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Review: Manipulation of the rumen using additives

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Abstract: Ruminant animals and rumen microbiota are in a constant symbiotic relationship that enhances fiber degradation and digestion. In developed countries, ruminant animals are now being placed on an abundance of grain with little fiber. When fed fiber-deficient rations, the physiological and biological mechanisms are disrupted, ruminal pH declines, microbial ecology is altered, and the animal is prone to metabolic and nutritional disorders and, in some cases, infectious diseases. In order to manage this condition, certain processes must be either inhibited or promoted in a bid to manipulate the ruminal biological and physiological mechanisms for improved productivity and performance. This review therefore provides insight into some specific additives that can be used to successfully manipulate ruminal processes. Specifically, it should also provide some guidance as to the effects of using of saponins, ionophores and organic acids in ruminant nutrition.
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1. Introduction

Acidosis, methanogenesis, poor rumen health and reduced production as a result of inadequacies in feed resources, in quality and quantity, faced by ruminant production is the basis for the recent spotlight on controlling certain metabolic and functional processes in the rumen. The rumen is arguably the most important organ in the ruminant digestive system. Maximum rumen fermentation and the flow of microbial protein to the duodenum are factors that influence Optimum feed utilization in ruminants. Ruminal microbial protein and volatile fatty acid (VFA) synthesis supply most of the protein and energy needs of the ruminant (Larry, 2015). Rumen function problems can reduce intake, digestion, and health of ruminants and culminate in death (Adesogan, 2009). Furthermore, animal performance and health are adversely affected by inefficient rumen function and also contributes to environmental pollution because of the content that will be in their wastes.

Ruminal fermentation is the medium through which huge amount of Volatile fatty acids (VFA) are produced. Because they provide more than 70 % of the ruminant's energy supply they are of utmost importance. Across the ruminal epithelium is where almost all of the acetic, propionic and butyric acids formed in the rumen are absorbed, from where they are carried to the portal vein by ruminal veins. For distribution sake and also to prevent excessiveness and damaging drops in pH of rumen fluid, continuous removal of VFA from the rumen is essential.

2. The need for rumen manipulation

In ruminants, especially sheep and goats, the main fermentation processes occur in the rumen. These processes to a great extent are possible because of the microorganisms inhabiting 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). One of the proven method to ensure and increase the efficient use of locally produced feed and also to stimulate productivity in ruminant especially those in the tropical environment characterized by low production performance of animals, increased population and inconsequentiality in climate change is manipulation of the Rumen (Wanapat, 2000; Hess *et al*., 2004). However, the microbial fermentation processes going on in the rumen has energy losses in the form of methane, and protein losses in the form of NH_3-N, inefficiencies that hinders the production performance of the host thereby grossly promoting the release of pollutants to the environment, causing global warming in the process. Any sustainable approach (es) that limit methane, NH_3-N, and optimally regulates ruminal pH should not only be practical and economical, but also able to achieve efficiency in ruminant livestock production.

More specific to say that the enteric methane emission in ruminants, as a result of the action by methanogenic archaea represents an approximate loss of 2 % to 12 % in gross energy of feeds and contributes to global greenhouse effects (Patra, 2012); averagely 10 % of the total digestible energy is lost as methane; and up to 80 % of the Nitrogen consumed is lost in feaces and urine. (Tamminga, 1992; Gunjan *et al*., 2012; Patra, 2012). In conditions where cattle are raised on poor quality forage, methane production rises to about 20%. Conditions, such as this, leads to a deficiency of microbial substrate, thus, hindering microbial growth during fermentation. Nevertheless, preventing the above from happening has the potential to reduce methane production to a minimum level (Gworgwor *et al*., 2006). Donald and Ward (1996) stated that ruminants contribute about 95% of the global methane emission by livestock due to their buoyant population, feed intake and body size. About 5 – 6 % gross energy in feed is lost to methane by ruminants (Donald and Ward, 1996). Different techniques to optimally convert feed into nutrients in the rumen are now in vogue and available to nutritionists.

A more important case in the manipulation approach is the pH. It is a unitary factor that regulates protonation in the rumen, presiding on the level and rate of acidity or basicity of the rumen chamber. Acidosis as a result of the depressed pH in the rumen could lead to a pathological acidity of the blood. Maintaining rumen pH is very important for persistence and stability of the gut microbiota. Rumen pH can vary from 5.5 to 7.5 and this variation is influenced by the type of diet and the feeding frequency according to different ruminant species (Franzolin *et al*., 2010). Clarke (1977) postulated that rumen ciliated protozoa are very sensitive to fluctuations in ruminal pH and that pH above 7.8 or below 5.0 threatens their existence. Dehority (2005) reported the death of in-vitro protozoa at pH values less than 5.4. The ability to arrest the proliferation of microbiota is the benchmark for successful control of the substrate level during metabolism for effective rumen manipulation.

The mechanisms that can be used to manipulate the concerted processes that occurs during fermentation so as to improve productivity and efficiency include but are not limited to the following:

3. Use of ionophores

Many researches have shown that cultures of rumen microbes' in vitro that are supplemented with ionophores reduces production of methane (CH_4) and increase production of propionic acid (CH_3CH_2COOH). In the studies of Richardson *et al*. (1976), the same effects were also recorded in vivo. However, the increase in the total amount of propionic acid were lesser when compare to the change in the rate of production and this shows that the effect of monensin on propionic acid production can be rendered insignificant if judged by measurement of VFA concentration in rumen fluid.

Improved energetics of rumen fermentation caused by monensin is illustrated by the work of Rogers and Davis (1982) in which Steers were fed on a basal diet consisting of corn silage (50 %) and concentrate (50 %) with monensin (33 mg kg^{-1} of DM) for experimental steer and without for control steer. Steer fed monenin have their daily ruminal production of acetic, propionic and total acids per kilogram of DM consumed increased by 29, 64 and 35 %, respectively. Total VFA energy produced in the rumen per kilogram of DM consumed was increased from 0.852 Mcal kg^{-1} of DM for control steers to 1.137 Mcal kg^{-1} of DM for experimental steers, resulting in an upsurge in ruminal digestible energy of the experimental steer by 33%.

Ionophores inhibit methanogenesis by reducing the availability of hydrogen and formate, the primary substrates for methanogens because bacteria that produce these substrates are sensitive to ionophores, although methanogens are more resistant (Chen and Wolin, 1979). Further proof for this mechanism is the fact that, methane production by mixed cultures of rumen microbes can be increased by adding hydrogen gas in the presence of monensin, (Van Nevel and Demeyer, 1977). Also, propionate production increases because bacteria that reduce succinate to propionate are resistant to ionophores. The adverse impact of ionophores on protozoans may also be partly responsible for the effect because protozoa produce hydrogen and are colonized by methanogens (Russell and Strobel, 1989). Also, Marounek and Hodrova (1989) reported that rumen fungi which are also hydrogen producing sensitive to monensin in vitro. They also reported that hindgut fermentation in ruminant is affected by ionophores treatment (Marounek *et al*., 1990). However, Yokoyama *et al*. (1985) did not notice any significant changes in ruminant hindgut fermentation with the application of ionophore treatment.

Feeding of ionophores changes the digestion site of dietary carbohydrate fractions and may descrease ruminal digestion of starch, but the total tract digestibility usually remains the same as postruminally starch digestion also increased (Funk *et al*., 1986; Muntifering *et al*., 1981). Ionophores doesn't affect the digestion of fibres (Allen and Harrison, 1979). Increase in the numbers of fibrolytic bacteria that are resistant to ionophore, such as *F. succinogenes* can neutralize the effect of the reduction in the numbers of ruminococci that are susceptible to

ionophore. Furthermore, maintenance of normal fiber digestion can be attributed to longer rumen retention time caused by ionophores (Lemenager *et al*., 1978). Feeding monensin to lactating cows decreased ruminal digestion of OM, acid detergent fiber and starch (Haimoud *et al*., 1995). Total tract digestibility of these components was not different between control steer and monensin fed steer.

Feeding on rapidly fermentable diets usually makes dairy cow prone to acidosis but ionophores have the potential of reducing the risk level via the following mechanism. Ionophores have effects on lactic acid producing strains of bacteria such as *Streptococcus bovis*. Dennis *et al*. (1981) reported that the major strains of rumen lactic acid producing bacteria are subsceptible to lasalocid and monensin while major strains of lactate fermenting bacteria were resistant to them. Also, colony counts of *S. bovis* and *Lactobacillus* (lactate producing gram positive bacteria) were reduced in rumen fluid taken from cattle mashed intraruminally with glucose and ionophore whereas the presence of ionophore does not affect the colony counts of lactate utilizing bacteria (gram negative).

4. Saponins

There is no doubt, that saponins have selective effects on ruminal microorganisms that might be useful in livestock production therefore a safe, persistent suppression of ciliate protozoa should have widest application. The considerable amount of turnover of bacterial protein which take place during fermentation are as a result of the activities of Ciliate protozoa (Ushida *et al*., 1991; Wallace and McPherson, 1987; Williams and Coleman, 1992). As a consequence, nitrogen retention is improved by defaunation, which has been shown in many studies where the protozoa were removed by chemical or physical means, or where the animals had been isolated from birth and thus had not been colonized by protozoa (Williams and Coleman, 1997).

However, the argument in favour of defaunation depends on other factors as well as some species of protozoa are cellulolytic, there are implications for fibre breakdown for removing protozoa (Demeyer and Van Nevel, 1986; Kayouli *et al*., 1984). Also, some protozoa are proteolytic, so there would be consequences there too (Ushida *et al*., 1991). Nevertheless, it is generally agreed that removing or suppressing protozoa would make the best use of nitrogenous resources, particularly on low-protein diets. Effects of saponins on the bacterial population need further examination. Wang *et al*. (2000) suggested that *Y. schidigera* extract would be best used with high grain diets, because of its suppressive effect on *S. bovis* which is a starch digesting, lactate-producing Gram-positive species which is a major cause of rumen fermentation lapsing into lactic acidosis (Stewart *et al*., 1997). Caution may be required in more fibrous diets. However, there could be serious consequences to overall digestion, with the suppression of those bacteria involved in fibre digestion, as described earlier.

General observations with the usage of saponins includes, where there is changes in ruminal fermentation characteristics, saponins administration decreases NH_3 concentration (Lu and Jorgensen, 1987; Lu *et al*., 1987; Makkar *et al*., 1998) and, where VFA are affected, propionate concentration increases (Lu *et al*., 1987; Hristov *et al*., 1999) are typical effects of decreased protozoal numbers (Williams and Coleman, 1992). Saponin containing *Y. shidigera* extract appeared to have ammonia-binding properties (Headon *et al*., 1991). However, the reduction in rumen ammonia concentrations when *Y. shidigera* extract was fed is most likely due to suppression of ciliate protozoa (Wallace *et al*., 1994; Wang *et al*., 1998).

5. Organic Acids

Fumarate and malate are part the different rumen modulators aspartate, can influence the growth of *Selenomonas ruminantium* (Martin, 1998). *S. ruminantium* bacteria use lactate as a source of energy (Khampa, and Wanapat, 2007). Malic acid induces propionate and succinate by these bacteria thereby preventing the availability of hydrogen (H_2) to methanogenic bacteria (Castillo *et al*., 2004). When malate is present, *S. ruminantium* effectively utilizes lactate. Nisbet and Martin (1990) noticed significant effects of malate in inhibition of a reduced ruminal pH. Organic acids have been suggested to act as the acceptor of lone electron from *S. ruminantium* (Nisbet and Martin, 1990; Newbold, *et al*., 2005). Addition of DL-malate to mixed ruminal microorganism fermentations showed responses similar to those of ionophores (i.e., increased propionate, decreased methane, decreased lactate), thereby suggesting that organic acids have an effect on electron flow (Martin *et al*., 1999). Ionophore effects closely associated with electron redistribution (decreased lactate, increased propionate) were boost by organic acid treatment (Callaway and Martin, 1996). Therefore, by providing an electron sink in the form of organic acids, the effects of monensin are booted in some cases.

All of the studies and researches reviewed up to this extent have dealt with examining the effects of organic acids on ruminal microorganism fermentation. Experiments have also been conducted to determine the effects of cellobiose and monensin on the in vitro fermentation of all three organic acids by mixed ruminal bacteria (Callaway and Martin, 1997). The

rate at which organic acid are being utilized by the mixed bacterial population has increased with the addition of Cellobiose to organic acid fermentations. Also, its addition to all fermentation has increased Total VFA concentrations. A lag period (< 4 h) occurred in monensin treated fermentations before organic acids were utilized; however, total VFA were enhanced and the acetate: propionate ratio was dropped by addition of monensin. Addition of both cellobiose and monensin to mixed bacterial population cause an increase in both propionate release and organic acid utilization. Disappearance rates of organic acids and concentrations of total VFA were found to be highest, and the acetate: propionate ratio was the lowest, in incubations treated with cellobiose plus monensin. Therefore, it can be concluded that the addition of both monensin and cellobiose increase the beneficial effects (i.e. increased total VFA and propionate concentrations) of organic acids on fermentation by mixed ruminal bacteria.

6. Conclusions

The major mechanism by which ionophores modify rumen function is by decreasing the ruminal population of gram positive bacteria relative to that of gram negative bacteria which give them the potential of lowering the substrate needed for methanogenesis. Organic acids and their salts can be used as rumen modifiers to improve animal health and performance. They potentially provide an alternative to the currently used antimicrobials. They stimulate, instead of inhibiting specific rumen microbes.

A detail understanding on rumen fermentation by judicious use of organic acids and ionophores is needed if nutritionists and microbiologists will successfully manipulate ruminal microorganism in the future experimental studies.

Declaration

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References

1. Adesogan T. A. (2009). Using Dietary Additives to Manipulate Rumen Fermentation and Improve Nutrient Utilization and Animal Performance. *University of Florida*
2. Bauman D.E. (1999). Bovine somatotropin and lactation: from basic science to commercial application. *Domestic Animal Endocrinology* 17:101-116.
3. Bell A.W. (1995). Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. *J. Anim. Sci*.73 (9):2804–2819.
4. Callaway, E.S. and Martin, S.A. (1997). Effects of Saccharomyces cerevisiae Culture on Ruminal Bacteria that Utilize Lactate and Digest Cellulose. *Journal of Dairy Science*, 80(9), 2035-2044.
5. Callaway, T.R. and Martin, S.A. (1996). Effects of organic acid and monensin treatment on in vitro mixed ruminal microorganism fermentation of cracked corn. *Journal of animal science*, 74(8), 1982-1989.
6. Cooper, R.J.; Klopfenstein, T.J.; Stock, R.A.; Milton, C.T.; Herold D.W. and Parrott, J.C. (1999). Effects of imposed feed intake variation on acidosis and performance of finishing steers. *J. Anim. Sci.,* 77: 1093-1099.
7. Demeyer, D. and Van Nevel, C. (1986). Influence of substrate and microbial interaction on efficiency of rumen microbial growth. *Reprod. Nutr. Develop*. 26:161-179.
8. Dennis, S.M.; Nagaraja T.G. and Bartley, E.E. (1981). Effects of lasalocid or monensin on lactate producing or -using rumen bacteria. *J. Anim. Sci*., 52: 418-426.
9. Donkin, S.S. (2012). Control of Hepatic Gluconeogenesis During the Transition Period. Department of Animal Sciences. *Environ. Microbiol*., 55: 1-6.
10. Drackley, J. K.; Overton, T. R. and Douglas, G. N. (2001). Adaptations of glucose and longchain fatty acid metabolism in liver of dairy cows during the periparturient period. *J. Dairy Sci*. 84(E. Suppl.): E100-E112.
11. Duffield, T.F,; Lissemore, K.D.; McBride B.W. and Leslie, K.E. (2009). Impact of hyperketonemia in early lactation dairy cows on health and production. *J. Dairy Sci*.;92(2):571–580.
12. Falkenberg, U.; Haertel, J.; Rotter, K.; Iwersen, M.; Arndt, G. and Heuwieser, W. (2008) Relationships between the concentration of insulin-like growth factor-1 in serum in dairy cows in early lactation and reproductive

performance and milk yield. *J Dairy Sci.* 91(10):3862-8. doi: 10.3168/jds.2007-0887.
13. Hristov, A. N.; McAllister, A. T.; Van Herk, F. H.; Newbold, C. J. and Cheng, K. J. (1999). Effect of Yucca schidigera on ruminal fermentation and nutrient digestion in heifers. *J. Anim. Sci.* 77:2554-2563.
14. James, K. D.; Thomas, R.; Overton, F. and Douglas, G.N. (2001) Adaptations of Glucose and Long-Chain Fatty Acid Metabolism in Liver of Dairy Cows During the Periparturient Period. *J. Dairy Sci*. 84. p100-p112.
15. John V. N., (1983) Balancing nutrients for efficient milk production in dairy cows. Conference: *Recent Advances in Animal Nutrition in Australia.*
16. Kayouli, C.; Demeyer, D. I.; Van Nevel, C. J. and Dendooven, R. (1984). Effect of defaunation on straw digestion in sacco and on particle retention in the rumen. *Anim. Feed Sci. Technol*. 10:165-172.
17. Khampa, S. and Wanapat, M. (2007). Manipulation of rumen fermentation with organic acids supplementation in ruminants raised in the tropics. *Pakistan Journal of Nutrition*, 6(1), 20-27.
18. Lu, C. D. and Jorgensen, N. A. (1987). Alfalfa saponins affect site and extent of nutrient digestion in ruminants. *J. Nutr*. 117:919- 927.
19. Lu, C. D.; Tsai, L. S. D.; Schaefer, M. and Jorgensen, N. A. (1987). Alteration of fermentation in continuous culture of mixed rumen bacteria. *J. Dairy Sci*. 70:799-805.
20. Lucy, M.C. (2008) Nutrient Partitioning and Reproductive Performance in Dairy Cows. Syracuse, NY: *Proceedings of Intermountain Nutrition Conference*. 139–150.
21. Lucy, M.C. (2016). Mechanisms linking postpartum metabolism with reproduction. *WCDS Adv Dairy Technol* 28:259–269.
22. Makkar, H. P. S.; Sen, S.; Blummel, M. and Becker, K. (1998). Effects of fractions containing saponins from Yucca schidigera, Quillaja saponaria, and Acacia auriculoformis on rumen fermentation. *J. Agric. Food Chem*. 46:4324-4328.
23. Martin, S.A. (1998). Manipulation of ruminal fermentation with organic acids: a review. *Journal of Animal Science*, 76(12), 3123-3132.
24. Martin, S.A.; Streeter, M.N.; Nisbet, D.J.; Hill, G.M. and Williams, S.E. (1999). Effects of DL malate on ruminal metabolism and performance of cattle fed a high-concentrate diet. *Journal of animal science*, 77(4), 1008-1015.
25. McDowell, G.H. (1983) Hormonal control of glucose homoeostasis in ruminants. *Proc Nutr Soc*. 42(2):149-67.
26. Newbold, C.J.; Lopez, S.; Nelson, N.; Ouda, J.O.; Wallace, R.J. and Moss, A.R. (2005). Propionate precursors and other metabolic intermediates as possible alternative electron acceptors to methanogenesis in ruminal fermentation in vitro. *British Journal of Nutrition*, 94(01), 27-35.
27. Nisbet, D.J. and Martin, S.A. (1990). Effect of Yeasacc1026 on lactate utilization by the ruminal bacterium Selenomonas ruminantium. In: *Biotechnology in feed industry* (Ed. T. P. Lyons). Alltech Technical Publications, Nicholasville, Kentucky, pp. 563-567.
28. Raun, A.P., (1974). Antibiotics monensin and A204 for improving ruminant feed efficiency. *Patent* 3,839,557, United States Patent Office, Washington, DC., USA.
29. Rogers, J.A. and Davis, C.L. (1982). Rumen volatile fatty acid production and nutrient utilization in steers fed a diet supplemented with sodium bicarbonate and monensin. *J. Dairy Sci.*, 65: 944-952.
30. Sniffen, C.J.; Ballard, C.S.; Carter, M.P.; Cotanch, K.W.; Dann, H.M.; Grant, R.J.; Suekawa, M. and Martin, S.A. (2006). Effects of malic acid on microbial efficiency and metabolism in continuous culture of rumen contents and on performance of mid-lactation dairy cows. *Animal feed science and technology*, 127(1), 13-31.
31. Stewart, C. S.; Flint, H. J. and Bryant, M. P. (1997). The rumen bacteria. In: The Rumen Microbial Ecosystem (Ed. P. N. Hobson and C. S. Stewart). *Chapman and Hall*, London, pp. 10-72.
32. Ushida, K.; Jouany, J. P. and Demeyer, D. I. (1991). Effects of presence or absence of rumen protozoa on the efficiency of utilization of concentrate and fibrous feeds. In: Physiological Aspects of Digestion and Metabolism in Ruminants (Ed. T. Tsuda, Y. Sasaki and R. Kawashima). *San Diego, California: Academic Press*, Inc. pp. 625-654.
33. Wallace, R. J. and McPherson, C. A. (1987). Factors affecting the rate of breakdown of bacterial protein in rumen fluid. Br. *J. Nutr*. 58:313-323.
34. Wang, Y.; McAllister, T. A.; Yanke, L. J. and Cheeke, P. R. (2000). Effect of steroidal saponin from Yucca schidigera extract on ruminal microbes. *J. Appl. Microbiol.* 88:887-896.
35. Williams, A. G. and Coleman, G. S. (1992). The Rumen Protozoa: *Springer Verlag.*

36. Williams, A. G. and Coleman, G. S. (1997). The rumen protozoa. In The Rumen Microbial Ecosystem (Ed. P. N. Hobson and C. S. Stewart). London: *Blackie Academic and Professional*. pp. 73- 120.

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