NUTRITIONAL MEASURES FOR MITIGATING METHANE EMISSION FROM LIVESTOCK

Anuraga Jayanegara
Department of Nutrition and Feed Technology, Faculty of Animal Science
Bogor Agricultural University, Jl. Agatis Kampus IPB Darmaga Bogor 16680
Phone: (0251) 8626213, Fax: (0251) 8626213, E-mail: anu_jayanegara@yahoo.com

Running title: Mitigating methane from livestock

Abstract

Livestock, particularly ruminant animals produce methane which plays an important role in global warming and in the destruction of ozone layer. Furthermore, methane production is also associated with considerable energy losses from ruminant and leads to decreasing energy gain and productivity. In this paper, a review is presented regarding nutritional measures for mitigating methane emission from livestock. The objective can be achieved by ration manipulation and the use of additives. Increasing proportion of concentrate and decreasing proportion of roughage in the diet may reduce methane production. Some additives that can be used are lipids, antibiotics, plant secondary compounds and probiotics. However, some of these options often cause detrimental effects to the productivity of livestock and the environment. Therefore, methanogenesis and its inhibition cannot be considered separately, but should be integrated to the entire system of livestock production. Moreover, reasonable options and cost effectiveness should be taken into account when applying these methods in the developing countries like Indonesia.

Key words: methane, livestock, nutrition

INTRODUCTION

Livestock, both monogastrics and ruminants play an important role as food sources for human, particularly as protein source. They derive various kinds of valuable products, such as meat, milk, egg and many others. Therefore, increasing their production both in quantitative and qualitative terms is a necessity. However, instead of their contribution to human, ruminants produce considerable amount of methane which plays an important role in global warming and in the destruction of ozone layer. Ruminant methane production is responsible for approximately 95% of total global animal and human methane emissions (Van Nevel & Demeyer 1995), and contributes to the anthropogenic greenhouse gases to be as high as 18% (Kreuzer & Soliva 2008). Furthermore, methane production is also associated with considerable energy losses and lead to decreasing energy gain and productivity. Around 6-10% of the gross energy of the ruminant diet is converted to methane (Immig 1996).

METHANE PRODUCTION IN THE RUMEN

The rumen ecosystem is anaerobic. Therefore the oxidations of feed substances such as carbohydrates and protein for energy production are made through dehydrogenations. During oxidation, NAD is reduced to NADH. NADH has to be re-oxidized to NAD to complete the fermentation of sugars:

$$2H + NAD^+ \leftrightarrow NADHH^+$$

$$NADHH^+ \leftrightarrow NAD^+ + H_2$$

The hydrogen gas (H_2) formed has to be eliminated to maintain the hydrogenase activity and to avoid negative feedback on microbial organic matter degradation. The reduction of CO_2 with H_2 via methanogenesis keeps the partial pressure of hydrogen very low, and this has an important effect on the overall fermentation: hydrogenase activity can proceed towards hydrogen production, thus avoiding the formation of lactate or ethanol as major end products and allowing more acetate to be produced (Van Nevel & Demeyer 1995). The removal of H_2 can be through methanogenesis and acetogenesis in the following pathways:

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ *methanogenesis*

$2CO_2 + 4H_2 \rightarrow CH_3COOH + 2H_2O$ *acetogenesis*

Therefore, formation of CH_4 is an essential metabolic pathway for H_2 removal in the rumen. However, methanogenesis should be optimized for digestive efficiency and possibly to be reduced to a certain extent without any detrimental effect on the major rumen functions (Beauchemin *et al.* 2008).

MITIGATING RUMEN METHANOGENESIS

Inhibition of rumen methanogenesis is aimed mainly at increasing feed efficiency and lowering green house gas emissions. By shifting electron flow from methane to propionate production, more energy and carbon are deposited in short chain fatty acids (SCFA), which become available to the animal (Jayanegara *et al.* 2012). Some of the promising options to mitigate methane production are through ration manipulation and use of additives.

A. Ration Manipulation

Type of carbohydrate fermented in the rumen influences methane production through impacts on ruminal pH and the microbial population. High amounts of concentrates decrease rumen pH and it has been known that methanogenic bacteria are inhibited at lower pH values (Van Nevel & Demeyer 1995). Fermentation of cell wall fibre produces higher acetic:propionic acid and higher methane losses (Johnson & Johnson 1995). Since roughage contains more fibre and concentrate contains more soluble substances, therefore the replacement of roughage in animal diet by concentrate may likely shift the composition of partial SCFA from higher to lower acetate production and more propionate. In the developing countries this option is still very much open despite the high cost of the concentrates. But in the developed countries, most of ruminant particularly dairy cows are already fed at high concentrate level.

However, the effect of concentrate is not linear, and only at very high dietary concentrate proportions seem to be really effective in decreasing methane emissions (Kreuzer & Soliva 2008). The scope of using concentrates to lower CH_4 emissions from the dairy sector is also limited as milk quality is negatively affected once concentrates exceed ~50% of the diet. Furthermore, increased dietary concentrate may sometimes increase total net emissions as more grain must be grown, processed and transported, leading to increased use of pesticides, fertilisers, and additional ancillary sources of emissions associated with production and transportation infrastructure (Beauchemin *et al.* 2008). Forage processing such as chopping, grinding and pelleting can further decrease methane production. Increase rate of passage of the processed forage likely contributes to the reduced methane production (Johnson & Ward 1996).

B. Use of Additives

Lipids: Lipids and lipid-rich feeds are among the most promising options for direct methane mitigation. Lipids can serve as a substitute for a part of dietary carbohydrates (maximum of 10% lipids in diet, but actually 2%), and lipids have a negative effect on ruminal methane production. Dietary lipid supplementation reduces CH_4 emissions by decreasing ruminal organic matter fermentation, the activity of methanogens and protozoal numbers, and for lipids rich in unsaturated fatty acids, through hydrogenation of fatty acids (Johnson & Johnson 1995). Saturated medium chain fatty acids, C10-C14, also contribute to methane reduction. At ruminal temperature, an increasing chain length of medium chain fatty acids seems to reduce their efficiency in inhibiting methanogens and methane formation due to lower solubility (Bucher *et al.* 2008). In practice, reductions of 10-25% of methane are more likely although reductions ≥40% are possible with high levels of lipid supplementation. Generally, it is recommended that total fat should not exceed 6-7% of the dietary dry matter otherwise a depression in dry matter intake may occur (Beauchemin *et al.* 2008).

Antibiotics: For many years, antibacterial substances have been used widely in animal production as growth promoting substances. An antibiotic chlortetracycline (11 ppm in feed) was found to lowering 9-22% methane production than control animals in *in vitro* incubations. The inhibition was not the result of direct effect of the antibiotic on methanogenic archaea, but due to inhibition of the microbes producing hydrogen and formate, both intermediate precursors of methane. Other antibiotic avoparcin, a glycopeptide, is known to act on Gram-positive bacteria, inhibit methanogenesis, simultaneously shifting the SCFA pattern to a higher propionate production at the expense of acetate and butyrate. Bacitracin, a polypeptide antibiotic which also affects Gram-positive bacteria, also lowered methane production, but its action was less potent than ionophores (Johnson & Johnson 1995). Ionophore additions to beef cattle diets, particularly monensin, reduces feed intake 5 to 6%, decreases acetic:propionic acid and decreases methane losses. The decrease in methane production ranges from slight to approximately 25%. The effect of ionophores is probably due to shifts in the microbial population towards ionophore-resistant organisms, which tend to produce more propionate (Johnson & Johnson 1995).

Plant secondary compounds: Among the promising natural feed additives to mitigate methane are plant secondary compounds such as saponins and tannins (Takahashi *et al.* 2007; Jayanegara *et al.* 2011; Jayanegara *et al.* 2012). The CH_4-suppressing effect of plants rich in saponins seems to be particularly related to their anti-protozoal effects. These protozoa-associated methanogens have been variously reported as contributing up to 37% of total rumen methane emissions (Klieve & Hegarty 1999). Saponins form complex with sterols in protozoal cell membranes causing inhibition of their activity and cell lysis (Cheeke 1999). Since a small portion of methane production is due to methanogens attached to protozoa, the decrease of protozoal counts due to the presence of saponins affecting also methane production. Several *in vivo* and *in vitro* studies provide evidence for CH_4 suppression from some saponin sources such as saponin-rich extracts of *Quillaja saponaria* and *Yucca schidigera* (Takahashi *et al.* 2007), although it seems that not all saponin sources are effective (Beauchemin *et al.* 2008).

Tannins in the form of hydrolysable tannins have been proved to decrease ruminal methane production *in vitro*, and the reduction of methane linearly increased by the increase of tannin activity with r^2=0.99 and P<0.001 using three different tannin containing plants. Tannin activity was expressed as the percentage of gas increase after adding polyethylene glycol (PEG) since PEG has a specific binding to tannins (Jayanegara *et al.* 2008). The authors then extended the sample size using 16 different plants and still got high correlation with r^2=0.87 and P<0.001 (Figure 1; Jayanegara *et al.* 2009). The proposed mechanisms whereby tannins reduce methane emissions from ruminants are: (1) indirectly through a reduction in fiber digestion, which decreases H_2 production, and (2) directly through an inhibition of the growth of methanogens (Tavendale *et al.* 2005).

However, intensive research is still required to classify the multitude of chemical forms of saponins and tannins for their efficiency and to evaluate the ideal doses for maximum effects at minimal adverse side-effects. Using saponins properly is also relevant to animal health due to their potential haemolytic activity, while with using tannins the major problem consists of low palatability and potential impairment of ruminal digestion. In turn, both groups of plant secondary metabolites may have co-benefit in reducing ruminal protein degradation to ammonia thus reducing the inclination of the manure to emit environmentally hazardous ammonia (Kreuzer & Soliva 2008).

Probiotics: The most common used probiotics for ruminants are based on *Saccharomyces cerevisiae* and *Aspergillus oryzae*. The addition of probiotics could reduce the number of protozoa. Because the close association between methanogens and ciliates, and between ciliates and other members of the bacterial population, the microbial additives could therefore change the composition of the microbial flora and decrease methane production indirectly by altering the balance of the population (Van Nevel & Demeyer 1995). However, the available data relating microbial additives and methane production are not convincing until now and much more research is needed before it can be concluded that probiotics decrease methane production *in vivo*. For example, *Saccharomyces cerevisiae* fed to bulls at 1.5 kg per tonne of feed and measured methane production from rumen fluid *in vitro*, did not decrease methane production from the control after 24 h although there was a 10% decrease after 12 h incubation (Mutsvangwa *et al.* 1992).

SELECTING THE APPROPRIATE METHODS

There are numerous strategies to mitigate methane emissions from livestock and some of the methods are described above. The question that may arise is, which method is the most appropriate to be chosen? Actually, there is no single approach can completely solve the problem. Each method has its own advantages and disadvantages. Increasing proportion of concentrate instead of roughage will enhance livestock productivity at the same time but too costly for ruminant feed. Chopping the forage is a simple technique and affordable in many developing countries, but require more labor force. Lipid is an interesting option but animals will reject the diet if it is too high proportion of lipids due to its inconvenient smell. Antibiotics and ionophores are very effective in reducing methane but banning of such products is of important to be considered. Tannins and saponins are abundantly available from nature but may cause adverse effects on palatability and animal health as well. Biotechnological interventions such as the use of probiotics are promising but more research needs to be carried out to establish such technology in practice. In the developing countries such as Indonesia, cheaper and easier technologies are preferable such as chopping, adding lipids to certain extent, and mixing a portion of tannins- and saponins-rich plant leaves to animal diets. Another thing that needs to be considered in selecting the appropriate methods to reduce methane emissions is its effect on the livestock as an entire system rather than only the rumen fermentation. It is unwise to reduce methane production but at the same time creating negative effects on livestock productivity and health, whereby they products are needed to feed to many people in many areas of the world.

CONCLUSIONS

The development of nutritional strategies to mitigate methane emissions from ruminant animals is possible and desirable. Mitigating methane emissions is not only improving feed efficiency and animal productivity, but also reducing the contribution of ruminant livestock to the global methane inventory. Some of available methods are based on ration manipulation, the use of additives and through biotechnological interventions. However, many factors need to be considered before applying a particular method, especially its advantages and disadvantages and its relationship with local condition. Reasonable options and cost effectivity should be taken into account when applying these methods in the developing countries such as Indonesia.

REFERENCES

Beauchemin KA, Kreuzer M, O'Mara F, McAlister TA. 2008. Nutritional management for enteric methane abatement: a review. *Aust J Exp Agric* 48: 21-27.

Bucher S, Meile L, Kreuzer M, Soliva CR. 2008. Inhibitory effect of four saturated fatty acids on different methanogenic *Archaea* in pure cultures. *Proc Soc Nutr Physiol* 17: 157.

Cheeke PR. 1999. Actual and potential application of *Yucca schidigera* and *Quillaja saponaria* saponins in human and animal nutrition. *Proc Am Soc Anim Sci* 1-10.

Immig I. 1996. The rumen and hindgut as source of ruminant methanogenesis. *Environ Monit Assess* 42: 57-72.

Jayanegara A, Makkar HPS, Becker K. 2008. Methane reduction potential of tannin-containing plants using an *in vitro* rumen fermentation system. *Proc Soc Nutr Physiol* 17: 159.

Jayanegara A, Togtokhbayar N, Makkar HPS, Becker K. 2009. Tannins determined by various methods as predictors of methane production reduction potential of plants in an *in vitro* rumen fermentation system. *Anim Feed Sci Technol* 150: 230-237.

Jayanegara A, Wina E, Soliva CR, Marquardt S, Kreuzer M, Leiber F. 2011. Dependence of forage quality and methanogenic potential of tropical plants on their phenolic fractions as determined by principal component analysis. *Anim Feed Sci Technol* 163: 231-243.

Jayanegara A, Leiber F, Kreuzer M. 2012. Meta-analysis of the relationship between dietary tannin level and methane formation in ruminants from *in vivo* and *in vitro* experiments. *J Anim Physiol Anim Nutr* 96: 365-375.

Johnson KA, Johnson DE. 1995. Methane emissions from cattle. *J Anim Sci* 73: 2483-2492.

Johnson DE, Ward GM. 1996. Estimates of animal methane emissions. *Environ Monit Assess* 42: 133-141.

Klieve AV, Hegarty RS. 1999. Opportunities for biological control of ruminal methanogenesis. *Aust J Agric Res* 50: 1315-1319.

Kreuzer M, Soliva CR. 2008. Nutrition: key to methane mitigation in ruminants. *Proc Soc Nutr Physiol* 17: 168-171.

Mutsvangwa T, Edwards IE, Topps JH, Paterson GFM. 1992. The effect of dietary inclusion of yeast culture (Yea-sacc) on patterns of rumen fermentation, food intake and growth of intensively fed bulls. *Anim Prod* 55: 35-40.

Takahashi J, Pen B, Asa R. 2007. Manipulation of rumen methanogenesis with saponin-containing plant extracts. *EAAP Publication* 124: 615-616.

Tavendale MH, Meagher LP, Pacheco D, Walker N, Attwood GT, Sivakumaran S. 2005. Methane production from *in vitro* rumen incubations with *Lotus pedunculatus* and *Medicago sativa*, and effects of extractable condensed tannin fractions on methanogenesis. *Anim Feed Sci Technol* 123-124: 403-419.

Van Nevel C, Demeyer D. 1995. Biotechnology in Animal Feeds and Animal Feeding. Weinheim: VCH Verlagsgesellschaft GmbH.

Figures

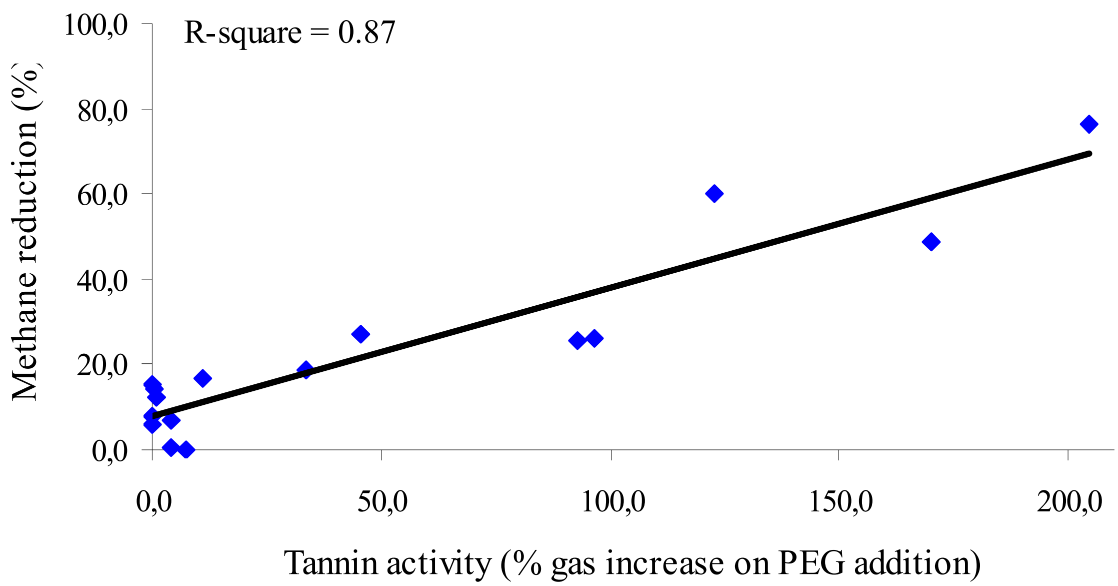

Fig. 1. Relationship of tannin activity and percentage of methane reduction