International Journal of Ecology and Ecosolution
Vol. 6(2), pp. 16-22, July 2019
ISSN: 2437 - 1327
Review

Strategies to reduce methane emission in ruminants

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Accepted 4 July, 2019

ABSTRACT

In this review, different approaches towards mitigation or reduction strategies of methane (CH_4) in ruminant animals are discussed. It is well documented fact that methane is one of the greenhouse gases with the potential to increase global warming. Ruminal fermentation is the major contributor to methane emission. Therefore, strategies to reduce methane output from livestock are required for ecological balance. Several strategies such as vaccination, enzyme inhibitors and phages; feed supplements, animal breeding, processing of feeds, altering the type of ration, defaunation, supplementation of fatty acids and organic acids, halogenated methane analogues, ionophores, microbial feed additives, non-ionic surfactants and sulphates are implemented. Numerous studies have been completed on use of plant secondary metabolites (PSM) in substitute for chemical feed additives because some of them modify rumen fermentation and reduce CH_4 production. Similarly, methane reduction can be performed from the manure of ruminant livestock. In general, methane emission from ruminants reduces the efficiency of nutrient utilization. Therefore, manipulation of rumen microbial ecosystem for reducing methane emission by ruminants to improve their performance is one of the most important goals for animal nutritionists. Reduction in methane emission from ruminants enhances the efficiency of nutrient utilization and increases productivity and also reduces methane impact on global warming.

Keywords: Methane, mitigation, plant secondary metabolites, ruminants, ecosystem, global warming.

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INTRODUCTION

Now a day, climate change is a major factor to the survival of many species, ecosystems and the sustainability of livestock production systems in many parts of the world. An attempt has been made in this review to understand the contribution of ruminant livestock to climate change and to identify the mitigation strategies or methods to reduce enteric and manure methane emission in livestock (Dawo, 2017). Animal husbandry (management) accounts for 18% of greenhouse gas emission (GHG) that cause global warming. Reducing the increase of GHG emissions from agriculture, especially livestock production should therefore be a top priority, because it could be warming fairly rapidly (Moss et al., 2000). Methane with the global warming potential of 25 times to that of CO_2 and longer residence time is an important GHG. This increase in the concentration of CH_4 is strongly related with increasing populations, and currently about 70% of its production arises from anthropogenic sources (Moss et al., 2000).

Agricultural activities contribute significantly to global GHG emissions; namely CO_2, CH_4, N_2O and ammonia (NH_3), which are major GHGs contributing to global warming (IPCC, 2001). In resent year, there is a growing interest in decreasing the potential threat of global warming by reducing emissions of GHGs into the atmosphere (Dawo, 2017). There is increasing awareness worldwide of the necessity to protect the environment (Meadows, 1992). Minimize the contamination of air with CO_2, CH_4, NH_3, and N_2O and other GHGs that contribute to the radioactive forcing (Tamminga, 1996). The effect of increasing the atmospheric concentration of GHGs responsible for the

radiative forcing and gradual elevation of average global temperatures, altered viability of plants, animals, insects and microbes with numerous adverse consequences to human well-being.

There are many methods of methane mitigation/reduction by the rumen microbes using various techniques have been investigated extensively with varying degree of success (Dawo, 2017). Lowering global methane emissions is an important part of any effort to reduce anthropogenic GHG emissions. However, reducing the number of ruminants is not an option as the worldwide demand for meat and milk is predicted to double by 2050 (FAO, 2008). Therefore, this review is to assess the methods of CH_4 reduction (mitigation) strategies and mechanism of action on ruminant livestock's and their manure.

STRATEGIES TO REDUCE ENTERIC METHANE EMISSION

According to Sejian and Naqvi (2012), there are two methods available by which methane production can be reduced (mitigated) in livestock. The first method is influence the availability of H_2 in the rumen and subsequent reduction of enteric CH_4 emissions by livestock, processes that yield propionate act as net proton-using reactions while those that yield acetate result in a net increase in protons. Hence, mitigation strategies aiming at reducing CH_4 production must work towards increasing the propionate production. This will reduce CH_4 production by removing some of the H_2 produced during ruminal fermentation. Other method by which CH_4 production may be reduced during the rumen fermentation process is through the provision of alternative hydrogen acceptors or sinks (Sejian et al., 2011a). Other method widely accepted is to supplement anti-methanogenic agents which will inhibit the process of methanogenesis either by directly inhibiting the methanogenic microbe in the rumen or by increasing more propionate production. In addition, strategies to mitigate net CH_4 emissions from livestock manure aim to change manure properties or the conditions under which CH_4 and N_2O are produced and consumed during manure storage and treatment (Sejian and Naqvi, 2012).

CH_4 mitigation or reduction strategies can be broadly divided into preventative and 'end of pipe' options. Preventative measures reduce carbon/nitrogen inputs into the system of animal husbandry, generally through dietary manipulation and, while a reduction in the volume of CH_4 emitted per animal may result, this is often secondary to the (primary) objective of improved productive efficiency. Alternatively, 'end of pipe' options reduce or inhibit the production of CH_4 (methanogenesis) within the system of animal husbandry (Sejian et al., 2011a). Any reduction strategies should be confined to the following general frameworks: develop priority, product demand, infrastructure, livestock resource and local resources. The most attractive emissions mitigation projects must balance the needs in all of these areas, so that no one factor creates a constraint on continued improvement in production efficiency, and the resulting CH_4 emissions reductions. Within this framework, CH_4 emissions (mitigation options) for enteric fermentation can encompass a wide range of activities across these areas. However, underlying these activities must be specific options for improving the production efficiency of the livestock. Without these options, CH_4 emissions cannot be reduced. The technologies that can reduce the amount of methane production in rumen or total release of methane into atmosphere are useful for efficient use of feed and making the environment more favorable (Sejian and Naqvi, 2012). Several options have been considered for mitigating methane production and emitting in the atmosphere by livestock, let us see in detail one by one:

Increase the amount of concentrate feeds in the diet

When we feed the animal with a higher proportion of concentrate feed in the diet, leads to a reduction of CH_4 emissions as a proportion of energy intake (Yan et al., 2000). The relationship between concentrate proportion in the diet and methane production is curvilinear (Sauvant and Giger-Reverdin, 2007). With a marked decrease in methane observed when dietary starch is higher than 40%, replacing plant fiber in the diet with starch induces a shift of Volatile Fatty Acids (VFA) production from acetate towards propionate occurs, which results in less hydrogen production (Singh, 2010). A positive response to high levels of grain based concentrate on methane reduction has also been reported by others (Beauchemin and McGinn, 2005). The amount of CH_4 formation is determined by the rate at which H_2 passes through the dissolved pool, The absolute amount of CH_4 formed per animal on different diets is related to characteristics of the feed in complex ways including the nature and amount of feed, the extent of its degradation, and the amount of H_2 formed from it (Singh, 2010).

Adding lipid to the diet

The amount of dietary fat seems a promising nutritional alternative to depress ruminal methanogenesis without decreasing ruminal pH as opposed to concentrates (Sejian et al., 2011b). Addition of oils to ruminant diets may decrease CH_4 emission by up to 80% in vitro and about 25% *in vivo* (Singh, 2010). Lipids cause depressive effect on CH_4 production by toxicity to methanogens, reduction of protozoa numbers and therefore protozoa associated methanogens, and a reduction in fiber digestion (Dawo, 2017). Oils containing lauric acid and

myrstic acid are particularly toxic to methanogens (Beauchemin et al., 2008). In the recent review, the effect of level of dietary lipid on CH_4 emissions over 17 studies and reported that with beef cattle, dairy cows and lambs, for every 1% (DMI basis) increase in fat in the diet, CH_4 (g/kg DMI) was reduced by 5.6 %. In another review of fat effects on enteric CH_4 (Martin et al., 2010), compared a total of 67 in vivo diets with beef, sheep and dairy cattle, reporting an average of 3.8% (g/kg DMI) less enteric CH_4 with each 1% addition of fat (Singh, 2010). But when we feed the animal with more than 10% of fat or lipid, it has a negative effect on digestion and feed intake of animals.

Ionophores

Ionophores (e.g. monensin) are antimicrobials which are widely used in animal production to improve performance (Tedeschi et al., 2003). Reports in a recent review indicated that on feedlot and low forage diets; tend to marginally increase average daily gain whilst at the same time reducing DMI, thus increasing feed efficiency by about 6%. Monensin should reduce CH_4 production because it reduces DMI, and because of a shift in rumen VFA proportions towards propionate and a reduction in protozoa numbers (Singh, 2010). In vivo studies have shown that animals treated with monensin emit reduced levels of CH_4 (McGinn et al., 2004). But others have reported no significant effect (Waghor et al., 2008). Monensin causes a direct inhibition on H_2 producing bacteria (Russell and Houlihan, 2003) that results in a decrease in methane production due to shortage of molecular H_2. Monensin also favors propionate producing bacteria (Newbold et al., 1996). As result methane will be reduced because it increase the amount of propionate and reduce the amount of acetate.

Sulphate supplementation

In the rumen fermentation, there are three H_2 utilizing microbes are the sulphate reducing bacteria, methanogens and carbon dioxide reducing acetogens, which have a threshold value of H_2 (m mole/ liter) as 0.0013, 0.067 and 1.26, respectively at which these bacteria act as the dominant electron acceptors (Kamra et al., 2004). Thus it appears that sulphate-reducing bacteria have the highest affinity to utilize hydrogen in the rumen, even better than methanogens, but the availability of sulphate in the rumen appears to be a limitation (Kamra et al., 2004). Sulphate supplementation helps in increasing the production of fiber degrading enzymes and fiber degradation in the rumen. As sulphate / sulphite have high affinity for utilization of hydrogen for its reduction to sulphide, therefore, a fiber diet, as prevalent in livestock, sulphate / sulphite supplementation can be a good mode of rumen amelioration / improvement for improving fiber degradability and inhibiting methanogensis, but a proper dose will have to be optimized, keeping in view the toxic levels of sulphide generated on sulphate reduction.

Plant secondary metabolites

The term plant secondary metabolite is used to describe a group of chemical compounds found in plants that are not involved in the primary biochemical processes of plant growth and reproduction (Agrawal and Kamra, 2010). These compounds might function as a nutrient store and defense mechanisms which ensures survival of their structure and reproductive elements protecting against insect or pathogen predation or by restricting grazing herbivores.

Saponins

Numerous studies have demonstrated that saponins and saponin-containing plants have toxic effects on protozoa, as a result methanogens live on protozoa is die. Forages containing condensed tannins have been shown to decrease methane production by the ruminants (Hess et al., 2003). Tannins present in *Calliandra calothyrus* reduced nutrient degradation and methane release per gram of organic matter degraded in in vitro experiments with rumen simulation technique (Hess et al., 2003). Woodward et al. (2002) investigated that the effect of feeding of sulla on methane emission and milk yield in Friesian and Jersey dairy cows, Cows feed sulla produced less methane per kg DMI (19.5 vs. 24.6 g) and per kg milk solid yield (243.3 vs. 327.8 g). Similar trends in methane emission and milk production have been observed in sheep fed on lotus silage (Woodward et al., 2001). There was also 16 % reduction in methane production in lambs fed on *Lotus pedunculatus* (lotus), which might be due to the presence of condensed tannins [Waghorn *et al.,* 2002]. Another condensed tannins containing forage *Sericea lespedeza* (17.7% CT) decreased methane emission (7.4 vs. 10.6 g/ kg and 6.9 vs. 16.2 g/kg DMI for *Sericea lespedeza* and crabgrass / *Tall fescue*, respectively) in angora goats (Puchala et al., 2005).

Essential oils

Like *Allium sativum*, *Coriandrum sativum*, *Eucalyptus globules*, *Foeniculum vulgare*, *Mentha piperita*, *Ocimum sanctum*, *Populus deltoids* and *Syzygium aromaticum* are some of the plants which contain high concentration of essential oils and are effective against methane emission and protozoa growth in the rumen, but some of them also

have adverse effects on degradability of feed and nutrient utilization by the animals (Dawo, 2017). The results of in vivo experiments with these plants are also variable and need further experimentation before their practical application in the livestock production (Agrawal and Kamra, 2010).

Tannins

Condensed tannins can directly inhibit methanogens through direct toxicity or indirectly limit methanogenesis through a reduction in hydrogen availability (Puchala et al., 2005).

Halogenated methane analogues

There is different halogenated methane analogues so far tried as methane inhibitors are such as carbontetrachloride, chloralhydrate, trichloroacetamide, trichloacetaldehyde, bromochloromethane, chloroform, methylene chloride, methylene bromide, nitrapyrin, hemi acetyl of chloral and starch, etc. (Haque, 2001). Generally, inhibit methanogens, favorable effects of these had been reported only in those animals fed on high roughage diets, as prevalent in livestock. Chloral hydrate is converted in the rumen to chloroform prior to inhibiting methanogens (Haque, 2001). Bromochloromethane is believed to inhibit methane production by reacting with reduced form of Vitamin B_{12} which inhibits methanogenesis.

Type of ration

Johnson et al. (2000) concluded that the most effective way of reducing methane output per unit of product was through production systems, which increased both animal growth and reproductive rates. Factors such as dry matter intake and diet composition are critical to the amount of methane produced in the rumen (Johnson and Johnson, 1995). Reported that there is a relationship between the level of dry matter intake and diet composition, so that providing carbohydrates of high digestibility associated with high ingestion levels might result in a decrease in gas production. The comparison between dry matter intake (DMI) and methane emission (g/day) evidenced that gas emission was related to the increase in DMI in animals. Protein supplementation in the diets increased the nutrient digestibility and decreased significantly methane production in rumen (Mehra et al., 2006). The higher efficiency of energy utilization is cited by O'hara et al. (2003), in which it is possible to reduce methane emission per kilogram of milk or meat in ruminants. Moss and Givens (2002) reported that higher animal performance might reduce methane emission because the number of animals in the production system might be decreased.

Bacteriophages

As we know, bacteriophages (bacterial viruses) are present in all biological ecosystems. Their relative simplicity and modular structure (Brussow et al., 2004) makes them important agents for genetic exchange between various microbial hosts (Stanton, 2007). In addition, their ability to penetrate and subsequently lyses their host cells makes phages and their genes potential sources of mitigation strategies. In contrast to the nearly 300 bacteriophage genomes reported by Ackermann and Kropinski (2007), only six archaeal phages have been sequenced and described so far, and only two are from methanogens: *Methanobacterium* phage (Pfister *et al.,* 1998) and *Methanothermobacter* phage (Luo et al., 2001).

Vaccination against rumen methanogens

Direct vaccination against rumen methanogens has the potential to reduce methane emissions by decreasing the number or activity of methanogens in the rumen. Such a vaccination approach against rumen-dwelling organisms has met with success in vaccinating animals against the rumen dwelling bacterium *Streptococcus bovis* (Gill et al., 2000).

Animal breeding

Animal breeding has long been shown to increase productivity and to reduce susceptibility to disease, because it improve the genetic materials of animals and has the potential to contribute towards reducing methane emissions from livestock (Chagunda et al., 2009). Breeding for increased productivity reduces methane emission intensity by increasing the proportion of feed energy used for production purposes while diluting the maintenance requirements (Chagunda et al., 2009). However, productivity increases also require the use of increasing amounts of concentrate feeds, so we feed high amount of concentrate reduce methanogens population in the rumen.

Microbial feed additives, probiotics and prebiotics

The use of acetogenic bacteria as microbial feed additive along with some antimethanogenic compound may be effective in methane inhibition, as acetogenic bacteria may not be able to compete with methanogenic bacteria due to poor affinity with hydrogen (Mutsvangwa et al., 1992). Probiotics such as yeast cultures are used to stimulate bacterial activity in the rumen. The probiotics

have been shown to stabilize rumen pH, increase propionate levels and decrease the amount of acetate, methane and ammonia production. Addition of *Sacchromyces cerevisiae* reduced methane production *in vitro* (Mutsvangwa et al., 1992).

Feed processing technologies

Feed processing can improve the feeding value by increasing its digestible energy content and increasing feed intake (Johnson and Johnson, 1995). Therefore, an attempt to increase feed intake may reduce methane emission of methane. These techniques are chopping and grinding of straws, alkali/ammonia treatment of straws and feed residues, urea-molasses blocks. These processing techniques are reported to depress the methane emission from rumen by 10%. Reduction in methane is associated with increased propionate production (Johnson and Johnson, 1995).

Defaunation

The methanogenic bacteria have an eco-symbiotic relationship with ciliate protozoa and remain attached to the outer surface of the protozoa. Protozoa in the rumen are associated with a high proportion of H_2 production, and are closely associated with methanogens by providing a habitat for up to 20% of rumen methanogens (Newbold et al., 1995). In defaunated ruminants, the methanogenic bacteria do not get the symbiotic partner and methane synthesis is partially inhibited. On defaunation, methane production is reduced by 20 to 50% (Nevel and Demeyer, 1996) depending on the various factors in the diet of the animal. This all are methods for the reduction or mitigation of methane though there are so many other methods implemented.

Methane mitigation strategies from livestock manure

Manure from intensive livestock operations is most often stored in solid or liquid form before being applied to agricultural land/organic fertilizer and fuel wood. Increasingly, however, manure is composted before land application or an aerobically digested to produce CH_4 as bio-fuel. Methane emissions from anaerobic digestion can be recovered and used as energy by adapting manure management and treatment practices to facilitate methane collection (Sejian and Naqvi, 2012). This methane can be used directly for on-farm energy, or to generate electricity/biogas for on-farm use or for sale. Successful applications include use as animal feed and aquaculture supplements, in fish farming, and as a crop fertilizer. Additionally, managed anaerobic decomposition is a very effective method of reducing the environmental and human health problems associated with manure management. Depending on the management system used, greenhouse gas emissions (mainly CH_4 and N_2O) from manure vary considerably. Strategies to mitigate net emissions aim to change manure properties or the conditions under which CH_4 and N_2O are produced and consumed during manure storage and treatment. The selection of successful methane emissions reduction options depends on several factors, including climate; economic, technical and material resources; existing manure management practices; regulatory requirements; and the specific benefits of developing an energy resource (biogas) and a source of high quality fertilizer (Newbold et al., 1995).

Covered anaerobic digesters

This is the simplest form of recovery system, and can be used at dairy or swine farms in temperate or warm climates. Manure solids are washed out of the livestock housing facilities with large quantities of water, and the resulting slurry flows into an anaerobic primary lagoon, the average retention time for the manure in the lagoon is about 60 days (Johnson and Johnson, 1995). The anaerobic conditions result in significant methane emissions, particularly in warm climates. The covered lagoons are air-tight and provide the anaerobic conditions under which methane is produced and recovered which can be used as energy; Lagoons are most commonly used at large confined dairy and swine facilities, the external cover is preventing the evaporation of methane in to the atmosphere (Sejian and Naqvi, 2012).

Complete mix digesters

This is the second method which prevent CH_4 production from manure of ruminant this type of digesters presents a methane recovery option for all climates. They are heated, constant-volume, mechanically-mixed tanks that decompose medium solids manure (3-8% total solids) to produce biogas and a biologically stabilized effluent. The manure is collected daily in a mixing pit where the percent total solids can be adjusted and the manure can be pre-heated (Sejian and Naqvi, 2012). A gas-tight cover placed over the digester vessel maintains anaerobic conditions and traps the methane that is produced. The produced methane, representing about 8 to 11% of the total manure, is removed from the digester, processed, and transported to the end use site (Johnson and Johnson, 1995).

Plug flow digesters

This is the third method of methane reduction technique

in manure of ruminants. This type of digesters only works with dairy scraped manure and cannot be used with other manures. These are constant volume, flow-through units that decompose high solids dairy manure (>11% solids) to produce biogas and a biologically stabilized effluent. The basic plug flow digester design is a long tank, often built below ground level, with a gas-tight, expandable cover. A gas-tight cover collects the biogas and maintains anaerobic conditions inside the tank. The amount of methane produced is about 40 cubic feet per cow per day (Sejian and Naqvi, 2012).

CONCLUSIONS

Generally, reduction methane production from ruminant animals is a difficult issue, because it needs appropriate adaptation and mitigation strategies or options. There is a variation in technological and economic infrastructures in the regions where, livestock carried out and in the feeding habits, but it can be useful if some of the precautions taken in part in solving this problem. We can achieve progress towards reducing methane production, i.e. reducing the number of animals by increasing the efficiency/productivity, producing high quality of forages and pastures, the use of high alternative forage, concentrate feeds and PSM which has high content of substances such as tannin and saponin and also using of probiotics, which can compete with methanogens by suppressing them with secondary plant components such as essential oils. Finally, we recommended that different researches should be indispensible to establish a set of mitigation strategy of methane from ruminant animals, easily practicable for livestock keepers.

ACKNOWLEDGEMENT

Authors' deepest gratitude goes to Debre Berhan University communities for their logistic and material supports.

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Citation: Alemneh T, Getabalew M, 2019. Strategies to reduce methane emission in ruminants. Int J Ecol Ecosolution, 6(2): 16-22.