

Enhancing Rumen Function for Efficient Utilization of Fibrous Feeds and Methane Abatement from Livestock

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OPEN ACCESS

Keywords

Fibrous feeds; Rumen function; Crop residues; Fibre digestibility; Enteric methane

How to cite this article:

Prasad, V. P., Vaibhav, K. and Maurya, V. 2026. Enhancing Rumen Function for Efficient Utilization of Fibrous Feeds and Methane Abatement from Livestock. *Vigyan Varta* 7 (10): 51-58.

ABSTRACT

Efficient utilization of fibrous agricultural residues is essential for sustainable livestock production, particularly in smallholder production systems where high-quality feeds are limited or expensive. Crop residues generally have low nutritive value because of their low protein and energy concentrations, poor digestibility and lignification of plant cell walls. Various approaches, including physical, chemical and biological treatments, strategic supplementation, complete feed blocks and ration balancing, can improve their feeding value and nutrient utilization. Rumen-modifying strategies such as ionophores, organic acids, exogenous fibrolytic enzymes, direct-fed microbials and plant bioactive compounds have also been investigated for improving rumen function and reducing enteric methane production. This article reviews important nutritional and rumen-based approaches for improving fibrous-feed utilization while reducing methane emission intensity. An integrated approach combining feed treatment, strategic supplementation, ration balancing and appropriate rumen-modifying strategies can support sustainable livestock production.

INTRODUCTION:

The global human population is expected to increase considerably in the coming decades, accompanied by increasing demand for milk and meat, particularly in developing countries. This increase in demand will place greater pressure on livestock production systems to produce animal-derived foods efficiently and sustainably. Crop residues and agricultural by-products will continue to be important components of livestock feeding systems, particularly in developing countries. Efficient utilization of these locally available resources can reduce feed costs and improve the sustainability of livestock production. However, many crop residues have low nutritive value because of their low protein and energy concentrations and poor digestibility (Sarnklong *et al.*, 2010). Agricultural residues obtained from cereals, pulses, oilseed crops, roots, tubers and other crops are abundant sources of fibrous feed. Nevertheless, their utilization is restricted by the complex structure of plant cell walls, particularly the association between lignin, cellulose and hemicellulose. Various physical, chemical and biological treatments have therefore been developed to improve their feeding value (Sarnklong *et al.*, 2010).

Livestock production contributes to greenhouse gas emissions through enteric fermentation, manure management, feed production and land-use-related activities. Among livestock greenhouse gases, methane is particularly important because it is produced during ruminal fermentation and represents a loss of dietary energy from the animal (FAO, 2013). During ruminal fermentation, carbohydrates are degraded by microorganisms to produce volatile fatty acids (VFAs), mainly acetate, propionate and butyrate. Hydrogen and carbon dioxide are also produced during fermentation.

Methanogenic archaea utilize these substrates, particularly hydrogen and carbon dioxide, to form methane. Consequently, manipulation of rumen fermentation and improvement of feed utilization are important approaches for reducing enteric methane production (Hook *et al.*, 2010; FAO, 2013). Methane mitigation should not be considered independently of animal productivity. Strategies that improve feed utilization, animal performance and feed conversion efficiency can reduce methane emissions per unit of milk or meat produced. Therefore, improving rumen function and increasing the efficiency of fibrous-feed utilization can provide both nutritional and environmental benefits.

Importance of Fibrous Feeds

Agricultural residues from cereals, sugarcane, pulses, oilseeds, vegetables, roots and tubers are important roughage resources, particularly in smallholder livestock production systems. Their importance increases during periods of green-fodder scarcity. Cereal straws generally contain relatively low concentrations of protein, energy, minerals and vitamins. However, they contain considerable quantities of structural carbohydrates, particularly cellulose and hemicellulose, which can provide energy to ruminants following microbial degradation. The major limitation to the utilization of these feeds is lignification of the plant cell wall. Lignin restricts microbial access to cellulose and hemicellulose and therefore reduces fibre degradation and digestibility. The nutritive value of crop residues can consequently be improved by physical, chemical or biological treatment (Sarnklong *et al.*, 2010). Sorghum stover is an important roughage resource for dairy animals in several parts of India, including western Maharashtra. Better utilization of such locally available residues can contribute to reduction

in feeding costs and improve the sustainability of dairy production.

Strategies for Improving Fibrous Feed Utilization and Reducing Enteric Methane

Improving the utilization of fibrous feeds and reducing methane production require a combination of nutritional, microbial and feed-management approaches. Major strategies include treatment of crop residues, strategic supplementation, ration balancing, complete feed systems and rumen-modifying feed additives (FAO, 2013).

1. Nutritional Improvement of Crop Residues

The nutritive value of crop residues can be improved through physical, chemical and biological processing.

Physical Processing

Physical methods include chopping, chaffing, grinding, soaking, mechanical threshing, steam treatment and other processing techniques. Reduction in particle size can improve handling and may influence feed intake and utilization. However, excessive grinding should be avoided because adequate physically effective fibre is essential for maintaining normal rumination and rumen function (FAO, 2013). Mechanical processing and threshing can also remove undesirable materials such as soil, stones and other contaminants. Advanced techniques such as steam treatment and irradiation can modify the physical structure of fibrous materials, but their high cost and technical requirements restrict their use under smallholder conditions.

Chemical Treatment

Chemical treatment can disrupt the lignocellulosic structure of crop residues and increase the accessibility of cellulose and hemicellulose to rumen microorganisms. Sodium hydroxide (NaOH) treatment has been

used to improve the utilization of wheat straw. Milling and sodium hydroxide treatment have been shown to influence intake and digestibility of wheat straw in sheep (Alawa & Owen, 1984). Despite its effectiveness, NaOH treatment has practical limitations, including chemical handling, water requirements, treatment cost and environmental concerns. Consequently, its application may be more suitable under controlled conditions than at smallholder farm level.

Urea Ammoniation

Urea ammoniation is an important method for improving the nutritive value of poor-quality crop residues. Urea provides nitrogen, while ammonia generated from urea hydrolysis modifies the lignocellulosic structure and increases the accessibility of structural carbohydrates to rumen microorganisms. Ammoniation can improve nitrogen content, fibre digestibility and feed intake of low-quality roughages (Sundstøl & Owen, 1984; Sarnklong *et al.*, 2010). Recent evidence also supports ammoniation as a practical strategy for improving the nutritive value of low-quality roughages in tropical and semi-arid livestock systems (Idowu *et al.*, 2026). However, adoption may be limited by labour requirements, moisture management, treatment time and the need for airtight storage. Farmer-friendly treatment methods are therefore essential for wider adoption.

Biological Treatment

Biological treatment involves the use of microorganisms capable of degrading lignin or modifying plant cell-wall components. White-rot fungi, including species of *Pleurotus*, have been investigated because of their ligninolytic activity. Biological treatment can improve fibre degradation and digestibility. However, loss of valuable dry matter during fungal growth can reduce the overall efficiency of the treatment. The objective should therefore be

selective degradation of lignin while minimizing the loss of cellulose and hemicellulose (Sarnklong *et al.*, 2010). The use of edible mushroom-producing fungi may provide an additional advantage because mushrooms can be harvested for human consumption and the treated residual material can subsequently be utilized as animal feed.

2. Strategic Supplementation

Strategic supplementation involves providing nutrients that are deficient in poor-quality roughage-based diets. Appropriate supplementation can improve rumen microbial activity, feed intake, fibre digestion and animal productivity. Protein-rich feeds such as oilseed cakes, leguminous fodders, tree leaves and concentrate mixtures can improve the nutritive value of crop-residue-based diets. Balanced supplementation can also improve the efficiency of nutrient utilization and reduce methane emissions per unit of animal product (FAO, 2012).

Tree Leaves

Tree leaves can provide protein, minerals and vitamins and may also contain secondary plant compounds capable of influencing rumen microbial activity. Their inclusion in suitable quantities can improve the nutritional quality of diets based on poor-quality crop residues. However, the presence of tannins and other antinutritional factors should be considered when selecting tree leaves for livestock feeding.

Leguminous Fodders

Leguminous fodders are valuable sources of crude protein, minerals and readily fermentable nutrients. Their inclusion in cereal-straw-based diets can improve the supply of nitrogen to rumen microorganisms and support microbial protein synthesis. Improved synchronization between available nitrogen and fermentable energy is particularly

important for efficient microbial utilization of fibrous feeds.

Oilseed Cakes

Oilseed cakes obtained from soybean, groundnut, sunflower, sesame, mustard, cottonseed and other oilseed crops are important sources of protein and nitrogen. Supplementation of protein-rich oilseed cakes can improve microbial activity and nutrient utilization in animals receiving poor-quality roughages. Such supplementation may therefore provide an economical approach to improving the feeding value of cereal residues.

3. Complete Feed Blocks

Complete feed blocks provide a practical method of incorporating roughages, concentrate ingredients, protein sources, minerals and other supplements into a single feed unit. Densification increases bulk density and facilitates transportation, storage and handling. Complete feed blocks can also provide a more uniform supply of nutrients and reduce feed wastage. Low-quality crop residues can be incorporated with protein-rich ingredients and minerals to produce nutritionally balanced blocks. Feed blocks and multivitamin supplements have particular relevance for livestock maintained on low-quality roughages in developing countries (Hristov *et al.*, 2013).

4. Ration Balancing

Under field conditions, livestock are frequently offered diets based mainly on locally available feed resources without accurately matching nutrient supply with animal requirements. This can result in nutrient deficiencies or excesses and reduce productivity. Ration balancing involves adjusting the quantity and proportion of available feed ingredients according to the requirements of animals for maintenance, growth, production and reproduction.

Balanced feeding can improve milk production, nutrient-use efficiency and economic returns. Importantly, improving animal productivity can reduce methane emissions per unit of milk produced. Ration balancing has been identified as one of the most practical approaches for reducing enteric methane emissions under Indian field conditions (Sherasia & Garg, 2018). Field-level studies in India have also demonstrated reductions in methane emissions following implementation of balanced rations. Therefore, ration balancing can simultaneously improve livestock productivity and reduce the emission intensity of milk production.

5. Feed Additives for Improving Rumen Function

Feed additives can modify rumen microbial populations and fermentation pathways. Several feed additives have been evaluated for their ability to improve feed efficiency and reduce methane production. A meta-analysis of dietary additives and rumen modifiers has demonstrated that the magnitude of methane reduction varies according to the type of additive, diet and animal-production system (Almeida *et al.*, 2021).

Ionophores and Organic Acids

Ionophores such as monensin and lasalocid modify bacterial activity by influencing ion transport across microbial cell membranes. Their use can alter rumen fermentation and generally favour propionate production. Greater propionate formation provides an alternative pathway for hydrogen utilization and may consequently reduce the hydrogen available for methanogenesis (FAO, 2013). Organic acids such as malate and fumarate have also been investigated as rumen fermentation modifiers. Their effects can vary with dose, diet and animal characteristics. Because of concerns regarding antibiotic use

and regulatory restrictions, considerable research has focused on alternative non-antibiotic methane-mitigation strategies.

6. Exogenous Enzymes

Exogenous fibrolytic enzymes have been investigated for their ability to improve the degradation of fibrous feed components. These enzymes may improve fibre degradation, nutrient availability and animal performance. However, their effect on methane production is variable and depends on enzyme type, dose, diet composition and method of application (FAO, 2013). Therefore, fibrolytic enzymes may be useful as part of an integrated feeding strategy, particularly when their use results in improved fibre digestion and feed efficiency.

7. Direct-Fed Microbials

Direct-fed microbials (DFM) are preparations containing live microorganisms that are supplied to animals to influence gastrointestinal and ruminal microbial activity. The yeast *Saccharomyces cerevisiae* has been widely investigated in ruminants. Yeast supplementation may stabilize rumen conditions, support beneficial microbial populations and improve fibre degradation. However, responses in methane production have been inconsistent. The effect depends on yeast strain, supplementation level, diet composition and animal characteristics. Other microorganisms, including species of *Propionibacterium* and *Lactobacillus*, have also been investigated for their potential to modify rumen fermentation. Nitrate-reducing microorganisms have attracted particular interest because nitrate can act as an alternative hydrogen sink and compete with methanogenesis. However, nitrate supplementation requires careful management because nitrite accumulation can cause toxicity (Almeida *et al.*, 2021).

8. Sulphate-Reducing Bacteria

Sulphate-reducing bacteria can compete with methanogens for hydrogen and other reducing equivalents. This provides a theoretical basis for reducing methane production through diversion of hydrogen towards sulphate reduction. However, practical application is limited by the relatively low abundance of suitable organisms under normal ruminal conditions and concerns associated with excessive sulphur intake. Further research is required before this approach can be recommended for routine livestock production.

9. Diversion of Hydrogen towards Acetogenesis

Reductive acetogenesis represents another potential pathway for diverting hydrogen away from methanogenesis. Acetogenic microorganisms use hydrogen and carbon dioxide to produce acetate. The process therefore provides an alternative hydrogen sink and may theoretically reduce methane production. However, methanogens generally have a competitive advantage in the rumen. Consequently, establishment and maintenance of acetogenic populations under normal ruminal conditions remain major challenges.

10. Plant Bioactive Compounds

Plant-derived bioactive compounds have received considerable attention as natural approaches for modifying rumen fermentation and reducing methane emissions. Important groups include condensed tannins, saponins and essential oils. These compounds may influence methanogens, protozoa and other rumen microorganisms, although their effects vary considerably according to plant source, concentration and diet (FAO, 2013).

Tannins

Tannins may reduce methane production through direct effects on rumen

microorganisms as well as indirect effects on feed degradation and hydrogen availability. Moderate concentrations may be beneficial, whereas excessive tannin intake can reduce feed intake, protein utilization and fibre digestion. Therefore, appropriate sources and inclusion levels are important.

Saponins

Saponins have been studied mainly for their effects on ruminal protozoa. Reduction in protozoal populations can alter interactions between protozoa, bacteria and methanogens and may influence methane production. However, ruminal microorganisms may adapt to saponins with prolonged exposure, which can reduce their effectiveness.

Essential Oils

Essential oils contain biologically active compounds that can influence ruminal microbial populations and fermentation pathways. They have therefore been investigated as potential alternatives to conventional antimethanogenic additives. Cinnamaldehyde and other plant-derived compounds have demonstrated antimethanogenic activity under experimental conditions. However, excessive concentrations may suppress desirable microbial activity and fibre degradation. Recent reviews emphasize that antimethanogenic feed additives should be evaluated not only for methane reduction but also for their effects on rumen fermentation, fibre digestion, animal productivity and product quality (Durmie *et al.*, 2025).

CONCLUSION

Efficient utilization of fibrous agricultural residues is essential for sustainable livestock production, particularly in smallholder production systems where high-quality feeds may be limited or expensive. The low nutritive value of many crop residues can be improved through physical, chemical and biological

treatments. Strategic supplementation with protein-rich feeds, leguminous fodders, tree leaves and oilseed cakes can further improve rumen microbial activity and nutrient utilization. Ration balancing is one of the most practical approaches for improving productivity and reducing methane emissions per unit of animal product under Indian conditions. Complete feed blocks and other densified feeding systems can further facilitate the efficient utilization of locally available fibrous materials. Rumen-modifying approaches, including ionophores, organic acids, fibrolytic enzymes, direct-fed microbials, nitrate-based strategies and plant bioactive compounds, offer additional opportunities for methane mitigation. However, their effectiveness varies according to diet, animal species, and dose and production system. Future methane-mitigation strategies should therefore focus on improving feed quality, optimizing rumen fermentation, increasing animal productivity and reducing methane emission intensity simultaneously. For smallholder livestock systems, priority should be given to low-cost, farmer-friendly technologies that can be implemented using locally available feed resources. An integrated approach combining crop-residue treatment, strategic supplementation, and ration balancing and appropriate rumen-modifying feed additives is likely to provide the most practical pathway towards efficient utilization of fibrous feeds and environmentally sustainable livestock production.

REFERENCES

- Alawa, J. P., & Owen, E. (1984). The effect of milling and sodium hydroxide treatment of wheat straw on intake and digestibility by sheep. *Animal Feed Science and Technology*, 12, 149–157.
- Almeida, A. K., Hegarty, R. S., & Cowie, A. (2021). Meta-analysis quantifying the potential of dietary additives and rumen modifiers for methane mitigation in ruminant production systems. *Animal Nutrition*, 7(4), 1219–1230.
- Durmic, Z., Duin, E. C., Bannink, A., Belanche, A., Carbone, V., Crüsemann, M., *et al.* (2025). Feed additives for methane mitigation: A guideline to uncover the mode of action of antimethanogenic feed additives for ruminants. *Journal of Dairy Science*, 108(1), 375–394.
- Food and Agriculture Organization of the United Nations (FAO). (2012). *Balanced feeding for improving livestock productivity: Increase in milk production and nutrient use efficiency and decrease in methane emission*. Rome: FAO.
- Food and Agriculture Organization of the United Nations (FAO). (2013). *Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO₂ emissions*. FAO Animal Production and Health Paper 177. Rome: FAO.
- Hristov, A. N., Oh, J., Firkins, J. L., Dijkstra, J., Kebreab, E., Waghorn, G., *et al.* (2013). Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. *Journal of Animal Science*, 91(11), 5095–5113.
- Hook, S. E., Wright, A. D. G., & McBride, B. W. (2010). Methanogens: Methane producers of the rumen and mitigation strategies. *Archaea*, 2010, 945785.
- Idowu, W., Pires, A. J. V., Teixeira, F. A., Reis, G. C., Queiros, G. M., Machado, I. S., *et al.* (2026). Ammoniation of low-quality roughages for dry-season ruminant feeding: A review. *Tropical Animal Health and Production*, 58, 344.

Sarnklong, C., Cone, J. W., Pellikaan, W., & Hendriks, W. H. (2010). Utilization of rice straw and different treatments to improve its feed value for ruminants: A review. *Asian-Australasian Journal of Animal Sciences*, 23(5), 680–692.

Sherasia, P. L., & Garg, M. R. (2018). Ration balancing: A practical strategy for reducing enteric methane emission and

carbon footprint of milk in India: A review. *Indian Journal of Animal Nutrition*, 33(4).

Sundstøl, F., & Owen, E. (1984). *Straw and other fibrous by-products as feed*. Elsevier, Amsterdam.