Indian J. Anim. Hlth. (2017), 56(2): 125-144

Review Article

METHANE MITIGATION STRATEGIES IN RUMINANT LIVESTOCK

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Greenhouse gas emissions have become an increasingly important worldwide due to their effects on global warming. Ruminant livestock are the most important source of anthropogenic emissions of methane worldwide. They produce about 8.1 gigatonnes of methane each year, accounting for about 28% of global emissions from human related activities. Therefore, it is compelling animal scientists to find solutions to mitigate methane emission from ruminants. The sustainability and profitability of the mitigation options are of prime concern to the researchers. The objective of this review is to explain several alternatives available to reduce enteric CH_4 emissions from ruminants that range from manipulating diet composition, supplementing feed additives (i.e. ionophores, organic acids, halogenated compounds and oils) and selection of forage plants of high quality and containing secondary metabolites (i.e. tannins and saponins) to animal breeding, immunization and manipulation of rumen microorganisms. Overall current mitigation strategies are focused to improve nutrition of ruminants through feeding high quality forages with sufficient concentrate that can result in high animal performance and reduce CH_4 emitted per unit of dry matter intake and per unit of product.

Key words: Emissions, Feed efficiency, Methane, Methanogen, Mitigation, Ruminant

Climate change is a subject of global environmental concern. It is well established that the release of greenhouse gases (GHG) is the driving factor (IPCC, 2006). Methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), and halocarbons are the main GHG which have increased in the last 150 years (Monteny *et al.*, 2006) and have different global warming potential. Methane is the most important agricultural contributor out of various GHGs, with a global warming potential 25 times that of CO_2. Burning of fossil fuels is the main source of CO_2 emissions, while agriculture activities are the main contributors of global emissions

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of CH_4 and N_2O (Wheeler *et al.*, 2008).

GHG production is recalculated to production of CO_2 as carbon dioxide equivalent (CO_2-eq), converted amounts of other gases to the equivalent amount of CO_2 with the same global warming potential. About 10% - 12% of global anthropogenic GHG emissions is due to agricultural activities (Todd *et al.*, 2011).

Quantitatively, agriculture sector alone accounted for 4.6 Gt (gigatonnes) of CO_2 -eq, of which enteric fermentation (emissions of CH_4 from ruminant animals) contributed 2 Gt CO_2-eq globally, in year 2010 (Tubiello *et al.*, 2013). Non-dairy cattle were the single largest source of enteric CH_4, followed by dairy cattle, buffaloes, sheep and goats. This is particularly due to CH_4 emissions from enteric fermentation and manure handling (Mihina *et al.*, 2012). Enteric CH_4 contributes 17% and 3.3% of global CH_4 and GHG emissions respectively, and is largely derived from ruminant livestock. Manure CH_4 from both ruminant and non-ruminant livestock contributes 2% and 0.4% of global CH_4 and GHG emissions respectively (Knapp *et al.*, 2014).

Ruminant animals and microbes have evolved together, filling a niche based on the conversion of complex plant carbohydrates to energy that is beneficial to both the host animal and the microbial symbionts. CH_4 is produced in the rumen and hindgut as a waste product of this fermentation process by a group of Archaea collectively known as methanogens, which belong to the phylum Euryarcheota.

Factors influencing methane yield in ruminants are mainly feed and rumen associated. Among feed associated factors- feed intake, ration type, type of roughage and concentrates, roughage and concentrates ratio, type of available pasture, frequency of feeding and composition of ration are important. Rumen associated factors are inflow of saliva, dynamics of passage of ingesta, rumen pH, type and population of rumen microbes, ruminal acetate and propionate ratio, rumen protozoa concentration, type of substrate fermented, rate of fermentation, type of VFA produced and absorption capacity (Knapp *et al.*, 2014).

Enteric CH_4 emissions can be reduced by various approaches like ration manipulation (e.g. from pasture to concentrate feed) (Sahoo and Soren, 2012); supplementation of various plant extract (Patra *et al.*, 2006; Wallace *et al.*, 2002 and Calsamiglia *et al.*, 2007), organic acids (Newbold *et al.*, 2005 and Wallace *et al.*, 2006), fats, oils (Beauchemin *et al.*, 2008) and nitrates (Morgavi *et al.*, 2010); immunization against methanogens (Li *et al.*, 2007 and Cook *et al.*, 2008); biocontrols (bacteriophage, bacteriocins) (McAllister and Newbold, 2008); chemical inhibitors directly target methanogens; improving productivity by use of growth enhancers and improving genetics; lower the supply of metabolic hydrogen to methanogens (McAllister and Newbold, 2008). Considering the aforesaid facts, the aim of this review is to provide an overview of possibilities and alternatives to reduce CH_4 emissions from ruminants.

Methanogenesis in ruminants

CH_4 is one of the end-products of ruminant digestion and its emission is influenced by animal factors such as chewing, salivation and digesta kinetics (Varga and Kolver, 1997); level of feed intake, type of carbohydrate fed and alteration of the ruminal microflora (Johnson and Johnson, 1995). Bacteria are the principal micro-organisms that ferment carbohydrates in the rumen and polysaccharides in the feed are converted into volatile fatty acids (VFA). Ruminal digestion generates gaseous CO_2 and hydrogen (H_2) as an end product, the amount of H_2 depends upon the amount and type of VFA produced. Fermentation of sugar into VFA is multiple-step pathways to produce and utilise metabolic hydrogen (Moss *et al.*, 2000) :

Glucose $\rightarrow$ 2 pyruvate + 4H (carbohydrate metabolism)

Pyruvate + $H_2O \rightarrow$ acetate + CO_2 + 2H
Pyruvate + 4H $\rightarrow$ propionate + H_2O
2 acetate + 4H $\rightarrow$ butyrate + $2H_2O$
$CO_2 + 8H \rightarrow CH_4 + 2H_2O$ (methanogenesis; H_2 converted to CH_4 by Archaea)

In the rumen, accumulation of H_2 could inhibit feed digestion and if not utilized by the methanogens, will reduce the carbohydrate degradation, rate of microbial growth and microbial protein synthesis (McAllister and Newbold, 2008). Nearly 87% - 90% of enteric CH_4 is synthesized in the rumen while remaining 10% - 13% is released in the large intestine through fermentation (Dini *et al.*, 2012). During exhaling, CH_4 is released into atmosphere mainly through mouth and nostrils. About 95% of CH_4 produced by forestomach is released by eructation while 89% of CH_4 produced in the hindgut released by exhalation and only 11% through rectum (Murray *et al.*, 1999). Due to this, ruminants loose between 2% - 12% of the gross dietary energy depending on the quality and quantity of diet offered and consumed (Johnson and Johnson, 1995). Among ruminant livestock, cattle produce about 7 - 9 times CH_4 than that of sheep and goat (Murray *et al.*, 1999). One adult cattle produces around 250L – 500L methane in a day, which not only reduces the efficiency of energy utilization but also contributes to environmental pollution significantly (Carlos and Edgar, 2010).

Mitigation strategies to reduce enteric methane production

Reduction of CH_4 emission from enteric fermentation can be done by modifying ruminal microbial fermentation processes at three levels: by enhancing animal productivity and feed efficiency by feeding and nutritional strategies; ruminal microbial manipulation by using certain ingredients that directly or indirectly reduce or inhibit methanogenesis or by biological control (immunization, bacteriophages and bacteriocins) and by enhancing animal production by genetic selection and breeding of animals that consume less feed or produce less CH_4 per unit of feed lead to an overall reduction in CH_4 production (liters/day) per individual animal. Besides these mitigation strategies, efficient manure-handling systems also reduce CH_4 production.

The immediate goal of livestock production systems should be to reduce CH_4 per unit of product (milk or beef). An approach to reduce livestock numbers to reduce CH_4 is possible but holding productivity per animal remains constant and profit from livestock farms will decline proportionately with reduction in numbers of animals. But livestock manipulation by shifting of old age cattle from heifers can efficiently increase the productivity and decrease the enteric methane production.

1.1 Feeding and nutritional strategies

1.1.1 Feeding higher grain diets: The relationship between amount of concentrates fed in ration and CH_4 production as a proportion of energy intake is curvilinear (Sauvant and Giger-Reverdin, 2007). By adding more concentrates, CH_4 production can be reduced to around 3% from 6.5% as compared to ruminants fed primarily on forage (Beauchemin and McGinn, 2005). Reducing plant fiber with starch shifts VFA synthesis from acetate to propionate, which results in less H_2 production (Van Nevel and Demeyer, 1996). Reduction of CH_4 production also depends on type of grain used in the ration. Beauchemin and McGinn (2005) reported that beef cattle, fed diets containing mainly corn grain, produce about 30% less CH_4 than diets containing mainly barley grain. Reduction of CH_4 release by adding more concentrates in the ration has also been reported by many researchers (Beauchemin and McGinn, 2005 and McAllister and Newbold, 2008).

1.1.2 Dietary manipulation: Diets with higher digestibility will reduce CH_4 production per animal. If dairy animals are given feeds with higher digestibility, the consumption will reduce and thus methane per unit of milk produced is decreased. Ruminants fed only on forage, there is positive correlation between methane production and organic matter digestibility (Archimède *et al.*, 2011). If digestibility is higher, there is increase in fermentation end products and at higher amount of structural carbohydrates; there is stimulation of acetate production to enhance methanogenesis. Methane emission increases with maturity of forage (Robertson and Waghorn, 2002). Methane emission can be reduced by enhancing nutritive value and digestibility of feed by balancing the ration with addition of concentrate in grazing animals.

Adding leguminous fodder also reduce of methane emission compared with those fed on grasses (McCaughey *et al.*, 1999 and Benchaar *et al.*, 2001), but CH_4 emission increases with maturity of fodder (Chaves *et al.*, 2006). With grain diets, the percentage of the energy consumed that is converted to CH_4 in the rumen is typically reduced to about 3%, from the 6.5% or more that is common for animals fed primarily forages (Beauchemin and McGinn, 2005). Use of corn silage and small grain silages, rather than grass silage, and hay, can also lower CH_4 production. The high starch content of grain-based silages favours the production of propionate rather than acetate in the rumen. These forages also promote high dry matter intake and have a faster rate of passage through the rumen. Furthermore, replacing grass silage or hay with grain silage often improves animal performance, thereby lowering CH_4 emissions per unit of animal product (O'Mara *et al.*, 1998).

1.1.3 Forage quality: Quality and availability of dry matter in pasture influence CH_4 emission. Higher emission was reported when pasture quality and availability were low, while it was lower in good quality pasture with high availability (Ominski *et al.*, 2004). Boadi *et al.* (2002) reported less energy loss as methane in steers grazing on pasture during early period of grazing season than mid and late grazing period. Temperate legumes and some tropical legumes reduce CH_4 emission as it contains condensed tannins which are toxic for some ruminal microbes, particularly ciliate protozoa, methanogenic archaea and fiber degrading bacteria (Carlos and Edgar, 2010).

1.2 Ruminal microbial manipulation

1.2.1 Lipid and fatty acids : Lipids have antimicrobial action against methanogens and also affect cellulolytic bacteria and protozoa (Maia *et al.*, 2007). The supplementation of vegetable or animal oil in ruminants ration lowers ruminal methanogenesis in sheep (Broudiscou and Lassalas, 1991) and dairy cattle (Martin *et al.*, 2008). Lipids are not fermented in rumen and hence do not produce H_2 for methanogenesis. Besides inhibitory effects on methanogenesis, fats are often incorporated in diets to increase the energy density of high yielding dairy cattle (Coppock and Wilks, 1991 and Cosgrove *et al.*, 2008). Moreover, fat sources containing high amount of polyunsaturated fatty acids had been attempted to include in diets of ruminants to augment concentrations of human health promoting n-3 fatty acids and bioactive conjugated linoleic acids in milk and meat (Lock and Bauman, 2004). The inhibitory response of fats on methane production depends upon concentration, type, fatty acid composition of fats, and nutrient composition of diets (Beauchemin *et al.*, 2008 and Machmüller, 2006). Higher concentrations of fats though substantially decrease methane production, but often exert detrimental effects on digestibility and fermentation of feeds including animal performance. Thus, an optimum concentration of fats in diets should be determined, which may improve animal productivity while decreasing methane release into atmosphere (Patra, 2013). About 5.6% of reduction in CH_4 has been reported with every percent of lipid added in ration (Beauchemin *et al*., 2008). About 27% reduction in CH_4 emission was reported when dairy cow supplemented with fish oil and sunflower oil at 500 g/day for 14 days (Woodward *et al*., 2006). Soybean oil has a direct effect on reduction of CH_4 production by inihibiting protozoa in sheep (Mao *et al*., 2010). Corn distillers' grains may be incorporated in high amounts in ruminant ration as it contains about 10% fatty acids. About 16% reduction of CH_4 per kg DM was reported in beef cattle when replacing barley (35% of the ration) with corn distillers' dried grains (McGinn *et al*., 2009).

1.2.2 Ionophores: Ionophores such as monensin are antimicrobials that affect the ruminal fermentation pathways and are used in commercial beef and dairy farms. Other ionophores like lasalocid, salinomycin, nigercin and gramicidin are also used. They reduce methanogenesis by increasing feed efficiency and reduce CH_4 production per unit dry matter consumed (Tadeschi *et al*., 2003). Monensin decreases the population of ruminal protozoa and other bacterial species, mainly gram-positive bacteria and results in shifting in ruminal VFA proportion towards propionate and finally reduction in CH_4 (Singh, 2010). Reduction in CH_4 production with monensin (McGinn *et al*., 2004) up to 10% with different dose was also reported (Beauchemin *et al*., 2008).

1.2.3 Probiotics: Probiotics are microbial feed additives that beneficially affect the host by improving its intestinal microbial balance. They improve the animal productivity by influencing rumen fermentation. Direct-fed microbials or probiotic is one of the accepted alternatives to the use of antibiotics and chemical substances that may induce a risk of antibiotic resistance and residues in animal products. However, to date there is little evidence to suggest the efficacy of direct-fed microbials to control the production of methane in ruminants (Jeyanathan *et al*., 2014). The major biochemical pathways to decrease methane emission by using direct-fed microbials are the redirection of hydrogen ions away from methanogenesis and decreased production of hydrogen during feed fermentation. Lactic acid utilizing bacteria like *Megasphaeraelsdenii*, *Propionibacterium spp.* and yeast like *S. cerevisiae* have major effects on methanogenesis by decreasing methane (Seo *et al*., 2010).

In cattle, broadly two types of probiotics are used: bacterial and fungal types. *In vitro* they can reduce methanogenesis (Frumholtz *et al*., 1989) but the results for CH_4 reduction have not been consistent (Martin *et al*., 1989). About 10% reduction in methanogenesis was reported in sheep when fed on forage and concentrate ration in ratio of 70:30 with *Trichosporon sericeum* but the production of CH_4 per unit dry matter intake was similar to that of control (Mwenya *et al.*, 2004). No effect of commercial yeast based product on CH_4 production in beef cattle was reported by McGinn *et al.* (2004). There is limited evidence that probiotics have direct influence on reduction of methanogenesis.

1.2.4 Organic acids: Many organic acids like malate, pyruvate, fumarate and acrylate are generally fermented to propionate in rumen thus causing reduction in amount of hydrogen used in CH_4 production. Fumaric and malic acids have also been studied as alternative hydrogen sinks in the rumen (Bayaru *et al.*, 2001; Molano *et al.*, 2008; Foley *et al.*, 2009 and Van Zijderveld *et al.*, 2011). Their mitigating potential has been questioned (Ungerfeld *et al.*, 2007) because it is generally lower than that of nitrates and results have been inconsistent. In a number of experiments, fumarate addition did not affect CH_4 production (McGinn *et al.*, 2004; Beauchemin and McGinn, 2006; Kolver and Aspin, 2006; McCourt *et al.*, 2008; Molano *et al.*, 2008 and Van Zijderveld *et al.*, 2011). With the exception of one study (Wood *et al.*, 2009), in which a 76% decrease in CH_4 production was reported 8 weeks after the introduction of fumaric acid, with gaseous emissions measured using a tunnel system, the long-term effects of these compounds have not been demonstrated. *In vitro* study showed increase in propionate production in rumen by malate addition and reduction in CH_4 (Martin and Streeter, 1995). Newbold *et al.* (2005) reported dose dependent response to fumarate in sheep. Proportionate reduction in CH_4 in sheep fed on encapsulated fumaric acid (0.1% of ration) was reported but the level of CH_4 reduction was uncertain (Wallace *et al.*, 2006). Fumarate has not shown to reduce in CH_4 production *in vivo* (Beauchemin and McGinn, 2006). High price of these organic acids is the main obstacle to this strategy which makes its use uneconomical.

1.2.5 Exogenous enzymes: Exogenous enzymes are added in feed for its fibrolytic action to increase feed digestibility and to enhance productive efficiency of ruminants. These enzymes are products of microbial fermentation either from bacterial (*Bacillus* spp.) or fungal (*Aspergillus, Trichoderma* etc.) origin. Grainger and Beauchemin (2011) recently reviewed their potential application to reduce CH_4 production in the rumen. No evidence is reported for direct effect on CH_4 production but they improve digestibility of feed and enhance production reported by some researchers. Recently, some exogenous enzymes were shown to increase feed efficiency in dairy cows (Arriola *et al.*, 2011 and Holtshausen *et al.*, 2011) and reduce CH_4 when added to the whole diet. On the other hand, some exogenous enzyme products may in fact increase CH_4 production. An exogenous enzyme with endoglucanase and xylanase activities, for example, increased CH_4 production per unit of DMI or milk yield by about 10% to 11% in a study by Chung *et al.* (2012).

1.2.6 Halogenated compounds: It is known that halogenated methane analogues (e.g. bromochloromethane) are able to reduce methane production from ruminants (Morgavi *et al.*, 2010). Bromochloromethane is one of the most effective inhibitors and apparently reduces methane production by interfering with the cobamide-dependent methyl transferase step of methanogenesis (Chalupa, 1977). Bromochloromethane complexed in cyclodextrin results in the sustained inhibition of methane production when fed to ruminants (Tomkins and Hunter, 2004). Moreover, an *in vitro* continuous fermentation system simulating rumen fermentation demonstrated that bromochloromethane significantly reduced methane production (85% - 90 %) and eliminated most methanogens, whereas there was no effect on total short chain fatty acid production, true degradability of feed and efficiency of microbial protein synthesis (Goel *et al.*, 2009). Although H_2 gas was not measured in the *in vitro* study, it is predicted that H_2 gas would accumulate in the rumen when methanogenesis is strongly inhibited by suppression of growth of ruminal methanogens (Janssen, 2010). About 54% reduction in CH_4 output was reported in cattle when fed with bromochloromethane complexed with cyclodextrin twice daily over 8 weeks (McCrabb *et al.*, 1997). These compounds are strong inhibitors of CH_4 production and reduce feed intake (McCrabb, 2000). Adaptation of microbial population to halogenated compounds is a potential problem that results CH_4 inhibition for a short period (Van Nevel and Demeyer, 1996).

1.2.7 Secondary plant metabolites: Many chemicals are synthesized by the plants which are not utilized by the plants for their growth, production, reproduction or other vital functions but their role is to protect plant from microbes, predators and interspecies competition. These are called secondary plant metabolites which may be utilized in animal nutrition as digestion modifiers which are associated with anti-antimicrobial activities (Jouany and Morgavi, 2007). These compounds like saponins, tannins and essential oils have been reported to have antimethogenic activity (Patra and Saxena, 2010). These compounds are prevalent in many tropical plants that improve ruminal fermentation at lower doses but when added in ration at higher doses, they affect ruminal fermentation, animal health and immunity adversely.

1.2.7.1 Saponins: Saponins are glycosides that influence methanogenesis, ruminal protein metabolism and have toxic effects on protozoa (Jouany and Morgavi, 2007 and Patra, 2010). Around 10% - 15% of reduction in methanogenesis was reported in sheep when fed on saponin source *Yucca schidigera* and *Quillaja saponaria* (Pen *et al.*, 2007 and Wang *et al.*, 2009). Reduction in methanogenesis was also reported from saponins from *Sapindus saponaria* (Hess *et al*., 2004) and tea saponins (Zhou *et al*., 2011). About 27% reduction in methanogenesis was reported in growing lambs with tea saponins (Mao *et al*., 2010).

1.2.7.2 Tannins: Tannins are the compounds produced by many tanniferous plants that reduce methanogenesis as they have inhibitory effect on protozoa and methanogens (Patra, 2010). About 16% (Waghorn *et al*., 2002) and 30% (Woodward *et al*., 2004) of reduction in methanogenesis is reported in ruminants fed on *Lotus pedunculatus* (lotus) plant that are rich in condense tannins. Many legumes of hot and arid region are rich in tannin content and serve as a source of valuable feed resource in some countries. Tannins contains anti-nutritional factor which affect fiber and protein digestibility, intake and performance when concentration of tannin is higher than 50 g/kg feed (Mueller-Harvey, 2006) as they reduce amino acid absorption (Waghorn, 2008). There are many plants with high tannin content which inhibits potentially CH_4 emission *in vivo* and *in vitro* by ruminal microbes like, *Emblica officinalis*, *Peltiphyllum peltatum*, *Rheum undulatum*, *Bergenia crassifolia*, *Quercus Incana*, *Vaccinium vitis-idaea*, *Terminalia chebula*, *Populus deltoids* and *Terminalia belerica* (Kumar *et al*., 2009).

1.2.7.3 Essential oils: Essential oils are known for reducing CH_4 production due their antimicrobial properties (Chao and Young, 2000). Their action is more active against gram positive bacteria than gram negative bacteria as they disrupt membrane stability, resulting in leakage of ions across the membrane. Some essential oils coagulate some cell structures by denaturation of protein and also inhibit some enzymes (Wendakoon and Sakaguchi, 1995). Many essential oils are studied *in vivo* and *in vitro* to see their effect on ruminal fermentation and methanogenesis (Calsamiglia *et al*., 2007) with variable outcomes. Decrease in CH_4 production in sheep by 12% was reported by oregano essential oil rich in carvacrol (Klevenhusen *et al*., 2011). Oil from cashew nut reduced CH_4 emission by 20% in dairy cows (Shinkai *et al*., 2010). Some oils had antimethanogenic effect, but affect ruminal fermentation negatively and some reduce ammonia concentration (Busquet *et al*., 2006). Diallyl sulphide, extract form garlic negatively affects ruminal fermentation in sheep (Patra *et al*., 2011).

1.2.8 Vaccination: Vaccinations by various combinations of antigens were tried by different researchers who claimed to improve ruminant performance by reducing methanogenesis. As the rumen epithelium is not secretory and immunologically inert, saliva is the only route for humoral antibodies to reach rumen. Due to glycoproteinous nature of antibodies, they are resistant to proteolysis to some extent and binds to target cells in the rumen (Williams *et al*., 2007). About 7.7% reduction in CH_4 production in sheep was reported by vaccine developed by mixture of three methanogens (Waghorn and Woodward, 2006). However, some author reported the efficacy of vaccine to be short duration due to proteolytic degradation in the rumen (Li *et al.*, 2007 and Cook *et al.*, 2008). Inhibition of methane was also tried through passive immunity where antibodies were given as a feed additive. Chickens could be immunized and eggs can be added in liquid or powder form (Cook *et al.*, 2008). These vaccines are still in primary stage and commercially these vaccines are not available due to insufficient efficacy.

1.2.9 Bacteriophages: These viruses are obligate parasite on specific bacteria. They infect bacterial cells and cause lysis. Many bacteriophages inhabit in the rumen to maintain homeostasis of ruminal microbial population. These phages are host-specific and hence lyse specific microbes like methanogens, *Streptococcus bovis* or pathogens like *E. coli* O157:H7 or salmonella; isolation of such phages is still a challenge. No bacteriophages from rumen methanogens have been isolated and still a matter of investigation (Klieve and Hegarty, 1999).

1.2.10 Bacteriocins: These are proteinaceous toxins produced by some bacteria. They are considered to be narrow spectrum antibiotics and have inhibitory effect on other microbes by affecting their cell membranes. Their role in reduction in CH_4 production in ruminants *in vitro* was reported by authors (Callaway *et al.*, 1997 and Lee *et al.*, 2002). Ruminal bacteria produce some bacteriocin like bovicin HC5 decreases *in vitro* CH_4 production up to 50% (Lee *et al.*, 2002). Nicin reported to inhibit hydrogen producing microbes (Callaway *et al.*, 1997). Bacteriocin or bacteriocin-like inhibitory substance (BLIS) plays an important role in microbial competition in rumen. They are detected in certain strain of *Ruminococcus, Lactobacillus, Butyrivibrio* and *Streptococcus*. Most of the bacteriocins are resistant to gut proteases but instead of using these peptides as feed additives many researcher are suggesting to use the organism that produces bacteriocin as a probiotic (Rychlik and Russell, 2002 and Whitford *et al.*, 2001). There are enormous possibilities for researchers as well as commercialization for utilization of bacteriocins or bacteriocin-producing bacteria in ruminants.

1.3 Genetic selection and breeding of animals

Genetics of animals also influence the methanogenesis in ruminants reported by many researchers (Robertson and Waghorn, 2002; Waghorn and Clark, 2004 and Pinares-Patino *et al.*, 2007). Different amount of CH_4 emission per unit intake of same quality ration at the same level of performance was recorded and they were identified as 'high' and 'low' CH_4 emitters (Pinares-Patino *et al.*, 2007). The cause of low CH_4 emission is not well explained and raises the possibilities of genetic difference among these animals. These genetic differences may lead to differences in salivation, retention and flow of feed and impact on fermentation may lead to low methane emission. Genetic selection and breeding of such animals that consume less feed and produce less CH_4 per unit of feed may be one of the management strategies for reduction in methanogenesis. Some researchers suggested the difference in gastrointestinal tract due to different genetic make-up has impact on fermentation and methanogenesis and ultimately has effect on digestion. Holstein cows from the Northern Hemisphere produced 15% less CH_4/kg of dry mater intake than that from New Zealand at the same stages of lactation given mixed ration in an experiment (Waghorn *et al.*, 2006). However, no significant difference was found on CH_4 emission between two breeds when Jersey and Simmental cattle fed *ad libitum* in open gas exchange chamber (Munger and Kreuzer, 2008).

1.4 Manure management

Stored animal manure is an important emissions source of CH_4 emission (Priano *et al.*, 2014). Animal manure from ruminant and non-ruminant livestock also contributes global CH_4 and GHG emission. Manures are organic compounds like carbohydrate and protein which are decomposed by anaerobic bacteria to transform carbon skeleton into CH_4. Production of CH_4 from manure from dairy cattle, beef cattle and dairy ewe was reported to be 33.2, 2.0 and 0.3 kg/head/year respectively (Merino *et al.*, 2011). Emission of CH_4 from excreta is influenced by many factors. For example, faeces from morning grazers emits more CH_4 than that of afternoon grazers (Priano *et al.*, 2014). Physical forms of faeces like density, humidity, amount of digestible material and climate (temperature and humidity) also influence CH_4 emission (Priano *et al.*, 2014 and Saggar *et al.*, 2004). Animal manure also contains various forms of complex nitrogenous compounds, and nitrous oxide (N_2O) is released to atmosphere due to nitrification and denitrification of animal waste by microbes (Swamy and Bhattacharya, 2006 and Scheehle and Kruger, 2006). N_2O emissions from manure contribute <1% of global GHG emissions (Ecofys, 2013). Enteric CH_4 and manure CH_4 and N_2O emissions are negatively significantly correlated and the mitigation strategies should be targeted to reduce the enteric CH_4 to affect manure CH_4 and N_2O emissions.

Conclusion and recommendations

The inhibition of CH_4 emission in ruminant animals is possible through several accepted ways which include enhancement of animal productivity and feed efficiency by suitable nutritional strategies, by ruminal microbial manipulation, by using certain ingredients that directly or indirectly reduce or inhibit methanogenesis, by biological control (immunization, bacteriophages and bacteriocins) and by enhancing animal production by genetic selection and breeding of animals that consume less feed or produce less CH_4 per unit of feed lead to an overall reduction in CH_4 production (liters/day) per individual animal. Hence, following points are recommended for mitigation of GHG emission from livestock.

- While selecting livestock for production enhancement, level of CH_4 emission should also be considered, which is often overlooked by the livestock owner.
- Enhancement of feed efficiency and reduction in feed intake without affecting production are the most suitable strategies. Hence, it is recommended to provide highly digestible forages along with sufficient grains as well as strategic supplementation of forages with plant metabolites.
- Although ruminal microbial manipulation is another suitable option but results from various research are not sufficient as well as cost effective to use this tool at commercial level. Hence, further investigation should be conducted in this area.

Competing Interests: The authors declare that they have no competing interests.

ACKNOWLEDGEMENTS

The authors are grateful to the Dean and Head, College of Veterinary Medicine, Mekelle University and Addis Ababa University for general support during this study.

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Article received on 21.10.2017 and accepted for publication on 20.11.2017