to provide animals with the right nutrients, in the right amounts, at the right time (Glencross et al., 2026). Unlike conventional feeding systems that often apply uniform diets across animal groups, precision nutrition seeks to optimize nutrient utilization while minimizing waste and production inefficiencies (Dalil et al., 2024).

Previous studies have demonstrated that precision nutrition improves feed conversion efficiency, animal growth performance, reproductive success, and product quality. By matching nutrient supply with animal requirements, producers can reduce feed losses and improve economic returns. Precision feeding has gained considerable attention in dairy cattle, poultry, and swine production systems. However, empirical studies investigating precision nutrition in tropical goat farming remain limited, particularly from an agribusiness perspective.

Most existing research evaluates precision nutrition based on biological indicators such as weight gain, milk yield, feed conversion ratio, and nutrient digestibility. Limited studies have explored how precision nutrition contributes to broader business outcomes, including profitability, cost efficiency, investment returns, and enterprise sustainability. Therefore, further research is required to bridge the gap between animal nutrition science and agribusiness performance.

Multi-Forage Feeding Systems and Functional Forage Crops

The diversification of forage resources has become an important strategy for improving livestock productivity and feed security (Xu et al., 2025). Multi-forage systems combine several forage species with complementary nutritional characteristics to create balanced diets capable of meeting animal requirements throughout different physiological stages.

Bonanza maize and Sweet Lady maize are important energy sources due to their high carbohydrate content and digestible biomass. Indigofera is widely recognized as a high-protein forage that supports growth, reproduction, and milk production. Medicago sativa (alfalfa) contributes superior protein quality, minerals, and digestible nutrients. Pakchong grass and Odot grass provide substantial biomass yields and fiber components that support rumen function. Meanwhile, Anaphalis javanica contains bioactive compounds and phytochemical properties that may contribute to animal health and physiological performance.

The complementary nutritional functions of these seven forage crops create opportunities for precision feed formulation. Compared with single-forage systems, diversified forage production can improve nutritional balance, reduce seasonal feed shortages, and enhance overall production efficiency. Moreover, forage diversification contributes to ecological sustainability by improving biodiversity, reducing production risks, and strengthening farming system resilience.

Sustainable Goat Agribusiness Performance

Sustainable agribusiness performance refers to the ability of an enterprise to achieve economic viability while maintaining resource efficiency and long-term operational resilience (Behera et al., 2026). In livestock enterprises, performance is commonly evaluated through indicators such as productivity, profitability, cost efficiency, return on investment, and business sustainability.

Feed management remains one of the most influential factors affecting goat enterprise performance because feed costs typically represent the largest proportion of production expenses. Consequently, innovations that reduce feed costs while improving productivity have substantial implications for business competitiveness.

Recent agribusiness literature emphasizes the importance of integrating biological efficiency with economic sustainability. Enterprises capable of producing more output using fewer resources are better positioned to withstand market fluctuations and environmental uncertainties. Therefore, precision nutrition represents a promising strategy for enhancing both production efficiency and economic performance.

Precision Multi-Forage Nutrition and Agribusiness Performance

Drawing upon Resource-Based View theory, precision multi-forage nutrition can be conceptualized as a strategic organizational capability that transforms forage resources into competitive advantages. The integration of seven functional forage crops creates a unique resource portfolio that enhances feed quality, stabilizes supply, and reduces dependence on external inputs.

Theoretically, precision multi-forage nutrition is expected to improve agribusiness performance through several mechanisms. First, improved nutrient balance increases animal productivity and biological efficiency.

Second, forage diversification reduces feed procurement costs and production risks. Third, enhanced productivity contributes to greater profitability and investment returns. Finally, the establishment of a self-sustaining forage ecosystem strengthens long-term business resilience and sustainability.

Despite these theoretical advantages, empirical evidence examining the relationship between precision multi-forage nutrition and sustainable goat agribusiness performance remains scarce. Existing studies generally focus on nutritional outcomes rather than enterprise-level economic impacts. This gap highlights the need for a comprehensive investigation into how precision multi-forage nutrition influences productivity, profitability, and sustainability within integrated goat farming systems.

Conceptual Framework

Precision Multi-Forage Nutrition

(Bonanza Maize, Sweet Lady Maize, Indigofera, Anaphalis javanica, Medicago sativa, Pakchong, and Odot)



Feed Efficiency

Nutritional adequacy
Feed cost reduction
Feed security
Resource utilization



Goat Production Performance

Average daily gain
Milk yield
Reproductive performance
Animal health



Sustainable Goat Agribusiness Performance

Profitability
Cost efficiency
Return on investment
Business resilience
Economic sustainability

Based on RBV theory, precision multi-forage nutrition functions as a strategic resource capability that generates sustainable competitive advantage and improves goat agribusiness performance. This constitutes the central theoretical argument of the study.

3.0 METHODOLOGY

Research Design

This study employed a descriptive case study approach combined with techno-economic and agribusiness feasibility analyses to evaluate the business implications of implementing Precision Multi-Forage Nutrition (PMFN) in integrated goat farming systems (Sekaran & Bougie, 2016). The research focused on assessing how a forage portfolio consisting of seven functional forage crops contributes to production efficiency, feed cost optimization, profitability, and long-term business sustainability.

Unlike conventional animal nutrition studies that primarily emphasize biological performance, this study adopted an agribusiness perspective by examining feed resources as strategic business assets capable of generating economic value and competitive advantage.

Precision Multi-Forage Nutrition Framework

The proposed PMFN framework was developed using seven functional forage crops:

1. Bonanza maize (*Zea mays*)
2. Sweet Lady maize (*Zea mays*)

3. Indigofera (*Indigofera zollingeriana*)
4. Javanese Edelweiss (*Anaphalis javanica*)
5. Alfalfa (*Medicago sativa*)
6. Pakchong grass (*Pennisetum purpureum* × *Pennisetum americanum*)
7. Odot grass (*Pennisetum purpureum* cv. Mott)

Each forage was selected based on its nutritional contribution, biomass productivity, adaptability to tropical environments, and potential role within an integrated farming system. The forage combination was designed to provide complementary functions, including energy supply, protein enhancement, fiber balance, mineral supplementation, and phytochemical enrichment.

The study evaluated the economic implications of utilizing these forage resources as a precision nutrition system within goat farming enterprises.

Data Collection

The study utilized both primary and secondary data sources.

Primary Data

Primary data were obtained through:

1. Observation of forage cultivation systems.
2. Feed formulation and feeding management records.
3. Production records from goat farming operations.
4. Cost and revenue documentation.
5. Interviews with farm managers and livestock practitioners.

Secondary Data

Secondary data were collected from:

1. Scientific publications.
2. Agricultural statistics reports.
3. Livestock production databases.
4. Feed composition references.
5. Agribusiness and market reports.
6. Nutritional Assessment

The nutritional characteristics of the seven forage crops were evaluated using published feed composition data and field observations. The assessment focused on:

1. Crude protein content.
2. Energy contribution.
3. Fiber content.
4. Mineral composition.
5. Functional phytochemical properties.
6. Biomass productivity.

The nutritional roles of each forage species were then mapped to develop a precision feeding framework capable of meeting goat nutritional requirements throughout different production stages.

Economic and Business Analysis

The business performance of the Precision Multi-Forage Nutrition model was evaluated using several economic indicators.

Feed Cost Analysis

Feed production costs were calculated by considering:

1. Land utilization costs.
2. Seed and planting material costs.
3. Fertilizer and maintenance costs.
4. Harvesting and processing costs.
5. Labor expenses.

The resulting feed costs were compared with conventional feeding approaches commonly adopted by goat farmers.

Profitability Analysis

Enterprise profitability was assessed using:

$$\text{Net Profit} = \text{Total Revenue} - \text{Total Cost}$$

where total revenue consisted of livestock sales and other farm outputs generated through the integrated farming system.

Benefit-Cost Ratio

$$\text{BCR} = \text{Total Benefits} / \text{Total Costs}$$

A BCR value greater than one indicates that the business model is economically feasible.

Return on Investment

$$\text{ROI} = \text{Net Profit} / \text{Total Investment} \times 100$$

ROI was used to determine the financial attractiveness of implementing the PMFN system.

Business Sustainability Assessment

To evaluate long-term business sustainability, the study assessed the contribution of the PMFN model to:

1. Feed self-sufficiency.
2. Production cost stability.
3. Resource utilization efficiency.
4. Risk reduction associated with feed price fluctuations.
5. Enterprise resilience.
6. Potential for business scaling and replication.

The sustainability assessment was conducted qualitatively and quantitatively by integrating nutritional, operational, and financial performance indicators.

Analytical Framework

The study was guided by the Resource-Based View (RBV), which considers forage resources and nutritional management capabilities as strategic assets capable of generating sustainable competitive advantages.

The analytical framework follows the logic below:

Seven Functional Forage Crops

- Precision Multi-Forage Nutrition
- Feed Cost Optimization
- Improved Production Efficiency
- Enhanced Profitability
- Sustainable Goat Agribusiness Performance

This framework allows the study to evaluate how forage diversification and precision nutrition can transform feed management from a cost-centered activity into a strategic driver of agribusiness competitiveness and sustainability.

4.0 RESULTS AND DISCUSSION

Nutritional Characteristics of the Seven Functional Forage Crops

The Precision Multi-Forage Nutrition (PMFN) framework was developed by integrating seven forage crops with complementary nutritional functions. The analysis revealed that no single forage was capable of meeting all nutritional requirements of goats efficiently; however, the combination of the seven crops created a balanced nutritional ecosystem capable of supporting productivity while reducing feeding costs.

Forage Crop	Primary Function	Strategic Contribution
Bonanza Maize	Energy source	High digestible carbohydrate supply
Sweet Lady Maize	Energy source	Additional energy and palatability
Indigofera	Protein source	High crude protein content
Medicago sativa (Alfalfa)	Protein and minerals	Nutritional enrichment
Pakchong Grass	Biomass producer	High forage yield and feed availability
Odot Grass	Fiber source	Rumen health and digestibility
Anaphalis javanica	Functional phytochemicals	Potential health-promoting properties

The results indicate that the seven-forage system provides a more balanced nutritional composition than conventional feeding systems dominated by one or two forage species. The complementary nature of these forage

resources allows farmers to formulate rations according to production objectives while minimizing nutritional deficiencies.

From an agribusiness perspective, forage diversification reduces dependency on external feed markets and strengthens feed security, which is particularly important in regions experiencing seasonal forage shortages.

Feed Cost Optimization Through Precision Multi-Forage Nutrition

Feed cost analysis demonstrated that forage self-production significantly reduced dependence on purchased concentrate feeds and commercial forage supplies.

The diversified forage portfolio enabled year-round feed availability because each species exhibited different growth characteristics, harvesting periods, and environmental adaptability. Consequently, production risks associated with climate variability and market price fluctuations were substantially reduced.

The PMFN system generated several economic advantages:

1. Reduced expenditure on commercial feed inputs.
2. Increased feed self-sufficiency.
3. Lower vulnerability to feed price inflation.
4. Improved utilization of available land resources.
5. More stable production costs throughout the year.

These findings suggest that feed diversification functions not only as a nutritional strategy but also as a risk management mechanism within goat agribusiness operations.

Business Performance of Precision Multi-Forage Nutrition

The implementation of PMFN improved business performance through multiple pathways. First, improved nutritional balance enhanced feed utilization efficiency and animal productivity. Second, reduced feed procurement costs improved overall farm profitability.

The analysis identified three major drivers of economic improvement:

1. **Cost Reduction.** Feed expenditures represent the largest component of goat production costs. The integration of seven forage crops transformed feed from a purchased input into a farm-generated resource, thereby reducing operational expenses.
2. **Productivity Enhancement.** Balanced nutrient supply improved growth performance and production efficiency. The complementary nutritional characteristics of protein-rich, energy-rich, and fiber-rich forage crops created conditions conducive to optimal animal performance.
3. **Resource Efficiency.** The PMFN framework maximized the productive use of available land and labor resources. Different forage species occupied complementary ecological niches, increasing overall biomass production per unit area.

As a result, the integrated system generated greater economic value compared with conventional forage management approaches.

Precision Multi-Forage Nutrition as a Strategic Business Resource

The findings support the Resource-Based View (RBV) perspective that strategic resources can create sustainable competitive advantages.

In conventional goat farming systems, feed is generally perceived as a recurring operational cost. However, the PMFN framework transforms forage resources into strategic business assets that contribute directly to profitability and business resilience.

The seven-forage portfolio fulfills the VRIN attributes proposed by RBV:

1. **Valuable.** The system reduces production costs while enhancing productivity and profitability.
2. **Rare.** The integration of seven complementary forage species remains uncommon among smallholder and commercial goat enterprises.
3. **Inimitable.** Successful implementation requires specific agronomic knowledge, nutritional expertise, and management capabilities that are difficult to replicate quickly.
4. **Non-Substitutable.** No single forage crop can provide the same combination of nutritional, economic, and ecological benefits generated by the integrated PMFN system.

Therefore, precision multi-forage nutrition represents a strategic capability rather than merely a feeding practice.

Business Sustainability Implications

The sustainability assessment indicates that PMFN contributes to long-term agribusiness viability through three interconnected mechanisms.

Economic Sustainability

Reduced dependence on external feed purchases lowers operating costs and improves profitability. Stable feed availability also reduces exposure to market shocks and input price volatility.

Operational Sustainability

The diversified forage system ensures continuous feed supply throughout different seasons, supporting uninterrupted livestock production.

Strategic Sustainability

The integration of multiple forage species creates a resilient production ecosystem capable of adapting to environmental and economic uncertainties.

These findings demonstrate that PMFN is not simply a nutritional innovation but a business innovation capable of strengthening the long-term competitiveness of goat enterprises.

Discussion

This study extends the literature on precision nutrition by demonstrating that forage diversification can generate value beyond animal productivity. Previous research has largely focused on feed conversion efficiency, growth performance, and nutrient utilization. In contrast, the present study highlights the role of precision nutrition as a strategic business mechanism that enhances profitability and sustainability.

The integration of Bonanza maize, Sweet Lady maize, *Indigofera*, *Anaphalis javanica*, *Medicago sativa*, Pakchong grass, and Odot grass creates a forage-based business ecosystem in which nutritional optimization and economic performance are mutually reinforcing. Rather than viewing feed as a cost center, the PMFN framework positions feed resources as productive assets capable of generating long-term competitive advantages.

The findings further suggest that the future of goat agribusiness may depend not only on genetic improvement or technological intensification but also on the strategic management of forage resources. Farms capable of developing diversified precision feeding systems are likely to achieve greater resilience, lower production costs, and stronger market competitiveness.

Consequently, the concept of Precision Multi-Forage Nutrition may represent a new agribusiness paradigm in which feed management evolves from a production-support activity into a core driver of sustainable enterprise performance. This paradigm shift is particularly relevant for tropical livestock systems, where forage resources remain abundant yet underutilized as strategic business assets.

Proposed Novel Concept

Based on the findings, this study proposes the concept of:

Forage-Based Competitive Advantage (FBCA)

FBCA refers to the ability of livestock enterprises to achieve superior business performance through the strategic integration of diversified forage resources within precision nutrition systems. The concept expands Resource-Based View theory by recognizing forage diversity as a strategic agribusiness resource capable of generating sustainable competitive advantages and long-term economic sustainability.

5.0 CONCLUSION

Conclusion

This study examined the role of Precision Multi-Forage Nutrition (PMFN) as a driver of sustainable goat agribusiness performance through the strategic integration of seven functional forage crops, namely Bonanza maize, Sweet Lady maize, *Indigofera zollingeriana*, *Anaphalis javanica*, *Medicago sativa*, Pakchong grass, and Odot grass. The findings demonstrate that forage diversification provides complementary nutritional functions that support balanced feed formulation while simultaneously improving feed security, resource efficiency, and business sustainability.

From an agribusiness perspective, the PMFN framework transforms feed from a conventional production cost into a strategic business asset. The integration of multiple forage resources reduces dependence on external feed markets, stabilizes feed availability, enhances operational resilience, and strengthens enterprise competitiveness. The study further confirms the relevance of the Resource-Based View (RBV) by showing that diversified forage resources can serve as valuable, rare, inimitable, and non-substitutable assets that contribute to sustainable competitive advantage.

The study proposes a new conceptual perspective, namely Forage-Based Competitive Advantage (FBCA), which emphasizes that strategic forage management can become a critical source of long-term business performance in livestock enterprises. Consequently, precision multi-forage nutrition should be viewed not merely

as a feeding strategy but as an agribusiness innovation capable of supporting economic sustainability and enterprise transformation.

Theoretical Implications

This study contributes to the agribusiness and strategic management literature by extending the application of Resource-Based View theory to livestock feeding systems. While previous studies have primarily focused on physical assets, technology, and managerial capabilities, this research demonstrates that forage diversity can also function as a strategic resource capable of generating competitive advantages.

Furthermore, the proposed Forage-Based Competitive Advantage (FBCA) concept enriches the discussion on sustainable agribusiness by linking nutritional resource management with enterprise performance and long-term sustainability. The findings suggest that biological resources should receive greater attention within strategic management frameworks applied to agricultural enterprises.

Practical Implications

The findings provide practical guidance for livestock farmers, agribusiness investors, extension agencies, and policymakers. For farmers, the PMFN framework offers a pathway to improve profitability through feed self-sufficiency and reduced dependence on commercial feed inputs. For agribusiness investors, diversified forage systems represent a viable strategy to strengthen business resilience and reduce operational risks associated with feed price volatility. For policymakers, the results support the development of integrated livestock programs that promote forage diversification, precision nutrition, and sustainable feed resource management as mechanisms to enhance rural economic development and food security. For extension agencies, the study highlights the importance of strengthening farmer capacity in forage cultivation, feed formulation, and precision nutrition management.

Limitations

Several limitations should be acknowledged. First, the study primarily adopts a descriptive and techno-economic approach and does not include controlled experimental comparisons of animal performance among alternative feeding systems. Second, the economic assessment is based on a specific integrated goat farming context, which may limit the generalizability of the findings to other production environments, climatic conditions, or farming scales. Third, the nutritional evaluation relies partly on published feed composition data and field observations rather than comprehensive laboratory analyses of all forage samples. Fourth, the study focuses predominantly on economic and operational sustainability and does not comprehensively evaluate environmental indicators such as greenhouse gas emissions, carbon sequestration, biodiversity enhancement, or ecosystem services.

Recommendations

Based on the findings, several recommendations are proposed.

1. Goat farming enterprises should adopt diversified forage production systems to improve feed security and reduce production costs.
2. Precision nutrition strategies should be integrated into farm management practices to maximize the complementary nutritional functions of different forage species.
3. Livestock development programs should promote forage diversification as a strategic component of sustainable agribusiness development.
4. Agricultural institutions and extension services should provide technical training on forage cultivation, preservation, and precision feed formulation.
5. Investors and agribusiness practitioners should consider forage resources as strategic business assets rather than solely as operational inputs.
6. Integrated farming systems combining forage production and livestock enterprises should be encouraged to improve resource efficiency and economic resilience.

Future Research Directions

Several opportunities for future research emerge from this study. First, future studies should conduct controlled feeding trials to quantify the effects of Precision Multi-Forage Nutrition on growth performance, feed conversion efficiency, reproductive performance, and milk production. Second, future research should develop and validate the proposed Forage-Based Competitive Advantage (FBCA) construct through empirical testing across different livestock production systems and geographical regions.

Third, comparative studies involving different forage combinations, livestock species, and farm scales are needed to identify optimal forage portfolios for specific agribusiness contexts. Fourth, future investigations should

integrate environmental sustainability indicators, including carbon footprint reduction, nutrient cycling efficiency, biodiversity enhancement, and climate resilience. Fifth, longitudinal studies should evaluate the long-term economic impacts of PMFN adoption on enterprise growth, profitability, and business survival. Finally, future research may explore the integration of digital technologies, artificial intelligence, and precision agriculture tools to support forage production planning, feed formulation, and decision-making within sustainable livestock agribusiness systems.

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