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STRATEGIES FOR MITIGATING METHANE EMISSIONS IN CATTLE: ADVANCING SUSTAINABLE LIVESTOCK PRODUCTION

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Abstract

The increasing recognition of methane emissions as a significant contributor to global warming necessitates urgent strategies for mitigating these emissions in cattle production systems. This minireview synthesizes current research on effective strategies to reduce enteric methane emissions while promoting sustainable livestock practices. Key strategies include improving feed efficiency and management practices, such as using rotational grazing systems, which have been shown to significantly lower methane emissions compared to continuous grazing methods. Furthermore, integrating livestock with crop production systems enhances nutrient recycling and improves overall system sustainability, thereby reducing reliance on external inputs and minimizing environmental impacts. Genetic improvements aimed at enhancing feed efficiency and reducing methane production are also critical, as ruminants are responsible for approximately 80% of livestock-related greenhouse gas emissions. Furthermore, the use of novel feed resources and innovative feeding systems can further contribute to lowering methane emissions while ensuring food security. This review highlights the diverse nature of methane mitigation strategies, emphasizing the need for a comprehensive approach that encompasses management practices, genetic advancements, and integrated agricultural systems to achieve sustainable livestock production.

***Key words**: methane emissions, cattle, livestock, sustainability.*

INTRODUCTION

Methane emissions from cattle are a substantial source of greenhouse gas (GHG) emissions worldwide; they are estimated to account for 15% to 25% of total methane emissions, with cattle accounting for up to 74% of this proportion (Volenzo et al., 2019; Chang et al., 2019). Enteric fermentation, a natural digestive process in ruminants, is the primary mechanism for feed breakdown in the rumen. Domesticated ruminants globally emit an estimated 86 million tonnes of methane per year as a consequence of fermentation (Blaxland et al., 2021). Cattle methane production is primarily determined by dietary composition, feeding procedures, genetics, and physiological status (Kamalanathan et al., 2023; Ramírez-Restrepo et al., 2017). Thus, methane from cattle has a considerable detrimental impact on the environment, contributing to global warming and highlighting the importance of effective mitigation strategies (Chang et al., 2021; McGinn et al., 2019; Hayes et al., 2016; Ramírez-Restrepo et al., 2017; Malik et al., 2021; Maze et al. 2024; Kamalanathan et al., 2023; Difford et al., 2018; Ye et al., 2024; Du et al., 2024). Cutting-edge strategies such as genetic selection, nutritional control, and innovative feed additives provide a holistic approach to lowering methane emissions (Church et al., 2015; Ramírez-Restrepo et al., 2017; Gheorghe-Irimia et al., 2024).

Over the last century, research in genetics, health, microbiology, nutrition, and physiology, as well as its application to dairy production, has

resulted in enormous advancements in animal performance. These enhancements enable a rising supply of milk while reducing the environmental impact of GHG emissions from dairy animals. Continued use of these procedures in dairy production, as well as research and development of new ways, can further lower enteric CH4 and other GHG per unit of product while boosting milk supply to meet the expected 58% increase in global dairy demand by 2050 (Volenzo et al., 2019; Chang et al., 2021; Maze et al., 2024).
The aim of this review is to investigate and evaluate several solutions for reducing methane emissions in cattle, focussing on their effectiveness, feasibility, and potential significance in promoting sustainable livestock production.

SOURCES AND MECHANISM OF METHANE PRODUCTION IN CATTLE

Enteric fermentation, a biological process inherent to ruminant digestive tracts, is the primary mechanism by which methane is generated in cattle. A diverse colony of bacteria breaks fibrous plant material in the rumen, releasing methane as a byproduct. Anthropogenic activities account for more than 70% of methane emissions, with livestock, particularly cattle, playing a significant contribution via enteric fermentation linked to their digestive processes (Kouazounde et al., 2015). Enteric fermentation in livestock accounts for approximately 27% of global methane emissions, making it an important target for mitigation efforts (Kouazounde et al., 2015; Wójcik-Gront, 2020; Wallace et al., 2015). Methanogenic archaea are important in the final stage of fermentation because they create methane from hydrogen and carbon dioxide, which serves to maintain the correct hydrogen balance in the rumen (Cherdthong et al., 2019). The amount of methane produced is directly influenced by the many species of methanogens found in the rumen, as well as considerable differences in their abundance and activity across individual animals and dietary conditions (Wallace et al., 2015; Malik et al., 2021). Certain microbial communities in cattle have been associated to higher methane outputs, implying that rumen microbiome manipulation could be a viable technique for reducing methane emissions (Wallace et al., 2015). A lot of factors influence cattle methane generation, with diet being the most essential. Because different diets create varying amounts of methane, feed type and composition have a significant impact on enteric fermentation dynamics. Ruminants consume carbohydrates more efficiently than fibrous feeds; hence diets high in concentrates typically produce less methane (Wójcik-Gront, 2020; Donadia et al., 2023). For example, because methanogenic populations in the rumen have varying levels of substrate availability and fermentation efficiency, high-forage diets are associated with higher methane emissions than high-grain diets (Herliatika et al., 2024; Donadia et al., 2023). Furthermore, dietary components such as lipids might limit methanogenesis, resulting in lower total emissions. Increased dietary fat has been shown to limit methane generation by changing the structure of the microbial population and reducing the quantity of methane-producing archaea (Donadia et al., 2023). Methane emissions are also heavily influenced by breeding and genetic selection. Research suggests that heritable traits influence the methane emission of cattle breeds or individual animals (Kamalanathan et al., 2023). Cattle that are more efficient at converting feed into energy produce less methane per unit of intake or body weight. Methane emissions are heavily influenced by management practices. Variables such as feeding schedule, environmental factors, and general animal husbandry techniques can all have an impact on rumen fermentation processes (Donadia et al., 2023; Smith et al., 2021; Maze et al., 2024; Clemmons et al., 2021).

STRATEGIES FOR MITIGATING METHANE EMISSIONS

Several measures, such as dietary interventions, genetic selection, microbial adjustments, managerial changes, and technological improvements, can be utilised to minimise methane emissions from cattle in a range of settings. Dietary interventions are crucial for lowering methane emissions (Gheorghe-Irimia et al., 2023; Șonea et al., 2023b; Șonea et al., 2023a). In this direction, feed ingredients serve as substrates for microbial fermentation, and changes in feed digestibility and chemical composition influence the quantity of energy taken by bacteria as well as the patterns of Volatile Fatty Acids (VFA) and CH_4 production. The quantities of VFA affect the quantity of CH_4 produced because propionate formation consumes reducing equivalents, whereas acetate and butyrate formation create H_2 for methanogenesis. As a result, any dietary component or intervention that promotes propionate formation will result in a decrease in CH_4 generation per unit of fermented feed, although acetate and butyrate production would increase. Rumen protein breakdown and absorption into microbial protein can lead to either net consumption or net generation of H_2. The biohydrogenation of fatty acids (FA) will result in the net consumption of H_2. High-quality (more energy-dense or more digestible) diets supply more energy for production as a proportion of the gross energy intake (GEI) and dilute the costs of maintenance than low-quality diets, resulting in less CH_4/ECM generation. Wallace et al. (2015) and Hristov et al. (2022) showed that feed additives such as ionophores, tannins, and lipids can lower methane production during fermentation by altering the microbial population and increasing feed efficiency.

Another study found that regular usage of 3-nitrooxypropanol (3-NOP) lowers intestinal methane emissions by up to 30% while maintaining productivity (Vyas et al., 2016; Vijn et al., 2020). Furthermore, other feed ingredients are being studied, such as seaweed, which has compounds that suppress methanogenesis (Vijn et al., 2020). Furthermore, methane generation can be significantly reduced and digestion optimised with precision feeding aimed at improving pasture quality (Donadia et al., 2023). Genetic selection is a possible technique to long-term methane reduction. Breeding programs can use genetic markers associated to methane traits to select calves that produce less methane (Hayes et al., 2016; Moate et al., 2016). The accuracy of genomic estimated breeding values (GEBVs) for methane traits will increase with more research into the genetic basis of methane generation, potentially leading to significant emissions reductions (Hayes et al., 2016). Moreover, m ethane emissions can potentially be controlled by modifying the rumen microbiome. Probiotics and inhibitors can be used to reduce methanogenic archaea, whereas rumen microbiome engineering can be used to encourage specific populations of bacteria that create less methane (Ye et al., 2024; Wallace et al., 2015; Ye et al., 2024). Methane emissions can be further reduced by better grazing management. Multi-species grazing and rotational grazing improve feed efficiency, carbon sequestration, and pasture health. In addition to minimising methane emissions from manure, manure management techniques such as anaerobic digestion and composting may use methane capture systems, which reduce overall greenhouse gas emissions (Vargas et al., 2024; Haisan et al., 2014).

CHALLENGES AND FUTURE PERSPECTIVES

To address the challenges of lowering cattle methane emissions, a multidisciplinary strategy that considers logistical, research, and economic factors is required. In this regard, methane emissions can vary both spatially and temporally, making it challenging to capture the full range of emissions. Another important concern includes creating sample protocols that adequately capture variability and accounting for seasonal and diurnal variations. Methane concentrations in the atmosphere are usually low, demanding precision monitoring techniques to accurately identify and measure emissions. To obtain reliable data, instruments must be precise and sensitive. It can be challenging to detect and measure methane emissions from individual sources in complex ecosystems. Combining several measuring techniques, modelling methodologies and data sources can improve the accuracy of source attribution. Standardised protocols, techniques, and quality assurance procedures must be developed to ensure that methane emission data is consistent and comparable across studies and locations. Implementing mitigation strategies in livestock farming is heavily limited by financial limitations.

Regarding the reduction of methane, the high costs of genetic selection programs, feed additives, and emerging technology prevent widespread use among farmers, particularly in underdeveloped countries (Goopy, 2019). Strong financial incentives, such as subsidies or carbon credits, are required to induce producers to use methane mitigation techniques (González-Recio et al., 2020). Furthermore, logistical challenges in the supply chain may render integrating sustainable practices into present systems more challenging, especially for specialised feed additives such as seaweed or tannins (Goopy et al., 2019; Fregulia et al., 2024).

CONCLUSIONS

In conclusion, the long-term sustainability of the agricultural economy and the environment is contingent upon the reduction of methane emissions in cattle. Genetic selection, microbial manipulation, dietary interventions, technological advancements, and management methods all contribute to a framework that effectively reduces methane emissions. The objective of these initiatives is to enhance rumen function by modifying the microbiota, breeding for low-emission traits, and improving the quality of the diet.

More study is needed to fully understand the complex connections between the ruminal bacteria and host genes, which greatly affect methane formation. Scientists, producers, and legislators working together will help to create and use effective methane reducing measures. By means of encouraging legislation and incentives, resolving economic and logistical concerns will help to raise the acceptance of sustainable practices.

New technologies such as precision cattle farming and microbiological biomarkers also show the possibility for better emissions monitoring and management. Finally, the efficient decrease of methane emissions from cattle would help the agriculture sector as well as the environment.

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