PLANT-DERIVED TANNINS AS NATURAL FEED ADDITIVES FOR SHEEP: A SYSTEMATIC REVIEW OF SOURCES, MECHANISMS, AND PRODUCTIVE RESPONSES

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ABSTRACT

Plant-derived tannins have been increasingly investigated as natural feed additives to improve rumen efficiency and environmental sustainability in sheep production. However, inconsistency in plant sources, tannin types, inclusion levels, and application forms has limited their practical utilization. This systematic review aimed to identify tannin-containing plants suitable for sheep diets, explain their mechanisms of action as rumen modifiers, determine optimal dosage ranges, and compare the effectiveness of tannin extracts and crude plant materials A systematic literature review was conducted following PRISMA 2020 guidelines using Scopus, ScienceDirect, SpringerLink, PubMed, and Google Scholar databases (2014–2024). Empirical studies were screened using predefined inclusion criteria and assessed for methodological quality using the Mixed Methods Appraisal Tool (MMAT 2018). Data were synthesized using a thematic approach across 105 included studies, which collectively identified 38 tannin-containing plant species. *Acacia mearnsii*, *Leucaena leucocephala*, and *Mimosa tenuiflora* were the most frequently reported sources.[1] The primary mechanisms involved tannin–protein complex formation, modulation of rumen microbial populations, and reduction of enteric methane emissions. Condensed tannins included at 2–4% of dietary dry matter consistently improved nitrogen utilization, average daily gain, and carcass quality without impairing digestibility. Tannin extracts produced stronger biological responses, while crude plant materials offered greater economic feasibility and sustainability for smallholder systems. In conclusion, plant-derived tannins function as multifunctional rumen modifiers that enhance sheep productivity while reducing environmental impacts.

Keywords : *Tannins; Sheep; Rumen Fermentation; Feed Efficiency; Sustainable Livestock*

INTRODUCTION

Global sheep production continues to increase, with the population now exceeding 1.2 billion worldwide, driven by growing demand for animal protein sources and the need for sustainable farming systems (International Wool Textile Organization 2022).1 However, sheep productivity still varies greatly between regions, largely influenced by feed efficiency, nutrient utilization, and rumen function. According to Mlambo (2020), improving rumen fermentation efficiency is one of the most effective strategies for improving livestock performance while reducing methane emissions. The growing interest in plant-based feed additives, particularly tannins, reflects a shift from the use of synthetic additives to environmentally friendly natural alternatives that are in line with the global agenda for sustainable livestock production (Patra and Saxena 2011).

Ruminant production systems face challenges from the environmental and economic impacts of inefficient rumen fermentation. Excessive nitrogen excretion, high enteric methane emissions, and low feed conversion efficiency contribute to substantial economic losses and environmental degradation (Beauchemin et al. 2020).1 Methane generated during carbohydrate fermentation in the rumen represents an energy loss of 14–18% of the total energy intake (Sosa-Perez et al. 2023; Al Rharad et al. 2025). This condition requires sustainable interventions that can optimize rumen microbial ecology without reducing livestock performance. Tannins are of particular interest due to their ability to reduce methane emissions while improving protein utilization through binding to feed proteins and modifying microbial populations (Patra and Yu 2014).

Tannins, which are polyphenolic compounds found in various plant taxa, possess significant potential as rumen modifiers capable of influencing fermentation pathways and increasing nutrient utilization efficiency (Jayanegara et al. 2019).1 However, it is widely recognized that excessive use of tannins can reduce feed palatability and nutrient digestibility (Makkar 2003). Several empirical studies have explored various sources and doses of plant tannins for sheep feed. Gao et al. (2024) reported that tannin extract from chestnuts increased average daily gain (ADG), antioxidant capacity, and fatty acid composition in Tan sheep during the fattening phase. Other findings suggest that supplementation of hydrolyzed tannins in high-concentrate feed improved slaughter performance, meat quality, and intestinal enzyme activity in sheep (Ma et al. 2024). Under tropical conditions, tannin supplementation has been shown to improve growth performance and the antioxidant status of sheep meat (Orzuna-Orzuna et al. 2021). Furthermore, tree fruits such as *Chloroleucon mangense* and *Acacia cochliacantha* are being explored as alternative feed supplements due to their high voluntary consumption and accessibility (Sosa-Perez et al. 2023; Hernandez-Morales et al. 2018).Despite these potential benefits, there is no comprehensive synthesis integrating the identification of tannin-producing plant sources, the mechanism of action, the optimal dosage, and a comparison between extract forms and plant simplisia. This research aims to fill that gap by providing an evidence-based framework for sustainable feed management (Valenti et al. 2019).

METHOD

This study utilized a Systematic Literature Review (SLR) design with a qualitative descriptive approach to identify, assess, and synthesize scientific evidence related to the use of plant tannins as feed additives in sheep. This design followed the PRISMA 2020 guidelines to ensure accuracy in reporting the stages of identification, screening, eligibility, and inclusion (Page et al. 2021). The population consisted of sheep fed a diet containing tannin; the intervention involved various plant tannin sources; and the outcomes measured productivity, feed efficiency, rumen health, and meat quality.

The literature search was conducted across Scopus, ScienceDirect, SpringerLink, PubMed, and Google Scholar for the period 2014–2024. Keywords included: ("tannin" OR "plant extract" OR "polyphenol") AND ("sheep" OR "ruminant") AND ("rumen modifier" OR "fermentation" OR "digestibility" OR "productivity"). Article quality was evaluated using the 2018 version of the Mixed Methods Appraisal Tool (MMAT) (Hong et al. 2018). Data were analyzed using a thematic approach to identify relationships between tannin type, dose, and productive response.

RESULTS AND DISCUSSION

Study Selection and Identification (PRISMA 2020)

The article identification and selection process in this study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al. 2021). From the initial search results through two main databases, namely Scopus and Web of Science (WoS), a total of 1,990 articles were obtained. After the duplication removal process, 384 articles were removed because they were duplicate entries. The next stage was preliminary screening based on inclusion and exclusion criteria, in which articles published before 2015, not in English, and with irrelevant publication types (such as review articles, conference papers, proceedings, book chapters, and errata) were excluded from the analysis.

From this process, 1,606 articles remained, which were then screened based on their titles and abstracts to assess their suitability for the research topic. The initial screening results showed that 193 articles met the criteria for full-text screening. However, 71 reports could not be accessed in full due to document availability or access limitations. Thus, only 123 articles were successfully assessed at the eligibility stage. Of these, 18 articles were excluded because the full text content did not match the research question. The final selection stage resulted in 105 articles that met all inclusion criteria and were used in the systematic synthesis.

This number represents approximately 5.3% of the total articles identified in the initial stage, indicating that the selection process was rigorous, transparent, and research-relevance oriented. This procedure also illustrates the importance of applying consistent methodological criteria to ensure that only literature of high quality and relevance is included in the analysis. Overall, the results of this article screening and selection confirm that the use of the PRISMA guidelines plays an important role in maintaining the integrity and replication of systematic review methodologies.

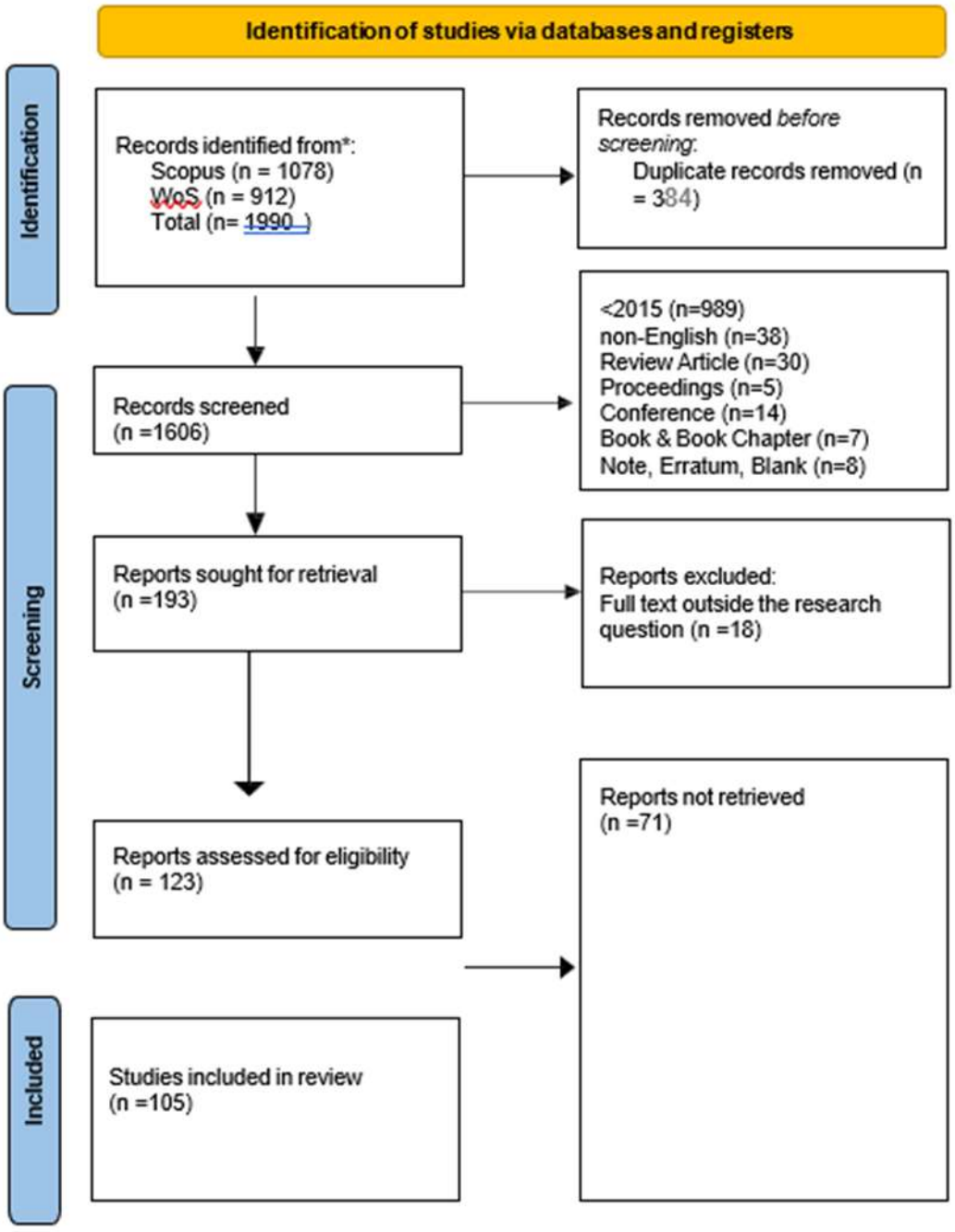


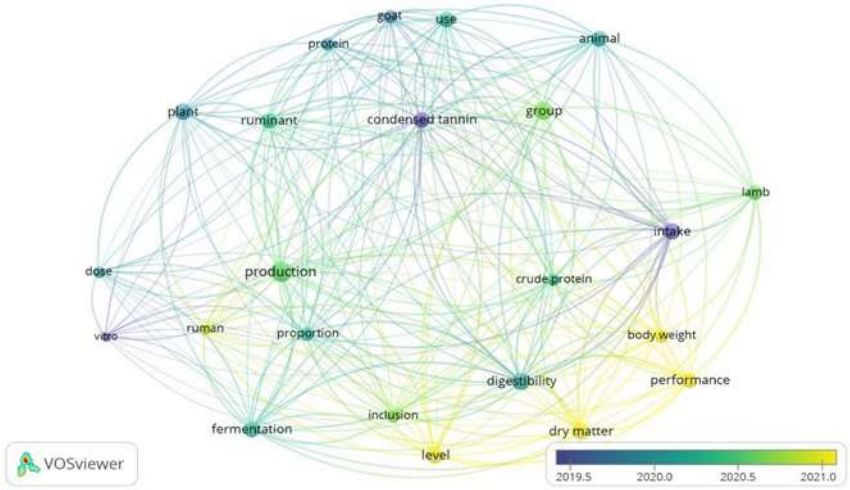
Figure 1. PRISMA 2020 Flow Diagram of the Systematic Review Process.

Bibliometric Analysis and Research Trends

The results of the bibliometric analysis using VOSviewer show that research related to the use of condensed tannins in ruminants is divided into three main clusters: (1) composition and sources of plant-based feed, (2) the effects of tannins and dosage on fermentation and rumen activity, and (3) livestock performance and productivity.1 As visualized in Figure 2, central nodes

such as "condensed tannin," "intake," "digestibility," and "body weight" show strong interconnections, confirming a primary research focus on balancing antinutritional effects with productive benefits.

Based on the temporal color gradation (2019.5 to 2021.0), research trends illustrate a clear evolution. Studies initially focused on basic mechanistic aspects, such as in vitro fermentation and rumen microbial activity (indicated by darker blue/purple nodes from 2019–2020). More recent research has shifted toward practical field applications, emphasizing performance parameters like average daily gain (ADG), carcass traits, and dry matter intake (indicated by lighter green/yellow nodes from 2020–2021).This shift reflects the maturation of tannin research from experimental laboratory validation to direct application in ruminant production systems for improved feed efficiency and sustainability.



!(https://image_url_placeholder.com/vosviewer_map)

Figure 2. VOSviewer bibliometric map showing keyword correlations and temporal research trends (2014–2024).

Taxonomic Distribution and Plant Sources

A total of 38 plant species were identified as suitable tannin sources.1 Acacia mearnsii, Leucaena leucocephala, and Mimosa tenuiflora were the most frequently reported (da Silva Aguiar et al. 2023; Jayanegara et al. 2015). Tropical legumes consistently provide positive effects on nitrogen retention and methane reduction.

3.4. Mechanisms of Action as Rumen Modifiers

Tannins function by forming tannin–protein complexes that reduce rumen degradation, allowing protein to bypass the rumen for absorption in the small intestine (Min et al. 2012; Sayd et al. 2022). This increases bypass protein flow and reduces nitrogen loss through urine. Tannins also modulate microbial populations by suppressing methanogens and protozoa, which reduces enteric methane emissions and shifts fermentation toward propionate (Jayanegara et al. 2015; Ibrahim and Hassen 2022).

Effective Dosage and Productivity

Analysis indicates that an optimal dose of 2–4% dry matter (DM) provides the best results for feed efficiency without impairing digestibility.1 Condensed tannins from Calliandra calothyrsus and Acacia spp. consistently show increases in body weight within this range. Doses

above 5% DM are associated with reduced palatability and inhibition of digestive enzymes (Makkar 2003).

Effectiveness of Extracts vs. Crude Plant Materials

Tannin extracts provide standardized dosing and significant improvements in ADG (up to 20%), while crude plant materials (simplisia) offer greater economic feasibility and safety for long-term rumen microbial health due to other protective metabolites (Besharati et al. 2022; Gao et al. 2024; Venter et al. 2024).

Discussion

The results of this review indicate that tannins play a multifunctional role in sheep nutrition, acting as bioactive agents that stimulate rumen fermentation balance (Makkar 2003; Mlambo 2020). As visualized in Figure 3, *Acacia mearnsii*, *Leucaena leucocephala*, and *Mimosa tenuiflora* dominate the scientific literature with the highest number of citations, ranging from four to six per species. This confirms their status as established prime candidates for sustainable feed strategies. The effectiveness of these species is well-supported by their ability to stabilize protein bonds, allowing for gradual release in the small intestine (Harun et al. 2017; Sosa-Perez et al. 2023). These findings align with the bypass protein theory, where the interaction between tannins and protein creates a controlled-release mechanism (Menci et al. 2021; Sayd et al. 2022).

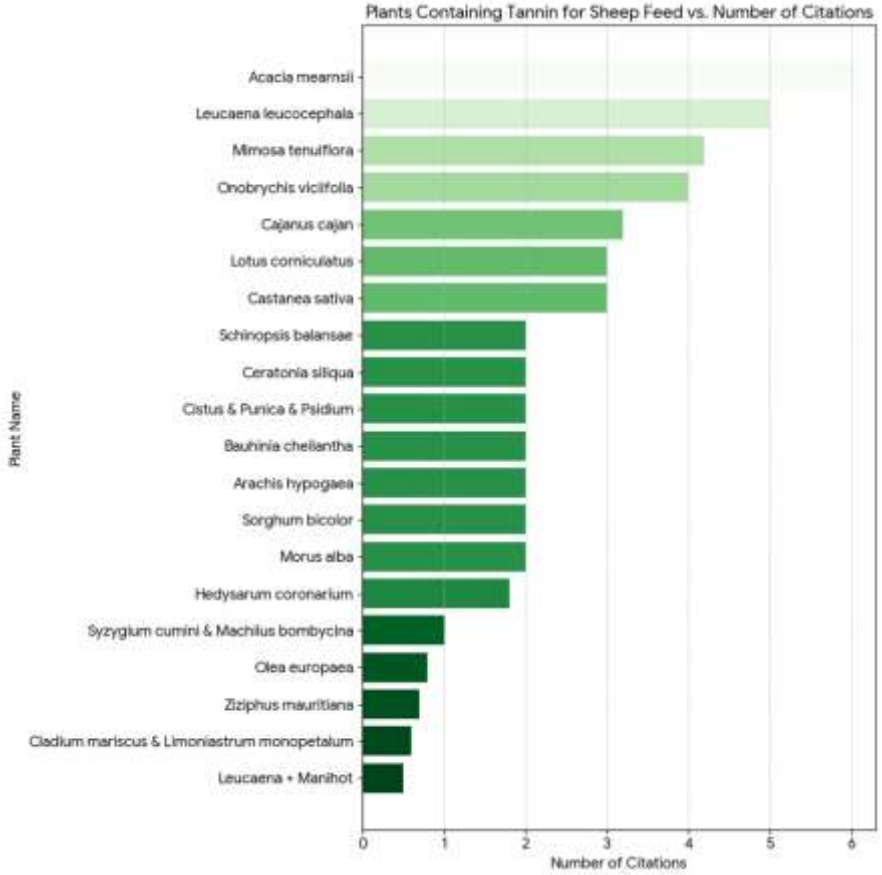


Figure 3. Distribution of plant species identified as tannin sources for sheep feed based on the number of citations.

Regarding microbial modulation, tannins suppress proteolytic microbes and methanogens, leading to a decrease in rumen ammonia and methane emissions (Jayanegara et al. 2015; Ibrahim and Hassen 2022).1 Supplementation of up to 4% DM has been reported to reduce methane by up to 35% (Menci et al. 2021).1 This shift in fermentation toward propionate represents a more energy-efficient pathway for the animal (Ma et al. 2024). Furthermore, tannins affect fat biohydrogenation, reducing the activity of enzymes that saturate fatty acids, thereby increasing beneficial unsaturated fatty acids (UFA) and conjugated linoleic acid (CLA) in meat (Harun et al. 2017; Al Rharad et al. 2025; Bioprocessing of Grape Pomace 2025). This improves the nutritional profile for consumers and enhances meat oxidative stability (Orzuna-Orzuna et al. 2021; Garcia-Salas et al. 2024).

The synthesis suggests an optimal dose of 2–4% DM for maximizing performance. This range balances nitrogen efficiency and methane reduction without causing the palatability issues often seen at higher doses (Makkar 2003; Sosa-Perez et al. 2023). Interestingly, some research shows that goats and certain sheep breeds may adapt to higher tannin levels through the secretion of proline-rich proteins in their parotid saliva, which neutralize the astringent effects (Austin et al. 1989; Lamy et al. 2009).

Knowledge gaps remain, particularly for minor species. More than 60% of identified tannin-rich plants, such as *Olea europaea* and *Ziziphus mauritiana*, have fewer than two citations (Figure 3), indicating that their use is still exploratory.1 Future studies should explore these local sources and integrate metabolomic analyses to understand long-term rumen adaptation (da Silva Aguiar et al. 2023; Jamarun et al. 2020).

Formatting of Mathematical Components

The impact of tannins on methane reduction can be modeled using the following relationship:

$$Y = a - bX \quad (1)$$

where Y is methane yield (g/kg DMI), X is tannin inclusion (% DM), a is the baseline methane, and b is the reduction coefficient. Nitrogen utilization efficiency is calculated by:

$$N\{retention\} = N\{intake\} - (N\{fecal\} + N\{urinary\}) \quad (2)$$

Moderate tannin levels decrease N{urinary} by shifting nitrogen excretion toward the feces (da Silva Aguiar et al. 2023).

CONCLUSIONS

This review confirms that plant tannins are strategic natural feed additives that improve nutrient efficiency and productivity in sheep while mitigating environmental impacts.1 Condensed tannins at 2–4% DM provide the most consistent positive effects. Tannins offer a sustainable alternative to synthetic growth promoters, supporting global efforts toward carbon neutrality in livestock production.

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