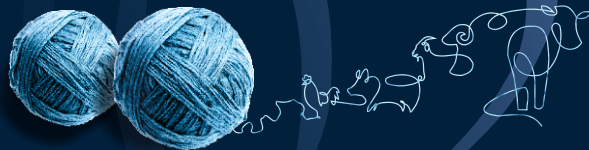


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CHESTNUT TANNINS IN LAMB NUTRITION: BALANCING PROTEIN UTILIZATION AND FEED EFFICIENCY IN SUSTAINABLE FATTENING SYSTEMS

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Abstract: Tannins are complex plant-derived polyphenols that are increasingly being investigated in ruminant nutrition due to their protein binding capacity, bioactive properties and potential to support sustainable production goals. They can modulate fermentation in the rumen, reduce protein degradation and alter the dynamics of nutrient absorption dynamics — but their dual role as functional and potentially antinutritive agents requires differentiated evaluation. This paper discusses the broader functional importance of tannins in ruminant diets based on a comprehensive literature review, focussing on their mechanisms of action, influence on digestibility, animal performance and metabolic responses. Within this framework, a practical model of lamb fattening will be analysed to investigate the controlled use of chestnut tannins under different feeding conditions and protein balances. The model serves to illustrate the general challenges of implementing tannin research in commercial feeding systems. The importance of dosage, tannin type, feed matrix and animal-specific factors that determine efficacy and safety is emphasised. Whilst the integration of tannins offers promising routes to nitrogen efficiency and reduced environmental impact, practical implementation requires a clear understanding of the economic trade-offs and variability at farm level. The findings presented will serve as a basis for future research designs and practical implementation strategies for plant additives in small ruminant diets.

Key words: tannins, lamb fattening, protein utilization, feed efficiency, sustainable livestock

Introduction

Tannins are naturally occurring plant secondary metabolites that belong to the broader group of polyphenolic compounds. They occur widely in trees, shrubs and legumes and have traditionally been regarded as antinutritional due to their astringency and protein-binding properties. In the last decades, however, due to their potential to modulate rumen fermentation and improve nitrogen utilization (Patra and Saxena, 2011; Hassanpour et al., 2011), studies emphasise their versatile role in ruminant nutrition for promoting animal health and performance, as well as environmental sustainability (Sharma et al., 2019). Furthermore, tannins can influence protein degradation, rumen microbial ecology and methane production (Decandia et al., 2011)

Among the various tannin types, hydrolyzable tannins (HT) derived from chestnut (*Castanea sativa* Mill.) have shown particularly promising effects when used as addition in rations (Mancini et al., 2019, Sun et al., 2025). Chestnut tannins are particularly rich in hydrolyzable forms, and represent a promising strategy to address protein utilization inefficiencies and mitigate nitrogen-related environmental impacts in ruminants (Hutchings et al., 2006).

Despite these advantages, certain knowledge gaps and several challenges remain unresolved. The dualistic nature of tannins-as both functional enhancers and potential antinutritional agents-raises concerns about their impact on digestibility, microbial balance, and animal health at higher inclusion levels (Barry and McNabb, 1999). The variation in tannin structure, concentration, and bioactivity across sources further complicates standardized application in commercial settings. Additionally, the lack of consistent labeling and formulation guidelines for commercial tannin products limits reproducibility across trials and hampers on-farm adoption.

This review aims to address these uncertainties by integrating experimental findings and literature-based insights into the effects of chestnut tannins in lamb nutrition. It highlights the biochemical nature of tannins, mechanisms of action, effects on fermentation, protein utilization, nutrient digestibility, evaluates their influence on growth performance and health of animals, and explores their role in environmental mitigation strategies. Furthermore, a practical fattening model is presented to illustrate how chestnut tannins perform under protein-deficient conditions. By exploring these themes, the paper provides a foundation for targeted research, precise dosing strategies, and informed implementation of tannin-based feed additives in small ruminant systems.

Classification and tannin properties

Although tannins can be classified in different ways, they are mainly divided into hydrolyzable (HT) and condensed tannins (CT), which are distinguished by their chemical structure and reactivity (Frutos et al., 2004a), as shown in Figure 1.

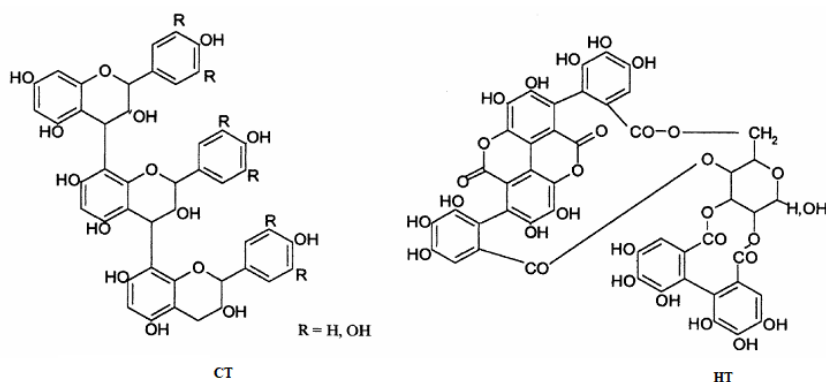


Figure 1. Tannin classification – CT i HT (Hassanpour et al., 2011)

CT, also known as proanthocyanidins, are polymers of flavan-3-ols and are mainly found in forage legumes such as sainfoin, birdsfoot trefoil, sericea lespedeza, sulla and others. HT, on the other hand, are esters of gallic acid or ellagic acid with with a sugar core (glucose) and are mainly found in trees such as oak, chestnut, acacia and others (Frutos et al., 2004a; Furlan et al., 2011). HTs are water-soluble and more susceptible to hydrolysis, while CT are oligomers or polymers of flavonoid units that are resistant to degradation (Furlan et al., 2011). However, in many cases one plant species can contain both groups of tannins (Besharati et al., 2022). Both types can bind proteins, but with varying affinity and stability depending on pH and molecular weight.

As mentioned, chestnut tannins mainly contain HT, notably castalagin, vescalagin, gallic ellagic acid, vescalin, castalin, and others, and often complemented by flavonoids such as rutin and quercetin (Braga et al., 2014; Soares et al., 2019). Their ability to form reversible complexes under rumen pH conditions

underlines their role in modulating protein degradation. Tannins have antioxidant and antimicrobial activity, with certain polyphenols contributing to gut health and potentially influencing rumen microbial populations. The exact composition of chestnut extracts can vary depending on processing, origin and standardization, highlighting the need for reliable characterization methods.

Sources and chestnut tannins extraction

Sweet chestnut (*Castanea sativa* Mill.) serves as both a traditional and industrial source of HT, which is mainly extracted from its bark and heartwood (Comandini et al., 2012). Modern extraction is carried out using aqueous or aqueous-alcoholic solvents to produce commercial formulations, among which are also Farmatan Plus® (Slovenia), Saviotan feed®, Silvafeed (Italy), Tannino50® (USA) and others.

However, the final composition and functionality of tannin extracts is influenced by several factors. These include the age of the plant, the seasonal and environmental conditions during harvest, the part of the plant used (wood vs. bark) and the extraction methods (Spina et al., 2013). Young trees can have different polyphenol profiles than mature ones, and stress and growing conditions (e.g. drought, pathogens) can increase their concentration. The solvent system, temperature and extraction time also influence the yield, reactivity and diversity of compounds (Ebrahim and Negussie, 2020) and as a result, even commercial HT extracts of the same botanical origin may differ in their bioactivity unless they are strictly standardized (Criminna et al., 2024).

This variability requires precise chemical profiling and validation using instruments such as HPLC-DAD-MS/MS, which enable the detection of important molecular constituents such as vescalagin, castalagin, gallic acid, vescalin, castalin and other compounds. Ensuring batch-to-batch reproducibility is critical to achieving predictable biological results in ruminant feeding trials. This consistency is critical for evaluating biological efficacy and determining effective supplementation levels in ruminant feeding systems (Das et al., 2020).

Mode of action in ruminant nutrition

The effect of tannins on ruminant performance is multifaceted and can influence a variety of factors, from feed intake to product quality (Figure 2). The most important nutritional effect of tannins lies in their ability to bind dietary proteins and protect them from microbial degradation in the rumen. This reduces ammonia production (Taha et al., 2022) and increases the proportion of rumen

undegradable protein (RUP) that reaches the small intestine, improving nitrogen utilization efficiency (Makkar, 2003; Barry et al., 2001). Tannins can also interact with cell wall polysaccharides (Hervas et al., 2003), enzymes (Horigome et al., 1988) and microbial membranes (Cannas, 2018) to alter nutrient availability and microbial colonization.

HTs from chestnut generally dissociate in the acidic post ruminal environment due to their reversible protein binding properties, releasing nutrients for enzymatic digestion. This enables better absorption of amino acids in the small intestine and supports improved protein efficiency. In addition, chestnut tannins have been shown to suppress methanogenic archaea and proteolytic bacteria, resulting in lower methane emissions and ammonia concentrations in the rumen (Jeronimo et al., 2016).

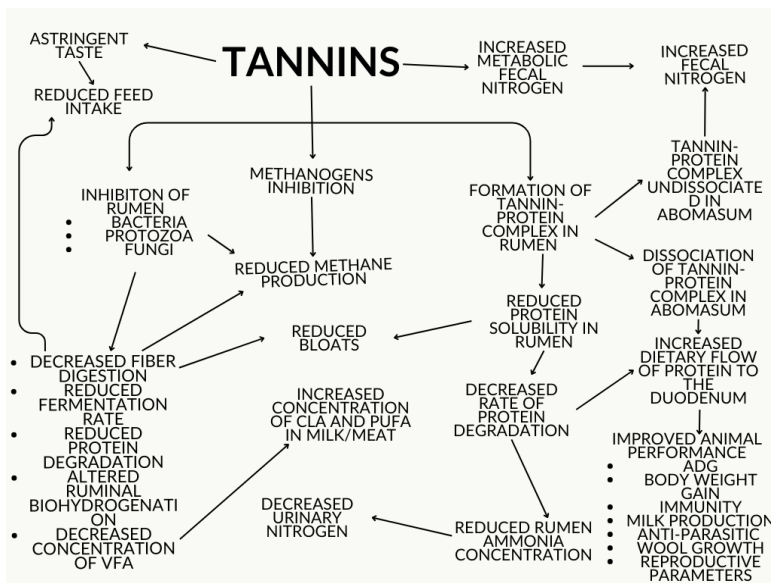


Figure 2. Tannin effects on ruminant performance

Experimental studies also show that chestnut tannins selectively modulate the rumen microbiota (Sun et al., 2025) and reduce the abundance of *Clostridium sticklandii* and other ammonia-producing species (Jayanegara et al., 2012). At the same time, tannins can reduce protozoan populations, which indirectly promotes bacterial protein synthesis by limiting the predation of rumen bacteria (Mueller-Harvey, 2006; Min et al., 2003).

These effects are strongly influenced by the type of tannins, the dosage and the overall context of the diet. However, excessive addition may impair fibre

digestion by inhibiting fibrolytic species such as *Ruminococcus albus*, as demonstrated in vitro and in vivo (Waghorn, 2008).

The efficacy of tannins also seems to depend on the adaptation of the rumen. Some studies report microbial tolerance or adaptation to moderate levels of tannin over time, suggesting that gradual inclusion of feedstuffs and monitoring of rumen parameters are key to optimizing benefits without compromising digestibility (Bueno et al., 2020). Therefore, understanding the nuanced interactions of tannins in the rumen is crucial for their effective and safe use in ruminant diets.

Effects on nutrient digestibility

Chestnut tannins affect digestibility results in a dose- and diet-dependent manner. Moderate use (up to ~20 g/kg DM) in lamb diets has been shown to reduce crude protein degradation in the rumen while increasing nitrogen fixation and overall protein efficiency (Mkhize et al. 2018; Sun et al., 2025). Some reduction in dry matter and organic matter digestibility may occur, especially at higher doses or in rations that already contain a low proportion of fermentable energy (Taghizadeh and Besharati, 2011).

In trials where lambs were fed diets deficient in metabolizable protein, supplementation with chestnut HT improved the apparent digestibility of ether extract and tended to stabilize nutrient utilization (Cekić et al., 2022). Also, fibre digestibility was maintained, supporting the idea that controlled HT levels are compatible with normal rumen function.

Although tannin supplementation may slightly reduce apparent digestibility of dry matter and crude protein, particularly at higher doses, these effects are often offset by gains in nutrient retention and utilization efficiency (Deaville et al., 2010a; Mezzomo et al., 2016).

Effects on protein utilization

Experimental studies show that tannins can improve the efficiency of nitrogen utilization in lambs by lowering rumen ammonia concentrations and improving the flow of undegraded dietary protein (Dentinho et al., 2014). At levels between 10 and 20 g/kg DM in low-protein rations, chestnut tannins increased nitrogen fixation and decreased blood urea concentrations, indicating improved post-ruminal nitrogen utilization (Deaville et al. 2010b; Ahmed et al., 2025). These results support the hypothesis that moderate tannin supplementation improves the

synchrony between rumen degradable protein and fermentable energy, allowing for greater microbial protein synthesis and more efficient nitrogen utilization.

In conditions of protein deficit, chestnut tannins improve the apparent digestibility of ether extract and may enhance microbial efficiency. The net outcome depends on the balance between protective protein binding and potential inhibitory effects on fibre digestion and enzyme activity (Barbehenn and Constabel, 2011). In a 60-day lamb fattening study, the group receiving 18.87 g/kg DM chestnut tannins had the highest protein efficiency (PER) and nitrogen conversion efficiency, despite lower metabolizable protein levels in the diet (Cekic et al., 2024). These lambs had more efficient incorporation of dietary nitrogen into body tissues, which was reflected in higher average daily gains and serum protein concentrations in the physiological range.

These effects appear to be particularly relevant in practice, as they offer the possibility of lowering total protein levels while maintaining performance. However, the effectiveness of chestnut tannins in improving nitrogen utilization depends on several factors, including the composition of the forage, the energy-to-protein ratio and the form and purity of the tannin source used. In trials with Farmatan Plus®, the bioactive profile of the extract was consistent, highlighting the link between standardization and efficacy in animal performance outcomes (Cekić et al., 2022; Cekic et al., 2024).

The influence of chestnut tannins on nitrogen metabolism is further supported by the reduction of nitrogen excretion in faeces and urine, which is consistent with the formation of tannin-protein complexes that are resistant to microbial degradation but can be dissociated in the acidic post ruminal environment (Deaville et al., 2010a). This mechanism facilitates the shift of nitrogen digestion from the rumen to the post-rumen, improving amino acid absorption in the small intestine and reducing nitrogen excretion.

Several studies have reported positive effects on growth and feed conversion in lambs following the administration of chestnut tannin. In a trial with MIS breed lambs, Farmatan Plus® was added at a dosage of 0, 9.46 and 18.87 g/kg DM to isocaloric and iso-nitrogenous feeds with a deficiency of metabolizable protein. During a 60-day fattening period, the lambs in the group with the highest tannin content showed significantly higher average daily weight gains (228 g/day), improved feed conversion rates (4.4) and increased protein efficiency rates (Cekić et al., 2022).

Influence on animal performance

Chestnut tannins, especially those derived from *Castanea sativa* and formulated in standardized extracts have shown significant potential to improve

growth performance and feed conversion in lambs, especially when diets are deficient in metabolizable protein. When chestnut tannins at 18.87 g/kg DM are added to such protein-limited diets, average daily gain (ADG) increases significantly to 228 g/day, feed conversion ratio (FCR) improves to 4.4 and both protein efficiency (PER) and Kleiber ratio increased, indicating better growth in relation to metabolic body weight (Cekic et al., 2024).

Chestnut tannins, when supplemented within recommended limits, do not impair dry matter intake and can improve growth parameters. In lambs fed rations deficient in metabolizable protein, supplementation with 20 g/kg DM chestnut tannins resulted in significantly higher average daily gain (228 g/day), improved feed conversion ratio (4.4 kg DM/kg BW gain), and elevated Kleiber ratio and protein efficiency ratios (Rivera-Mendez et al., 2017). These improvements are attributed to the improved synchronization of energy and protein supply in the post-ruminal tract and enhanced nutrient absorption.

These improvements are primarily attributed to improved post ruminal protein availability (Qi et al., 2022). The hydrolyzable tannins of chestnut (HT) form reversible complexes with dietary proteins at rumen pH and protect them from extensive microbial degradation (Gao et al., 2024). As these complexes dissociate under the acidic conditions of the abomasum and small intestine, amino acids become available for absorption, leading to more efficient nitrogen utilization and lean tissue build-up. Improved synchronization between available nitrogen and energy after rumination also supports optimal microbial and animal growth (Valenti et al., 2018).

In addition, studies confirm that moderate tannin intake does not affect dry matter intake (DMI), which is a crucial factor for maintaining growth in lambs (Baraza et al., 2005). These results are consistent with previous observations where CT from sainfoin and coltsfoot improved growth performance under grazing conditions (Barry et al., 2001; Min et al., 2003), providing further evidence that moderate levels of tannin can be beneficial in different feeding systems.

The presence of specific compounds such as vescalagin and castalagin— - major components of chestnut tannins— - was associated with improved rumen modulation, antimicrobial effects and better nutrient uptake, supporting the biological plausibility of the observed performance improvements (Furlan et al., 2011; Comandini et al., 2012).

These results support the strategic inclusion of chestnut tannins in lamb fattening systems, especially when nutrients are deficient. They also provide compelling arguments for further on-farm evaluations, particularly with regard to breed, production conditions and long-term results (Mueller-Harvey, 2006; Bueno et al., 2020).

Effects on health and metabolic parameters

Tannins have long been considered antinutritional or even toxic due to their adverse effects on feed intake, protein and mineral digestibility, and their potential to cause gastrointestinal irritation, hepatic and renal lesions, and in extreme cases, death (Decandia et al., 2011; Jeronimo et al., 2016). Their toxicity depends on dose, molecular weight, and adaptation of rumen microbiota, with hydrolyzable tannins being especially harmful if animals are not properly adapted (Chung et al., 1998; Jeronimo et al., 2016). Nevertheless, Sharma et al. (2019) concluded that moderate levels (up to 15,000 mg/kg for ruminants) are generally safe, though effects depend not only on tannin content but also on source, chemical form, interactions, and diet composition. In the numerous studies, inclusion of chestnut tannins in the diet of lambs has been shown to be metabolically safe and functionally beneficial under controlled conditions (Buccioni et al. 2017; Frutos et al., 2004b; Zimmer i Cordesse, 1996; de S. Costa et al., 2020; Min et al., 2019).

These results are critical given the well-documented concerns regarding tannin toxicity at high doses (Reed, 1995). The favourable metabolic profile observed with HT from chestnut supports its use in moderate amounts, especially in low-protein diets. In particular, serum urea concentrations were significantly lower in lambs receiving tannin, suggesting reduced rumen ammonia production and improved nitrogen retention — a result associated with improved protein utilization efficiency.

In addition to maintaining systemic health, chestnut tannins may also contribute to cell protection through their polyphenolic antioxidant effects. Compounds such as gallic acid and ellagic acid, which are abundant in *Castanea sativa*, exhibit strong free radical scavenging properties *in vitro*, and their inclusion in the diet could help to mitigate oxidative stress in intensively reared lambs (Furlan et al., 2011; Comandini et al., 2012). Although the direct antioxidant effect *in vivo* in lambs is still poorly understood, the correlation between reduced oxidative markers and tannin supplementation in other livestock species supports this hypothesis.

Furthermore, the antimicrobial and anti-inflammatory properties of chestnut tannins could provide additional benefits for gut health and immune modulation. These effects could be mediated in part by reduced exposure to rumen and intestinal pathogens, as has been observed with other tannin-rich feeds (Mueller-Harvey, 2006; Jeronimo et al., 2016). Although direct evidence in lambs is still limited, the observed improvement in performance indices without signs of metabolic disorders suggests an overall health-promoting effect.

Taken together, these results suggest that chestnut tannins, when used in nutritionally relevant amounts, do not pose a health risk and may provide metabolic

and immunological benefits in small ruminant production. However, further studies are needed to explore the long-term effects, especially under different physiological conditions such as gestation, lactation or disease susceptibility.

Practical applications, sustainability and considerations for implementation

Improved protein efficiency through chestnut tannin supplementation leads to reduced nitrogen losses via urine and faeces, thereby lowering ammonia volatilization and nitrate leaching (Ali et al., 2017). Additionally, these tannins selectively suppress methanogenic archaea in the rumen, resulting in lower methane emissions (Valenti et al., 2020; Jeronimo et al., 2016). Together, these effects enhance the environmental sustainability of lamb production and support circular bioeconomy principles by integrating plant-derived by-products into feed systems (Vasta et al., 2019).

The underlying mechanism involves the formation of reversible tannin-protein complexes in the rumen, which reduce ammonia release and increase amino acid availability in the small intestine. This protein-sparing effect enables reduced dietary crude protein input without compromising animal performance, offering both nutritional and ecological advantages. Chestnut tannins, sourced from wood-processing residues, thus represent a sustainable feed additive aligned with both productivity and environmental goals.

Nonetheless, the efficacy and safety of tannins depend on multiple factors. HT, like those in chestnut, differ from CT in chemical structure and post-ruminal bioavailability. Appropriate dosing—typically within the 10–20 g/kg DM range—is critical, as excessive levels may impair dry matter intake and digestibility. The dietary matrix, along with animal-specific traits such as age, physiological status, and adaptation period, further modulate the response to tannins.

Despite demonstrated benefits, on-farm implementation remains limited. Challenges include inconsistent product labelling, variability in extract composition, and insufficient farmer knowledge regarding tannin-protein interactions. Although tannins may reduce feed protein costs and nitrogen losses, their economic viability depends on the balance between tannin products price and performance outcomes. For successful adoption, clear supplementation guidelines and technical advisory support are essential.

Future research should focus on long-term field trials evaluating reproductive traits, product quality, and environmental impacts. Integrating rumen microbiome and metabolomic analyses will provide deeper insights into host-tannin interactions. Standardizing methods for tannin quantification and bioactivity

will enhance comparability between studies and support the development of precision supplementation tools tailored to specific production conditions.

Conclusion

Chestnut tannins represent a valuable strategy to improve protein utilization, growth performance and nitrogen efficiency in lamb production. Their reversible binding to dietary proteins helps to protect amino acids from degradation in the rumen and promote post-rumen absorption. Experimental evidence confirms improved nitrogen retention and growth on low protein diets when chestnut tannins are added in moderate amounts.

In addition to the nutritional benefits, chestnut tannins contribute to environmental sustainability by reducing urinary nitrogen excretion and methane emissions. Their extraction from wood processing by-products also strengthens their compatibility with circular bioeconomy models.

In practical application, however, careful attention must be paid to dosage, standardization of extracts and feed formulation. Variations in response due to animal factors and feed composition must be taken into account to avoid negative effects on intake or digestibility. When used correctly, chestnut tannins offer a promising route to more resilient and sustainable systems for small ruminants.

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Conflict of interest

The authors declare no conflict of interest.

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