

Cashew Nut Shells (*Anacardium occidentale*) in Sheep Rations: Potential, Challenges, and Opportunities: A Systematic Review

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Abstract: Feed security is a major challenge in livestock production systems, especially with the limited availability of conventional feed ingredients competing with human food needs and high price volatility. The use of cashew nut shell (CNS) as an alternative feed component can address this challenge. This study adopts a systematic literature review design to identify, analyze, and synthesize empirical research on the utilization of CNS in sheep rations published within the last decade (2016–2025). The aim of this study is to analyze the nutritional potential, biological benefits, as well as the challenges and development opportunities of CNS as sheep feed. The findings show that CNS contains energy levels comparable to conventional feed ingredients, and it also contains bioactive compounds such as anacardic acid and cardol, which act as natural antimicrobial agents and can reduce enteric methane emissions. However, the use of CNS faces challenges related to the presence of toxic phenolic compounds, although these can be mitigated with processing technologies such as fermentation, thermal treatment, and extraction. CNS holds significant potential as an affordable, environmentally friendly, and sustainable alternative feed. Its use contributes to climate change mitigation by reducing methane emissions. This article provides a significant contribution to applied science by offering empirical evidence to support the sustainability of livestock systems through the utilization of alternative feed resources.

Keywords: Alternative feed; Cashew nut shell; Nutrition; Sheep; Sustainability.

Introduction

Sheep production plays a strategic role in supporting the supply of animal-based food and improving rural livelihoods. The sustainability of sheep farming systems is increasingly challenged by constraints related to limited and unstable feed resource availability and the growing impacts of climate change on feed supply. These conditions pose significant risks to the capacity of livestock systems to sustain farmers' livelihoods while meeting the increasing demand for animal products in a sustainable manner (Alltech, 2025; Beauchemin et al., 2020; Godde et al., 2021).

The livestock sector contributes substantially to food security, employment, and economic development. Animal-derived products such as meat, milk, and eggs

account for approximately 15% of global caloric intake and 31% of per capita protein supply, while millions of households depend on livestock production as a primary source of income (FAO Statistical Database., 2020). In Indonesia, livestock production contributes meaningfully to the national economy and the agricultural sector through household participation and its share of gross domestic product (BPS, 2021, 2023). These figures highlight the broad implications of livestock sustainability, including sheep production, for food security, economic stability, and social welfare.

An imbalance between feed resource availability and animal nutritional requirements represents a major constraint to sustainable sheep production. Heavy reliance on conventional feed ingredients that compete directly with human food needs and exhibit high price

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volatility has intensified interest in alternative and more sustainable feed resources. The utilization of agro-industrial by-products has received increasing attention over the past decade as a strategy to improve feed efficiency and sustainability. Cashew nut shell (CNS), a by-product of the cashew processing industry, is abundantly available in cashew-producing countries and shows potential as a non-conventional feed resource for ruminants. According to Feedipedia (2022), cashew by-products possess relatively high energy content, supporting their potential inclusion in ruminant diets (Chung et al., 2024; Rashmi, 2024). Additionally, the use of fruit waste in biogas production through anaerobic digestion is gaining traction as a sustainable practice, similar to the potential for CNS to contribute to environmental sustainability and reduce waste (Purwasih et al., 2025). Moreover, recent studies indicate that integration of plant secondary metabolites in ruminant diets, including condensed tannins, saponins, and flavonoids, can significantly reduce enteric methane emissions, thereby supporting more sustainable livestock production systems (Ku-Vera et al., 2020). Further research on plant-based feed additives has demonstrated that secondary plant metabolites, such as tannins, saponins, and flavonoids, significantly influence rumen fermentation dynamics and microbial populations, offering an environmentally friendly alternative to conventional feeding strategies (Jayanegara et al., 2018; Ku-Vera et al., 2020; Patra, 2016). These findings support the increasing interest in non-conventional feed resources and highlight the need for continued investigation to optimize their application in sustainable livestock production systems (Ku-Vera et al., 2020; O'Brien et al., 2023).

The use of CNS as a feed ingredient is closely associated with the presence of bioactive phenolic compounds, particularly anacardic acid and its derivatives, which may influence rumen microbial activity and feed palatability. Recent studies demonstrate that these compounds can exert beneficial biological effects when applied at appropriate inclusion levels. Experimental evidence indicates that cashew nut shell liquid (CNSL) modulates rumen fermentation through a surfactant-like mechanism that suppresses methanogenic microorganisms and alters rumen microbial community structure, resulting in reduced enteric methane production and improved feed energy utilization (Cuervo et al., 2024; Kang et al., 2018; Koike et al., 2020; Oh et al., 2017; Saenab et al., 2017). These effects have been consistently observed under both in vitro and in vivo conditions across different dietary regimes (Adetunji et al., 2020; Goetz et al., 2023; Jalal et al., 2025; Rashmi, 2024).

The application of CNS has also been associated with animal performance responses. Dietary

supplementation with CNSL in sheep diets has demonstrated potential to support growth performance while maintaining carcass and meat quality, with responses influenced by inclusion level and feeding strategy (Cuervo et al., 2024; Ramos et al., 2021). Similar responses have been reported in other ruminant production systems, including dairy cattle, indicating that CNSL may function as a broadly applicable functional feed additive (Goetz et al., 2023; Vieira, 2022).

The practical application of CNS in sheep feeding systems remains constrained by challenges related to dose optimization, potential anti-nutritional effects, and integration into economically viable ration formulations. Recent research emphasizes the importance of innovative formulation approaches, including the combination of CNSL with other sustainable feed additives, to maximize biological benefits while minimizing potential risks to animal health and production performance (Belanche et al., 2016; Silva, 2024; Vieira, 2022).

An integrated assessment of feed availability, nutritional characteristics, biological effects, production performance, and application challenges of CNS in sheep feeding systems is required. This mini-review aims to synthesize scientific evidence from the past decade regarding the potential of cashew nut shell as an alternative feed resource for sheep. The findings are expected to provide a robust scientific basis for the development of efficient and sustainable feeding strategies while contributing to environmental mitigation efforts in ruminant production systems (Baca Gonzalez et al., 2020; Beauchemin et al., 2020).

Method

Research Design

This study adopts a systematic literature review design to identify, analyze, and synthesize empirical research on the utilization of cashew nut shell (*Anacardium occidentale*) in sheep rations published within the most recent decade (2016–2025), with the objective of providing a coherent and up-to-date synthesis of its potential, limitations, and development opportunities as an alternative feed resource for small ruminant production systems. The term *mini review* is used to emphasize that the scope of this study is directed toward a qualitative and thematic synthesis of recent empirical findings rather than quantitative aggregation or statistical meta-analysis, thereby enabling an in-depth examination of key patterns, underlying mechanisms, and research gaps associated with the use of cashew nut shell in sheep feeding systems while accommodating heterogeneity in study designs, methodological approaches, and outcome measures across the reviewed literature.

Data Sources and Inclusion Criteria

The data sources comprise scientific journal articles, conference proceedings, and research reports published in national and international outlets. Studies were included if they examined the nutritional composition, biological effects, or practical applications of cashew nut shell in ruminant feeding systems, were written in English, and were available in full text to enable comprehensive analysis. Publications that lacked empirical evidence, were not directly aligned with the research focus, or were inaccessible in full-text form were excluded from the review.

Literature Search Strategy

A systematic literature search was conducted using major international scientific databases, including Scopus, ScienceDirect, SpringerLink, Wiley Online Library, and Google Scholar, complemented by selected national repositories. The search strategy employed combinations of keywords such as “cashew nut shell for ruminant feeding,” “cashew nut shell liquid sheep nutrition,” and “*Anacardium occidentale* animal feed” to ensure broad and comprehensive coverage of relevant and recent scientific literature.

Data Analysis Technique

Data were analyzed using content analysis by systematically examining each article that met the inclusion criteria to extract key information, including publication identity, research objectives, methodological approaches, principal findings related to the utilization of cashew nut shell, reported challenges, and identified opportunities for future development. The extracted information was then synthesized using a narrative and thematic approach to generate an integrated and comprehensive understanding of the evidence. The procedures of literature identification and selection followed a structured and transparent process, which was organized in alignment with the PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) framework. The stages of record identification, screening, eligibility assessment, and final inclusion of studies are visually summarized in the PRISMA flow diagram presented in Figure 1.

The PRISMA flow diagram presented in Figure 1 provides a concise and systematic overview of the literature selection process applied in this study. The process began with the identification of 1,529 records retrieved from various scientific databases, with no duplicate records removed prior to screening. All records were subsequently screened based on titles and abstracts, resulting in the exclusion of 1,464 articles that were not relevant to the research focus. A total of 65 articles were then sought for full-text retrieval, of which 51 could not be accessed or did not meet the retrieval

criteria. During the eligibility assessment, an additional 3 articles were excluded due to the lack of open-access availability. At the final stage, 11 studies met all inclusion criteria and were included for in-depth analysis in this mini review.

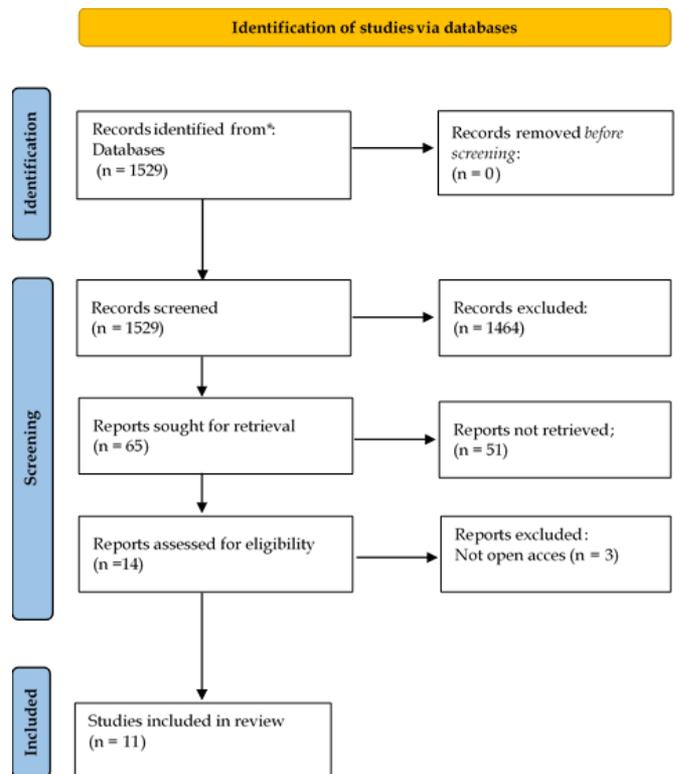


Figure 1. PRISMA Flow Diagram of the Literature Selection Process (Page et al., 2021)

Ethical Considerations

Since this study is based exclusively on a literature review, it does not involve direct experimentation on human or animal subjects and therefore does not require ethical clearance. Nevertheless, all sources included in the review are cited and acknowledged in accordance with established academic and publication ethics to ensure respect for intellectual property, transparency, and scientific integrity.

Result and Discussion

Potential Nutritional Value and Biological Benefits of Cashew Nut Shell (CNS)

Recent studies consistently demonstrate that cashew nut shell (CNS) has strong potential as an alternative feed ingredient for small ruminants, particularly sheep, both in terms of its nutritional value and biological benefits. CNS has been reported to contain metabolizable energy, protein, and lipid components comparable to conventional feed ingredients (Araújo et al., 2023; Ramos et al., 2021), as well as secondary metabolites and phenolic compounds

that support physiological and metabolic functions in livestock (Rashmi, 2024; Sruthi and Naidu, 2023). From a nutritional standpoint, the inclusion of CNS in sheep diets has shown positive responses in digestibility, feed efficiency, and production performance without adverse effects on intake or nutrient utilization (Araújo et al., 2023; Ramos et al., 2021; Vieira, 2023).

In addition to its nutritional contribution, CNS provides biological advantages through cashew nut shell liquid (CNSL), which possesses antimicrobial properties and the ability to modulate rumen fermentation. Several studies have demonstrated that CNSL can suppress methanogenic archaea, alter fermentation pathways, and reduce methane emissions,

thereby supporting more environmentally sustainable livestock production (Cuervo et al., 2024; Goetz et al., 2023; Jalal et al., 2025; Kang et al., 2018; Oh et al., 2017; Silva, 2024; Vieira, 2022). Overall, scientific evidence from the past decade indicates that CNS is a promising, sustainable, and feasible feed resource for application in sheep production systems.

Table 1 presents a summary of research conducted over the past ten years regarding the use of cashew nut shell (CNS) in sheep, including its nutritional value, digestibility, production performance, and its effects on rumen fermentation and methane emissions. In general, the data indicate that CNS has strong potential as a viable alternative feed ingredient in sheep production.

Table 1. Opportunities for the Utilization of Cashew Nut Shell in Sheep Rations

Researcher and Year	Subject or Study Focus	Identified Opportunities
Oh et al. (2017)	Rumen modulation using cashew nut shell liquid under different diets	Acts as a natural surfactant that alters rumen microbial activity and improves fermentation efficiency
Kang et al. (2018)	Sheep, dietary supplementation and withdrawal of CNSL	Demonstrates adaptive rumen responses and reversibility, supporting practical feeding strategies
Saenab et al. (2017)	In vitro rumen fermentation, anacardic acid from CNS	Suppresses methanogenesis while maintaining rumen fermentation stability
Adetunji et al. (2020)	In vitro rumen fermentation	Reduces methane production significantly, supporting climate-smart livestock systems
Koike et al. (2020)	Rumen microbiome network analysis	Modifies methanogen behavior without disrupting overall microbial balance
Ramos et al. (2021)	Growing-finishing lambs	Improves growth performance and maintains meat quality attributes
Narabe et al. (2021)	Ruminant fecal microbiota	Reduces methane emission through modulation of post-ruminal microbial communities
Vieira (2022)	CNSL combined with chitosan	Enhances feed additive potential through synergistic effects on rumen fermentation
Compton et al. (2023)	Continuous culture rumen system	Improves nutrient digestibility and fermentation efficiency
Goetz et al. (2023)	In vitro fermentation compared with monensin	Offers a natural alternative to ionophore antibiotics for methane mitigation
Araújo et al. (2023)	Lamb growth and meat fatty acid profile	Enhances meat quality while supporting sustainable feeding practices
Gaspe et al. (2024)	Dairy cattle in vivo	Lowers methane emissions without compromising milk production

Challenges in the Utilization of Cashew Nut Shell in Sheep Rations

Although numerous studies indicate that cashew nut shell (CNS) is a promising feed ingredient for sheep, its utilization is still constrained by several technical and biological challenges. The main limitations relate to potential toxicity, palatability issues, and possible effects on digestibility (Araújo et al., 2023; Ramos et al., 2021; Sruthi and Naidu, 2023). Recent studies emphasize that these challenges are primarily associated with the presence of phenolic compounds and bioactive constituents in CNS, which may negatively affect feed acceptance and physiological responses if not properly managed (Goetz et al., 2023; Rashmi, 2024).

Phenolic components such as anacardic acid, cardanol, and cardol are recognized as the major constraints in CNS utilization, particularly when the material is unprocessed or used at excessive inclusion levels. These compounds have been reported to potentially impair palatability, induce irritation in the gastrointestinal tract, and trigger adverse metabolic reactions when inadequately handled (Sruthi and Naidu, 2023; Vieira, 2022). Therefore, proper processing is essential to ensure its safe and effective application in ruminant feeding systems.

To overcome these limitations, several processing approaches have been recommended, including heat treatment, solvent extraction, microbial fermentation,

and technological refining of CNS-derived products. Such techniques have been shown to reduce antinutritional factors, improve palatability, and mitigate toxicity risks, thereby enhancing the feasibility of CNS utilization in practical feeding systems (Goetz et al., 2023; Silva, 2024; Vieira, 2022). However, these technologies may require additional cost, infrastructure,

and technical capacity, which can pose constraints particularly for smallholder farmers.

Table 2 provides a summary of the major technical and biological challenges associated with CNS utilization in small ruminants, along with recommended mitigation strategies reported in recent studies.

Table 2. Challenges in the Utilization of Cashew Nut Shell in Sheep Rations

Researcher and Year	Study Focus (Animal Type)	Identified Challenges
Oh et al. (2017)	Rumen modulation in sheep and cattle (in vitro)	Strong surfactant activity may suppress beneficial rumen bacteria at high inclusion levels
Kang et al. (2018)	Sheep (in vivo CNSL supplementation and withdrawal)	Rumen fermentation responses are dose-dependent and require adaptation period
Saenab et al. (2017)	Ruminants, primarily sheep (in vitro)	Phenolic compounds exhibit antimicrobial effects that may reduce fermentation efficiency if inclusion levels are not controlled
Adetunji et al. (2020)	Ruminants, sheep model (in vitro)	Methane reduction may be accompanied by decreased short-chain fatty acid production
Koike et al. (2020)	Sheep (rumen microbiome analysis)	Long-term shifts in methanogen behavior may alter microbial network stability
Narabe et al. (2021)	Native ruminant livestock (cattle and buffalo)	Long-term ecological effects on fecal and gut microbiota remain unclear
Vieira (2023)	Ruminants (in vitro, sheep-based diet)	Optimal CNSL–chitosan ratios are required to avoid negative effects on digestibility
Compton et al. (2023)	Ruminants, sheep and cattle model (continuous culture)	Variable fermentation responses depending on diet composition
Goetz et al. (2023)	Ruminants, sheep-based in vitro system	Effects on fermentation parameters may be neutral under specific dietary conditions
Araújo et al. (2023)	Growing lambs (in vivo)	Economic feasibility and consistent availability of CNSL remain limiting factors
Gaspe et al. (2024)	Dairy cattle (in vivo)	Cost-effective extraction methods and long-term field validation are required

Opportunities for Developing CNS in Sustainable Feed Systems

Table 3. Opportunities for Developing CNS in Sustainable Feed Systems

Researcher and Year	Focus (Animal Type / Model)	Identified Opportunities
Oh et al. (2017)	Ruminants, rumen fermentation (in vitro)	Development of natural rumen modifiers to improve fermentation efficiency
Kang et al. (2018)	Sheep (in vivo)	Practical supplementation strategy with reversible rumen adaptation
Saenab et al. (2017)	Ruminants, rumen fermentation (in vitro)	Functional feed additive derived from agro-industrial by-products
Adetunji et al. (2020)	Ruminants, rumen fermentation (in vitro)	Development of functional feeds with combined nutritional and environmental benefits
Koike et al. (2020)	Ruminants (sheep and cattle microbiome model)	Targeted manipulation of methanogen activity through microbiome modulation
Ramos et al. (2021)	Growing–finishing lambs (in vivo)	Improvement of growth performance while maintaining meat quality
Narabe et al. (2021)	Native ruminant livestock (cattle and buffalo)	Diversification of locally available feed resources and methane mitigation
Vieira (2022)	Ruminants, rumen fermentation (in vitro)	Synergistic feed additive development using CNSL combined with chitosan
Compton et al. (2023)	Ruminants, continuous culture system	Precision evaluation of nutrient digestibility and fermentation efficiency
Goetz et al. (2023)	Ruminants, rumen fermentation (in vitro)	Natural alternative to antibiotic ionophores for methane mitigation
Araújo et al. (2023)	Lambs (in vivo)	Enhancement of meat physicochemical and fatty acid profiles
Gaspe et al. (2024)	Dairy cattle (in vivo)	Sustainable feed ingredient improving environmental performance without reducing productivity

Despite several challenges, the utilization of cashew nut shell (CNS) offers promising opportunities for ruminant feeding systems. CNS is abundantly available as a by-product of cashew processing and remains largely underutilized (Feedipedia, 2022; Alltech, 2025). Recent studies demonstrate that CNS and cashew nut shell liquid (CNSL) not only provide nutritional value but also contribute to methane mitigation through their bioactive compounds, which enhance rumen fermentation efficiency (Goetz et al., 2023; Cuervo et al., 2024; Jalal et al., 2025; Sruthi and Naidu, 2023). These characteristics support the transition toward more sustainable and environmentally friendly livestock production systems (Godde et al., 2021).

Current findings also indicate that CNS can be strategically developed as an alternative feed resource due to its nutritional functionality and positive effects on rumen metabolism and animal performance (Ramos et al., 2021; Vieira et al., 2022; Vieira et al., 2023). Table 3 presents a summary of recent research exploring CNS and CNSL inclusion in ruminant diets, highlighting inclusion levels, application forms, and key biological responses related to rumen fermentation, productivity, and methane reduction.

Discussion

Potential of Cashew Nut Shell (CNS) as an Alternative Feed for Sheep

Cashew nut shell (CNS) has shown significant potential as an alternative feed ingredient for ruminants, particularly sheep, as highlighted in recent studies. CNS contains various essential nutrients, especially energy, making it a promising resource to replace conventional feed ingredients such as grains and oilseeds (Araújo et al., 2023). Recent studies, such as Kang et al. (2018) demonstrate that the supplementation of CNS in sheep diets enhances dry matter digestibility and provides available energy, thereby improving feed performance. Additionally, Ramos et al. (2021) report improved meat quality in lambs fed CNS, indicating its potential in livestock production.

Despite its promising potential, the application of CNS as an alternative feed varies across studies. Research by Goetz et al. (2023) reveals that CNS supplementation in ruminant diets can lead to increased energy metabolism and feed efficiency, particularly when combined with other feed additives such as monensin. However, Compton et al. (2023) found minimal effects of CNS on ruminal fermentation in continuous culture studies, highlighting that the outcomes of CNS supplementation depend on various factors, including the method of administration and dietary conditions.

The inconsistency in results may also be attributed to variations in processing techniques. Studies by

Adetunji et al. (2020) emphasize the need for proper processing methods to maximize the nutritional benefits of CNS. Oh et al. (2017) also note the presence of phenolic compounds in CNS, which, if not properly treated, could hinder its nutritional potential. Therefore, the processing method plays a critical role in determining the efficacy of CNS as a viable alternative feed ingredient.

Although CNS shows promise, further research is needed to standardize its processing methods and assess its long-term benefits in livestock production. Understanding the optimal dosages and processing techniques will be crucial for enhancing the practical application of CNS in sheep feeding systems.

Challenges in Using CNS as Feed for Sheep

Although CNS holds promise as an alternative feed, its use is accompanied by challenges largely due to the presence of phenolic compounds such as anacardic acid, cardol, and cardanol, which are abundant in cashew nut shell liquid (CNSL) and can negatively impact palatability, digestibility, and animal health if not properly processed; processing methods like roasting or detoxification are needed to reduce these anti-nutritional factors and improve feed safety and nutrient utilization in livestock diets (Yeniçeri et al., 2025).

Several studies have investigated strategies to mitigate the anti-nutritional effects of cashew nut shell (CNS). Recent research indicates that processing methods such as roasting, ensiling, or detoxification can reduce the toxicity of CNS, improving palatability, digestibility, and nutrient availability (Yeniçeri et al., 2025). Nevertheless, thermal treatment alone may not be sufficient to eliminate all adverse effects. Therefore, additional approaches, including fermentation or incorporation with other feed ingredients, are recommended to further enhance feed quality and minimize the negative impacts of phenolic compounds (Araújo et al., 2023; Compton et al., 2023)

Another challenge is the variability in CNS dosages used across different studies. Ramos et al. (2021) reported that higher CNS levels in sheep diets improved meat quality but raised concerns about the effects on ruminal fermentation and nutrient absorption. Conversely, Kang et al. (2018) observed positive effects on growth performance with lower CNS inclusion levels. The discrepancy in findings highlights the importance of determining the optimal CNS dosage to ensure both safety and efficacy.

In addition to the dosage and toxicity concerns, the method of supplementation also plays a significant role in CNS effectiveness. Goetz et al. (2023), Observed that when CNS was combined with monensin, it led to greater improvements in feed efficiency and reduced

methane production. However, Adetunji et al. (2020) noted that CNS supplementation in isolation showed less significant benefits. These findings underscore the need for further exploration of CNS supplementation methods and their interactions with other feed additives to optimize its use.

Biological Effects of CNS on Ruminant Digestive Systems

Beyond its nutritional content, CNS has notable biological effects on rumen fermentation in ruminants. Koike et al. (2020) reported that CNS supplementation could alter ruminal microbiota by reducing methanogen populations, thereby decreasing enteric methane emissions. This antimicrobial activity, as observed by Mota and Silva, (2011), contributes to improved feed efficiency and potentially reduces the environmental impact of livestock production. Kang et al. (2018) also confirmed that CNS can enhance nutrient utilization efficiency in ruminants, which is crucial for improving overall livestock productivity.

However, the biological effects of CNS on rumen fermentation are not consistent across all studies. Compton et al. (2023) found limited effects on methane production in *in vitro* ruminal fermentation, suggesting that the benefits of CNS may vary depending on the fermentation conditions and dosages used. Goetz et al. (2023) further emphasized that CNS's effectiveness in modulating methane emissions is more pronounced when combined with other feed additives, such as monensin.

The influence of CNS on nutrient digestion in ruminants is also complex. Narabe et al. (2021) demonstrated that CNS could improve fiber digestion in the rumen by promoting the activity of certain cellulolytic microbes, which enhances feed digestibility. Beauchemin et al. (2020) similarly found that CNS improved carbohydrate digestion in dairy cows, supporting its potential to enhance rumen fermentation. Nonetheless, the effects on fiber digestion vary depending on the specific microbial populations present in the rumen and the composition of the diet.

Despite these promising findings, there is still a need for further research to clarify the exact mechanisms by which CNS affects ruminal microbiota and fermentation processes. Ramos et al. (2021) and Adetunji et al. (2020) suggest that exploring the interaction between CNS and other feed additives, such as chitosan or essential oils, could enhance its biological effects and improve feed efficiency. This line of research is crucial for fully understanding the potential of CNS as a sustainable feed ingredient.

Implications for Applied Science in Sustainable Feed Innovation

The utilization of cashew nut shell (CNS) as an alternative feed ingredient for sheep presents substantial potential in creating a more sustainable feeding system. CNS can reduce reliance on conventional, costly, and environmentally harmful feed ingredients such as imported grains. With proper processing, CNS can provide significant nutritional benefits and decrease methane emissions from ruminal fermentation, thus supporting the sustainability of livestock industries. Innovations in feed technology, such as more efficient processing techniques for CNS, are crucial in maximizing its potential, reducing environmental impact, and enhancing food security (Goetz et al., 2023; Kang et al., 2018).

Recommendations for Future Research

Cashew nut shell (CNS) shows significant promise as an alternative feed for sheep, with positive effects on digestibility, growth performance, and feed efficiency. However, the primary challenge lies in the presence of toxic compounds within CNS, which require proper processing to mitigate negative impacts. Future research should focus on exploring more efficient processing techniques, determining the optimal dosage of CNS, and assessing its long-term effects on livestock health and productivity. Additionally, further studies are needed to evaluate the interaction of CNS with other feed ingredients and its potential for reducing methane emissions in more sustainable livestock production systems (Chung et al., 2024; Compton et al., 2023).

Implications for Education and Applied Science

The use of CNS in alternative feed ingredients has important implications for applied science education, particularly in the fields of animal nutrition and feed biotechnology. Introducing non-conventional feed materials such as CNS into the curriculum can enrich agricultural and livestock education, providing students with insights into sustainable livestock practices and environmentally friendly feed technologies. This knowledge will prepare future generations to address global food security challenges and climate change by innovating sustainable feed systems that enhance livestock independence and support local economic development (Koike et al., 2020; Silva, 2024).

Conclusion

Cashew nut shell (CNS) demonstrates substantial potential as an alternative feed for sheep, offering improvements in digestibility, growth performance, and feed efficiency. However, the presence of toxic compounds remains a significant challenge, requiring

effective processing methods to mitigate adverse effects. Future research should focus on optimizing processing techniques, determining the ideal CNS dosage, and evaluating its long-term impact on livestock health and productivity. Additionally, further studies are needed to explore CNS interactions with other feed ingredients and its potential for reducing methane emissions in sustainable livestock production systems. In conclusion, future research should prioritize applied science-based approaches to develop practical solutions for optimizing CNS use in livestock feed, contributing to more sustainable agricultural practices.

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Author Contributions

All authors contributed equally to conceptualization, literature collection and analysis, drafting, and final manuscript refinement. All authors have read and approved the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest and confirm that this research was conducted independently for academic purposes.

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