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Willow silage as a nutritional feed resource for small ruminants

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Abstract

Feed scarcity, rising concentrate costs, and the environmental footprint of ruminant livestock are driving renewed interest in alternative, non-conventional forages for small ruminant production. Willow (*Salix* spp.), a fast-growing, multipurpose woody species traditionally cultivated for bioenergy, soil stabilization, and agroforestry, has re-emerged as a candidate feedstuff for sheep and goats owing to its high foliar crude protein content, favorable mineral profile, and a distinctive suite of bioactive plant secondary metabolites, principally condensed tannins (CTs) and salicylate-derived phenolics (salicinoids). Ensiling offers a practical route for converting seasonally abundant willow biomass into a storable, year-round feed. This review synthesizes current evidence on the agronomic characteristics of willow, the fermentation dynamics and nutritive value of willow silage, and the physiological and productive consequences of feeding willow silage to sheep and goats, including effects on rumen fermentation, nitrogen utilization, and intake, digestibility, growth, carcass, and milk performance. Ensiling preserves the macronutrient value of willow fodder while substantially transforming its phenolic profile, notably de-glycosylating salicin to salicylic and acetylsalicylic acid and depleting flavan-3-ol monomers. Moderate dietary inclusion (approximately 15-20% of dry matter) appears compatible with maintained intake, digestibility, and milk yield in goats and ewes, while higher condensed tannin doses can depress fiber and protein digestibility. In fattening Awassi lambs, willow silage can replace wheat straw as the sole roughage source without impairing intake or growth, while favorably shifting carcass fat partitioning and improving meat tenderness. Willow-derived condensed tannins also show consistent potential to reduce ruminal ammonia and shift nitrogen excretion from urine to faeces, positioning willow silage as a multifunctional feed with nutritional and environmental value. Gaps remain regarding standardized ensiling protocols, genotype- and season-dependent tannin variability, and long-term health and reproductive outcomes in dairy sheep. Willow silage represents a scientifically promising, though not yet fully validated, component of sustainable small ruminant feeding systems.

Keywords: Willow silage, small ruminants, forage conservation, ruminant nutrition

1. Introduction

Small ruminant production systems worldwide are increasingly constrained by seasonal forage shortages, competition between livestock feed and human food crops (Mottet *et al.*, 2017) ^[7], and mounting pressure to reduce the environmental footprint of livestock, particularly enteric methane and reactive nitrogen losses (Gerber *et al.*, 2013) ^[4]. Silage-making from grasses, legumes, and crop residues remains the principal strategy for buffering feed availability across seasons, but conventional silage crops are themselves vulnerable to drought and require arable land that increasingly competes with food production. Against this backdrop, non-conventional and "alternative" forages including crop residues, agro-industrial by-products, and browse from trees and shrubs have attracted growing research interest as resilient, climate-adapted feed resources for sheep and goats (Ben Salem & Smith, 2008) ^[2].

Willow (*Salix* spp.) is among the most extensively studied of these alternative woody forages. Willows are fast-growing, coppicing trees widely planted for bioenergy, phytoremediation, riparian buffering, and soil conservation, and their foliage is increasingly recognized as a nutritionally valuable and functionally bioactive livestock feed. Willow leaves and fine stems combine a crude protein concentration that can exceed 18-22% of dry matter with a rich

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profile of plant secondary metabolites principally condensed tannins and salicylate-derived phenolic glycosides (salicinoids) that are largely absent from conventional temperate forages (Landau *et al.*, 2018; Thompson *et al.*, 2025b) ^[6, 10].

Because willow is typically available as a seasonal browse or coppice harvest, ensiling provides a practical mechanism for converting this biomass into a stable, storable feed that can be offered to small ruminants year-round, in the same manner as grass or legume silage (Muklada *et al.*, 2021) ^[8]. However, the ensiling process itself substantially alters the phenolic chemistry of willow fodder, with consequences for its nutraceutical and anthelmintic properties that are only beginning to be characterized (Muklada *et al.*, 2021; Yan Landau *et al.*, 2023) ^[6, 8]. This review integrates recent research on the botanical and nutritional characteristics of willow, the fermentation and preservation of willow silage, and the physiological, health, and productive responses of sheep and goats to willow silage feeding, with a view to evaluating its potential as a scientifically grounded and sustainable feed resource for small ruminant systems.

2. Nutritional Characteristics of Willow

2.1 Nutritive composition

Across studies, willow fodder is characterized by a moderate-to-high crude protein content (approximately 130-220 g/kg DM, with leaf-only fractions higher in protein than mixed leaf-and-stem material), moderate fiber concentrations, and metabolisable energy values broadly comparable to average-quality grass forage (Diaz Lira *et al.*, 2008; Landau *et al.*, 2018) ^[3, 6]. Willow foliage also supplies appreciable concentrations of calcium and other minerals, while heavy-metal contamination remains below regulatory thresholds even when willow is irrigated with treated wastewater (Landau *et al.*, 2018) ^[6]. However, *in vitro* organic matter digestibility of willow fodder and silage is often lower than that of grass silage, reflecting both the lignified stem fraction and the anti-nutritional binding action of condensed tannins on cell-wall and protein digestion (Thompson *et al.*, 2025a) ^[9].

2.2 Bioactive plant secondary metabolites

The nutritional distinctiveness of willow lies less in its proximate composition than in its phenolic chemistry. Willow foliage contains condensed tannins (proanthocyanidins) composed of procyanidin and prodelphinidin subunits, with the ratio and mean degree of polymerization varying substantially between willow varieties and genotypes; some cultivars contain condensed tannin concentrations exceeding 1% of dietary dry matter when included at moderate inclusion rates, while others contain negligible amounts, underscoring the importance of variety selection in willow fodder programmes (Thompson *et al.*, 2025b, 2025c) ^[10-11]. In addition to condensed tannins, willow is a natural source of salicinoids phenolic glycosides including salicin which are metabolic precursors of salicylic acid and, following further transformation, acetylsalicylic acid, an aspirin-like compound (Muklada *et al.*, 2021) ^[8]. Willow leaves also contain flavonoids such as catechin, galliccatechin, epicatechin, hyperin, and rutin, contributing to the antioxidant capacity of the forage (Muklada *et al.*, 2021; Haj-Zaroubi *et al.*, 2024) ^[8, 5].

3. Ensiling of Willow Fodder: Fermentation Characteristics and Silage Quality

Ensiling willow fodder is agronomically and microbiologically feasible, but presents specific challenges

related to its relatively low moisture-buffering capacity, woody stem fraction, and phenolic content, which can inhibit epiphytic lactic acid bacteria (Muklada *et al.*, 2021) ^[8]. Laboratory-scale ensiling trials indicate that willow fodder can reach a stable pH near 4.2 when supplemented with lactic acid bacteria (LAB) inoculants, with *Lactobacillus plantarum* becoming the dominant *Lactobacillus* species after approximately 30 days of fermentation; un-supplemented willow silage tends to stabilize at a higher pH (approximately 5.1-5.8), reflecting the relatively high native soluble-sugar content of willow fodder (which can exceed 100 g/kg DM) but comparatively weaker buffering of undesirable fermentation (Muklada *et al.*, 2021) ^[8]. Molasses supplementation has been shown to lower neutral and acid detergent fiber content relative to unsupplemented silage without depressing *in vitro* dry matter digestibility (Muklada *et al.*, 2021) ^[8].

Importantly, the principal proximate nutritional attributes of willow fodder crude protein, fiber fractions, and *in vitro* digestibility appear to be largely unaffected by ensiling itself, indicating that the conservation process does not compromise the basic feeding value of the forage (Muklada *et al.*, 2021) ^[8]. What ensiling does substantially alter is the phenolic and specialized-metabolite profile of willow. Under anaerobic fermentation, the salicinoid salicin undergoes extensive de-glycosylation (up to approximately 74%), accompanied by a marked increase in salicylic acid concentration and the appearance of acetylsalicylic acid; the flavonol glycosides hyperin and rutin are similarly de-glycosylated, and flavan-3-ol monomers such as catechin, galliccatechin, and epicatechin can be almost completely metabolized during fermentation (Muklada *et al.*, 2021) ^[8]. These transformations mean that willow silage is chemically distinct from fresh willow fodder, with potential consequences as yet incompletely understood for its nutraceutical and anthelmintic value, since aglycone and glycosylated forms of these compounds differ in bioavailability and bioactivity (Muklada *et al.*, 2021; Yan Landau *et al.*, 2023) ^[8, 12].

4. Rumen Fermentation, Nutrient Digestibility, and Nitrogen Metabolism

Because condensed tannins bind to dietary and microbial proteins in the rumen, protecting them from ruminal degradation, willow inclusion in ruminant diets has direct consequences for nitrogen metabolism. Controlled feeding studies in ewe hoggets comparing grass silage with grass silage diets containing 20-21% dietary dry matter as willow leaves from contrasting varieties have demonstrated that condensed tannin structure not merely concentration determines the nutritional outcome (Thompson *et al.*, 2025a, 2025b) ^[9, 10]. A willow variety with a higher condensed tannin inclusion (approximately 1.1% of dietary DM) reduced the apparent digestibility of energy, fiber, and crude protein relative to a control grass silage diet and to a lower-tannin willow variety (approximately 0.1% of dietary DM), while simultaneously shifting nitrogen excretion from urine toward faeces (Thompson *et al.*, 2025a) ^[9]. This shift is nutritionally and environmentally significant: faecal nitrogen is less prone to ammonia volatilization and nitrous oxide formation than urinary urea-nitrogen, suggesting that appropriately selected willow varieties could reduce the environmental nitrogen footprint of sheep production even where digestibility is modestly reduced (Thompson *et al.*, 2025a) ^[9].

Complementary metabolomics and microbiome analyses in the same experimental system indicate that willow condensed tannins alter rumen microbial populations and metabolomics profiles in ways consistent with reduced proteolysis and altered fermentation pathways, reinforcing the mechanistic link between willow tannin structure (procyanidin: prodelphinidin ratio, mean degree of polymerization) and its physiological effects (Thompson *et al.*, 2025b) ^[10]. These findings collectively suggest that the nutritional and environmental value of willow silage cannot be generalized across the genus *Salix*, and that variety-specific evaluation is a prerequisite for its rational use in small ruminant diets (Thompson *et al.*, 2025a, 2025b) ^[9, 10].

5. Effects on Intake, Digestibility, Growth, and Milk Performance

Direct feeding studies with willow silage in dairy goats provide the most relevant evidence for its practical use as a small ruminant feed. In a cross-over trial, lactating Damascus goats offered a diet in which willow silage (from *Salix acmophylla* irrigated with saline water) replaced part of the hay ration, representing approximately 20% of total dry matter intake, showed no significant reduction in milk yield or gross milk composition relative to an all-hay control diet (Yan Landau *et al.*, 2023) ^[12]. Goats fed willow silage exhibited lower milk urea content consistent with the nitrogen-protective action of condensed tannins together with higher concentrations of plant phenolic derivatives and greater antioxidative capacity in milk, while none of the major feed flavonoids were detected as intact compounds in milk (Yan Landau *et al.*, 2023) ^[12]. These results indicate that, at moderate inclusion levels, willow silage produced even from marginal, saline-irrigated land can serve as a nutritionally safe supplement for dairy goats without compromising productivity (Yan Landau *et al.*, 2023) ^[12], building on earlier evidence that willow fodder irrigated with treated wastewater is a viable feed crop for dairy goats more broadly (Landau *et al.*, 2018) ^[6].

Broader digestibility evidence from willow-based diets in ewe hoggets has found that higher-tannin willow varieties depress dry matter, fiber, and protein digestibility relative to grass silage controls (Thompson *et al.*, 2025a) ^[9]. Taken together, the performance evidence suggests a threshold or dose-dependent relationship: moderate willow or willow silage inclusion (approximately 15-20% of dietary DM) appears compatible with maintained intake and productivity in goats (Yan Landau *et al.*, 2023) ^[12], whereas higher inclusion rates or higher-tannin varieties can measurably depress nutrient digestibility (Thompson *et al.*, 2025a) ^[9], underscoring the importance of matching willow variety and inclusion rate to production objectives.

Evidence in growing and fattening sheep further supports the practical viability of willow silage as a roughage source. In a 90-day fattening trial with weaned Awassi lambs, wastewater-irrigated willow silage replaced wheat straw at 0, 10, and 20% of dietary dry matter constituting the sole roughage source at the highest inclusion level within iso-caloric, iso-nitrogenous high-concentrate diets; feeding willow silage did not affect dry matter, crude protein, NDF, or ADF intake, average daily gain, or feed-to-gain ratio, and hot and cold carcass weights, dressing percentage, and internal organ weights were unaffected (Awabdeh *et al.*, 2022) ^[1]. Willow silage inclusion did, however, alter carcass fat partitioning, with less non-consumable mesenteric and kidney fat but more valuable tail fat deposited in lambs fed willow silage, and was associated

with lower shear-force values and improved tenderness scores in the Longissimus dorsi, albeit alongside smaller loin cuts and lighter L. dorsi muscles (Awabdeh *et al.*, 2022) ^[1]. These findings indicate that willow silage can substitute for a conventional roughage source such as wheat straw in intensive lamb fattening systems without compromising growth performance, entailing a trade-off between improved carcass fat deposition patterns and meat tenderness on one hand and smaller high-value muscle cuts on the other.

6. Research Gaps and Future Directions

Despite encouraging findings, several gaps constrain the translation of willow silage research into confident on-farm recommendations for small ruminants. First, condensed tannin concentration and structure vary substantially among willow species, genotypes, and even between growing seasons and irrigation regimes, yet relatively few studies have systematically linked genotype-specific tannin chemistry to silage fermentation outcomes and animal response, limiting the ability to recommend specific cultivars for ensiling (Thompson *et al.*, 2025b, 2025c) ^[10-11]. Second, most *in vivo* performance data in small ruminants derive from goats or from sheep fed fresh willow browse or fodder blocks rather than willow silage per se (Diaz Lira *et al.*, 2008; Yan Landau *et al.*, 2023) ^[3, 12], although a recent fattening trial in Awassi lambs indicates that willow silage itself is well tolerated as a sole roughage source in growing sheep (Awabdeh *et al.*, 2022) ^[1]; dedicated feeding trials evaluating willow silage specifically in pregnant and lactating ewes and dairy sheep are still needed to confirm whether the favorable outcomes observed in goats and fattening lambs extend across the full physiological range of small ruminant production. Third, the long-term consequences of chronic salicylate and condensed tannin intake on reproductive performance, mineral and vitamin status, and product quality warrant further investigation, particularly given the aspirin-like pharmacological activity of salicylate metabolites generated during ensiling (Muklada *et al.*, 2021) ^[8]. Finally, optimization of ensiling protocols including additive selection, moisture management, and particle size reduction to lower wood content merits further agronomic and fermentation research to standardize willow silage quality across production settings (Muklada *et al.*, 2021) ^[8].

7. Conclusion

Willow (*Salix* spp.) silage combines a nutritionally respectable protein and mineral profile (Landau *et al.*, 2018) ^[6] with a distinctive suite of bioactive condensed tannins and salicylate-derived phenolics that together confer nutritional and potential environmental benefits beyond those of conventional forage silages. Ensiling is technically feasible and preserves the core nutritive value of willow fodder while substantially reshaping its phenolic chemistry, generating salicylate metabolites and depleting certain flavan-3-ol monomers (Muklada *et al.*, 2021) ^[8]. Evidence from dairy goats indicates that moderate inclusion of willow silage does not compromise milk yield or composition and confers favorable nitrogen and antioxidant profiles (Yan Landau *et al.*, 2023) ^[12], while evidence from fattening Awassi lambs shows that willow silage can fully replace wheat straw as a roughage source without impairing intake or growth performance, while improving carcass fat partitioning and meat tenderness (Awabdeh *et al.*, 2022) ^[1]. At the same time, higher-tannin willow varieties and higher inclusion rates can depress digestibility (Thompson *et al.*, 2025a) ^[9], and the

transfer and safety implications of salicylate metabolites in milk and meat remain incompletely characterized. On present evidence, willow silage merits recognition as a promising, multifunctional, and locally resilient feed resource for small ruminants, best deployed at moderate inclusion levels, with variety selection and ensiling protocol treated as key determinants of its nutritional and functional value. Further targeted research in sheep, particularly dairy sheep, is needed before evidence-based inclusion guidelines can be established for commercial practice.

References

1. Awabdeh S, Sweidan R, Landau SY. Growth performance and carcass characteristics of fattening Awassi lambs fed willow silage. *Small Rumin Res.* 2022;215:106758.
2. Ben Salem H, Smith T. Feeding strategies to increase small ruminant production in dry environments. *Small Rumin Res.* 2008;77(1-3):174-194.
3. Diaz Lira CM, Barry TN, Pomroy WE, McWilliam EL, López-Villalobos N. Willow (*Salix* spp.) fodder blocks for growth and sustainable management of internal parasites in grazing lambs. *Anim Feed Sci Technol.* 2008;141(1-2):61-81.
4. Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, *et al.* Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities. Rome: Food and Agriculture Organization of the United Nations; 2013.
5. Haj-Zaroubi M, Mattar N, Awabdeh S, Sweidan R, Markovics A, Klein JD, *et al.* Willow (*Salix acmophylla* Boiss.) leaf and branch extracts inhibit *in vitro* sporulation of coccidia (*Eimeria* spp.) from goats. *Agriculture.* 2024;14(5):648.
6. Landau SY, Muklada H, Deutch T, Ungar ED, Dvash L, Perevolotsky A, *et al.* Initial evaluation of willow (*Salix acmophylla*) irrigated with treated wastewater as a fodder crop for dairy goats. *Small Rumin Res.* 2018;163:76-83.
7. Mottet A, de Haan C, Falcucci A, Tempio G, Opio C, Gerber P. Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. *Glob Food Secur.* 2017;14:1-8.
8. Muklada H, Davidovich-Rikanati R, Awabdeh S, Weinberg ZG, Hen Y, Deutch T, *et al.* Ensiling willow (*Salix acmophylla*) fodder modifies the contents of plant specialized metabolites, but not nutritional attributes. *Anim Feed Sci Technol.* 2021;278:115019.
9. Thompson JP, Cristobal-Carballo O, Yan T, Zeller WE, Huws S, Safo L, *et al.* Supplementation with willow containing condensed tannins shifted nitrogen excretion from urine to faeces in yearling ewes. *Animal.* 2025;101698.
10. Thompson JP, Cristobal-Carballo O, Yan T, Lawther K, Dimonaco NJ, Zeller WE, *et al.* Unlocking the potential of willow condensed tannins: Effects on rumen fermentation, microbiome, and metabolome for sustainable ruminant nutrition. *Anim Microbiome.* 2025;7:71.
11. Thompson JP, Stergiadis S, Cristobal Carballo O, Zeller WE, Yan T, Lively F, *et al.* Willow silvopastoral systems as a strategy to reduce methane emissions while maintaining cattle performance. *Sci Rep.* 2025;15:19310.
12. Yan Landau S, Glasser TA, Zachut M, Klein JD, Davidovich-Rikanati R. Milking performance and plant specialized metabolites in the milk of goats fed silage

from willow (*Salix acmophylla*) irrigated with saline water. *Small Rumin Res.* 2023;221:106952.

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