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RUMINANTS ENTERIC METHANE PRODUCTION: ITS DELETERIOUS EFFECT ON ENVIRONMENT AND MITIGATION STRATEGIES-A REVIEW

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ABSTRACT

The purpose of this review is to understand the importance of methane emissions from ruminant livestock. It highlights the advances made in the past century for understanding methane reduction possibilities and constraints. Therefore, recent research papers and publications are reviewed in this paper to aid farmers and researchers in pinpointing research gaps and mitigation strategies. Methane is a natural gas produced from activities such as agriculture, animal digestion and the decomposition of organic matter. Methane is a potent greenhouse gas exhibiting a warming effect more than 21 times that of $CO_{2.}$ Ruminant appears as the primary anthropogenic source of methane emission globally. Various approaches including feed manipulation, management practices, genetic selection etc. all were aimed at mitigating CH_4 emission. Different methods for measuring methane emissions from livestock were made but each method has limitations, reducing enteric CH_4 emissions should always consider its economic impact on farm profitability. However, using these technologies beyond their intended purpose is risky. Therefore, combining different methods may offer the most comprehensive approach, but further research is needed

Keywords: Ruminants, Enteric Methane, Environment Pollution, Mitigation Approach and Innovative Strategies

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INTRODUCTION

The phenomenon known as the greenhouse effect takes place within the troposphere, the lower layer of the Earth's atmosphere where life and weather activities happen. Without the greenhouse effect, scientists think the average temperature on Earth would be very cold, around -19°C but because of the greenhouse effect, the normal temperature is about 14°C. (Le Treut *et al*., 2007).The greenhouse effect increase the temperature mainly caused by special gases called greenhouse gases (GHGs) in the air. These gases can absorb and release a certain kind of energy called radiation in the air. This helps to keep the Earth's surface at a temperature that's good for living things (Edenhofe, 2015). The greenhouse plays a crucial role in the regulation and preservation of the Earth's surface temperature. In the past few years, there has been an increasing focus on the greenhouse effect, associated with the increasing drift in global warming. The primary greenhouse gases contributing to this phenomenon are carbon dioxide, methane and nitrous oxide. These gases play a crucial role in absorbing solar heat, thereby heating the atmosphere by retaining energy and delaying its escape into space. The intensification of this effect poses major effects on human well-being, animal life and the overall environment (Calabrò, 2009).

Enteric methane is a naturally occurring gas produced during the digestive process in ruminants, as microorganisms break down and ferment food and fibres within the digestive tract, generating energy and nutrients for the animal. In the rumen, a wide community of bacteria, ciliate protozoa, methanogenic archaea and fungi synthesize enzymes that break down complex macromolecules from the animal's feed (Matthews *et al*., 2019).This phenomenon, known as "enteric fermentation. This fermentation process generates short-chain volatile fatty acids (SCFAs) and microbial crude protein, serving as a crucial source of energy and protein for the host organism. The rumen provides an appropriate habitat for the microbes to live and proliferate (Cammack et al., 2018). The key components of (SCFAs) in anaerobic fermentation supply 80% of the animal's energy which are acetate (65%), propionate (20%), and butyrate (15%). As a result of anaerobic fermentation, methane-producing microorganisms in the gastrointestinal tract produce methane. Consequently, methane is released as a result of digestible energy loss, accounting for approximately 12 per cent of the ruminant's overall energy intake through the enteric fermentation process (Palangi *et al*., 2022). The quantity of enteric methane emitted by the animal is dependent upon the amount and quality of the feeds, the health condition, reproductive status, and ecological factors. Methane is a potent greenhouse gas contributing to global warming. The livestock sector, especially ruminants, stands as a significant contributor to anthropic methane emissions globally. Specifically, enteric methane emissions from both ruminants and the management of manure practices contribute to over 32 % of total emissions. (FAO, 2023)

Cattle breeding and production, accounting for approximately 1.5 billion cattle worldwide, represents a primary source of CH_4 emissions compared to other ruminants like sheep and goats. The worldwide demand for livestock products is anticipated to double by the year 2050, primarily driven by a massive increase in population. Livestock not only plays a role in global warming but is also affected by its consequences. The challenges posed by climate change extend to animal production, influencing the quality of feed crops and forage, water availability, animal and milk yield, livestock diseases, reproduction and biodiversity (Rojas-Downing *et al*., 2017). Prasad *et al*. (2022) concluded that climate change adversely influences livestock production rising temperatures, drought, flooding and fluctuations in rainfall patterns all have negative effects on the livestock industry.

In addition to contributing to climate change, methane emissions from ruminants present a direct economic challenge for producers, due to energy loss associated with feed. The Food and Agriculture Organization (FAO, 2022) reports that 12% of the energy contained in feed is typically lost through methane (CH_4) production. In anaerobic environments, the microbial colonies within the digestive system of animals generate VFAs by fermenting nutrients. Principal VFAs, including acetate, propionate, and butyrate, serve as both energy sources for the animal and contributors to CH_4 and CO_2 emissions (Sharifi *et al*., 2022)

Anthropic activities play a significant part in global CH_4 production, contributing to about two-thirds of the total (Saunois *et al*. 2020). Human activities, particularly the burning of fossil fuels and deforestation, are the primary drivers of the current era of global warming, with transportation (29%), electricity production (28%) and industrial activity (22%) being the largest sources of greenhouse gases in the United States (Turrentine, 2022). Deforestation, which contributes to approximately 25% of global greenhouse gas emissions, is another significant factor, as forests and trees are essential for absorbing carbon dioxide and creating oxygen, but when they are destroyed, the stored carbon is released into the atmosphere (Berry, 2023). Ruminant enteric fermentation, manure management and rice cultivation among agricultural practices contribute 41% specifically involving. Ruminants contribute approximately 16% to the overall global CH4 production. Predictions from the United Nations (UN) indicate a global population of 9.8 billion by 2050 (Rate 2017). Alongside this population growth, there is an expected flow in the consumption of milk and meat products, reaching 1.04 million tons and 465 million tons, respectively (Ribeiro *et al*., 2015). This increasing demand for ruminant livestock is expected to result in increased methane production, thereby contributing to the stepping up of global warming (Salter *et al*., 2017)

Globally, grazing animals like goats, cattle and sheep release significant quantities of gases which are not environment friendly, methane is the primary contributor among all. Livestock generates an estimated 86 million metric tons (Tg) of CH_4 annually (Ghanbari *et al*., 2020). Approximately 7 Giga tons of carbon dioxide equivalent per year is produced by domesticated ruminants, which is approximately 14.5% of the total global anthropogenic greenhouse gases (Tomkins *et al*., 2011). EPA, (2020) indicated that emissions from agriculture and waste range between 191–240 Tera grams of CH_4 annually, equivalent to approximately 24–30 kilograms per head, based on a global population of eight billion individuals. Considering a greenhouse effect potential of 24, this is equivalent to 572–720 kilograms of CO_2 per person per year. Due to its role in the buildup of GHGs in the environment, the emission of CH_4 through enteric fermentation is a major global issue for the entire planet. Other sources which contribute to global warming and methane emission are: wetlands account for about 30% of methane emissions, Termites contribute to methane emissions through the breakdown of organic material, Wildfires and Biomass Burning Permafrost and oceans are a minor source of methane emissions, with methane-producing bacteria in seafloor sediments releasing the gas into the water column (NASA, 2023). The effectiveness of mitigation strategies can be influenced by production system, feed resources and other environmental factors. Holistic life cycle assessments are needed to quantify the full impact on greenhouse gas emissions beyond just enteric methane (Fouts et al., 2022).

This review paper will focus on enteric methane production in ruminants, its effect on global warming, contributing factors and current research and the various mitigation strategies that can be implemented to reduce methane emissions. The objective of this review paper is to develop a comprehensive understanding of methane production within the context of global warming. It aims to evaluate current approaches, their advantages, disadvantages, and explore future options for reducing enteric methane emissions from ruminants

DISCUSION

Enteric Methane emission intensity varies greatly worldwide and is often high in developing countries where meat and milk demand is growing fast, but productivity is low. Ruminants are raised in diverse production systems. The variety or type of feed given to ruminants and grazing sharing in the feeding system are the main defining factors of this heterogeneity. Additional major components comprise the hand management practices, species and race of the livestock, household dependence on ruminants, level of integration of the cropping system and the level of market integration (Alfauzi *et al*., 2023)

Zooming into the agricultural sector, livestock accounts for a substantial 73% of methane emissions (US EPA, 2013). This contribution is predominantly exhibited by beef (35%) and dairy cattle (30%), with a comparatively smaller share of 15% coming from small ruminants and buffalos (Opio et al., 2013; Islam et al., 2019). Methane emission from buffalo species is 13% of the total annual enteric methane emission reported by Malik et al. (2021). Methane emissions from feral camels in Australia contribute merely 1 to 2% of the total methane produced by domestic ruminants (Dittmann et al., 2014). Ruminants are important for the lives of millions of farmers and can be vital to human beings, nutritional security and international food. Approximately 430 million farmers living in rural and marginal areas mostly own ruminants for their livelihoods. (Gerber et al., 2013). Many studies have shown that the ruminal end-products methane, carbon dioxide, and nitrous oxide from the livestock sector have the largest contribution to GHG emissions (Gernaat et al., 2015). The livestock sector demands a large quantity of natural resources, and greenhouse gas emissions depend 14.5% on livestock end products (Gerber et al., 2013). A study by the FAO (2023) states that approximately 44% of livestock emissions consist of CH_4, while the remaining portion is almost evenly divided between nitrous oxide (29%) and carbon dioxide (27%). Another study by the US EPA (2023) also highlights that methane, nitrous oxide, and carbon dioxide released from the agriculture part for 10% of total U.S. greenhouse gas emissions

According to Ungerfeld *et al*. (2022), there is an inverse association between CH_4 emission and productivity level because ruminant production systems with low efficiency require extra power to produce each unit of livestock outcome compared to those with high production. Through production systems, increasing productivity ultimately increases feed safety, enhances farmers' livelihoods and is beneficial for weather change. The significant connection between increased animal efficiency and reduction in enteric CH_4 production offers great prospects for social, and economic benefits and low-cost mitigation. Milk production and daily weight gain are reduced by feeding tropical grass as fodder.The advantage of supplying grazing animals in tropical areas with nitrogen-containing feed, for example, L. leucocephala which can reduce methane emissions. (Rira *et al*., 2015). Rojas–Downing *et al*. (2017) indicated that in the time ahead, the demand for food should be increased, so how can people meet the demand for food if such a program was taken; such an operation should not be followed.

Due to the mutual dependence between human well-being, food production, and enteric methane's detrimental effects on atmospheric conditions, the government, conservationists, and ecologists are paying attention to the emission of CH_4 from many species of livestock. If large ruminants are banned from human food consumption, then it will be better (Sabaté & Soret, 2014). Daily methane production for the maximum number of animals in the herd should be calculated through new technologies that are beneficial for animal breeding plans and authentication of methane emissions (Pickering *et al*., 2015). Ruminant livestock can produce 250–500 L of CH_4 each day; therefore, they are fundamental CH_4 producers (Dana & Peter, 2017)

Enteric Methane: Methane is naturally emitted from sources like wetlands, termites, oceans, forests, wildfires, wild animals, permafrost and geological sources (EEA, 2022). Anthropogenic sources of methane include landfills, oil and natural gas systems, agricultural activities, coal mining, combustion processes, wastewater treatment, and certain industrial activities (EPA, 2023). The plant material eaten by animals is digested by bacteria, protozoa and fungi in the rumen, and this natural process is enteric fermentation. Plant material changes into volatile fatty acids by fermentation, and this process gives maximum energy to the animal and converts cellulose and hemicellulose into their digestive forms. The gases that are the outcome of enteric fermentation are CH_4, CO_2 and NO_2, which are removed during eructation (McAllister & Newbold 2008).

In another study, Beauchemin & McGinn (2008) described that methane is generated naturally by anaerobic fermentation in the stomachs of ruminants, where bacteria break down organic matter by producing H_2, CO_2, and CH_4. Methane is primarily produced in ruminant guts or rumens by intestinal fermentation, in which microorganisms break down plant cells such as cellulose, fibre, sugar, and starch. The animal body excretes CH_4, a secondary product of digestion, through burping. The other byproducts are absorbed and used by animals as energy sources to produce meat, milk, and wool. CH_4 production is directly correlated with the level of consumption, quality and type of diet, amount of energy consumed, size of the animal, level of production, growth rate, and ambient temperature. Approximately about 2-12 per cent of the energy consumption of ruminants is naturally lost through enteric fermentation.

Method of Estimation of Enteric Methane Emission

Respiration Chambers: For many years, respiration chambers have served as the established method for assessing the energy expenditure of individual animals. While traditionally considered the standard for measuring methane (CH_4) production from individual animals, current research has revealed the efficacy of various alternative techniques closed circuit chamber and open circuit chamber. Respiration chambers offer precise measurements of CH_4, encompassing hindgut emissions; nevertheless, they come with a high cost and technical complexity (Rosenstoc *et al*., 2016). Despite their utility, these chambers have inherent limitations that prove challenging to address. For instance, factors such as changed metabolism rates (e.g., gluconeogenesis, ketogenesis, or lipogenesis) are observed in ruminants within the chambers (Gerrits, *et al*., 2015). Additionally, respiration chambers may disrupt normal animal behaviours, leading to decreased feed consumption and potentially underestimating actual CH_4 emissions when compared to animals in free-ranging conditions on a farm (Huhtanen *et al*., 2019). In typical study scenarios, animals undergo metabolism or performance trials, during which CH_4 is measured throughout 3 to 5 consecutive days by relocating trained ruminants to the chambers (Sakita *et al*., 2022).

Madsen *et al*., (2012) reported the best methods for methane emission calculation and control were Chambers/respiration chambers, SF6 method and laboratory gas productivity technical skill along with modern carbon dioxide technique. For the calculation of the national economy and each cow, CH_4 production from consumption and diet formulation model estimations were used. Micrometeorological methods, compound feeders, methane evaluators, and proxy procedures are currently under development. Selection of techniques for assessment of enteric methane emission-based purposes, tools, knowledge, budget and time available. Before explaining the results, we must obtain information regarding the advantages and disadvantages that are beneficial while planning the experiment.

Spot Sampling: Spot sampling methods measure the CH_4 concentration in the breath of individual animals over transitory pauses. Certain approaches integrate these concentration readings with airflow data to calculate a flux, exemplified by automated head chamber systems (AHCS) like the GreenFeed Emission Monitoring system (Hristov *et al*., 2015). The GreenFeed Emission Monitoring system employs a head chamber featuring an overhead hopper to assess the elevation in CH_4 and CO_2 quantity resulting from an animal's breath in contrast to the surrounding ambient air. The system calculates a flux each time the animal visits the system. The system relies on dispersed visits over the 24-hour cycle. To prevent a bias towards daytime emissions, Manafiazar *et al*. (2016) suggested calculating the averaging of the spot fluxes throughout the timetable of quantification using six 4-hour bins representing different times of the day.

Hegarty (2013) suggested incorporating considerations of the circadian rhythm to mitigate faults in CH_4 approximations when utilizing the GreenFeed Emission Monitor system. To ensure robust data collection, a substantial number of days are crucial, as emphasized by Hammond *et al*. (2015) and Thompson and Rowntree (2020). Achieving a successful sampling routine is easier when using the system with animals kept in stalls. This enables proper positioning in front of each animal at the scheduled period.

Following this methodology, Hristov *et al*. (2015) supported for collection of samples 8 times during a 24-hour provision of feed, distributed over three days. For animals in group housing, Gunter and Bradford (2017) suggested a minimum of 2.4 stays each day for 6.3 days. Alternative suggestions propose a baseline of a minimum of 20 visits within 7- to 14 days during quantification time (Manafiazar *et al*., 2016). Arbre *et al*. (2016) conducted regular measurements, achieving a repetition of 70 per cent in 17 days, with a rise to 90% over 40 days. Coppa *et al*. (2021) observed a repeatability of 60% over a one-week measurement period for everyday CH_4, which improved to 78% over an 8-week. Connecting these diverse research findings underscores the importance of a thoughtful sampling approach aligned with the animals' housing conditions and feeding cycles.

Zhao *et al*. (2020) reported that the applicability of the GreenFeed Emission Monitoring system extends to both research environments and commercial farms housing diverse populations of large and small ruminants, as highlighted. This versatile system is well-suited for various settings, including grazing situations, indoor, and outdoor group-housing arrangements and separately confined ruminants, such as those in tie-stalls. It's important to note that successful implementation requires animal training and not all animals may adapt to the system. While the handheld laser proves user-friendly for application on commercial farms, it is essential to conduct studies to determine the accuracy and precision of the collection.

Tracer Techniques: Detecting CH_4 emissions can be accomplished by utilizing a tracer gas, such as SF6, this substance is emitted from a bolus or permeation tube at a set release rate within the animal's rumen. To collect samples, the release of gasses was periodically measured, typically at intervals of 24 hours, and directed into cylinders which absorb the gases. This is achieved by positioning a tube close to the nose of the animal, often secured to a halter. Regular animal handling, a necessity for exchanging collection canisters, is a routine aspect of research involving methane emissions. Numerous investigations have highlighted the similarity between estimates obtained through the tracer gas technique and respiratory chambers, provided a 3% correction for rectal methane is functional to the tracer estimations (Hammond *et al.*, 2016). Conversely, differences exceeding 10% between SF6 and respiration chambers have been documented in other studies (Ramírez-Restrepo *et al.*, 2020).

Proposed enhancements to the SF6 technique, aiming to enhance predictability, include continuous 24-hour Gathering consistently and the substitution of capillary tubes with orifice plates to regulate sample collection rates (Deighton *et al.*, 2014). Arbre *et al.* (2016) advocated for a 3-day collection period to attain a 70% repetition of CH_4 emissions in relation to the amount of feed consumed, there is no apparent improvement in repeatability as the measurement periods are extended. Notably, the SF6 tracer gas method exhibits versatility for livestock, with potential applications in well-ventilated outdoor (Ramírez-Restrepo *et al.*, 2010) and indoor environments (Ramírez-Restrepo *et al.*, 2016).

However, challenges arise in poorly aerated structures where background CH_4 (and occasionally SF6) concentrations in ambient air can impede accurate CH_4 calculations (Hristov *et al.*, 2016). Restrictions concerning proximity to other CH_4 means (e.g., Sludge, organic waste, additional livestock, and damp regions) and SF6 sources (e.g., Electric power transformers and industrial locations), rendering the technique unsuitable in such contexts (Jonker and Waghorn, 2020)

Open-Path Laser Technique: The method of open-path laser measurement is employed to quantify the spreading of a particular gas released from its origin and the resulting amount of the gas in the air downwind. This is done to determine the emanation proportion, utilizing an "inverse dispersion" method, as demonstrated by McGinn *et al.* (2006). This method was applied to assess emissions of CH_4 (McGinn *et al.*, 2006) and NH3 (McGinn *et al.*, 2007) from animal sets such as those found in feedlots and pastures.

In recent developments, the open path laser technique has undergone enhancements, incorporating various analyzers and atmospheric conditions, and has been implemented on aeroplanes (Hacker *et al.*, 2016) and drones. These advancements have yielded reliable and promising results in the measurement of gas dispersion. In a study conducted by Tomkins *et al.* (2011), an evaluation was made of daily CH_4 emissions utilizing the open path laser method on grazing areas, comparing it with breathing chamber measurements on Rhodes grass fodder for ruminants sourced from the same pasture. The regular approximations yielded 136 and 114 g CH_4/d, correspondingly. Scientists recommended the need for additional evaluations involving diverse fodders and ruminants.

Afterwards, Tomkins and Charmley (2015) performed experiments utilizing the open-path laser method near water sources where animals were present. The scientists found that using the open-path laser method on grouped grazing cattle for at least seven hours each day for 7 to 14 days is a viable option. However, they noted that the 24-hour design of CH_4 releases may not be completely captured. The open-path laser method is useful for directly measuring methane emissions from cattle in herds while they are grazing and in intensive livestock operations.

In-vitro Methods: The assessment of ruminal fermentation in feedstuffs has a longstanding history utilizing the in vitro fermentation technique, with recent applications extending to the evaluation of diverse nutritional strategies aimed at mitigating methane (CH_4) emissions (Yáñez-Ruiz *et al.*, 2016). Given the complicated and costly nature of the technique of directly measuring enteric CH_4 emissions from animals, in vitro systems offer a promising alternative. These systems prove particularly valuable for conducting preliminary screenings involving an excess of samples, each exploring different ways to slow the process of methane production, such as the incorporation of essential oils, tannins and secondary metabolites from plants (Tedeschi *et al.*, 2021).

Nevertheless, a critical consideration arises regarding the need to adjust fermentation end products for microbial mass, as highlighted by Makkar (2005). Various in vitro methods exist, ranging from systems utilizing batch culture (Pell and Schofield, 1993; Mauricio *et al.*, 1999) to continuous fermenters like RUSITEC (Czerkawski and Breckenridge, 1977) or dual-flow continuous culture systems (Hoover and Stokes, 1991). Among the batch culture systems, the widely adopted in vitro gas production method serves as a valuable tool for determining the fermentation kinetics and provides insights into the nutritional value of feeds. (Tedeschi *et al*., 2009).

In their study, Yáñez-Ruiz *et al*. (2016) delved into exact aspects related to in vitro method, exploring the nuances of designing experiments, putting them into practice, and interpreting the results within the context of assessing enteric CH_4. They extensively examined factors influencing outcomes in vitro fermentation techniques, including considerations such as animals contributing samples, dietary considerations, collecting and processing the inoculum and utilizing diverse substrates and the details of incubation buffer and procedures.

Building upon this foundation, Danielsson *et al*. (2017) contributed further insights, revealing a noteworthy association (r = 0.98) between in vitro methodologies and a headstall system, specifically the GreenFeed Emission Monitoring arrangement. However, it's crucial to note that the reported values demonstrated an underprediction in the studied context. This connection between the research by Yáñez-Ruiz *et al*. and Danielsson *et al*. underscores the significance of considering diverse methodologies and variables in understanding enteric CH_4 emissions.

Other Methods for Methane Estimation: Several other methane Estimation techniques, measuring methane production from barns and dung have been explored at an investigational level by Mathot *et al*. (2016). However, applying these methods on commercial farms poses challenges. The absence of global standardization for animal house-scale assessments is attributed to the significant diversity in bedding conditions. The intricacy of various measurement processes further hinders the development of a comprehensive methodology to ascertain measurement accuracy. The predominant approach in use is the utilization of direct methods. To find out how much gas is released, you multiply the ventilation rate of the enclosure by the methane concentration inside. Then, you subtract the concentration in the background, as outlined by Holden *et al*. (2021). Ventilation rate consists of three primary approaches to calculate methane emission: the utilization of internal tracer gas, external tracer gas, and the application of sensors. On the other hand, to determine the emission rate, it is necessary to measure methane concentrations both within and outside the barn. Powers and Capelari (2016) outlined numerous methods frequently utilized to measure CH4 concentrations. These include gas chromatography, infrared spectroscopy, Fourier transform infrared spectroscopy, photoacoustic spectroscopy, mass spectrometry etc

Apart from the open-path laser method mentioned earlier, there has been a growing utilization of airplane, satellites and drones in the past five years to aid in greenhouse gas calculations and approximations, predominantly relying on the upward method.

Influence of Ruminants on Climate: Climate change is a term used to describe any major long-term change in the Earth's weather. Global warming is a term used to describe a shift in the climate that increases the average temperature of the lower atmosphere. Although there are several potential reasons for global warming, the most frequent is human activity, notably the high emissions of greenhouse gases (Moumen *et al*., 2016). In the same way, Giuburunca *et al*. (2015) described that Changes in weather conditions for longer periods refer to climate change. The change in the average temperature of the lower atmosphere has increased due to the difference in weather conditions known as global warming.

Ruminants have a complex digestive system that digests fibrous feed into a nutritious form with the help of microflora present in the rumen but yield CH_4 gas as a final product of rumen metabolism that contributes to GHGs (Chhabra *et al*., 2009). Enteric fermentation and methane production dependency changes from species to species. Ruminants also release gases other than methane, such as carbon dioxide and nitrous oxide; however, methane contributes more to global warming (Gill *et al*., 2010; Gloub *et al*., 2013). These are the largest components that interfere with global warming and are related to the livestock sector (Sejian *et al*., 2010). These gases permit anaerobic fermentation and manuring of the livestock sector (Naqvi & Sejian, 2011). Methane gas generation occurs when the environment is anaerobic, such as in ruminant enteric fermentation and manure processing under anaerobic conditions and during rice field production, which interferes with methane production and contributes to global warming (Knapp *et al*., 2014; Zhang *et al*., 2011).

The important gases that interfere with greenhouse gases are CH_4 and N2O, which are formed by anaerobic fermentation in the rumen and when dung is stored. Methane has 28 times greater results on global warming than CO2. N2O are 265 times more affected by global warming than carbon dioxide, which is produced by manure and fertilizer applications (Stocker *et al*., 2013). Researchers examined that Fodder production along with connected soil CO2 and nitrous oxide releases is another significant problem for animals. Soil carbon dynamics release soil CO2, which includes the decomposition of plant residues, mineralization, and production of fertilizers and pesticides. Nitrous oxide is produced when inorganic and organic fertilizers are used on land.

Abdelmajid *et al*. (2016) described that Buffalo, sheep, goats and cattle are distinctive ruminants owing to their unique digestive system. Their digestive system performs a special function of converting waste plant material into beneficial nutrition-rich food and fibre. A powerful gas, CH_4, is also produced in this digestive system owing to the fermentation process in the rumen, which affects the global climate. Greenhouse gases are delivered to the environment by both common origins and anthropogenic activities. Environmental modification is viewed as a main danger to the existence of numerous species, biological systems and manageability of domesticated animal frameworks in different areas of the globe (Ingale *et al*., 2015).

Klopatek (2016) reported that According to the Environmental Protection Agency in the United States in 2012, methane emissions from ruminants are the major cause of global warming due to gastrointestinal fermentation. In the United States, 25% of methane comes from agriculture-related sources.

Impact of Enteric Methane on Global Warming:

Methane has been linked to rapid warming events in Earth's history, with destabilized methane hydrates potentially causing drastic and quick planetary warming. Methane has a lifespan of about 12 years. In the initial two decades after being released into the air, it can trap 84 times more heat than C02 (FAO, 2016). Enteric CH_4 production was the most important GHG emissions from ruminant agriculture. Methane, which is mainly yielded by anaerobic enteric fermentation and dung stock, has a profound effect on climatic global warming posing health risks, and affecting air quality and vegetation. (Grossi et al., 2019)

Lascano *et al*. (2011) noted that methane has 28 times greater potential for climatic warming than carbon dioxide over a hundred years. Approximately 70% of methane emanations from the agricultural sector are attributed to rumen fermentation (FAO, 2016). According to IPCC (2007), between the pre-industrial periods and 2005, agricultural activities increased the global atmospheric concentration of methane by 251 per cent. Understanding the interactions between methanogens and other rumen microbes is critical when considering methane mitigation strategies. Methane can be reduced effectively in one of two ways: directly by affecting methanogens or indirectly by strategically increasing the availability of substrates for methanogenesis. CH_4 production from the livestock sector is the capital cause of global warming. Enteric fermentation is caused by 1/3 of CH_4 production which takes place in ruminants. In 2016 methane produced from fermentation was the major contributor of GHG 39% globally (FAOSTAT, 2019). Since 1970 CH_4 production has increasing worldwide.

Ingale *et al*. (2013) found that, in several regions of the world, global warming is viewed as a serious challenge to the existence of numerous species, ecologies and animal production systems. Santra *et al*. (2012) reported that both anthropogenic sources and natural sources produce GHGs in the environment. A significant portion of global warming is caused by livestock, This review evaluates the accuracy, usefulness, and practicability of the numerous options for mitigating risk that have been suggested In recent years, by both scientists and practitioners. This review spans the breadth of the literature on mitigation Kvalevåg *et al*. (2013) concluded that methane causes 28 times more global warming than carbon dioxide and is one of the most initiative gases that increase global warming. Methane production from livestock ruminants interferes with one-third of global warming (Lassey, 2014)

CH_4 production by the livestock sector is the main cause of global warming. Enteric fermentation is the cause of 1/3 of the CH_4 production that occurs in ruminants. In 2016, methane produced from fermentation was the major contributor to global GHG emissions (39%) (FAOSTAT, 2019). Since 1970 CH4 production has been increasing worldwide but according to Nielsen *et al*., (2017) due to a reduction in animal numbers, methane production has also decreased in Denmark.

Methane Reduction Strategies: As a result of enteric fermentation, methane gas is produced by the ruminant complex digestive system, due to the methane production in rumen carbon losses that occur in the rumen, resulting in energy wastage, and many studies have introduced different strategies to suppress CH_4 emission and enhance the efficacy of production. Various methods have been used to decrease CH_4 emission and its effect on the atmosphere in the livestock sector (Abdalla *et al*., 2012; Patra & Yu, 2013). Strategies are used to reduce the emission of methane by genetic selection, in which the selected animal produces low methane, improves the nutritional value of feed components, enhances the grazing area, proper management of grasses, full care and proper health management of animals, and dietary composition by using urea molasses treatment that helps in the low production of methane (Sejian *et al*., 2011).

Dietary Manipulation: Manipulation of feed formation has been examined as a potential mitigation strategy. Studies are being conducted to evaluate the impact of feed manipulation on CH_4 emissions in the rumen. To calculate the daily methane production, CH_4:CO2 is used in the equation with the performance characteristics and diet, by measuring short-term gaseous emissions of methane and CO2. By-product inclusions, forage quality, and use of Monessen have been evaluated in diets fed to growing ruminants, and diet quality was found to be the main determinant of methane production (Kelly *et al*., 2023)The elements in the diet fed to ruminants, especially carbohydrates, are essential for CH4 emission because they can affect the pH of the rumen and change the microbiota present CH4 generation is more closely correlated with hemicellulose and cellulose digestion than with soluble carbohydrates (Johnson *et al*., 1995).

Plaizier *et al*. (2008) experimented and showed that the efficiency of transit from the stomach can be accelerated and ruminal pH can be decreased by improving the proportion of quickly fermentable carbohydrates in the feed. This increment in the passage rate can shift methanogenesis to the hindgut and manure, possibly setting off the reduction in ruminal methane output. Ruminant ingestion of fast fermentable carbohydrates can boost the assembly of volatile fatty acids. The pH of the rumen decreases, causing subacute acidosis in the rumen, and the ruminal microbiota is disrupted if volatile fatty acid generation is greater than absorption. (Hindrichsen *et al*., 2006).

The feed consumed by animals (sheep, goats and cattle) has an important impact on methane production. Feed offered and methane production rate show inverse relationships in ruminants; therefore, strategies should be adopted to reduce methane production by changing the feed composition (Hammond *et al*., 2013). When concentrate feed is used for ruminants, methane production decreases because of the lower acetate and propionate ratio in the feed (Bannink *et al*., 2011). By using the starch-based diet, the propionate ratio increases due to amylolytic bacteria, which results in lower ruminal PH and depletion of methanogenic bacteria activities (Hegarty, 1999). The use of fibrous feed results in an increase in methanogenic bacterial activities due to the presence of methyl groups, which increases methane production and reduces the propionate ratio (Hegarty, 1999).

Camila *et al*., (2018) expressed that the addition of concentrates to the diet was an impressive strategy to minimize CH_4 production. In milking cattle, it is rarely observed during delayed lactation. This experiment was led to investigate the influence of concentrate supplementation at two different levels on methane emission and milk production in late lactation .24 Holstein Friesian cows in late lactation were supplemented daily during milking time with 8 kg of hay and 2 kg of fresh grass. On day 21 of the experiment, CH_4 production was calculated using the sulfur hexafluoride tracer method for seven days. Milk yield, milk fat, and milk lactose proportion were not affected by any of the treatments. In cow milk, 8 kg of concentrated protein was increased. A higher level of concentrate increases only the weight but does not improve the condition score. The treatment of 8 kg increased the total methane ejection by 10.7%, as methane production decreased by 12.7%. Treatment did not affect the methane intensity. Concentrate supplementation in the diet was ineffective in reducing the intensity of methane emissions during delayed lactation.

Hristov *et al*. (2015) claimed that bromo-chloromethane may efficiently reduce methane, but it has an adverse effect on the ozone layer and causes depletion. Bencher, (2016) concluded that monensin had different effects on methane reduction. Enhances the efficiency of animals and changes the end product of fermentation, thereby minimizing acetate formation, which reduces methane production. An anaerobic environment is beneficial for microbes; if a yeast-containing product is fed directly to an animal, it will clear oxygen. It improves the performance of the digestive system and increases the number of microbes, thereby reducing methane production (Bayat *et al*., 2015). Dinh *et al*., (2019) declared that enhancing the quantity of concentrate and crude protein will minimize the CH_4 production increase dry matter intake and also enhance the meat production. The selection of a unique protein level in the diet will reduce CH_4 production and increase the production rate of animals.

Animals growing on green forage or silage exhibit better fermentation, milk quality and quantity. The use of corn silage increases palatability, rumen health, digestibility, passage rate and nutrient absorption which affect methane emission potential in manures (Appuhamy *et al*., 2014). Probiotics are beneficial bacteria that aid in the digestion of feed in the rumen. They are normally used in the diet to increase milk production and improve feed digestibility. These bacterial species produce various products that reduce methane emissions from the rumen (Mcallister *et al*., 2011). Greenhouse gas emission by ruminants is reduced by changing the dietary composition, improving the consumption process and introducing modified food by evaluating the nutritional value of food and their impact on climatic changes by using different strategies (Mechado *et al*., 2011). Usually, in dry tropical areas, ruminant livestock feed forages of inferior quality with low CP and DE and maximum contents of NDF and lignin, which causes an upsurge in the release of CH_4, which reduces the capacity of N and energy utilization (Chaokaur *et al*., 2015).

The manipulation of feed composition emerges as a promising opportunity for mitigating methane emissions in ruminants, with studies focusing on its impact on rumen methane production. Strategies such as optimizing carbohydrate composition to influence ruminal pH and microbiota dynamics show potential for reducing methane output while enhancing animal performance.

Monensin: Monensin is an antibiotic produced by Streptomyces cinnamonensis that helps animals gain weight and consume more food (Sauer *et al*., 1998). Monensin is used worldwide as a feed additive for cattle because it has the potential to minimize the production of methane. Monensin, a carboxylic polyether ionosphere is commonly used to improve energy efficiency (Appuhamy *et al*., 2013). Dietary addition of monensin in animal feed has demonstrated the ability to decrease methane emissions in ruminant animals including dairy cattle, without negatively impacting livestock efficiency. In a meta-analysis of research investigations, it was observed that monensin led to a 5.4% decrease in both daily methane production and methane yield (Marumo *et al*., 2023).

Several feed additives, including saponins, tannins, flavonoids, probiotics and organic acids, have been explored for their potential to decrease methane production (Króliczewska *et al*., 2023). Nevertheless, monensin stands out as a sustainable and widely used feed additive in both beef and dairy production. The utilization of feed additives like monensin holds significance in mitigating methane emissions from ruminants, a factor contributing to global warming and diminishing feed efficiency (Perna *et al*., 2020).

Kelly& Kebreab, (2023) investigated that monensin is used as a mitigation strategy for CH_4 production because it inhibits gram-positive bacteria responsible for methanogenesis, these effects caused by monensin are facilitated by the capability to delay iron flux. Monensin inhibits the growth of microorganisms that provide substances for methanogens, ultimately hindering methane production in the rumen. Further investigation is required to progress the development of compounds which reduce CH_4 to mix in the diets of ruminants towards complete market maturity. This will enable farmers to attain cost savings on feed while concurrently reaping environmental advantages.

Organic Feed Additives: Biochar has gained significant popularity in the past decade due to its proven benefits in enhancing development, egg production, and blood count, inhibiting the production of rumen microbes and reducing CH_4 emissions (Man *et al*., 2021). Seaweeds, or macroalgae, categorized into brown (Phaeophyta), red (Rhodophyta), and green (Chlorophyta), have emerged as preferred feed supplements owing to their ability to mitigate methane production (Roque *et al*., 2021). Numerous in vitro investigations on seaweed addition in diet have revealed an inverse relationship with methane production, particularly with Asparagopsis taxiformis (Min *et al*., 2021) and its counterparts, leading to a substantial reduction in in-vivo CH_4 emissions in dairy cattle, the reduction ranges from 50% to over 80%. (Roque *et al*., 2019).

Additionally, probiotics like chitosan, inulin and yeast by-products have demonstrated the potential to mitigate the release of CH_4 from the rumen by altering the Composition of the bacterial population in the rumen structure (Tong *et al*., 2020). Yeast products and inulin stimulate the proliferation of additional rumen bacteria, engaging in competition with methanogens for available hydrogen. (Vallejo-Hernández *et al*., 2018), Chitosan interferes with the cell wall permeability of methanogens, resulting in a reduction in cell count (Zanferari *et al*., 2018). Nevertheless, the utilization of these prebiotics in ruminants remains relatively restricted related to other feed supplements and permits additional studies to promote wider implementation (Sun *et al*., 2021).

Different organic acids had different effects on reducing methane emissions. In 2009, Wood and colleagues treated lambs with 100 g/kg fumaric acid and discovered a 62–76% reduction in methane emissions. According to research, the feed has an impact on how well organic acid supplements reduce methane, with higher-concentration meals having a stronger impact. Organic acids can have a positive impact on CH_4 mitigation, although further in vivo research is required (Wood *et al*., 2009; Foley *et al*., 2009).

Methanogen vaccine: Buddle *et al*. (2011) reported that there is some discussion regarding the safety of adding chemical supplements to animal feed. Humans use all livestock commodities, including milk, meat, and eggs; this raises questions about how safe they are. A cutting-edge artificial immunity method was recently established to boost the effectiveness of nutrient uptake in ruminants while reducing methane emissions.

Clark, (2013) examined that giving the animal an injection of the vaccine to boost its immune system and evoke an immunological response to generate antibodies against the methanogens. Wright *et al*. (2004) noted that the invention of a vaccination that stimulates ruminant immune systems to yield antibodies in contradiction of CH_4-producing microbes was another CH_4 treatment approach that has been researched. Two vaccines were developed called VF7 and VF3 that induce a 7.7% reduction in methane emission per unit of dry matter intake. The same research team developed a vaccine. Three vaccinations with five different methanogenic strains were administered to sheep (Williams *et al*., 2009).

Wright *et al*. (2007) claimed that methane output increased by 18% after vaccination, even though the vaccine only specific 52% of the methane-producing microbes detected in sheep rumens, directing the researchers to conclude that the vaccine did not specifically target the microbes responsible for producing the majority of the CH_4. The fact that the population of methane-producing microbes in the rumen can vary depending on the feed and host site makes a single-targeted approach challenging when using vaccines against methanogens. A more comprehensive methodology and in-depth knowledge of the rumen methanogen population are undoubtedly essential for a successful approach because this failure may be caused by the appearance of new methanogens after vaccination.

Nitrates: According to Olijhoek *et al*. (2015), nitrate directly reduces emissions and quadratically expands hydrogen discharge from milking animals without having a significant impact on blood MetHb levels or intestinal fermentation, and it has no negative effects on the digestibility of rumen and digestive tract supplements or the combination of rumen microbial proteins. In general, nitrate is a potential strategy for reducing methane; however, it should be noted that if nitrate is placed on top of a diet that is sufficiently high in protein, there may be increased nitrogen contamination.

Lipids: Dietary lipids exert their CH4 mitigating impact through various mechanisms, such as toxicity to methanogens and protozoa. Additionally, the bio-hydrogenation of unsaturated fatty acids (UFA) acts as a limited hydrogen sink, and there is a shift in rumen fermentation that encourages propionate production, ultimately leading to reduced CH4 production (Newbold *et al*., 2015). Furthermore, due to their predominantly un-fermentable nature (excluding the glycerol component), substituting carbohydrates with dietary lipids contributes to these effects.

The addition of dietary lipids proves to be a successful strategy for mitigating CH_4 emissions, with its effectiveness depending on factors such as the formula, source and quantity of the supplementary fat. The level of saturation, lengths of fatty acid carbon chains, as well as the nutrient and fatty acid composition of the base feed also influence the overall efficacy of this approach (Patra, 2013).

Lipids can reduce methane production in several ways. Rumen is unable to ferment the fatty acid present in lipids, which leads to a reduction in carbohydrates that are essential for fermentation and minimizes methane production (Fiorentini *et al*., 2014).Due to their impact on anaerobic fermentation, lipids (fatty acids in oils) being conducted both in vitro and in vivo as alternatives for supplemental diets. By inhibiting protozoa, boosting the formation of propionic acid, and "bio hydrogenating unsaturated fatty acids," raising the lipid content of the food has been shown to reduce rumen methane production (Johnson K & Johnson D, 1995).

Using fat supplementation results in a decrease in methanogenic activity without changing the pH of the rumen or instead using concentrates (Sejian *et al*., 2011; Sing, 2010). The use of fat in the feed diminishes the activity of methanogens by reducing the colonies of lipids and by improving the amylolytic bacteria that increase the propionate ratio. When using oils, unsaturated fatty acids absorb and accept hydrogen, resulting in a decrease in carbon dioxide production; these fatty acids form bonds and destroy the dietary membrane that acts as a transporting system (Beauchemin *et al*. ., 2005). Eugene *et al*. (2008) observed that dietary fat introduction affects methane production in a way that reduces the fermentation of organic matter and acts as an anti-methanogen weapon. Ether extract also reduces methane production, and the provision of lipids in diets as a supplement with more ether extract also decreases methane production.

Researchers have explored the interactions of incorporating dietary lipids with various mitigation approaches. The combined use of canola oil and 3-NOP demonstrated a confirmed additive effect in reducing CH_4 emissions (Zhang *et al*., 2021), while the combination of linseed oil with nitrate also exhibited a similar positive impact on CH_4 reduction (Guyader *et al*., 2015). Conversely, no additive result was observed when soybean oil was paired with tannin-rich extracts (Lima *et al*., 2019) or saponins (Mao *et al*., 2010).

More exploration is needed to find affordable and sustainable sources of fats and lipids to determine the right amount to reduce CH_4 emissions without affecting how well animals digest their food and produce. We also need studies to understand the long-term effects of adding fats and lipids to reduce CH_4. Since this strategy can impact feed emissions and nutrient excretion, we should assess how well it works using a life cycle assessment (LCA).

Oils: Several plant-derived oils provide sufficient quantities of medium to long-chain fatty acids (Soliva *et al*., 2004). Studies have shown that sunflower oil causes about an 11.5-22% decrease in CH_4 production (Beauchemin *et al*., 2007). Lactating cows supplemented with linseed oil at 5% of their dry mass showed a decrease in methanogenesis by approximately 55.8% each day (Martin *et al*., 2008). Tomkins *et al*. (2015) examined the antimicrobial effects of EOs. Many essential oils inactivate the enzyme and cause an interruption in the cell membrane, which causes a reduction in microbial activity, leading to low methane production. By using various essential oil supplements (coconut oil and sunflower oil), methane gas production decreases (Chuntrakort *et al*., 2014). Coconut oil reduces methane production from 13 to 73% based on its level of inclusion and varies from species to species (Machmuller *et al*., 2000).

Essential oils, including those derived from oregano, thyme, and garlic, have demonstrated the potential to reduce methane (CH_4) production in in-vitro studies (Cobellis *et al*., 2016). However, findings from experiments conducted in in-vivo have yielded less convincing results (Hristov *et al*., 2022). Some commercially available feedstuffs comprising diverse EO have exhibited a capacity to reduce enteric methane emission although with varying outcomes in in-vivo experiments. For example, oregano oil product and a combination of green tea extract, when administered to milking dairy cattle, had no impact on overall methane emission or concentration of methane but did lead to a reduction in CH_4 yield by 16 to 22% (Kolling *et al*., 2018). Another example involves a livestock feed supplement developed by Mootral GmbH incorporates a unique blend of citrus extract and allicin from garlic. This innovative product is designed specifically for feedlot steers, offering a natural and effective solution to enhance their overall well-being and performance, resulting in a 23% reduction in enteric CH_4 yield after 12 weeks of addition to diet; however, the persistence of this reduction was not determined (Roque *et al*., 2019). Additionally, a meta-analysis reported a 9% decline in absolute CH_4 production over the long term when a mixture of coriander, eugenol, geranyl acetate and geraniol was given to dairy cattle at a proportion of 1 g/d (Blanche *et al*., 2020).

The most popular oil used in methane reduction strategy is coconut oil, which has been found to cause a significant reduction in ruminal methanogenesis by up to–13-72% depending on the diet, added quantity, and livestock species used (Jordan *et al*., 2006) Because palm kernel oil has a 3:1 ratio of lauric to myristic acid, it is more effective than coconut oil in reducing methanogenesis. There is an indication that palm kernel oil is more effective than olive oil because it reduces CH_4 production by up to 34% compared with olive oil by 21 %(Dohme *et al*., 2000).

More in-vivo studies are required to find out how well essential oils work because there are so many types available (more than 3,000). To figure out which oils are best at reducing CH_4 in the digestive system more research is needed. Some concentrations that work in test tubes are not practical for use in vitro, so we need to find the right amounts to use in different diets. Studies on animals are more important than studies in test tubes because animals might react differently. We also need to see how essential oils affect the quality of meat and milk from animals. Studying how essential oils work together with other methods to reduce gas is also a good idea.

Defaunation: Defaunation, which involves removing protozoa from the rumen, has been used to study the function of protozoa in the rumen as well as their impact on methane generation. Rumen Together, protozoa and methanogen collaborate in the transfer of interspecies hydrogen, giving methanogen the hydrogen it needs to convert carbon dioxide to methane. According to estimates, 9–37% of the CH_4 produced in the rumen is produced by methanogens that are linked to ciliated protozoa, removal of protozoa minimizes CH_4 by up to 10%. (Arndt *et al*., 2022).Protozoa removal from the rumen has been achieved through various methods such as the application of chemicals and lipids, freezing of rumen contents, or the isolation of neonatal (Newbold *et al*., 2015). The defaunation effect on methane production is a long term of about 365 days (Ranilla *et al*., 2004). Defaunation increases the digestion of nitrogen but adversely affects the digestion of the cell wall, but maintains the reduction of methane (20%) in sheep for approximately two years (Morgavi *et al*., 2008)

Maintaining animals free of protozoa in commercial production environments poses a significant challenge due to rapid re-inoculation and cross-contamination between animals. Therefore, defaunation could be a helpful strategy if we can find simple and long-lasting ways to make animals protozoa-free. Defaunation offers insights into rumen function and methane reduction by removing protozoa, yet its long-term impact on digestion and methane production underscores the need for sustainable methods. Despite challenges in maintaining protozoa-free environments, effective strategies could offer valuable solutions for livestock production's environmental footprint.

Plant Compounds: Many plant secondary metabolites, such as tannins and saponins, are used to reduce methane production by methanogenic bacteria (Kobayashi, 2010). In the previous 10 years, natural secondary metabolites of plants have been used as feed additive supplements instead of chemical strategies, resulting in the reduction of methane emissions. Saponins do not have a direct impact on methane production, but in some instances, saponins decrease the protozoan colony and inhibit the growth of methanogens by increasing the propionate ratio (Patra & Sexena, 2010). Tannin is a natural component of plants in the form of polyphenols, but it is attached to proteins and carbohydrates and is unavailable to animals, although it has a beneficial effect on the reduction of methane produced by animals. Burt *et al*. (2004) wrote that Saponins, condensed tannins, and essential oils are the 3 main plant chemicals that are beneficial in lowering CH_4 emission in vitro. By limiting hydrogen availability and inhibiting protozoa, saponins effectively reduce methanogenesis.

Calsamiglia *et al*. (2007) found that condensed tannins containing Lespedeza cuneata were supplemented in goats and found to lower CH_4 by up to 57% in terms of g/kg of DM consumption, parallel to goats fed a blend of Festucous arundinaceous and Digestive ischemia (Guo *et al*., 2008). Condensed tannins directly inhibit luminal methanogens and indirectly limit methanogenesis by reducing hydrogen availability (Tavendale *et al*., 2005). Essential oils have antibacterial properties that inhibit Gram-positive bacteria like that of monensin. The scientists concluded that in vitro methane production was probably caused by less feed fermentation and digestion because no in vivo effects of plant supplementation were observed (Holtshausen *et al*., 2009).

Genetic selection: Different animals in a group can produce varying amounts of methane (CH_4), even when they are in the same herd and eating the same feed, this was pointed out by De-Haas *et al*., (2017). Rowe *et al*. (2019) discovered that the inheritability of total methane (CH_4) production in cows and sheep is moderate. This surpasses the inheritability of CH_4 yield in sheep. Similarly, in dairy cattle, the heritability of CH_4 production was lower, according to Manzanilla-Pech *et* *al*. (2021). It's important to mention that, just like any specific trait we focus on, the decreases in methane (CH_4) production due to host genetics are lasting and build up over time, as highlighted by De-Haas *et al*. (2021).

Cavanagh *et al*. (2008) mentioned that Using the natural differences or variations among animals to selectively breed that produce less methane would be another low-cost mitigation strategy that has a long-term impact. Animal genetics may have an effect on release amount at the individual animal level as well as the entire farm scale, according to recent studies (Wall *et al*., 2010). Pinares-Patiño *et al*. (2013) and Clark (2013) conducted a study and concluded that a particularly cost-effective technology that results in long-lasting and cumulative performance improvements is the genetic improvement of livestock. Animals that value better energy ratios should logically result from genetic selection based on improved feed efficiency so that they generate less methane. This could be regarded as a selection that is more determined by the capacity of animals to produce less CH_4. According to Yan *et al*. (2010), choosing dairy cows with high rates of milk production and energy conservation is an efficient strategy to lower methane production from lactating animals.

If genetic selection strategies are used to mitigate methane, they have a long-term effect on reducing methane production (De *et al*., 2011; Capper *et al*., 2009). Genetic selection improves animal performance by enhancing production efficiency and reducing waste removal in the livestock sector through its efficient production system, consumption of nutritive feed diet, and less energy wastage (Wall *et al*., 2010). The impact of selection at the level of a single animal may be translated to impacts at the stage of a farm or higher system, with the aid of a more thorough life cycle evaluation of methane reduction (Del Prado *et al*., 2010)

One of the primary hurdles in identifying ruminants with low methane emission lies in the challenge of calculating CH_4 levels in a higher number of animals on commercial farms, a task beyond the means of maximum commercial producers (de Haas *et al*., 2021). Utilizing sniffers to calculate methane quantity in breathing out the air, particularly at feeding or during milking, has demonstrated some success (Difford *et al*., 2019). The process of measuring methane production extends over several weeks, and the implementation of a genetic selection program demands thousands of measurements (Løvendahl *et al*., 2018). However, focusing on CH_4 production in sires has the potential to accelerate the dissemination of genetic advancements. Various substitutions for CH_4 production, including feed consumption, feeding behaviour, rumen volatile fatty acid (VFA) concentration, microbial count composition and methanogen membrane lipids in faecal excretion, have been explored as substitutes to direct measurement (Beauchemin *et al*., 2020). Although the initial results of estimating milk fatty acid composition through mid-infrared spectroscopy were promising on an experimental scale, they proved less effective under commercial conditions with a larger number of animals (Løvendahl *et al*., 2018).

In conclusion, Animal breeding stands out as one of the limited anti-methanogenic approaches applicable to extensive production systems without supplementary animal feed. This method offers an additional benefit as it is expected to have minimal impact on other greenhouse gas (GHG) emissions both upstream and downstream. However, the primary hurdles in the selection of animals with low methane emission include the potential presence of unwanted correlations between methane emission and production performance, as well as the development of dependable and feasible proxies for predicting CH_4.

Bee Propolis Extract: Propolis, a substance sourced by honeybees from the secretions and buds of diverse plant types, represents a plant-origin bee product. Its potential application in ruminant diet as a feed additive has been explored (Santos, *et al*., 2016). Notably, propolis induces changes in total volatile fatty acids (VFA), thereby stimulating rumen microorganisms to consume hydrogen. This has prompted a call for comprehensive investigations into the impact of propolis on mitigating methane-based emissions. Such studies should consider factors like phytogeography, botanical origin, environmental circumstances and means of collection to enhance the efficacy of propolis applications for methane mitigation in vivo (Morsy *et al*., 2015).

The phenolic compounds present in propolis have been identified as key contributors to the enhancement of rumen fermentation and the reduction of NH3-N (Ehtesham *et al*., 2028) and methane emissions. Researchers such as Morsy *et al*. (2021) have demonstrated the anti-methanogenic activity of bee propolis extract, establishing its potential for diminishing methane emission. Additionally, Kara *et al*. (2014) have observed that propolis exhibits the capacity to decrease methane production within the rumen.

In conclusion, propolis derived from various plant sources by honeybees, offers promising potential as a feed additive in ruminant diets, notably in mitigating methane emissions by stimulating rumen microorganisms. With phenolic compounds identified as key agents, its anti-methanogenic properties underscore the need for comprehensive investigations into its application, considering factors like botanical origin and environmental circumstances to enhance methane mitigation in vivo.

Use of algae: Different researchers like Brooke *et al*. (2020); Makkar *et al*. (2016); and Machado *et al*. (2014) reported that red algae reduce the methanogenesis process and studies confirm that the addition of micro and macro algae as feed additives reduce the methane production. Bromoform (CHBr3) emerged as the most potent active substance in algae for suppressing methanogenesis. It is crucial to explore the impact of this compound on both animals and atmospheric chemistry (Glasson *et al*., 2022). As highlighted by Min *et al*. (2021) there are reservations regarding the sustainable cultivation of seaweeds and the potential adverse effects of bromoform on rumen digestibility and overall animal health.

The addition of algae as an anti-methanogenic strategy shows promise in confined and mixed systems, but its implementation in extensive systems presents considerable challenges. To effectively supplement animals in such expansive settings, innovative animal delivery mechanisms must be planned to ensure the preservation of the bioactive compounds' efficacy within algae.

Managemental Approach: Calsamiglia *et al*. (2007) described that by increasing the level of the feeding of animals, the passage rate increased and as a result, bacteria will unable to catch the feed particles in a short duration of time and fermentation will be reduced in turn decrease CH_4 production in the rumen. Proper grazing of pastures by animals affects methane production in such a way that continuous grazing will cause a decrease in passage rate and less fermentation which will negatively affect methane production (McCaughey *et al*., 1997).

Several alternative manure management practices can help reduce methane emissions from livestock. Some of these practices include the anaerobic Digestion process involves capturing methane from decomposing manure and converting it into renewable energy, such as biogas or electricity (El Mashad *et al*., 2023). Scientists reported that Solid or Dry Scrape Manure Management Systems involve scraping manure from the surface of a barn or storage area and allowing it to dry, reducing the Conditions lacking oxygen that result in the generation of methane report also shows that Solid-Liquid Separation Systems separate solid and liquid components of manure, allowing the solids to dry and reducing the anaerobic conditions that lead to methane production. Compost-bedded pack Barns were designed to allow manure to dry and aerate. Researchers also described in his report that allowing animals to spend more time at pasture can help reduce manure accumulation and minimize the anaerobic environment subsequently methane emission. These alternative manure management practices can help reduce methane emissions from livestock operations while also providing additional benefits, such as better quality of air and water, reduced smell and accumulation of manure and compost.

Consideration of using Feed additive: Utilization of antibiotics in livestock has been prohibited due to the adverse impacts they pose. Specifically, the European Union has banned the use of ionophore antibiotics and other chemical supplements since 2006, mentioning concerns about the emergence of microbial resistance. Consequently, in light of these characteristics found in animal products, researchers are actively exploring alternative approaches to enhance animal production while simultaneously reducing environmental pollution (Dey *et al*., 2021).

Despite the considerable potential for reducing CH_4 production from ruminal fermentation, there has been limited progress in commercializing such initiatives. Bovaer™ serves as a noteworthy case of a positive commercial product. The producer's site claims that administering a 1/3tbs of Bovaer per cattle daily inhibits the enzyme responsible for triggering CH_4 emission in the rumen of cattle, constantly resulting in a reduction of approximately 30% in enteric methane emissions for dairy cattle and the case of beef cattle’s, even larger proportions up to 90%. In September 2021, DSM obtained a full governing agreement for the commercialization of Bovaer from both Brazilian and Chilean authorities, allowing its experiment in beef, dairy cattle, goat and sheep. Subsequently, in February 2022, DSM secured EU marketplace approval for Bovaer for dairy cows. This approval followed a positive EFSA View confirming that Bovaer effectively decreased CH_4 from dairy cattle and is believed harmless for both the animals and consumers. Notably, this marks the first instance of a feed additive authorized in the EU for its ecological welfare being eligible for marketing (DSM, 2022).

It is crucial to convince farmers with different herd sizes to embrace strategies that reduce CH_4 production. The correlation between lower methane emissions, heightened feed efficiency, and consequently improved economics offers a compelling argument for securing support throughout the chain of processes involved in the ruminant industry. The economic benefits are direct, while the climate advantages were obvious over long durations. It's crucial to acknowledge the adverse influence of weather variation on livestock production, as highlighted by studies such as Palangi *et al*. (2022) and Chen *et al*. (2017) mitigating CH_4 emissions becomes a priority for those involved in meat and milk production with ruminant livestock due to the negative feedback loop associated with climate change.

Furthermore, there is the potential to accrue carbon credits for reducing enteric methane. In Australia, the Department of Primary Industries and Regional Development, Government of Western Australia, two approved methods for feed additives or supplements have been authorized to control methane emissions. This involves providing nitrates to beef cattle and adding dietary supplements for milking cows. These initiatives not only align with environmental sustainability but also offer noticeable economic benefits for farmers in the short term and contribute to addressing the challenges for longer periods of time posed by climate change in livestock production.

Ruminant-Related CH_4 Abatement: Economic Perspectives: In a recent analysis conducted by DeFabrizio *et al*. (2021), the costs of mitigating CH_4 emissions were examined. The study revealed that feed additives are considered among the more expensive procedures, while "animal health monitoring" exhibits an equivalent influence on CH_4 potential and can even result in the reduction of cost. It is essential to note that globally, there are over 1.5 billion cattle, and educating each small-scale farmer and cattle breeder, regardless of herd size, on the application of tailored measures for their specific industry is crucial. This undertaking is of utmost importance and should be guided by a consensus on the most effective controls for mitigating CH_4 emissions.

Future Directions

The livestock sector is the largest source of methane emissions, and reducing these emissions is crucial to mitigating climate change. The literature suggests that reducing methane emissions from the livestock sector is necessary and feasible through more efficient production, dietary changes, and manure management (Reisinger *et al*., 2021). Future directions for methane mitigation from the livestock sector and techniques include:

1. Improved feed management: Optimizing animal diets and feeding strategies can help reduce enteric fermentation and methane production. This includes providing animals with more fibre and fewer grains, as well as offering feed additives that can improve digestive efficiency and decrease CH_4 production. Developing and implementing more efficient production practices to minimize the release of CH_4 (Reisinger *et al*., 2021). Developing and implementing dietary changes to reduce methane emissions (Thompson *et al*., 2020) and Encouraging the use of feed additives to reduce methane emissions (Islam and Lee, 2019)

2. Manure management: Implementing anaerobic digestion systems can convert manure into biogas, reducing methane emissions and producing renewable energy. Additionally, separating solids from liquids in manure can reduce the overall methane production potential of the manure. Developing and implementing manure management practices to reduce methane emissions (Tseten *et al*., 2022). Encouraging the use of Technologies to reduce enteric methane emissions in ruminant livestock and the use of alternative manure management practices.

3. Methane inhibitors: Feeding animal diets containing methane inhibitors, such as nitrates can reduce enteric methane emissions by 2% to 4% without negatively affecting animal performance.

4. Genetic selection: Selecting animals with lower methane emissions through genetic improvement programs can help reduce the overall methane production from the livestock sector.

5. Housing and bedding: Improving housing and bedding management can help reduce methane emissions from animal waste. This includes providing dry bedding materials and maintaining proper ventilation to reduce moisture and odor.

6. Precision livestock farming: Implementing precision livestock farming practices, such as pasture and range management, can help reduce methane emissions by optimizing animal numbers and resource management.

7. Methane capture and utilization: Developing technologies to capture and utilize methane from livestock operations can help reduce emissions and produce renewable energy. This includes anaerobic digestion systems and other methane capture techniques

8. Genetic Selection: Identifying and selecting for animals with favorable genetic traits that reduce methanogenesis in the rumen can lead to long-term, sustainable reductions in methane output. Also Advances in genomics and animal breeding techniques can accelerate the progress in developing low-methane emitting livestock (Tseten et al., 2022).

9. Microbe Level: Probiotics; identifying potential probiotics that can minimize rumen methane generation while maintaining a balanced gastrointestinal ecosystem is an attractive mitigation strategy (Tsetten et al., 2022). Probiotics that can alter the rumen microbiome composition and suppress methanogenic archaea show potential for reducing enteric methane emissions (Bruns, 2023). Further research is needed to understand the mechanisms of action and optimize the use of probiotics for effective methane mitigation.

10. Nutrient Level: Prebiotics; Dietary interventions using prebiotics that selectively promote the growth of beneficial rumen microbes can indirectly reduce methane production. Prebiotics that shift the rumen fermentation towards propionate production, which is a competing pathway to methanogenesis, can help lower methane emissions. Optimizing the type and proportion of carbohydrates in the diet, such as increasing the inclusion of starch-rich feeds, can also contribute to reduced methane output (Moss et al., 2000).

11. Plant Level: Developing and utilizing plant-based feed additives and essential oils that can inhibit methanogenic archaea in the rumen is a promising approach. Breeding and selecting for forage varieties with lower methane-producing potential, such as those with higher levels of secondary plant compounds, can contribute to reduced enteric methane emissions (Moss et al., 2000).

By implementing these future directions and techniques, the livestock sector can work towards reducing its methane emissions and contributing to global efforts to minimize climate change.

Implications

Urgency of Methane Emissions Reduction: Immediate and significant reductions in methane emissions are crucial to limit global warming and achieve climate goals, with methane playing a substantial role in near-term temperature changes. Methane abatement, especially in the next decade, can have a substantial impact on global temperature rise, making it a critical component of climate change mitigation efforts (EU, 2023).

Global Methane Pledge and Policy Framework: The Global Methane Pledge, supported by numerous nations and organizations, signifies a growing international commitment to addressing methane emissions through coordinated efforts and reduction targets (Rabe, 2023)**.** Policy frameworks, such as the EU's methane strategy, focus on reducing methane emissions across various sectors like energy, agriculture, and waste, highlighting the importance of cross-sectoral approaches in mitigating methane emissions (EU, 2023).

Technological and Regulatory Measures: Technological advancements in methane detection, measurement, and mitigation are essential for achieving emission reduction targets, emphasizing the need for research and innovation in this field. Regulatory measures, such as mandatory leak detection and repair, bans on venting and flaring, and stringent emission standards, play a crucial role in enforcing methane reduction strategies in industries like oil and gas (Pollard).

Recommendations for Researchers and Policy Makers:

Investment in Research: Researchers should focus on developing innovative technologies for methane detection, quantification and mitigation to support effective emission reduction strategies. Research efforts should also explore the effectiveness of different mitigation approaches, such as genetic selection in animals, probiotics and prebiotics, to identify the most efficient methods for reducing methane emissions at various levels (EU, 2023).

Policy Development and Implementation: Policy makers need to prioritize the development and implementation of robust regulatory frameworks that enforce methane reduction measures across industries, including oil and gas, agriculture, and waste management. Collaborative efforts at the international level, like the Global Methane Pledge, should be supported and expanded to ensure a coordinated approach to methane emission reduction globally (EU, 2023).

Public Awareness and Engagement: Increasing public awareness about the environmental impact of methane emissions and the importance of reducing them is crucial for garnering support for policy initiatives and encouraging behavioral changes that contribute to emission reductions. Engaging stakeholders, including industry representatives, environmental organizations, and communities, in the development and implementation of methane reduction strategies can enhance the effectiveness and acceptance of mitigation measures.

Conclusion: Reducing methane production from the animal sector is achievable through various means. It highlights the effectiveness of policies enhancing animal production, genetic selection in ruminants, and the impact of feed intake on methane production. While discussing inhibitory measures like dietary interventions, plant compounds, and chemical additives, it acknowledges limitations due to cost and short-term effects. The review article underscores the heritability of methane production, suggesting the potential of indirect and genomic selection for emission reduction. Additionally, it explores the role of diet, fermentable carbohydrates, fat, fiber and biotechnological methods in minimizing methane emissions. Despite challenges in modern techniques, the conclusion stresses the importance of addressing methane emissions from livestock for global temperature goals. Recommendations include more efficient production, dietary changes, manure management and advancements in enteric methane mitigation technologies, alternative manure management, and feed additives. Addressing this persistent challenge demands additional research and focused consideration. Various strategies may need to be formulated and these could vary based on geographical location and other relevant factors.

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