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ORIGINAL ARTICLE

Manipulation of rumen fermentation by physical, chemical and biological means

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ABSTRACT

Ruminants naturally consume high fibrous plant materials, and convert it to a marketable commodity such as meat, milk and wool. With fiber fermentation in the rumen, energy and microbial protein are obtained for maintenance, growth, lactation and reproduction. Optimum feed utilization by ruminants is dependent on achieving maximum rumen fermentation and flow of microbial protein to the duodenum. Manipulation of rumen microbial fermentation to decrease methane and ammonia production from ruminant livestock using antibiotic feed additives has proved to be useful strategy.

Key Words: Rumen manipulation, defaunation, Milk Production, Fiber fermentation

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 such as 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). 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.

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). Manipulation of rumen microbial fermentation to decrease methane and ammonia production from ruminant livestock using antibiotic feed additives has proved to be useful strategy.

NON GENETIC RUMEN MANIPULATION

Microbial feed additives (Probiotics):

The digestion process in ruminant occurs by chemical reaction and by the fermentation provided by the rumen microbial flora. During the last decade, the rumen as well as intestinal microbial flora balance has been recognized as main factors to manipulate in order to obtain the best growth performance of the animals. These microbial floras are essential to the animal's health, whereas, their equilibrium is constantly threatened by proliferation of undesirable microbes, detrimental to the health and performance of the animals. Therefore, use of live microbial cultures (probiotics) is being tried now a day as natural feed additives for enhancing rumen metabolic activity and thereby overall animal production. Supplementation of different probiotics (fungi/yeast and bacteria) resulted in improved nutrient status and productivity of the ruminants under certain conditions. The term "Probiotic" which was a Greek word and meaning for life was first of all used by the Parker (1974). He described it as the organisms or substances those positively contribute to intestinal microbial balance. The commonly used probiotics for animal feeding are broadly divided into two categories i.e., bacterial origin and yeast origin.

The primary micro-organisms currently used in animal feeding are:

Bacillus licheniformis, Lactobacillus casei, Bacillus subtilis, Bifidobacterium suis, Lactobacillus acidophilus, Lactobacillus bulgaricus, Streptococcus thermophilus, Lactobacillus cellobiosus, Lactobacillus sporogens, Lactobacillus reuteri, Bifadobacterium hermophilum.

Yeast origin: Lactobacillus brevis, Aspergilus oryzae**,** Saccharomyces cerevisiae

The micro organisms which used as probiotics should possess the following properties:

Resistance to low pH and bile salt, Production of lactate and other antimicrobial agents,

A normal inhabitant of the gut in the target animal species, able to survive, colonize and multiply at a faster rate in the gut, Viable product can be formed at industrial scale for its commercialization, Stable and viable during long storage and field conditions, Must produce beneficial effect in host animals. The effects of probiotics are greatest in the fastest growing animals and diminish with age.

The utilization of probiotics in farm animals may contribute in the following aspects:

- Growth promotion
- Improved feed conversion efficiency
- Better absorption of nutrients by control of gut epithelial cell proliferation and differentiation,
- Improved metabolism of carbohydrate, calcium and synthesis of vitamins
- Neutralization of anti nutritional factors i.e., trypsin inhibitor, phytic acid etc

- ❖ Microbial enzyme production, compensating for deficient intestinal enzyme activities of the host.
- ❖ Elimination or control of intestinal microorganisms producing sub clinical or clinical diseases
- ❖ Stimulation of non specific and specific immunity at the intestinal level.

Administration of probiotics in livestock may be most effective under following conditions: After birth to encourage the early establishment of beneficial rumen microflora, Following antibiotic treatment, In the presence of enteric pathogen such as *E. coli*, *Salmonella*, Coccidia. During environmental or mangemental stress. In calves, administration of probiotics may be most effective under the following circumstances: After birth, before and after transportation, At weaning, Following over eating or antibiotic administration.

EFFECT OF PROBIOTIC FEEDING ON ANIMAL PERFORMANCES

Feed intake: Effect of probiotic supplementation on dry matter intake by the animals are inconsistent. Supplementation of yeast in the animal's feed improved it palatability as glutamic acid produced by yeast is responsible for improvement in the taste of feed stuffs (Agarwal, 2002). However, Erdman and Sharma (1989) observed no change in daily dry matter intake whereas Putnam et al. (1997) reported higher daily dry matter intake in yeast culture fed/supplemented dairy cows.

Nutrient digestibility: Numerical significant improvements have been reported in digestibility of dry matter, organic matter, crude protein and fibre in yeast fed animals. Higher retention of nitrogen and energy have also been reported in yeast fed animals whereas, the effects have been variable and the response influenced by the type of diet, physiological state of the animals and microbial strain employed. Basal diet of the yeast culture fed animals influence the nutrient digestibility and productivity of the animals (Williams and Newbold, 1990; Moloney and Drennan, 1994).

Growth and feed conversion efficiency: Adams et al. (1981), Edwards et al. (1990) did not find any significant increase in gain or feed conversion efficiency on yeast (*Saccharomyces cervisiae*) supplementation to the animals, whereas, Fallon and Harte (1987), Singh et al. (1998), Saha et al., 1999 and Pandey et al. (2001) reported that young calves respond well to dietary supplementation of yeast in the starter diet in terms of live weight gain and feed conversion efficiency.

Milk production : Positive response on milk production have been reported in yeast fed animals (Harris and Lobo, 1988; Gunter, 1989; Huber et al., 1990). Responses have been greater in early compared to mid of lactation (Alarcon et al., 1991) and the response was greater with diets containing the higher proportion of concentrate (Williams et al., 1990).

Incidence of diarrhoea : Incidence of diarrhoea reduced due to feeding of probiotic to the young calves (Abe et al., 1995; Abu-Tarboush et al., 1996; Saha et al., 1999). There was considerable reduction in the number of total coliform bacteria in the rumen liquor as well as faeces of calves fed probiotic in their diet, irrespective of the chemical composition of the ration offered to the animals (Kamra et al., 1997).

Rumen pH : Yeast has a buffering effect in the rumen medium and prevents sharp drops in rumen pH and thus stabilizes the pH even in the high concentrate fed animals. Newman and Dawson (1987) reported a rise in rumen pH from 6.36 to 6.55 when *Saccharomyces cervisiae* was added in rumen fermenter fulled with roughage ration.

Volatile fatty acid production: Williams et al. (1990) observed lower ruminal TVFA's concentration in the yeast culture fed steers whereas Andrighetto et al. (1993), Kumar et al. (1994) and Dutta et al. (2001) reported that the mean molar concentration of VFA's was higher in the rumen liquor of yeast culture fed animals.

Ammonia nitrogen: An increased in microbial protein synthesis with altered amino acid profile of duodenal digesta was observed in dairy cows (Erasmus et al., 1992).

Rumen enzyme profile: The yeast supplementation in the diet increased the activity of carboxymethyl cellulase enzyme in the rumen of animals (Maurya et al., 1993). Panda (1994) observed no effect on ruminal amylase and protease activity but a stimulatory effect on carboxymethyl cellulase activity by yeast feeding in goats. Similar results were also reported by Widmeier et al. (1987), Harrison et al. (1988) and Dawson et al. (1990).

Oxygen scavenger*:* Yeasts act as a oxygen scavenger in the rumen (Wallace, 1996). During feed ingestion, some amount of oxygen enters the rumen along with feed and its adversely effect the rumen environment as well as growth of the rumen microbes. There was increased oxygen disappearance (between 46-89%) by adding *Saccharomyces cervisiae* in rumen fluid *in vitro* and stimulate rumen bacterial growth (Newbold et al., 1996).

DEFAUNATION

The process of making the rumen of animals free of rumen protozoa is called defaunation and the animal is called defaunated animal. The role of rumen ciliate protozoa on the performance of host animals became debatable issue when Becker and Everett (1930) demonstrated that rumen protozoa were non-essential for growth in lambs. Rumen protozoa are the largest in size among rumen microbes and contribute 40-50% of the total microbial biomass and enzyme activities in the rumen (Agarwal et al., 1991).

Methods of defaunation: There are several ways to defaunate the animals and to obtain a ruminant animal free from rumen ciliate protozoa.

METHODS OF DEFAUNATION

Isolation of new born animals*:*

One of the methods of producing defaunated animals is the separation of newborn animals from their dams after birth and preventing them from any contact with the adult ruminant animals. The newborn animals should be separated 2 to 3 days after birth (Jouany, 1978). During this time the newborn animals gets contaminated with the native bacterial population but do not get rumen ciliate protozoa (Fonty et al., 1984). However, once the animal is separated, proper care should be taken so that the isolated animals do not come in contact with any adult animals as well as any contamination from the handlers who look after faunated and defaunated animals.

Chemical treatment :

Another method of defaunation is by use of chemicals and majority of researchers has used this method for obtaining animals free from rumen ciliate protozoa. The chemicals which have been widely used to defaunate the animals are copper sulphate (Ramprasad and Raghavan, 1981), manoxol (Chaudhary et al., 1995) and sodium lauryl sulphate (Santra et al., 1994a; Santra and Karim, 1999).

Chemicals which are used as defaunating agent are introduced in the rumen of animals either orally by a stomach tube or through rumen fistula. However, these chemicals are not only toxic to the rumen protozoa but also kill the other rumen microorganism like bacteria. These chemicals are also toxic to the animals resulting in depressed feed intake, dehydration and some time mortality also reported (Jouany et al., 1988).

Dietary manipulation:

The ciliate protozoa are very much sensitive to change in rumen pH. The activity of ciliate protozoa is adversely affected when the pH of the rumen fall below 5.8 and if the rumen pH fall below 5.0, the ciliate protozoa are be completely eliminated. Therefore, offering high energy feed (especially cereal grains like barley, maize etc) to the starved (for 24 hours) animals, creates acidic condition in the rumen and rumen pH fall below 5.0. This fall in rumen pH eliminates the ciliate protozoa completely and the animals become defaunated.

ANIMAL PERFORMANCE

Feed intake and nutrient digestibility:

The first and the most easily detectable influence of defaunation (by chemical method) on the animal is the loss of appetite and therefore decreased feed intake for a few days after defaunation of the animals. In case the animal does not regain its appetite even after 5 to 7 days of defaunation it can be induced by offering highly palatable feed. Once stabilized, daily dry matter intake in defaunated animals attend the level similar to that of faunated animals.

Methane production:

Defaunation is reported to considerably decrease the methane production compared with the normal faunated animals (Jouany et al., 1988; Williams and Coleman, 1992; Santra et al., 1994b). Rumen protozoa contribute hydrogen moiety for the production of methane by the methanogenic bacteria (Prins and Van Hoven, 1977; Van Hoven and Prins, 1977). Further, ectosymbiotic attachment methanogens have with ciliate protozoa and elimination of their symbiotic partner on defaunation results in reduced methane production.

Genetic manipulation of rumen microbes:

There are several teams in the world currently working in this field. Recombinant DNA and molecular biology techniques have been developed to improve the digestion of cell-wall carbohydrate in herbivores, to limit the degradation of proteins in the rumen or produce more microbial amino acids, to inhibit the growth or metabolic activity of undesirable organisms, and to produce substances that are of benefit to the microbes or the host animal (Forano, 1991). Most of the work so far has consisted of cloning genes of rumen cellulolytic bacteria the well-known genetic system of Escherichia coli. The cleaved DNA fragments are inserted into a vector plasmid that will replicate in E coli. The recombinant plasmids are introduced into the cell by transformation or by conjugation. A genomic library can then be established. There have been at least 50 scientific reports on the cloning of gene coding for fibre degrading enzymes. Most experiments were carried out on F. succinogenes, R. albus, R .Flaveciens, B. fibrisolvens and B. ruminicola.

CONCLUSION

This is concluded that rumen manipulation by methods enhances the feed intake, nutrient digestibility, health of growing animals and milk production in lactating ruminants well as reduction in methane emission in ruminants.

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