Recent advances in enteric methane mitigation: insights from a meta-analysis of tannin diets in small ruminants

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Introduction – The challenge
Low-Methane Forages project

- **Role of small ruminants**: Sheep and goats are vital in smallholder systems → food, income, cultural functions; support **>600 million people** worldwide
- **Climate challenge**: Ruminants produce **~32% of anthropogenic methane**, a potent greenhouse gas with **~28× the warming potential of CO_2 over 100 years**
- **Future trend**: Under business-as-usual, livestock methane emissions are expected to **increase with growing demand** for animal products (population growth + 40% increase in income per capita by 2050)
- **Tension**: Must reduce methane emissions **without undermining productivity, food security, or farmer livelihoods**
- **Candidate solution**: **tannin diets** — naturally occurring secondary compounds in forages or extracts that may reduce methane formation in the rumen and represent an **economically affordable option** for farmers

LMF WP3 objectives:

- Generate critical evidence on mitigation potential and productivity impacts
- Identify promising low-methane traits to guide CGIAR genebank screening
- Build foundations for scaling through MRV development and carbon market readiness

Objectives

This meta-analysis aimed to:

Quantify enteric methane (CH_4) mitigation from tannin diets

- Total CH_4 (g/animal/day)
- CH_4 yield (g/kg DMI)

Evaluate animal performance

- Dry matter intake (DMI)
- Average daily gain (ADG)

Assess trade-offs in nutrient utilization

- Digestibility of DM, OM, NDF, ADF

Identify key drivers of variability

- Compound source, diet type, dose, animal class, duration

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Methodology

What we looked at:

- Reviewed 44 studies (1972–2024) on sheep and goats
- Extracted 130 treatment–control comparisons
- Focus: diets with anti-methanogenic compounds (AMCs)

Outcomes evaluated:

- **Methane emissions** (per animal, per kg feed)
- **Animal performance** (feed intake, growth)
- **Digestibility** (how well animals use the feed)

- How we analyzed it
- Compared **treatment vs. control groups**
- **Error terms** converted: SEM → SD
- **Effect size:** Relative mean difference (% of control mean)
- **Variance estimation:** Pooled SD & sample sizes
- **Robust Variance Estimation (RVE):** handled multiple treatments with shared controls
- **Random-effects models** (metafor & robumeta in R) estimated tannin effects & heterogeneity
- **Explanatory variables** centered on means

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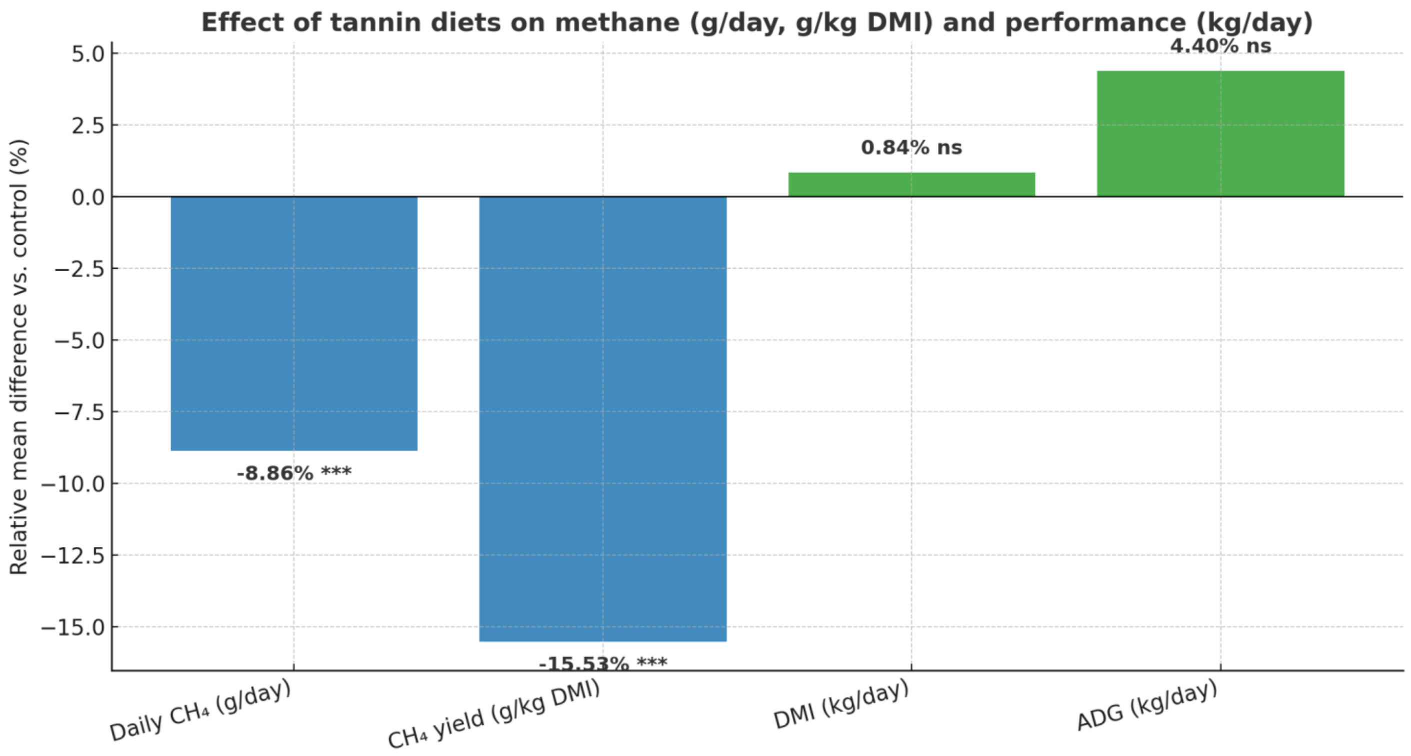
Tannin diets achieved a ~15% reduction in methane emissions, with promising trends toward improved productivity

- **Daily CH_4 (g/day):** −8.9% ± 2.3 (***P*=0.001; df=42.6**)
- **CH_4 yield (g/kg DMI):** −15.3%±1.89 (***P*<0.001; df=31.8**)
- **Dry matter intake (DMI):** +0.84% ±0.82 0.82 (ns; *P*=0.31; df=37.2ns)
- **Average daily gain (ADG):** +4.4% ± 4.38 (ns; *P*=0.32; df=26.00)

Tannins cut methane without hurting intake or growth. But what about feed use efficiency?



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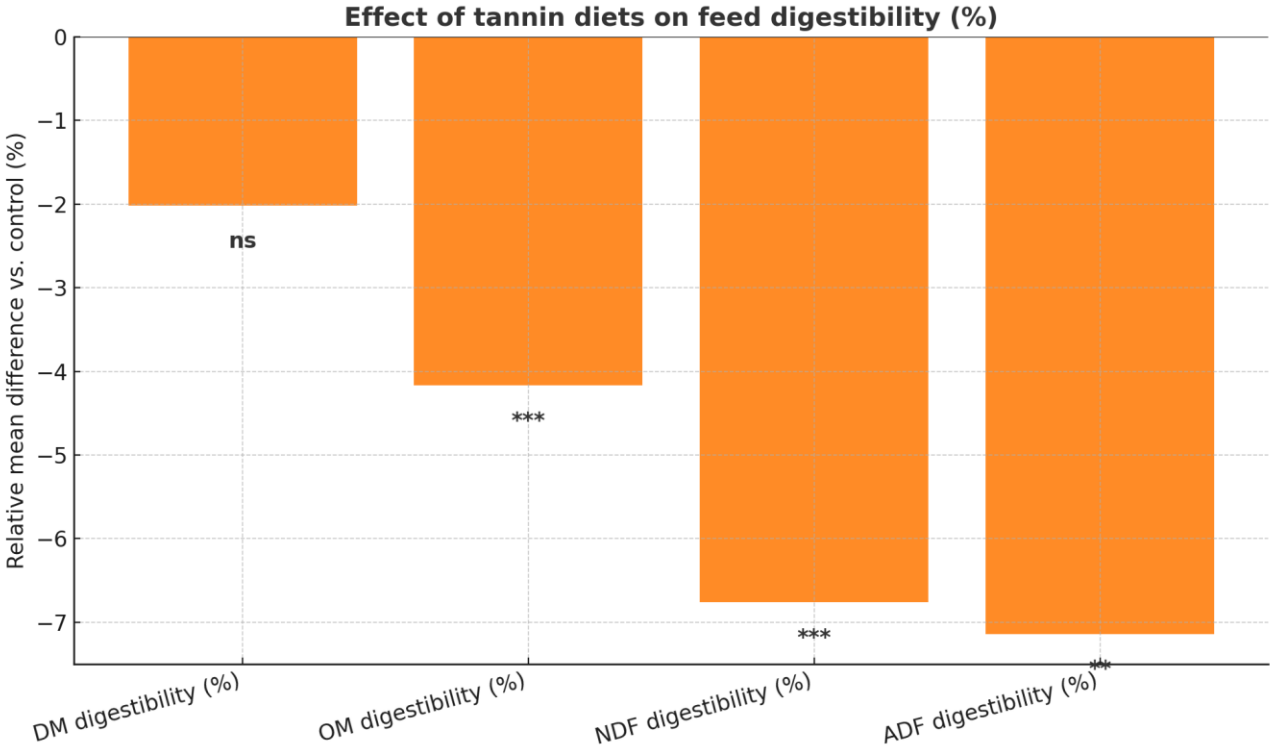
Results: Methane reductions come with 4–7% fiber digestibility losses

This means, slightly less energy from forage — but not enough to reduce intake or growth

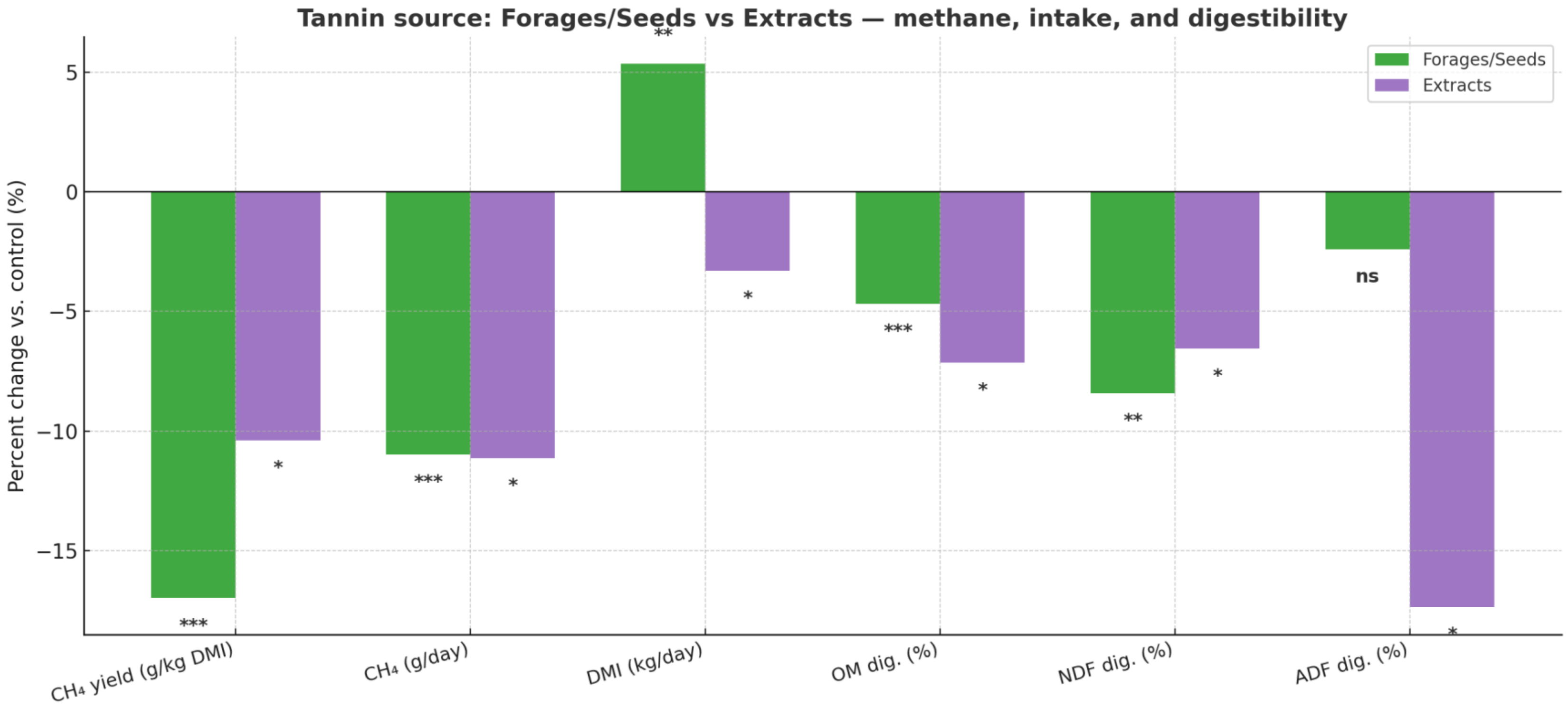
- **Organic matter digestibility (OM):** −4.2% ± 0.87 (***P*=0.001; df=29.88**)
- **Neutral detergent fiber (NDF):** −6.8% ± 1.27 (***P*=0.001; df=22.44**)
- **Acid detergent fiber (ADF):** −7.1% ± 2.59 (***P*=0.001; df=22.48**)
- **Dry matter (DM):** −2.0% ± 1.47 (ns; ***P*=0.18; df=30.82**)



Results: Forages/seeds cut more methane with fewer penalties than extracts

Tannins Source

- **Forages/Seeds** → methane ↓ substantially (*yield and g/day*), animals eat more, smaller digestibility loss
- **Extracts** → methane ↓ a little, animals eat less, bigger digestibility loss
- **Bottom line:** Forages/Seeds = **more effective and safer** option, but tannin concentrations are less controlled than in extracts, meaning their effects can be more variable in practice



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Results: Effects vary by animal class, duration, and measurement method

Animal class

- Both growing and mature animals show CH_4 reductions (~15% yield)
- Both growing and mature animals show CH_4 reductions (~15% yield). ADG data were only available in growing animal studies, so no inference can be made about animal class differences in productivity

Duration

- Longer supplementation does **not** produce stronger reductions
- Effects appear early and remain relatively stable over time

Measurement method

- SF_6 studies report **larger CH_4 reductions** than chambers
- Likely reflects **differences in technique**, not true biological variation

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Discussion

AMC diets reduce methane, but context and trade-offs matter:

- **Consistent mitigation:** Across studies, CH_4 yield reductions ~15% confirm AMCs are effective mitigation tools
- **Productivity maintained:** No significant effect on intake or growth, showing that mitigation is possible without reducing animal performance
- **Main trade-off:** Fiber digestibility decreases (4–7%) → animals extract slightly less energy from forage
- **Source matters:** Forages/seeds perform better than extracts (higher methane reduction, fewer intake/digestibility penalties)
- **Context dependence:** Results are highly variable (I^2 >90%), influenced by diet composition, compound type, and measurement method

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Final considerations

AMC diets are a viable option for small ruminant methane mitigation

Mitigation potential: AMC diets reduce CH_4/day by ~9% and CH_4 yield by ~15% across trials

⚠️ **Key trade-off – costs & digestibility:** Fiber digestibility penalties (4–7%) must be considered, especially in **low-quality forage systems** where energy supply is already limiting

Safe for productivity: Feed intake (DMI) and growth (ADG) remain unchanged on average → mitigation can occur without reducing performance

Best sources: Tannin-rich forages/seeds are more effective and sustainable than commercial extracts, though with less control over tannin concentration

Practical application: Greatest benefits occur when AMCs are integrated into balanced diets **adapted to contextualized conditions**

Choice of methods: Analytical approach (meta-analysis + RVE models) tailored to the scale and complexity of available data, ensuring robust and comparable estimates

Next steps: Extend the analysis to cattle (dairy and beef), providing greater statistical power, enabling cross-species comparisons, and strengthening the upcoming manuscript

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Thank you!

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