Dietary Manipulation to Reduce Rumen Methane Production

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ABSTRACT

Global warming has been attributed by various sources including animal agriculture. Ruminants' digestive fermentation result in fermentation end-products of volatile fatty acids, microbial protein and methane production in the rumen. Rumen microorganisms including bacteria, protozoa and fungal zoospores are closely associated with the rumen fermentation efficiency. Manipulation of the rumen in reducing methane using chemicals, feed additives, roughage and concentrate utilization; and the use of plants containing secondary compound, oils have been reported. However, under this review paper, dietary approaches are emphasized and presented.

Key words: Ruminants, Plant secondary compounds, Plant oils, Methane production

INTRODUCTION

Global warming is a hot issue which affects environment and livestock production. Total emissions of greenhouse gases (GHGs) from agriculture, including livestock, are estimated to be between 25-32%, depending on the source (USEPA, 2006; IPCC, 2007) and on the proportion of land conversion that is ascribed to livestock activities. Moreover, Goodland and Anhang (2009) reported that livestock production and its by-products are responsible for at least 51 percent of global warming gases or account for at least 32.6 billion tons of carbon dioxide per year. CO_2 is the largest of the green house gases at 55-60% and methane is the second of the green house gases at 15-20%. Therefore, livestock is the one sector of methane producer from the rumen. It has been estimated that global anthropogenic greenhouse gas (GHG) emissions from the livestock sector approximate to between 4.1 and 7.1 billion tonnes of CO_2 equivalents per year, equating to 15-24% of total global anthropogenic GHG emissions (Steinfeld et al., 2006).

Currently, researchers try to reduce methane production in the rumen by using many feed additives to inhibit methanogenesis. Meanwhile, plants produce a diverse array of plant secondary metabolites to protect against microbial and insects attacks (Wallace, 2004). These natural plant ecochemicals such as essential oils (EO), saponins, tannins and organosulphur compounds have been shown to selectively modulate the rumen microbial populations (Wallace, 2004; Patra and Saxena, 2009a), resulting in an improvement of rumen fermentation and nitrogen metabolism, and a decrease in methane production and nutritional stress such as bloat or acidosis, thus improving the productivity and health of animals (Wallace et al., 2002; Kamra et al., 2006; Rochfort et al., 2008). Recently, a number of studies have discussed the potential of plant bioactives as modifiers of rumen microbial fermentation and ruminant production (Wallace et al., 2002; Wallace, 2004; Hart et al., 2008; Calsamiglia et al., 2007; Patra and Saxena, 2009b). The objective of this review paper is to discuss the effects of dietary supplementation on methane production and associated fermentation in the rumen as well as ruminant production performances.

Mitigation of rumen methane production by dietary supplementation and feeding

Currently, climate change will affect livestock productivity directly by influencing the balance between heat dissipation and heat production and indirectly through its effects on the availability of feed and fodder (Gworgwor et al., 2006; Rowlinson et al., 2008). However, it is notable that, nowadays greenhouse technology is using as useful agricultural technology in plant production (Kumar et al., 2006). However, the most areas for research how to reduce methanogenesis in the rumen have been development the local feed resources for antimethanogenic compounds or alternative electron acceptors in the rumen and reduction in protozoal numbers in the rumen as well as these strategies most cost and long-term effective. Methane production in the rumen is driven by the content of the food supply (substrate) on rumen fermentation and methane production (Cardozo et al., 2004, 2005; Busquet et al., 2005, 2006). Bodas et al. (2008) screened 450 plant extracts for their ability to inhibit methane production in *in vitro* incubations of rumen fluid and found that 35 plants extracts decreased methane production by more than 15% vs those with corresponding control cultures and that, with six of these plant additives, the depression in methane production was more than 25%, with no adverse effects on digestion or fermentation.

Plant secondary compounds

Plant secondary compounds (tannins and saponins) are more important as ruminant feed additives, particularly on CH_4 mitigation strategy because of their natural origin in opposition to chemicals additives. Tannins containing plants, the antimethanogenic activity has been attributed mainly to condensed tannins. There are two modes of action of tannins on methanogenesis: a direct effect on ruminal methanogens and an indirect effect on hydrogen production due to lower feed degradation. Also, there is evidence that some condensed tannins (CT) can reduce CH_4 emissions as well as reducing bloat and increasing amino acid absorption in small intestine. Methane emissions are also commonly lower with higher proportions of forage legumes in the diet, partly due to lower fibre contact, faster rate of passage and in some case the presence of condensed tannins (Beauchemin et al., 2008). Supplementation of PCH at 600 g/hd/d was beneficial in swamp buffaloes fed rice straw as a basal roughage, as it resulted in increased DM intake, reduced protozoal and methane gas production in the rumen, increased N retention as well as efficiency of rumen microbial CP synthesis (Chanthakhoun et al., 2011). Legumes containing condensed tannin (e.g., Lotuses) are able to lower methane (g kg^{-1} DM intake) by 12-15% (Beauchemin et al., 2008; Rowlinson et al., 2008). Also, some authors reported that condensed tannins to reduce CH_4 production by 13 to 16% (DMI basis) (Grainger et al., 2009; Woodward et al., 2004), mainly through a direct toxic effect on methanogens. More recently Woodward et al. (2004) carried out a similar trial with cows fed Lotus corniculatus, on methane was 24.2, 24.7, 19.9 and 22.9 g kg^{-1} DMI for the respective treatments. The CT in lotus reduced methane kg^{-1} DMI by 13% and the cows fed lotus produced 32% less methane kg^{-1} milk solids (fat+protein) compared to those fed good quality ryegrass. McAllister and Newbold (2008) reported that extracts from plants such as rhubarb and garlic could decrease CH_4 emissions. However, there is only limited information on the effect of different saponins on rumen bacteria (Figure 1).

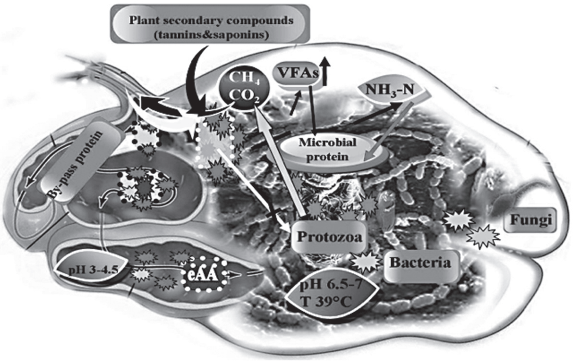

Figure 1. Plant secondary compounds (tannins&saponins) and rumen fermentation (Wanapat et al., 2010).

Saponins are natural detergents found in many plants. There have been increased interests in saponin-containing plants as possible means of suppressing or eliminating protozoa in the rumen. A decrease in protozoa numbers has been reported in the rumen of sheep infused with saponins or fed on saponin-containing plants. Decreased numbers of ruminal ciliate protozoa may enhance the flow of microbial protein from the rumen, increase efficiency of feed utilization and decrease methanogenesis. Saponins are also known to influence both ruminal bacterial species composition and number through specific inhibition, or selective enhancement, of growth of individual species. Saponins have been shown to possess strong defaunating properties both *in vitro* and *in vivo* which could reduce CH_4 emissions (Rowlinson et al., 2008). Beauchemin et al. (2008) recently reviewed literature related to their effect on CH_4 and concluded that there is evidence for a reduction in CH_4 from at least some sources of saponins, but that not all are effective (Rowlinson et al., 2008). While extracts of CT and saponins may be commercially available, their cost is currently prohibitive for routine use in ruminant production systems. However, still required on the optimum sources, level of CT astringency (chemical composition), plus the feeding methods and dose rates required to reduce CH_4 and stimulate production.

Moreover, there have been reports of decreased methane emission by ruminants consuming plant secondary compounds (Carulla et al., 2005; Puchala et al., 2005). Supplementation of pellets containing condensed tannins and saponins (MP and soapberry fruit) influenced rumen ecology by significantly lowering methane concentration in rumen atmosphere and reduced methanogen population (Poungchompu et al., 2009).

However, high CT concentrations (>55 g CT/kg DM) may reduce voluntary feed intake and digestibility (Beauchemin et al., 2008; Grainger et al., 2009). Waghorn et al. (2002) reported a 16% depression in CH_4 emissions kg^{-1} DMI (from 13.8 to 11.5 g kg^{-1} DMI) due to the presence of CT in a diet of Lotus pedunculatus fed to sheep housed indoors.

Processing and preservation of feeds

Forage processing and preservation affect enteric CH_4 production but limited information with regard to these effects is available in the literature. Methanogenesis tends to be lower when forages are ensiled than when they are dried and when they are finely ground or pelleted than when coarsely chopped (Martin et al., 2007). Grinding or pelleting of forages to improve the utilization by ruminants has been shown to decrease CH_4 losses per unit of feed intake by 20-40% when fed at high intakes.

Roughage and concentrate

The forage to concentrate ratio of the ration has an impact on the rumen fermentation and hence the acetate: propionate ratio (declines with F: C ratio). The CH_4 reduction is well in line with the observations of Bannink et al. (1997) that concentrate rich diets showed lower and higher coefficients of conversion of substrate into acetate and propionate, respectively. However, many experimental databases suggest that a higher proportion of concentrate in the diet leads to a reduction in CH_4 emissions as a proportion of energy intake (Blaxter and Clapperton, 1965; Yan et al., 2000) due mainly to an increased proportion of propionate in ruminal VFA. The scope for reductions in CH_4 emissions depends on the starting level of concentrates, as there are dietary limitations and there are large differences in current usage of concentrates in different regions of the world (Rowlinson et al., 2008). The poor tolerance to low pH by protozoa and cellulolytic bacteria decreases further hydrogen production. A positive correlation between cellulolytic and methanogens in the rumen of different animal species (cattle, sheep, deer) has been shown (Rowlinson et al., 2008), except in the buffalo. This exception was explained by the fact that *F. succinogenes,* a non-hydrogen-producing cellulolytic species, was the major cellulolytic bacteria of this animal. On the contrary to other researchers, Sejian et al. (2011) reported that higher proportion of forage to concentrate resulted in decreasing ruminal methane production. They stated that lower CH_4 production from high forage: grain diet can be attributed to the effect of the high content of fat in the diet which could potentially reduce fiber degradation and amount of feed that is fermentable as well as forage grinding effects. Yurtseven and Ozturk (2009) observed that amount of ruminal methane produced from corn was lower than that of barley grain in ruminant. This is may be due to higher starch content and slow starch degradability of corn vs. barley grain. With regard to the ingredient composition of concentrates, selecting carefully defined carbohydrate fractions, such as more starch of a higher rumen resistance and less soluble sugars could significantly contribute to a reduction in CH_4 emission (Tamminga et al., 2007). Sejian et al. (2011) reported that Total mixed ration (TMR) feeding leads to decrease methane production vs. separate forage-concentrate feeding.

Plant oils

There are five possible mechanisms by which lipid supplementation reduces CH_4: reducing fibre digestion (mainly in long chain fatty acids); lowering DMI (if total dietary fat exceeds 6-7%); suppression of methanogens (mainly in medium chain fatty acids); suppression of rumen protozoa and to a limited extent through biohydrogenation (McGinn et al., 2004; Beauchemin et al., 2008; Johnson and Johnson, 1995). Oils offer a practical approach to reducing methane in situations where animals can be given daily feed supplements, but excess oil is detrimental to fibre digestion and production. Oils may act as hydrogen sinks but medium chain length oils appear to act directly on methanogens and reduce numbers of ciliate protozoa (Machmuller et al., 2000). However, Kongmun et al. (2010) reported that supplementation of coconut with garlic powder could improve *in vitro* ruminal fluid fermentation in terms of volatile fatty acid profile, reduced methane losses and reduced protozoal population. In contrast, Johnson et al. (2002, 2008) found no response to diets containing 2.3, 4.0 and 5.6% fat (cottonseed and canola) fed over an entire lactation. Beauchemin et al. (2008) recently reviewed the effect of level of dietary lipid on CH_4 emissions over 17 studies and reported that with beef cattle, dairy cows and lambs, there was a proportional reduction of 0.056 in CH_4 (g kg^{-1} DM intake) for each 10 g kg^{-1} DM addition of supplemental fat. While this is encouraging, many factors need to be considered such as the type of oil, the form of the oil (whole crushed oilseeds vs. pure oils), handling issues (e.g., coconut oil has a melting point of 25°C) and the cost of oils which has increased dramatically in recent years due to increased demand for food and industrial use. In addition, there are few reports of the effect of oil supplementation on CH_4 emissions of dairy cows, where the impact on milk fatty acid composition and overall milk fat content would need to be carefully studied. Strategies based on processed linseed turned out to be very promising in both respects recently. Most importantly, a comprehensive whole system analysis needs to be carried out to assess the overall impact on global GHG emissions (Rowlinson et al., 2008).

Manh et al. (2011, unpublished data), Khodyhotha et al. (2011, unpublished data) who reported that supplementation of Eucalyptus leaf meal at 100 g/day for ruminants could be on alternative feed enhancer which reduces rumen methane gas production in cattle, while nutrient digestibilities were unchanged. On the other hand, Pilajun and Wanapat (2011) reported that increasing coconut oil and mangosteen peel pellet levels decreased the proportion of methane reduction, but the suitable level should not exceed than 6% for coconut oil and 4% DM for MPP supplementations, respectively. Recently, the comprehensive research based on individual components of essential oils, physiological status of animals, nutrient composition of diets and their effects on rumen microbial ecosystem and metabolism of essential oils will be required to obtain consistent beneficial effects (Patra, 2011). Moreover, Wanapat et al. (2012) comprehensively reported based on both *in vitro* and *in vivo* trials, concerning rumen microorganisms, methane production and the impacts on rumen mitigation of methane using plant secondary compounds and oils are showing great potential for improving rumen ecology in ruminant productivity (Table 1).

Table 1. Effects of plant secondary compounds and plant oil on digestibility and methane gas production in various studies.

Substrates	Level	Methane, %	Animal	References
Garlic powder	16 mg	(-) 22.0*	Buffalo (rumen fluid)	Kongmun et al. (2010)
Coconut oil	16 mg	(+) 6.4*	Buffalo (rumen fluid)	Kongmun et al. (2010)
Soapberry fruit and mangosteen peel pellet	4%	10.0		Poungchompu et al. (2009)
Mangosteen peel powder	100g/h/d	(-) 10.5	beef cattle	Kongmun et al. (2009)
Tea saponins	0.01 0.02 0.03 0.04mg/mg diet	1.4 9.7 10.0 2.6		Wongnen and Wachirapakorn (2011)
Coconut oil	7%	(+) 39.5*	beef cattle	Kongmun et al. (2009)
Coconut oil	7%	(-) 10.2*	Buffalo	Kongmun et al. (2010)
Coconut oil and Sunflower oil	50:50 ratio at 5% in concentrate	10	Buffalo	Pilajun et al. (2010)
Coconut oil Garlic powder	8:4 (mg)	(-) 18.9*	Buffalo	Kongmun et al. (2010)
Coconut oil + Garlic powder	7% + 100g	(-) 9.1*	Buffalo	Kongmun et al. (2010)
Eucalyptus oil	0.33-2 ml L^{-1}	30.3-78.6%	Sheep	Sallam et al. (2009)
Eucalyptus oil	0.33-1.66 ml L^{-1}	4.47-61.0%	Buffalo	Kumar et al. (2009)
Eucalyptus meal leaf	100 g/d	reduce	Cow	Manh et al. (2011, unpublished data); Khodyhotha et al. (2011, unpublished data)

*are significantly different (P<0.05) from control group; +,- the values were increased or decreased from control group.

CONCLUSION

Based on this review, it shows that ruminants can produce methane from their fermentation by microbes, which would influence greenhouse gas (GHG) production by ruminants and global warming. Nutritional strategies including type, processing and ratio of roughage and concentrate as well as the use of plant secondary compounds (tannins and saponins) and plant oils can be used to mitigate rumen methane. However, further research is required regarding the mode of actions and level of use of various sources.

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