Reducing methane emissions in ruminants: is it an achievable goal ?

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Reducing methane emissions in ruminants: is it an achievable goal?

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Abstract. Decreasing methane emissions and, more generally, decreasing the environmental footprint of ruminants is one pressing challenge facing the ruminant production sector. Notwithstanding, because of the intricate relationships existing between the efficiency of feed fermentation in the rumen and methanogenesis, mitigation options have to be evaluated not just in terms of their effect on methane or total GHG emissions but also on other rumen functional parameters and on their final consequences on animal production. The sustainability and profitability of the proposed mitigation options have to be considered as well. Several strategies that focus on the farm, the animal and the gastrointestinal microbes are currently being explored to decrease GHG emissions throughout the whole production cycle. Some of these strategies will be presented and discussed with a particular emphasis on the information available on technologies and feeding and management practices applicable to small ruminant production systems.

Keywords. Enteric methane– Small ruminants – Mitigating strategies.

Réduire les émissions de méthane chez les ruminants: est-ce un objectif réalisable ?

Résumé. *La réduction des émissions de méthane, et plus généralement la diminution de l'empreinte carbone de l'élevages, est un défi auquel doit faire face le secteur des productions animales des ruminants. Parce qu'il existe des relations étroites entre l'efficacité de la fermentation des aliments dans le rumen et la méthanogenèse, les options d'atténuation doivent être évaluées en termes d'efficacité sur le méthane et sur l'ensemble des gaz à effet de serre, mais aussi sur d'autres fonctions du rumen et* in fine *sur la production animale. La durabilité et profitabilité des options d'atténuation proposées doivent aussi être prises en compte. Plusieurs stratégies de réduction qui se situent soit au niveau de la ferme, de l'animal et des microorganismes gastrointestinaux sont actuellement à l'étude, afin de diminuer les émissions sur l'ensemble du cycle de production de l'animal. Certaines de ces stratégies seront présentées et discutées avec une attention toute particulière pour les biotechnologies, l'alimentation et les pratiques de gestion applicables aux systèmes de production des petits ruminants.*

Mots-clés. *Méthane entérique – Petits ruminants – Stratégies de réduction.*

I – Introduction

Livestock contribution to the anthropogenic greenhouse gas (GHG) emissions is important, about 18% according to FAO estimates (Steinfeld *et al.*, 2006). In ruminants' production systems, if emissions from land use and land use change are not considered, enteric methane represents about half of all GHG produced. The large share of methane in the GHG balance has spurred research to better understand and to propose strategies for reducing enteric methane production. Small ruminants, like other livestock, are expected to increase in numbers due to the predicted increase in demand for meat and milk. Much of the increase in sheep and goat numbers will come from developing countries and from hot and/or arid-semiarid areas (Herrero *et al.*, 2008; Thornton *et al.*, 2009) and any strategy to be successful should be sustainable and improve the food security of smallholders.

This short review provides an update on the knowledge and effectiveness of the approaches used to mitigate enteric methane emissions. Whereas possible the focus is given on in vivo results and those that can be applied to small ruminant production systems. The literature citation is not exhaustive and for more general, comprehensive reviews in the area readers are referred to Beauchemin *et al.* (2009), Martin *et al.* (2010) and Cottle *et al.* (2011).

II – Overview of rumen methanogenesis

Methane is produced by a particular group of microorganisms: the methanogenic archaea. In the rumen, these microorganisms reduce carbon dioxide to methane using mainly dihydrogen as electron donor. Methane production is a natural process that prevents the accumulation of the dihydrogen end product released by bacteria, protozoa and fungi during the fermentation of feeds, particularly the carbohydrate fraction. Although the complete elimination of methanogenesis is not desirable, methane production can be modulated without affecting, or even improving, animal performance. Methane production depends obviously on the methanogenic community but also on the availability of the dihydrogen substrate and the interactions existing between the different rumen microbes producing and consuming dihydrogen (Morgavi *et al.*, 2010). The physical and chemical conditions of the rumen, influenced by the diet and the host animal, such as rate of passage, profile of volatile fatty acids and pH also have an effect on methane production.

III – Diet composition

The increase in the amount of starch concentrates in the diet causes a decrease in methane production per kg DM intake. This is probably the most widely known approach to reduce methane emissions in ruminants. In high-starch diets the percentage of methane corresponding to the gross energy intake can be as low as 3% as compared to 6 to 8% in diets with forages as the main feed component. However, this marked decrease is only observed at levels of intake that are equal or above 2.5 times the intake required for maintenance and when the concentrate represents more than 50% of the ration (Sauvant and Giger-Reverdin, 2007, 2009). Although these types of diets can be found in fattening lambs temperate areas they are not common in the more extensive small ruminant production systems prevailing in arid-semiarid areas. Reduction in methane emissions can be also achieved by increasing the amount of soluble sugars in the diet that can be provided by the grazed plant and hence applicable to extensive production systems. Ryegrass varieties containing high soluble sugar contents (*i.e.* 20.5 g/kg DM) have been shown to decrease methane production per kg of live weight gain by up to 25% in growing lambs (Kim *et al.*, 2011). Ulyatt *et al.* (2002) also showed that methane yield from sheep grazing kikuyu grass (*Pennisetum clandestinum*) a sub-tropical C4 plant, decreased when the pasture had higher content of soluble sugars and lower proportion of fibre. The reduction of methane in diets rich in rapidly fermentable carbohydrates was explained by an increased production of propionate at the expense of acetate –pathways consuming and producing dihydrogen, respectively– by a decrease in rumen pH, by a decrease in the concentration of protozoa –high producers of dihydrogen– or by a combination of these three factors (Martin *et al.*, 2010).

In forage-only diets, methane production is positively correlated with organic matter digestibility and the proportion of NDF (meta-analysis of Archimède *et al.*, 2011). At higher digestibility, there is more fermentation end products produced and at higher amount of structural carbohydrates (NDF), acetate production is stimulated. In both cases, more substrates for methanogenesis are available in the rumen. As forage matures, methane emission increases (Robertson and Waghorn, 2002) although in some trials no change in methane production as a percentage of gross energy or organic matter ingested was reported (Pinares-Patiño *et al.*, 2003).

A replacement of grass by legumes was tested by several authors as a strategy for reducing emissions but such an effect was not observed with clovers (*Trifolium repens*, *T. pratense*) or alfalfa (*Medicago sativa*) (Niderkorn *et al.*, 2011; Rogosic *et al.*, 2008; van Dorland *et al.*, 2007). Similarly, sheep receiving white clover or ryegrass had similar methane yield (Hammond *et al.*, 2011) and a meta-analysis of forage-only diets did not reveal any difference in methane emission between temperate grasses and legumes (Archimède *et al.*, 2011). However, some studies suggest that alfalfa has a lower methanogenic potential. McCaughey *et al.* (1999) observed a 10% decrease in methane production per kg of weight gain in grazing beef cattle when grasses in pasture were replaced by a mixture of grass and alfalfa. Some alfalfa varieties are rich in secondary metabolites such as malate (Martin, 1998) and saponins (Klita *et al.*, 1996) (see below) that might reduce methane production. The meta-analysis of Archimède *et al.* (2011) also showed that animals fed grasses with a C4 photosynthesis pathway, typical of hot climates, produce 10 to 17% more methane than animals fed C3 grasses with comparable digestibility and NDF content. The reasons are still unexplained. Conversely C4 legumes produce lower methane than C3 legumes, likely due to the proportion of tannins that are on average more abundant in tropical legumes. Tannins are secondary metabolites that can contribute to the reduction of methane emissions. Forages containing tannins can be a major component of the diet but for clarity reasons their role will be detailed in the section below.

IV – Feed supplements and additives

The supplementation of lipids in the diet is a promising strategy to reduce enteric methane emissions. Lipids have been extensively used to increase the energy density of the diet without altering ruminal pH and, in the case of polyunsaturated fatty acids, to improve the nutritional quality of meat and milk (Sliwinski *et al.*, 2002a). Lipids have a direct anti-microbial action against methanogens and also affect protozoa, the cellulolytic bacteria and other bacteria (Doreau and Ferlay, 1995; Maia *et al.*, 2007)

In addition, fatty acids are not fermented in the rumen and hence they do not contribute dihydrogen and other substrates for methanogenesis. A decrease in methane production of 2 to 4% has been reported for every percent increase in lipid content in the ration (reviews of Eugène *et al.*, 2008; Grainger and Beauchemin, 2011; Martin *et al.*, 2010). The long term efficacy of lipid supplementation in reducing enteric methane emissions was also demonstrated in dairy cows receiving extruded linseed for more than a year (Martin *et al.*, 2011).

New sources of lipids are the byproducts of ethanol production. Corn distillers' grains contain about 10% of fatty acids but it may be incorporated in high amounts in the diet. McGinn *et al.* (2009) decreased methane production per kg DM intake by 16% in beef cattle by replacing barley (35% of the ration) with corn distillers' dried grains with solubles. Other by-products of biofuels such as rapeseed meal containing 10% lipid have a similar abating effect (Moate *et al.*, 2011). A limited number of trials showed no change or even a slight increase in methane production per kg DM intake with lipid supplementation (e.g. Cosgrove *et al.*, 2008). This reflects the high variability of response perhaps due to interactions of different lipid supplements with other components of the diet. The majority of trials reporting the effect of lipid supplementation on methane have been obtained with fattening beef cattle and dairy cows due to the higher intensification of these production systems. If supplementing with lipids is economically favorable, small ruminants should react in a similar way than cattle.

Plants synthesize a great number of chemicals that are not involved in their growth, reproduction and other vital functions. These so called secondary compounds have broad, non-specific, protective and defensive functions against predators, infections and interspecies competition. Secondary plant compounds are used in animal nutrition as feed flavorings and conservatives and as modifiers of the digestion, the latter utilization mainly associated to their antimicrobial activity (Jouany and Morgavi, 2007). The main groups of chemicals that have been reported as potentially having an antimethanogenic activity are tannins, saponins and some compounds extracted by distillation and broadly classified as essential oils.

Tannins reduce methane due to their inhibitory effect upon methanogens, protozoa and other hydrogen-producing microbes (Patra, 2010; Tavendale *et al.*, 2005). Temperate plants rich in tannins such as *Lotus pedunculatus* have been shown to reduce methane production by up to 30% (Waghorn *et al.*, 2002; Woodward *et al.*, 2004) and can replace other forages in the diet. In hot and arid regions many legumes, particularly foliage from leguminous trees, are rich in tannins and they represent a valuable feed resource in some countries. However, differently from temperate legumes, tropical legumes have low digestibility that is often associated to their high tannin content. Fiber and protein digestibility as well as intake and performance can be affected when tannin concentration is higher than 50 g/kg feed (Mueller-Harvey, 2006), which is the reason why, in some situations, the use of tannin binders are proposed to reduce the antinutritional effects of tropical forages (Carulla *et al.*, 2005; McGinn *et al.*, 2009). The use of forages rich in tannins as a major feed component seems difficult to implement in arid and subtropical conditions but in production systems where the use of supplements is possible the utilization of tannin-containing extracts could be a viable alternative. And in many situations, tannin extracts have been proven effective for reducing methane production (reviewed by Robertson and Waghorn, 2002). In their meta-analysis, Jayanegara *et al.* (2002) reported that noticeable effects of tannins are observed at levels higher than 20 g/kg feed. Tannins are chemically characterized as condensed tannins or proanthocyanidins, which are polymers of flavonoid units joined by highly stable covalent carbon-carbon bonds, and hydrolysable tannins, which contain a carbohydrate with hydroxyl groups partially or totally esterified with phenolic acids such as gallic acid (gallotannins) or ellagic acid (ellagitannins). Most of the antimethanogenic effect are attributed to condensed tannins but hydrolysable tannins are also efficacious as well as non-tannin phenolic compounds (van Dorland *et al.*, 2007). There is a large diversity within each class of tannins (Mueller-Harvey, 2006) and it is probably that the precise chemical structure and the level of supplementation can partially explain differences observed with different sources of tannins by various authors. For instance, Carulla *et al.* (2008) showed that the extract of acacia tannins at 2.5% of feed DM reduced methane production by 13% in sheep, while no effect of tannins were found by Beauchemin *et al.* (2007) using quebracho distributed at a rate of 2% and Sliwinski *et al.* (2002b) with levels up to 2% of chestnut tannin in the feed.

Saponins are glycosides found in many plants. They contain a sugar moiety and a hydrophobic terpenoid or steroid aglycone, the 'sapogenin'. They influence methane production and protein metabolism in the rumen by their toxic effect on protozoa (Jouany and Morgavi, 2007; Patra, 2010). The sources of saponins most studied are *Yucca schidigera* and *Quillaja saponaria* but they were mainly assayed for their effect on protein metabolism. In sheep, decreases of 10 to 15% in methane production were reported with these saponin sources (Pen *et al.*, 2007; Wang *et al.*, 2009). Similar results have been reported with saponins from *Sapindus saponaria* (Hess *et al.*, 2004) and tea saponins (Zhou *et al.*, 2011) while Mao *et al.* (2010) reported a decrease in methane production of 27% in growing lambs with tea saponins. The available data in vivo are encouraging but still scarce for drawing conclusions on the application opportunities of certain plants rich in saponins as antimethanogenic agents. It has been reported that saponins can be inactivated by rumen bacterial populations and the saliva of adapted animals (Newbold *et al.*, 1997; Teferedegne, 2000) meaning that their effect may dissipate over time.

Under the term essential oils a great variety of plant chemical compounds are included. Their effect in reducing methanogenesis is achieved through their antimicrobial effect. They show great promise as modifiers of the rumen fermentation and were the subject of several reviews in the last few years (e.g. Benchaar and Greathead, 2011). Carvacrol, thymol, eugenol, cinnamaldehyde, and organosulfur compounds, particularly those derived from garlic, are the compounds more studied to date. However, most of the published data is from in vitro trials and in vivo confirmation is still lacking. Some initial results using garlic extract or derivatives such as diallyl disulfide were not positive in sheep (Klevenhusen *et al.*, 2011; Patra *et al.*, 2011). In contrast, an additive containing oregano essential oil, rich in carvacrol, decreased methane production in sheep by 12% (Wang *et al.*, 2009). The effect of oregano on methanogenesis was also recently reported by Hristov *et al.* (2010). A promising new active compound from cashew nuts that reduced methane emissions in dairy cows by 20% was recently reported (Shinkai *et al.*, 2010). Similar to other plant-derived additives, additional in vivo trails have to be performed to demonstrate the efficacy of certain essential oils including their optimal dose and long term effect.

Several obstacles have to be cleared before plant extracts can be used as feed additives to decrease methanogenesis in field applications. These will be similar to those already identified for plant additives used for other purposes. The overall effect on nutrition and production have to be evaluated as for many of these compounds the decreasing effect on methane production may be seen at concentrations that affect negatively fermentation and production traits (Jouany and Morgavi, 2007).

IV – Other strategies

Many other approaches are being explored to reduce enteric methane emissions in ruminants but they will not be treated here because they are either in the initial phases of study or because they are not immediately applicable under field conditions. These include the use of probiotics and vaccines as modifiers of the rumen microbiota, the use of ionophore antibiotics as their use is restricted in many countries and the use of organic acids that is economically not possible in most production systems. Sulfates and nitrates are alternative dihydrogen sinks that offer competing metabolic pathways to methanogenesis (Morgavi *et al.*, 2010). Briefly, certain bacteria are capable of oxidizing hydrogen using sulfates, nitrates or other nitrogen compounds. The number of these specific bacteria, normally low, increases in the presence of their substrate of choice. The use of sulfates present the risk of formation of toxic hydrogen sulfide, but a recent in vitro test showed that sulfate-reducing microorganisms could reduce methane without disrupting digestion and without producing hydrogen sulfide (Paul *et al.*, 2011). The incorporation of nitrate into the diet, if controlled to avoid the excess production of toxic nitrite, is a viable alternative to reduce methanogenesis (Leng and Preston, 2010). A sheep trial using nitrates, sulfates and both compounds as additives showed a reduction of methane of 32, 16 and 47%, respectively (van Zijderveld *et al.*, 2010), a second trial on dairy cows has shown the long-term effectiveness of the addition of nitrate on reduction of methane (van Zijderveld *et al.*, 2011). In other report, the use of another nitrogen compound, nitroethane, reduced methane production in a short-term cattle trial (Brown *et al.*, 2011). The end product of nitrogen compounds in the rumen is usually ammonia that is used by rumen microbes for growth. Nitrate could replace urea as a nitrogen supplement for poor quality forages and straws.

In recent years, the genetic potential for selecting animals with a lower ability to produce methane has been investigated by many research groups. The most encouraging results to date were reported by Pinares-Patiño *et al.* (2011) who showed an acceptable repeatability and hereditability for methane production in a flock of 105 sheep The sheep at the extremes, 10 high producers and 10 low producers, conserved their ranking when fed different diets indicating that selection of low emitter might be possible. These results need to be confirmed over several generations. The efficiency of feed utilization by ruminants measured as the residual feed intake, another parameter that has a genetic implication, is being explored as an indirect means to reduce enteric methane emissions per kg of dry matter intake or per kg of product. We are not aware of data on small ruminants but positive results have been reported for beef cattle (Hegarty *et al.*, 2007; Jones *et al.*, 2011).

IV – Conclusions

Considerable advances have been made in the last few years on the understanding of enteric methane production and on mitigation alternatives. Many mitigation options can only be applied in intensive production systems and exclude, either by cost or by the difficulty to administer, the pastoralists and mixed agro-pastoral systems typical of small ruminants that prevail in hot and arid-semiarid regions. Although some promising alternatives are starting to emerge for extensive systems based on grazing, more research is needed on forage types, the influence of secondary plant metabolites and animal phenotypes. And, at the same time, an integrative approach that considers other GHG, as well as the economic and societal impacts of any proposed practices have to be assessed for sustainability. It is important to remember that reduction in methane emissions can be achieved by improving productivity, a concept that was clearly demonstrated in dairy cows (Gerber *et al.*, 2011) and that is certainly applicable to small ruminants systems. In systems of low productivity, application of existing know-how and technologies to increase the quantity and quality of feed resources and to improve nutrition, reproduction and health of the herd, are the first steps for reducing the burden on the environment of ruminant products.

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