Rumen Manipulation for Enhanced Feed Utilization and Improved Productivity Performance of Ruminants: A review

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ABSTRACT

Feed resources are inadequate both in quality and quantity in most developing countries, like Ethiopia. Natural pasture, crop residues and agro-industrial by-products constitute the major proportions of feeds available to most ruminants under smallholder production systems. The rumen has been recognized as an essential fermentation 'Chamber'. Up to 12% of gross energy, however, is lost in the form of methane from ruminants. Methane is also one of the major green house gasses. Methane is produced by bacteria species, collectively called methanogens. Reduction in methane production increases the efficiency of feed utilization in ruminant animals. Manipulation of ruminal fermentation processes for reducing methane production by ruminants to improve the production performance of ruminants is the current major target of many animal nutritionists. The methods to effectively reduce methane production in the reticulo-rumen include processing of feeds, altering the ration, supplementation of unsaturated fatty acids, defaunation, supplementation of organic acids, halogenated compounds, ionophores, microbial feed additives (probiotics), plant extracts and their secondary metabolites. All these have to be validated in vivo studies in specific dose(s) to make it economically viable.

Keywords: Rumen, Fermentation, Methane, Plant Extracts, Ethiopia.

1. INTRODUCTION

Feed scarcity is often cited as the primary constraint to smallholder livestock production in developing countries and with good cause. Assessment from around the world confirms the fact that smallholder farmers are chronically short of feed to sustain their livestock and to produce livestock outputs, such as meat and milk (Patra and Saxena, 2009). Ruminants naturally consume high fibrous plant materials, and convert it to a marketable commodity, meat, milk and wool. With fiber fermentation in the rumen, energy and microbial protein are obtained for maintenance, growth, lactation and reproduction (Lu et al., 2005). However, due to the physical and chemical characteristics of high fiber feeds in semi-arid environments, not enough nutrient may be provided for cost-efficient production (Alexander and Mandonnet, 2005; Silanikove, 2000). Feed resources are inadequate in both quantity and quality. Fibrous feeds, including crop residues, agro-industrial by-products and natural pasture or native grass, of low digestibility, constitute the major proportion of feeds available to most ruminants under smallholder production systems in the developing countries (Wanapat et al. 2009). Characteristic features of tropical forages are their slow rate of microbial breakdown in the rumen, with the result, that much of the nutrients of the feed are voided in the faeces (Rege, 1994; Teferedegne, 2000; Wanapat, 2000). These deficiencies can be overcome by supplementing with high density feeds and proteins of animal origin. However, these are often beyond the economic reach of most farmers in the developing countries (Teferedegne, 2000). The objective of this work is, therefore, to review the research work done so far regarding manipulation of rumen to enhance ruminant production by reducing methane. This review will be dealing with rumen fermentation and rumen manipulation, the latest being the major focus.

2. RUMEN FERMENTATION

The rumen has been well recognized as an essential fermentation vat that is capable of preparing end-products particularly volatile fatty acids and microbial proteins as major energy source and protein for the ruminant host. That means, microorganisms in the rumen degrade nutrients to produce volatile fatty acids, also called short chain fatty acids, and synthesize microbial protein as an energy and protein supply for the ruminant animal, respectively. The more efficient the rumen is, the better the fermentation end-products being synthesized. Optimum feed utilization by ruminants is dependent on achieving maximum rumen fermentation and flow of microbial protein to the duodenum.

In ruminants, such as domestic cattle, buffaloes, sheep and goats, the main fermentation processes of nutrients in the consumed feed ration occur first in the fore-stomach i.e, the rumen. These processes to a great extent are possible because of the microorganisms colonizing it. The microbial population in the rumen consists of bacteria at 10^{10} cells/ml, protozoa at 10^{6} cells/ml, fungi at 10^{3} – 10^{7} cells/ml and methanogens at 10^{9} cells per ml (Kamra, 2005). Rumen manipulation has, therefore, been proved to be effective to increase the efficient use of local feed resources and enhance productivity in ruminants in the world in general and in the tropics in particular (Wanapat, 2000; Hess et al., 2004). However, microbial rumen fermentation process has energy losses as methane, and protein losses as ammonia N, inefficiencies that limit the production performance of the host animal and contribute to the release of greenhouse gas pollutants to the environment. Any sustainable solution to inhibit loss of energy, as methane and protein, as ammonia N, should be practical, cost effective and have no substantial adverse effect on the profitability of ruminant livestock production.

Rumen fermentation of carbohydrates and proteins in ruminants is accompanied by loss of energy and amino N, respectively. In fact, enteric methane emission in ruminants, which is produced via fermentation of feeds in the rumen and lower digestive tract by methanogenic archaea represents a loss of 2% to 12% of gross energy of feeds and contributes to global greenhouse effects (Patra, 2012); 8 to 12% of the digestible energy ingested by ruminants is lost in the rumen as methane; and 75 to 85 % of the Nitrogen consumed by dairy cows is excreted in the faeces and urine (Tamminga, 1992; Gunjan et al., 2012; Patra, 2012). Methane up to 15 – 18% of the digestible energy may be produced where cattle are fed on poor quality forage. This condition results because a number of essential microbial nutrients may be deficient and microbial growth efficiency in the rumen may be low due to asynchrony of nutrient availability during fermentation. However, the correction of these deficiencies may reduce this to as low as 7% (Gworgwor et al., 2006). According to Donald and Ward (1996), about 95% of the global animal enteric methane is from ruminants a consequence of their large population, body size and intake. Since consumption is largely known and must be predicted, accuracy is limited often by the distribution of animals by class, weight and productivity. The fraction of the diet lost as enteric methane mostly falls into the range of 5.5 – 6.5% of gross energy intake for the world's ruminants (Donald and Ward, 1996). Different methods of optimizing feed conversion into nutrients in the rumen are in vogue and available to the scientists.

3. RUMEN MANIPULATION

Ruminal fermentation can be manipulated to reduce methane production in the rumen, among others, using:

- Plant extracts and their secondary metabolites
- Altering the forage : concentrate ratio
- Supplementation of organic acids
- Ionophores
- Halogenated compounds
- Processing of feeds, and microbial feed additives

Manipulation of rumen microbial fermentation to decrease methane and ammonia production from ruminant livestock using antibiotic feed additives has proved to be useful strategy to improve production efficiency in ruminants (McGuffey et al., 2001). However, because of risk of residues in the food of animal origin (Russel and Houlihan, 2009) and emergence of multi-drug resistant bacteria (Gustafson and Bowen, 1997) that may threaten human health, the European Union (EU) banned the use of antibiotics in 2006 and growth hormones as feed additives for increasing production efficiency. Ionophores, such as monensin, lasalocid, laidlomycin, salinomycin and narasin are antimicrobial compounds that are commonly fed to ruminant animals to improve feed efficiency. These antimicrobials specifically target the ruminal bacterial population and alter the microbial ecology of the intestinal microbial consortium, resulting in the increased carbon and nitrogen retention by the animal. The use of antimicrobials as growth promoters in food animals has fallen under scrutiny due to fears of the spread of antibiotic resistance (Callaway et al., 2003). The effects of ionophores on enteric methane production are related to ciliate protozoal populations and ciliate protozoal populations can adapt to the ionophores present in either low- or high-concentrate diets (Guan et al., 2006). Ever since, different researchers are increasingly looking into plant extracts and plant secondary metabolites that generally are recognized as safe for human consumption (Baraka et al., 2012).

Factors such as the type of carbohydrate in the diet, level of feed intake, digesta passage rate, presence of ionophores or lipids in the diet, and ambient temperature influence the emission of methane from ruminants (McAlliste et al., 1996).

Tree legumes have been investigated as potential supplements for ruminants because of their beneficial effect of increasing metabolizable energy intake, N intake and feed efficiency, and improving animal performance. The foliage of some legumes has been shown to be selectively toxic to rumen protozoa, suggesting a nutritional value beyond simply their nutrient content (Teferedegne, 2000). Adopting feeding strategies that will minimize the amount of energy lost as methane, can improve feed conversion efficiency, improve animal productivity and is good for the environment. Farmers can reduce their herd's methane production between 5-25% by making changes in their management practices and diet which add to the cost of producing meat and milk (Beauchemin and McGinn, 2010). Increasing atmospheric concentrations of methane have led scientists to examine its sources of origin. Ruminant livestock can produce 250 L to 500L, of methane per day. Decreasing enteric methane emission from ruminants without altering animal production is desirable both as a strategy to reduce global greenhouse gas emissions and as a means of improving feed conversion efficiency.

In the last few years there is an increasing interest of nutritionists in bioactive plant factors - phytofactors as natural feed additives that can modify the rumen fermentation processes such as defaunation, improve the protein metabolism and, at the same time, reduce ammonia production and emission, and curb methane production and emission to the atmosphere. High diversity of bioactive phytofactors contained in many plant species has been identified as a potential factor affecting the above-mentioned processes. No effect of the phytofactors has been fully confirmed since it depends on many factors, including: animal species and production purpose and thus concentration of structural carbohydrate in a feed ration, type of the used feed, latitude of occurrence of an animal, and plant type of a factor, its structure and activity, synergistic or antagonistic relations with other feed ration components (Szumacher-Strabel and Cieślak, 2010).

The interest in phytofactors results from mainly its properties and the ability of influencing the rumen environment. However, a very significant reason that additionally determined the trend and broadening of the research on the use of plants and their biologically active compounds, were subsequent legislation factors related to the ban on the use of antibiotics and other additives in animal nutrition and the trend towards natural additives, previously observed particularly in Europe (Szumacher-Strabel and Cieślak, 2010).

Approaches to control methanogens through vaccination or the use of bacteriocins highlight the difficulty to modulate the rumen microbial ecosystem durably. The use of probiotics, that is, acetogens and live yeast, remains a potentially interesting approach, but results have been either unsatisfactory, not conclusive, or have yet to be confirmed in vivo. Elimination of the rumen protozoa to mitigate methanogenesis is promising, but this option should be carefully evaluated in terms of livestock performances. In addition, satisfactory and practical on-farm defaunation techniques are not available up to now. Several feed additives such as ionophores, organic acids and plant extracts have also been assayed. The potential use of plant extracts to reduce methane is receiving a renewed interest as they are seen as a natural alternative to chemical additives and are well received by consumers. The response to tannin-and saponin containing plant extracts is highly desirable and more research is needed to assess their effectiveness and possible undesirable residues in animal products (Martin et al., 2010).

Plants have been used for centuries for various purposes, such as traditional medicine and food preservatives, among others, due to their antibimicrobial properties (Davidson and Naidu, 2000; cited in Busquet et al. 2005). Natural plant products including essential oils, saponins, tannins and related compounds have attracted a number of researchers. The antimicrobial activity of plant extracts is attributed to a number of secondary plant metabolites, which include saponins, tannins and essential plant oils. The use of plants and plant secondary metabolites opens a diverse variety of choices for scientists to investigate the most effective, safe and economically within the reach of smallholder farmers, specially, in developing countries (Teferedegne, 2000).

Polyphenolics are widely distributed in the plant kingdom and are often present in the diet of herbivores. The two major groups of plant polyphenolics, other than lignin, are condensed and hydrolysable tannins. Several studies on the effect of saponins and tannins on ruminant production have also been reported in the past few years. Manipulation of rumen microbial fermentation for enhanced nutrient utilization has already been reported by Harrison et al. as early as 1975 in which they demonstrated the manipulation of rumen fermentation in sheep by increasing the rate of flow of water from the rumen, an increased flow of α-linked glucose polymer, total microbial amino acids into the small intestine and with an increased efficiency of microbial protein synthesis within the rumen (Harrison et al., 1975). A change in roughage to concentrate ratio, as well as the supplementation of soapberry fruit – mango steen peel, containing condensed tannins and saponins, caused changes in ruminal microorganisms and their fermentation end-products in fistulated Holstein Friesian heifers (Poungchompu et al., 2009). Yaghoubi et al. (2010) also reported reduced ammonia, total gas production, and protozoa numbers in batch culture of mixed rumen microorganisms by flavonoid extracts. A number of plants extracts (thirteen), selected for their high content in flavonoid, and were screened for their action on fermentation and protozoa numbers by Laurent-Philippe et al. (2000) where only *Lavandula officinalis* and *Solidago virgaurea* for promoting the extent of fermentation, and *Equisetum arvense* were proposed for further selection for their possible inhibitory action on methane production.

In an in vitro study on rumen microbial fermentation, Busquet et al. (2005) confirmed methane reduction up to 19.5% and a reduction of acetate and increased proportion of propionate and butyrate proportion using garlic oil at doses 300 and 3000 mg/L and benzyl salicylate at doses 300 and 3000 mg/L suggesting that methane was inhibited while at the same time improved efficiency of energy use in the rumen. In an in vitro study, Busquet et al. (2006) have reported a 30 to 50 % reduction in ammonia N concentration using at 3000mg/L capsicum oil, carvacrol, carvone, cinnamaldehyde, cinnamon oil, clove bud oil, eugenol, fenugreek, and oregano oil. In a separate study using cinnamaldehyde and garlic oil an increased proportion of propionate and butyrate and decreased proportion of acetate was reported where garlic oil resulted in an increased small peptide plus amino acid N concentration (Busquet et al., 2005). Studies on efficacy of plant extracts rich in secondary constituents to modify rumen fermentation revealed substantive effects of the saponin- rich and tannin-rich products on ruminal nitrogen metabolism. This effect was observed, however, only at doses exceeding those recommended by the manufacturers (Śliwińrski et al., 2002).

Production and export of different tropical fruits may generate additional income to smallholder farmers in the tropics, as there is an increasing demand for saponin-rich products in the developed countries. A study conducted by Śliwińrski et al. (2002) on ruminal fermentation, methanogenesis and nitrogen utilization of sheep receiving tropical grass hay-concentrate diets offered with *Sapindus saponaria* fruits, a saponin-rich plant and *Cratylia argntea* foliage revealed reduced methane release by parallel reduction of total ciliate protozoa and increased total bacteria count and improving body protein retention in sheep indicating that supplementation with *Sapindus saponaria* fruit is a useful means to reduce methane emission from sheep given both tropical grass-based and grass-legume based diets (Śliwińrski et al., 2002). Likewise, including legumes in N-limited tropical diets seems to represent an environmental friendly way to improve ruminant productivity due to methanogenic inhibition (Hess et al., 2004). In a study on lambs fed diets containing plant extracts rich in tannins (at doses 1 and 2g/kg DM of hydrolysable tannins; castanea sativa wood extract) and saponin (at doses 2 and 30mg/kg DM sarsaponin; *Yucca schidigera* extract), and associated emission of nitrogen and methane, low tannin dose significantly decreased bacteria count compared to the high saponin dose. Whereas saponin supplementation and high tannin dose showed some potential to reduce ruminal ammonia concentration (Śliwińrski et al., 2002). In an in vivo study on non-lactating Holstein Friesian crossbred dairy cows by Manh et al. (2012), observed that the supplementation of eucalyptus (*camaldulensis*) leaf meal powder at 100g/day for ruminants inhibited methane gas production, which could be an alternative feed enhancer in cattle, according to this study.

In an in vitro manipulation of rumen fermentation efficiency by coupled fumaric acid- bentonite addition as an alternative feed additive to antibiotics, the fermentation pattern revealed that coupled addition was associated with and additional decrease in methanogenesis and volatile fatty acids utilization. Furthermore, increased total volatile fatty acids concentration and decreased pH value parallel with ammonia nitrogen (NH_3-N) concentration and butyrate proportions was reported. The author concluded that coupled addition would improve the impact of fumaric acid on rumen fermentation pattern and can be appropriate alternative for antibiotic feed additives in improving ruminants feed efficiency (Abdl-Rahman, 2010). In vitro evaluation of sheep rumen fermentation pattern after adding different levels of Eugenol+Fumaric acid combination revealed a decrease in pH value, ammonia N concentration and methane production while molar proportion of valeric and isovaleric acids increased and 200mg/l eugenol+fumaric acid combination was recommended as an alternative antibiotic feed additives to optimize rumen fermentation pattern (Baraka and Abdi-Rahman, 2012). Narvaez et al. (2011) reported that effect of whole hops on ruminal fermentation being diet and dose dependent and may offer a means of decreasing ruminal methane emission without compromising fermentability of feed.

Plant extracts have the potential to be exploited as rumen manipulating agents. Effects have been reported on volatile fatty production, increased total fatty acid production, enhanced proportion of propionate, and decreased methane production with subsequent decrease in rumen methanogens by Hart et al. (2008). Ethanol and methanol extracts of fennel and garlic have the potential to inhibit rumen methanogenesis, in an in vitro study, without adversely affecting rumen fermentation (Patra et al., 2010). In addition to tannins- and saponin containing plants, essential oils are also the third group increasingly attracting animal nutritionists. Over the last few years, several studies have been conducted examining the effects of essential oils, and their active components, on rumen microbial fermentation (Calsamiglia et al., 2007; Benchaa et al., 2008; Castillejos et al., 2008; Hristov et al., 2008). Essential oils have antimicrobial properties, which can be effective against undesirable rumen microbes. Several studies have been conducted to exploit essential oils as natural feed additives to improve rumen fermentation such as short chain fatty acids (mainly acetate, propionate, and butyrate), inhibition of methanogenesis, improvement in protein metabolism and efficiency of feed utilization and increasing conjugated essential fatty acids, like linoleic acids, in foods of ruminant origin (Patra, 2011; Patra et al., 2006; Baraka and Abdi-Rahman, 2012). In an in vitro ruminal fermentation study with essential oils, however, Hirstov et al. (2008) reported a subtle effect of essential oils on rumen fermentation where only one (Caraway) of the forty essential oils tested reduced ammonia concentration, by 8%, compared with the blank and concluded that the moderate in vitro effects would not correspond to any substantive impact on rumen fermentation. Different plant oils have shown inhibitory effect on methanogenesis and degradability of feeds in rumen liquor of cattle in vitro, where total gas production and methane emission (ml/g DM) differed significantly due to inclusion of vegetable oil and sunflower oil in an incubation medium suggesting these plant oils appear to have a potential to manipulate rumen fermentation favorably (Santra et al., 2009). In an in vitro screening of plant extracts to enhance the efficiency of utilization of energy and nitrogen in ruminant diets, Alexander et al. (2008) reported that aqueous methanol extract of *Moringa oleifera* seed and aqueous extract of *Picrorhiza kurroa* root may have potential as feed additives to increase efficiency of utilization of energy and nitrogen in ruminant diets following their inhibition of gas production. In a recent study the effect of supplementation of *chestnut* tannins and *coconut* oil on growth performance, methane emission, ruminal fermentation and microbial population in sheep was investigated by Liu et al. (2011) resulting in a decreased methane emission from sheep by reduction of methanogens and protozoa population with no negative effect on growth performance which seems to be a feasible means. In a more recent investigation on the effect of a combination of essential oils at an equal ratio at 500mg/l along with fumarate on in vitro rumen fermentation trial resulted in a sharply decreased ruminal protozoa; the population of fungi and fibrolytic bacteria were also decreased indicating combination of essential oils with organic acids (fumarate) can inhibit methane production in which case inclusion of fumarate can further decrease it, which is attributed mainly to inhibition of protozoa and methanogens (Lin et al., 2012). In a comparative study using batch and continuous fermentation on effects of bromochloromethane on microbial communities and rumen fermentation revealed a persistence effect of bromochloromethane (5μm once in a day for 9days) on methane reduction (85-90%) in the continuous fermentation while a 89-94% reduction in methane was obtained in the batch fermentation study confirming the anti-methanogenic activity of bromochloromethane (Gunjan et al., 2009). The effect of supplanting disodium fumarate to sheep fed on high forage diets on ruminal fermentation and microbial communities was studied recently by Zhou et al. (2012) which resulted in a decreased ruminal pH and inhibition of growth of methanogens, protozoa and fungi. Further study by them on adaptive response of rumen microbes to disodium fumarate affected a decrease in the population of methanogens in the fluid collected from sheep supplemented with disodium fumarate at the level of 20g per day. Similarly, other researchers have reported that combined use of cassava hay and malate at 1,000g in high-quality feed block with concentrates containing high levels of cassava chips at 65% DM could improve significantly the rumen ecology and digestibility of nutrients in dairy steers (Khampa et al., 2009). Capric acid (C10:0), a medium chain fatty acid, was also evaluated for its anti-methanogenic activity and its potential to modify the rumen biohydrogenation of linoleic (C118:2n-6) and α-linolenic (C18:3n-3) acids where its inhibitory effect on methane was more pronounced at 20mg (85%). Gunjan et al. (2009) also confirmed the dual action of capric acid being inhibitory to both methane production and biohydrogenation of linoleic and linolenic acids.

Any long lasting solution to lower methane emissions from ruminant animals will have to be practical, cost effective and have no substantial adverse effect on the profitability of ruminant livestock production. Manipulating diet composition to induce changes in rumen fermentation characteristics remains the most feasible approach to lower methane production. Recent research has made significant progress and potential in nutritional strategies to lower ruminal methanogenesis, mainly using natural plant extracts, organic acids, condensed tannins, increasing the starch: fiber ratio of the diet, and fat supplements, however, none of the strategies reported satisfy all the necessary criteria for immediate implementation. Reducing methane production per unit product over the lifetime of a ruminant should be seen as the central goal to decrease methane emission from ruminant livestock systems. This highlights the need for integrated solutions that result in improved digestive efficiency, reproductive performance and animal health to extend the productive lifetime of growing or lactating ruminants.

It is concluded that the research results reported by the researchers although quite promising, they are mainly of in vitro studies, so, they will have to be validated in vivo with specific dose/s. Till then, the search for an effective plant /extract will continue.

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