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Nutritional strategies for reducing enteric methane emission from ruminants

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Introduction

Methane (CH_4), a significant greenhouse gas that is mostly produced by ruminants during the enteric fermentation of feed, has a 21-fold greater potential to cause global warming than carbon dioxide. Though the exact role domesticated ruminants play in worldwide methane emissions is a hotly debated topic, anaerobic enteric fermentation of diets is considered to account for approximately 15% of methane emissions overall. Furthermore, methane emissions cause ruminant animals to waste a significant (8–12% of gross energy) portion of feed energy that could otherwise be transformed into metabolizable energy for beneficial uses. As a result, it becomes a responsibility of ruminant nutritionists to reduce methanogenesis for a number of reasons, including the efficient use of feed and, more recently, the impact of global warming. Thus, it is necessary to develop multifaceted strategies for mitigating and adapting to climate change, including genetic improvement strategies (breeding for increased animal productivity, and specific traits related to reduced methane emissions, selection for better feed and nitrogen utilization efficient animals, biotechnological strategies, and nutritional strategies). The most advanced and practically applicable method for lowering methane emissions from livestock is proper nutritional management. The commonly used effective nutritional strategies for reducing enteric methane emission from ruminants include:

- ✓ **Fat and oils supplementation**
- ✓ **Nitrates and sulphates supplementation**
- ✓ **Ionophores and organic acids**
- ✓ **Elimination of protozoa (Defaunation)**
- ✓ **Inclusion of exogenous enzymes**
- ✓ **Plant bio-active compounds (PBAC)**
- ✓ ***Fat and oils supplementation***

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Dietary fats and oils have emerged as the potential dietary substitute to lower ruminal methanogenesis without lowering ruminal pH. Three mechanisms exist for fat to inhibit methanogenesis: direct inhibition of methanogens, reduction in the digestibility of fibre, and bio-hydrogenation of fatty acids. Medium-chain fatty acids (FAs) are known to affect the ruminal methanogen. Owing to their toxic action on cellulolytic bacteria and protozoa, polyunsaturated fatty acids also contribute to the lowering of enteric methane emissions. The multiple actions of fats and oils tend to impair digestion if the number and activity of primary microbial fermenters is affected to an increased extent or if the negative effect on methanogens leads to an accumulation of hydrogen in the rumen. Bio-hydrogenation of polyunsaturated FAs results in an uptake of hydrogen. Dietary supplementation of linolenic acid also contributes to improve the quality of fatty acids of ruminant products, which compensates for the additional cost of lipid supply.

Nitrates and sulphates supplementation

It is well known that nitrate successfully outcompetes methanogenesis as a hydrogen sink during fermentation. Reducing nitrate is more advantageous energetically than reducing CO_2, as it outcompetes methanogens for hydrogen. Recent studies have demonstrated that nitrate supplementation in the ruminant diet can reduce enteric CH_4 emission by as much as 50% (Hulshof *et al*., 2012). As rumen bacteria may benefit from non-protein sources in low-protein diets, providing nitrates therefore proves to be a promising enteric methane mitigation strategy. However, the toxicity of the intermediate product nitrite proves to an impeding factor in the possible use of nitrate to reduce rumen methanogenesis. Nitrate can build up in the rumen due to the quick microbial conversion of nitrate to nitrite, which is then converted to ammonia at a slower pace. Consequently, it is critical to take into account an appropriate dose and animal adaption in order to prevent nitrite toxicity.

The addition of sulphate to the ruminant diet increases the number of sulphate-reducing bacteria (SRB) in the rumen (Paul *et al*., 2011), which can operate as an alternate hydrogen sink to compete with methanogens. However, the likelihood of sulphide (H_2S) toxicity as a result of sulphate reduction may be a substantial hurdle to its use as a methane inhibitor. When sulphate and nitrate are used together, a synergistic effect is observed. Many SRBs appear to have multiple activities, as they decrease both inorganic and organic sulphur, and most of them can convert nitrite to ammonia. Furthermore, when sulphate (2.6% of DM) and nitrate (2.6% of DM) were combined, an additive effect on the decrease in CH_4 emission in vivo has been found (van Zijderveld *et al*., 2010).

Ionophores and organic acids

Ionophore antibiotics such as monensin and lasalocid have long been used successfully as feed

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additives to improve animal production efficiency and reduce methane emissions (Beauchemin *et al*., 2008). The interaction of ionophores with bacterial cell membranes reduces the transmembrane ionic gradient, resulting in lysis or decreased cell growth. The modification of a certain group of microbial population results in a shift in fermentation toward propionogenesis, however modern feed regulations prohibit the use of these antibiotics in cattle rations.

Organic acids (malate and fumarate) have been tested as feed additives, however the results in vivo are inconsistent. Martin (1998) suggested that the high malate concentration of new forages at the early development stage, particularly lucerne, could cause considerable changes in rumen fermentation. McCaughey *et al*. (1999) found that replacing grasses with a lucerne-grass mixture (70:30) reduced methane generation by 10%. A 3% increase in dietary malate may explain the decrease in methane. However, further study is required in these directions.

Elimination of protozoa (Defaunation)

Although methanogens exist as individuals, there is a physical relationship between protozoan cells and methanogens in the rumen environment. Methanogens coupled extracellularly and intracellularly with ciliate protozoa are estimated to contribute 9 to 37% of rumen methanogenesis. The removal of protozoa (defaunation) from the rumen can lower CH_4 generation by up to 50% depending on the diet (Hegarty, 1999). The 26% decrease in methane production per kg DM intake in protozoa-free lambs was associated with a decrease in the proportion of methanogens in the overall bacterial population of the ruminal content. As a result, reducing rumen protozoa by the use of saponin-rich diets and other methods could be another promising technique to reducing bovine enteric methane emissions.

Inclusion of exogenous enzymes

The role of exogenous enzymes in lowering intestinal methane generation has been widely studied. Although there is little evidence that these preparations have a direct influence on CH4 emission, several studies suggest that they improve feed digestibility and animal output. Thus, there may be an opportunity to promote fibre digestion in ruminants, which would improve the feed efficiency of forage-based diets. Improved feed digestibility may reduce fermentable organic matter in (stored) manure, thereby lowering total CH_4 emissions from ruminant production systems.

Plant bio-active compounds (PBAC)

Due to their natural origin, plant bio-active substances (condensed tannins, saponins, essential oils) are becoming increasingly popular as a CH4 mitigation technique in place of chemical additives. Tannin-containing plants' anti-methanogenic activity has been attributed primarily to condense tannins (Dey *et al*., 2008), with a direct effect on ruminal methanogens and an indirect effect on hydrogen production due to decreased feed breakdown. Saponins' mechanism of action appears to be clearly tied to their anti-protozoal impact. Essential oils (EOs) are gaining popularity in ruminant nutrition due to their ability to reduce enteric methanogenesis while also improving animal health and production. The antibacterial activity of EOs supports their potential use as an antimethanogenic feed additive, but the problem is to maintain feed digestibility. It is indicated that essential oil inhibits methane synthesis either by blocking methanogenic archaea, changes in the phylogenetic distribution of archeal population, or activity of methane-producing genes. PBACs have the ability to improve nutrient usage efficiency while also reducing the environmental effect of cattle production. Essential oils and their components, in particular, have the potential to lower enteric methane and ammonia emissions by altering rumen microbial community structure and serve as phytogenic feed additives. However, their effects have to be investigated through long-term in vivo study, as adaptability of rumen bacteria may render them ineffective. The optimal dose of bioactive components and their appropriate combinations must be standardized in respect to animal food composition in order to get consistent benefit from feeding for enteric methane reduction and improvement in ruminant health and output.

Conclusion

Reducing enteric methane emissions in ruminants through nutritional intervention holds significant promise for mitigating greenhouse gas emissions and improving the sustainability of livestock farming. Various nutritional strategies have been explored, including dietary manipulation, feed additives, and the selection of forage types. Adjusting the composition and quality of ruminant diets can influence methane production by increasing the proportion of easily digestible carbohydrates and reducing the proportion of fibrous material in the diet. Incorporating additives such as ionophores, tannins, essential oils, and methane inhibitors into ruminant diets has shown potential in reducing methane emissions. These additives can modify rumen microbial populations and fermentation processes, leading to decreased methane production without compromising animal performance. However, while nutritional interventions offer promising avenues for reducing methane emissions, it is essential to consider potential trade-offs, such as impacts on animal health, productivity, and the nutritional quality of animal products. Furthermore, the effectiveness of these interventions can vary depending on factors such as animal species, diet composition, and management practices. Continued research and innovation in this field are crucial for developing sustainable and practical solutions to mitigate enteric methane emissions from ruminant livestock production. Collaboration between researchers, farmers, policymakers, and industry stakeholders is essential to implement effective

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strategies that balance environmental, economic, and social considerations in livestock farming systems.

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