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Strategies to Reduce the Negative Environmental Impacts of Ruminants

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ABSTRACT

Climate changes get a big interest in recent years due to the environmental deterioration and crisis. One of the most interested causes of global warming is the production of Green House Gases (GHG) of which methane (CH_4) especially produced from livestock which has a high warming potential. Methane emissions from ruminants contribute about 30 to 40% of the total anthropogenic CH_4 emissions. In the current review some of strategies for reducing methane emissions from ruminant are summarized. Changing feeding pattern, using feed additives and anti-methanogen vaccines is for inhibiting enteric CH_4 producing bacteria and reducing CH_4 production in the rumen.

Key words: Methane emission, ruminant, rumen fermentation, nutrients digestibility, feeds, feed additives

INTRODUCTION

The composition of earth's atmosphere got much interest due to the observed rise in atmospheric temperatures were recently indicated. The increase of gasses emissions and concentration results an increase in global temperature[1]. Methane is one of the most effective greenhouse gasses contributing in global warming[2]. Agriculture is responsible of 18.5% of greenhouse gasses world-wide as reported by FAO[3]. Livestock and manure contribute by 27.5% of agricultural activities in gas emission and 36% of total methane produced in the world are produced from livestock. In more detail, observed that adult cattle produce 70 and 120 kg of methane/year[3]. The International Panel on Climate Change (IPCC) has asked nations to quantify the amount of gases they produce and to develop research to limit further emissions. In order to compare emissions of greenhouse gases (GHG), the Global Warming Potential (GWP) of the individual gases was used, with CO_2 as the reference gas. The GWP of CH_4 is known to be 21-fold greater than that of CO_2[4]. Different approaches have been proposed to reduce CH_4 production by ruminants. In this review some of the current management practices available for mitigation and new strategies were proposed to mitigate enteric CH_4 emissions from ruminants.

METHANE PRODUCTION IN THE RUMEN

The advantages of ruminants are its abilities to degrade and utilized non-degradable cellulolytic materials by anaerobic fermentation through microflora in rumen, depending on the anaerobic microbial community. The rumen is a unique organ identified as restricted obligate anaerobic chamber (no oxygen), with pH range 6-7 and temperature of 39°C; this condition fit an ideal condition for its anaerobic microbial habitats (bacteria, fungi, protozoa); to microbial ferment consumed feeds (~ 9 h)[3]. Rumen microbial population diversity includes different genera and species of anaerobic bacteria (cellulolytic, hemicellulolytic, amylolytic, proteolytic, ammonia producers, vitamin synthesizers, methane producers and fungi).

Anaerobic digestion of feeds in the rumen results volatile fatty acids (acetate, propionate, butyrate, valerate, iso-butyrate and iso-valerate) which are energy sources for ruminant animal. Some gasses were produced as secondary metabolic component include Methane, CO_2 and H_2. In the rumen, simple and complex carbohydrates) were break down to 5- and 6-carbon sugars by microbial enzyme produced by ruminal microbial population. Carbohydrates are anaerobically fermented to VFA through multiple-step metabolic pathways that produce reducing equivalents (i.e., metabolic hydrogen), which can be summarized in the following equation[5-7]:

2H producing reactions:

Glucose → 2 pyruvate + 4H

Pyruvate + H_2O → acetate (C_2) + CO_2 + 2H

2H using reactions:

Pyruvate + 4H → propionate (C_3) + H_2O

$$2\,C_2 + 4H \rightarrow \text{butyrate}\ (C_4) + 2H_2O \qquad (1)$$

Fermentation of glucose equivalents released from plant polymers or starch, is an oxidative process under anaerobic conditions occurring in the Embden-Meyerhof Parn as pathway and giving reduced co-factors like NADH. These reduced cofactors have to be re-oxidized to NAD to complete the fermentation of sugars. NAD+ is regenerated by electron transfer to acceptors other than oxygen (CO_2, sulphate, nitrate and fumarate). Although H_2 is one of the major end products of fermentation by protozoa, fungi and pure monocultures of some bacteria, it does not accumulate in the rumen because it is immediately used by other bacteria which are present in the mixed microbial ecosystem. The collaboration between fermenting species and H_2-utilising bacteria (e.g., methanogens) is called "interspecies hydrogen transfer"[8].

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O \qquad (2)$$

When H_2 is not correctly used by methanogens, NADH can be re-oxidized by dehydrogenases of the fermenting bacteria to form ethanol or lactate. Demeyer and Van Nevel[9] proposed the following equation obtained from the previous reactions:

$$2\,C_2 + C_3 + 4\,C_4 = 4\,CH_4 + 2\,C_3 + 2\,C_4 \qquad (3)$$

PREDICTION OF ENTERIC METHANE EMISSION

Several attempts were carried out to create equations estimate the feed energy lost as methane by ruminants. Different regression equations were carried out to predict loses of feed energy as methane through digestion in ruminants. Different prediction equations were also suggested to determine predicted methane considering the factors affecting the CH_4 output of feed stuffs or diets. The concept of regression equation models estimate production of methane depends on different variables such as Dry Matter Intake (DMI), Gross Energy (GE) and Digestible Energy (DE)[10].

One of the most common prediction equation is Blaxter and Clapperton equation[11]:

$$CH_4\ (\%\ \text{of GEI}) = 1.3 + 0.112\,D + L\,(2.37 - 0.05D) \qquad (4)$$

Where:
GEI = Gross energy intake
L = Level of feed intake
D = Dry matter digestibility

Other attempts to increase accuracy of prediction based on different levels of available information were investigated. The considerable level of sequential approach was mainly, gross energy, dietary and milk composition (fat, protein and nonfat soluble) and animal information (body weight and breed), as long as variables from the dietary level were potential predictors[12-14].

STRATEGIES FOR REDUCING METHANE EMISSION FROM RUMINANT

Several strategies on mitigation of CH_4 emission from ruminant had been recently investigated. In most promising strategies to reduce enteric CH_4 emissions were classified as:

- Dietary manipulation
- Anti-methanogen vaccines
- Rumen manipulation and feed additives

Dietary manipulation

Increasing intake: The increase in animal feed intake, methane emission was increased by 5 to 15% for each multiple of intake as shown in above maintenance requirements[11]. Different studies showed that feeding high quality forages reduced methane production per DMI units due the increase of passage rate of feed of rumen[15-17]. As a result of increased passage rate, the extent of access of rumen microbes to organic matter was decreased and this in turn reduces the extent and rate of feed digestibility[15]. Also, a rapid passage associated with high intake rate favors propionate production, which is a competitive pathway for the use of H_2.

Type of carbohydrates fed: Volatile fatty acids produced from anaerobic fermentation of carbohydrates in the rumen can be influenced by the type of carbohydrates in the diet and thus the amount of CH_4 produced. Fermentation of structural carbohydrates produces more CH_4 than fermentation of soluble sugars, which in turn produce more CH_4 than fermentation of starch[16]. From a previous study, written that diets rich in starch boon propionate production and decrease CH_4 production per unit of fermentable organic matter in the rumen. The diets based on roughage boon acetate production and increased CH_4 production per unit of fermentable organic matter[17].

Many experiments showed that feeding processed and conserved forages: Grinding or pelleting forages can decrease CH_4 production per unit of feed intake by 20 to 40%[16]. A reduction in fiber digestibility and a faster rate of passage associated with ground or pelleted forages can be associated with a decline in CH_4 production[18-20]. Feeding ground diets also enhance propionic acid production and reduce acetic acid and increases the proportion of propionic and valeric acids[21].

Anti-methanogen vaccines: In inoculation, some methanogen antibodies were found in the serum of vaccinated sheep[22]. The initial two antibodies of methanogen were set up from entire cells of three and seven chosen methanogens in Australia and these antibodies responded in no or insignificant (just 8% contrasted with control) decline in CH_4 emission[23]. The inefficacy was credited to the little quantities of methanogen species that the antibodies could targeted. Notwithstanding, methanogen plenty or CH_4 generation was not diminished by inoculation utilizing an antibody that depended on a blend of five methanogen species representing >52% of the rumen methanogen populaces, despite the fact that the structure of methanogens was changed[24]. It was proposed that antibodies of methanogen ought to be created dependent on cell surface proteins that are rationed among rumen methanogens to accomplish successful outcomes[25]. It ought to be noticed that most antibodies flow in the blood of a host and just a minor sum can enter the rumen through saliva. The measure of antibodies entering the rumen is likely too little to even think about having any impact. Likewise, antibodies entering the rumen can be quickly corrupted by proteolytic microscopic organisms in that. It makes sense that inoculation may not be a possible way to deal with moderate CH_4 discharge from animals.

Rumen manipulation and feed additives

Supplementing diets with fats and fatty acids: The H_2 production through anaerobic fermentation and metabolism consider the main factor determines the CH_4 production from rumen, so, many experiments were carried out to find alternative pathway for utilizing H_2 produced, one of the promising way were supplementing diets with unsaturated fatty acids[26,27]. Based on a meta-analysis, fat supplementation declined CH_4 by 3.77% in dairy cattle and 4.30% in sheep per 1% dietary fats[28,29]. C18:3 and other polyunsaturated unsaturated fats (PUFA) are more powerful than unsaturated fats[28,30]. The CH_4-suppressing efficacy of fats for the most part continues[28], Fats enhanced up to 6% of the consumed regimen (DM) can likewise improve milk production while obviously reducing CH_4 production (15%) in cows. Medium-chain Unsaturated Fats (MCFA) and PUFA can bring down plenitude and metabolic activities of rumen methanogens and change their species composition[26,30,31]. PUFA can repress protozoa and fill in as hydrogen sink through biohydrogenation[32]. Both MCFA and PUFA seem to harm the cell membrane, along these lines abrogating the particular penetrability of cell layer, which is required for survival and development of methanogens and different microorganisms[33]. The inhibitory impact of fat on methanogensis is increasingly articulated in dairy cattle fed concentrate-based diets than in cattle fed forage-based diets[28]. Since C12: and C14:0 is progressively inhibitory to *M. ruminantium* at pH 5 than at pH 7[34], the concentrate level-dependent anti-methanogenic efficacy of MCFA and PUFA is most likely credited to the lower pH related with high-concentrate consumed less calories.

Inhibitors to hydrogen-producing bacteria

Ionophores: Ionophores, such as monensin, salinomycin and lasalocid, are commonly used in ruminant diets to improve rumen microbial metabolism. The mode of action of ionophores as profoundly lipophilic particle transporters, they go through the cell wall of gram-positive microbes and infiltrate into the cell membrane. In that, they fill in as H+/Na+ and H+/K+ antiporters, scattering particle slopes that are required for ATP union, supplement transport and other fundamental cell exercises and at last bringing about deferred cell division and even cell passing[35]. Ionophores the primary impact in rumen microflora is restraining some Gram-negative rumen microscopic organisms[36,37], particularly microorganisms that produce formate and H_2[38]. Consequently, a standout amongst the most advantages of ionophores is bringing down CH_4 discharge by diminishing H_2 generation. For precedents in certain tests, monensin brought CH_4 creation by up down to 10% (g kg^{-1} DM admission)[39-42]. As more than once noted, at high supplementation level, DM admission was brought down, which clarifies the greater part of the watched reduction in CH_4 emanation. Ionophores were not expressed as immediate inhibitor for methanogens, however it help in changing the microflora populace elements particularly methanogen species. For instance, monensin diminished the number of inhabitants in *Methanomicrobium* spp. while expanding that of *Methanobrevibacter* spp.[43]. Additionally, monensin noted in diminishing complete methanogens in dairy cattle[44]. These can be clarified by diminished accessibility of H_2 and contrasts in fondness for H_2 and development energy among methanogen species.

Bacteriocins: Bacteriocins are proteins or peptides created by bacteria and inhibit selected microbial species in the rumen and different natural surroundings. There are just a couple of studies exploring the impact of bacteriocins on CH_4 discharge. Bovicin HC_5, a bacteriocin created by Streptococcus spp. from the rumen, was accounted for to smother CH_4 by half *in vitro*[45]. Nisin, a bacteriocin created by *Lactobacillus lactis* subsp. *lactis*, has additionally been appeared to diminish CH_4 generation *in vitro* by up to 40% contingent on its fixation[46]. Like monensin, bacteriocins presumably tweak rumen maturation driving towards expanded propionate, in this manner diminishing CH_4 creation. Bacteriocins may hold some potential in moderating enteric CH_4 emanation, however further research is expected to affirm their adequacy *in vivo* and to decide their expense.

Plant secondary metabolites: Plants Secondary Metabolites (PSM), for example, saponins, tannins, flavonoids, organo-sulfur components and essential oils, have inhibition characterization for microbial activities against several types of microorganisms[47].

Development of antibiotics resistant bacteria cannot be ignored; therefore, it is essential to find more desirable alternatives from natural and safe sources. Various PSM removes have been perceived as potential inhibitors of rumen methanogens and CH_4 creation[48,49]. Some forage plants rich in tannins and saponins have likewise appeared at alleviating CH_4 emanation from ruminants[50,51]. Be that as it may, the adequacy of PSM in smothering CH_4 generation fluctuates impressively relying upon the sort, sources, atomic weight, dosages, just as eating regimen types.

Tannins: Tannins decline CH_4 generation by legitimately hindering methanogens and by implication diminishing H_2 creation because of diminished fiber assimilation and protozoal populace in the rumen[48]. The inhibitory movement of tannins removed from Lotus pedunculatus was exhibited on unadulterated societies of methanogens[52]. Puchala *et al*.[50] likewise demonstrated restraint of methanogen populaces by tannins in the rumen of goats encouraged weight control plans containing tannins. Concentrates on structure-action connections have demonstrated that types and sub-atomic loads of tannins are critical in deciding their intensity in bringing down CH_4 generation and bounty and assorted variety of rumen methanogens, with high sub-atomic weight Consolidated Tannins (CT) being progressively strong[53,54]. Such structure-action connections have been exhibited utilizing individuals from Methanobacteriales including Methanobrevibacter[55]. Notwithstanding, individuals from Methanomicrobiales show no differential reaction to CT with various atomic loads and unclassified Thermoplasmata-related methanogens were even invigorated with expanding sub-atomic loads of CT[55]. One of the CT parts likewise expanded the general plenitude of *Methanomicrobium* spp. The differential reactions of methanogens to various CT and variety in the CT utilized among studies may clarify the conflicting impacts revealed regardless of utilizing comparable dosages of tannins.

Flavonoids: Flavonoids have not been broadly assessed as for rumen methanogenesis. Oskoueian *et al*.[56] detailed that consideration of flavone, myricetin, naringin, rutin, quercetin, or kaempferol diminished *in vitro* CH_4 production by 5 to 9 mL g^{-1} DM. Their power positioned as pursues: myricetin $\geq$ kaempferol $\geq$ flavone > quercetin $\geq$ naringin>rutin $\geq$ catechin. Catechin diminished CH_4 creation both *in vitro*[57] and *in vivo*[58]. Every one of the flavonoids, when encouraged at 0.2 g kg^{-1} DM, discernibly diminished relative bounties of hydrogenotrophic methanogens and (Citrus aurantium) extricate wealthy in blended flavonoids and its unadulterated flavonoid parts, neohesperidin and naringin, seemed to result in the best restraint[59]. *Methanosarcina* spp. were additionally repressed by poncirin, neohesperidin, naringin and their blend. Flavonoids straightforwardly repress methanogens and furthermore likely acts as H_2 sinks through cleavage of ring structures (e.g., catechin) and reductive dihydroxylation.

Saponins: The impacts of saponins on rumen maturation, rumen microbial populaces and ruminant efficiency have been inspected widely and surveyed already[60-63]. Quillaja saponin at 1.2 g L^{-1}, butnot at 0.6 g L^{-1} [64], brought down CH_4 generation *in vitro* and the bounty of methanogens (by 0.2-0.3 log) and modified their creation. Ivy organic product saponin diminished CH4 creation by 40%, altered the structure of the methanogen network and diminished its decent variety[65]. Saponins from Saponaria officinalis diminished CH_4 and wealth of the two methanogens and protozoa *in vitro*[66]. Be that as it may, in other *in vitro* investigations, Quillaja saponins at 0.6 g L^{-1} did not bring down CH_4 generation or methanogen bounty[30] and Yucca and Quillaja saponins at 0.6 to 1.2 g L^{-1} even expanded archaeal wealth (by 0.3-0.4 log), notwithstanding a diminishing in protozoal plenitude by Quillaja saponin[67]. Tea saponins (30 g day^{-1}) additionally did not bring down CH_4 outflow from cows or wealth of all out methanogens however expanded the bounty of methanogens and protozoa[68]. In this way, the impacts of saponins on methanogenesis and methanogen bounty are exceedingly factor among studies. Saponins most likely have minimal direct impact on methanogens however are known to restrain rumen protozoa, lowering H_2 generation and diminishing the plenitude of Plant Secondary Metabolites (PSM)[69]. It has been evaluated that PAM produce 9-25%[70] or progressively (37%) of absolute CH_4 creation in sheep. The distinction in PAM and their extent of absolute methanogens, diet arrangement and portion and substance nature of saponins can be inferable from the disparities among studies.

Essential oils: The most beneficial effect of Essential Oils (EO) on rumen fermentation, microbial population and ruminant yield performance have much of the time been studied[71-72]. The impacts of EO on CH_4 generation and methanogens are variable relying upon portion, types and diet. Patra and Yu[30] analyzed five EO (clove, eucalyptus, peppermint, origanum and garlic oil) that have distinctive synthetic structures *in vitro* at three unique portions (0.25, 0.50 and 1.0 g L^{-1}) for their impact on CH_4 generation, archaeal wealth and competent variety. In general, all these EO stifled CH_4 generation and bounty of archaea and protozoa in a portion subordinate way, however they varied in power. Thyme oil or cinnamon oil encouraged to Holstein steers at 0.5 g day^{-1} diminished the overall bounty of complete protozoa and methanogens[73]. Be that, as it may, bolstering hamburger steers a mix of EO (CRINA®) did not influence CH4 generation, methanogen wealth or its assorted variety[74]. In general, methanogens might be legitimately hindered or by implication repressed by EOs by means of restraint of protozoa and H2-delivering microorganisms in the rumen[75,76].

CONCLUSION

It is concluded that reducing the methane gas, cattle generation not only slits greenhouse gas emissions but potentially allows more of the feed cattle consumption to be directed to their body and production. That in return can lead to larger, stronger cows and steers, more milk and beef. Therefore, researchers showed through several strategies to control CH_4 emission from ruminant and from the experiments declared that the most promising strategies to reduce enteric CH_4 emissions were dietary manipulation, anti-methanogen vaccines, rumen manipulation and feed additives.

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