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Manipulation of Rumen Fermentation with Organic Acids Supplementation in Ruminants Raised in the Tropics

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Abstract: Locals feed resources are prime importance for ruminants raised in the tropic particularly low-quality roughages and agricultural crop-residues. Manipulating rumen fermentation through treatment of roughage, concentrate and strategic supplementation with organic acids could improve rumen efficiency by maintaining higher pH, optimum ammonia-nitrogen ($\text{NH}_3\text{-N}$), thus reducing methane (CH_4) and increasing microbial protein synthesis and essential volatile fatty acid (VFAs), for enhancing ruminant productivity in the tropics. The manipulation of rumen efficiency through the use of organic acids especially malate with local feeds would be an advantage. Indeed, organic acids potentially provide an alternative to currently used antimicrobial compounds by stimulating rather than inhibiting specific ruminal microbial populations. At the same time, local feed resources especially cassava chip could be used effectively at high level as an energy source for ruminants especially for beef and lactating cows. More recently, the combined use of concentrates containing high level of cassava chip with supplementation of sodium di-malate and urea could improve rumen ecology and subsequent performance in dairy steers receiving urea-treated rice straw as a roughage. In addition, the high level of cassava chip in the diet resulted in increase population of bacteria and fungi, decreasing protozoal populations, and improving microbial protein synthesis and efficient microbial nitrogen supply in the rumen. Under these circumstances, malate was also effective in reducing the drop in ruminal pH normally seen 1 to 2 h after feeding a high-grain diet and improved cows performance efficiency. In summary, supplementation of organic acid like malate with local feed resources especially cassava chip or other carbohydrate sources with high rumen degradation would be a desirable alternative because there is no risk of developing antibiotic resistance or having unwanted residues appear in either meat or milk products as well as improving ruminal fermentation efficiency and productivity in ruminants in the tropics.

Key words: Organic acids, malate, feed resources, cassava chip, rumen fermentation, ruminants, tropics

Introduction

The rumen has been well recognized as an essential fermentation that is capable of preparing end-products particularly volatile fatty acids (VFAs) and microbial protein synthesis as major energy and protein for the ruminant host, hence, the more efficient the rumen is, the optimum the fermentation end-products are being synthesized. In recent years, there have been increasing interests, researches conducted as well as reviews in relation to rumen studies, rumen ecology and rumen manipulation (Ørskov and Flint, 1989; Martin *et al.*, 1999; Wanapat, 2000; Dann, 2005; Khampa *et al.*, 2006, 2006a). In the tropics, most of ruminants have been fed on low-quality roughages, agricultural crop-residues, industrial by-products which basically contained high levels of lingo-celluloses materials, low level of fermentable carbohydrate as well as low level of good-quality protein. In addition, long dry season and prevailing harsh environment especially high

temperature, low fertile soil and less quantity of feeds available throughout the year-round feeding regimes would influence rumen fermentation of quantity and quality (Wanapat, 2005).

Rumen as a fermentation vat (Fig. 1): As it has been established, the rumen has an important role and function in preparing fermentation end-products for biosynthetic processes of ruminants. It is therefore essential that the rumen is healthy and be able to establish an optimum ecology in order to perform well in regards to rumen microorganisms (bacteria, protozoa and fungi), pH, substrates (e.g. roughage, energy, effective fiber etc), fermentation end-products ($\text{NH}_3\text{-N}$, VFAs), and microbial synthesis of VFAs, the major sources of energy, glycogenic and lipogenic compounds particularly propionate (C_3), acetate (C_2) and butyrate (C_4) while $\text{NH}_3\text{-N}$ is essential source of nitrogen for microbial protein synthesis, respectively. As a

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consequence, it results in healthy rumen and preventing other unflavorable conditions e.g. acidosis, ketosis, mastitis, rumen-parakeratosis etc. Factors which contribute to the production and absorption of these compounds have been reported in a number of scientific reports as well as review papers. It was found that an established rumen be required and was affected by types of feeds, roughage to concentrate ratios, which consequently influenced on rumen microorganisms and fermentation pattern. As there were significant differences in type of feeds and quality between temperate and tropical feed resources which would remarkably influence on rumen microorganisms and fermentation-nutrient pool. Furthermore, different practical feeding systems prevailing in these regions would affect on rumen ecology. In ruminants fed on temperate feeds, increasing levels of concentrate feeding dramatically lowered rumen pH and resulted in acidosis. As a consequence, the VFAs could decrease rumen pH but lactic acid accumulated in the rumen had a more pronounced effect on lowering rumen pH. For the same reason, rumen pH was most affected by type of feeds and roughage to concentrate ratios in regards to saliva secretion, rumination, VFAs production and microbial population (Slyter, 1976). It was also shown that at lower rumen pH, increasing level of concentrate, on the contrary fiber digestion was inhibited and reduced in methanogenesis. The ultimate rumen pH value appeared to exert effect on type of rumen microorganisms. In addition, pure or mixed cultures could perform differently in fermenting available rumen substrates (Wallace, 1979).

Manipulation of ruminal fermentation with organic acids: A goal of rumen microbiologists and nutritionists is to manipulate the ruminal microbial ecosystem to improve the efficiency of converting feed to produce consumable products by humans. One approach that is used is the addition of feed additives (e.g. ionophores) to diets that alter the microbial ecosystem and decrease fermentation losses (e.g., methane (CH₄) or ammonia (NH₃)). Earlier studies investigating much of the research in the past 20 to 25 years has focused on the effects of antimicrobial compounds on rumen fermentation. Specifically, ionophore antibiotics are used in feedlot diets to reduce energy losses associated with methanogenesis in the rumen (Russell and Strobel, 1989). These compounds appear to inhibit hydrogen-producing microorganisms and gram-positive lactate-producing bacteria such as *Streptococcus bovis* (Russell, 1987; Russell and Strobel, 1989). Reductions in hydrogen production reduce ruminal methanogenesis and improve feed utilization by increasing the amount of metabolizable energy available to the animal as propionate (Bergen and Bates, 1984; Russell and Strobel, 1989). Recently, there has been increased

public scrutiny about use of antibiotic feed additives in food animal production, especially in Europe (Castillo *et al.*, 2004). Use of organic acids, non-antibiotic feed additives may alleviate public skepticism. Organic acids may be beneficial feed additives for ruminants (Martin, 1998; Castillo *et al.*, 2004) because they have effects on ruminal fermentation analogous to ionophores (↓ CH₄, ↓ lactate, ↑ propionate; Castillo *et al.*, 2004). However, the mode of action for the organic acids is different than ionophores (Castillo *et al.*, 2004). Scientists have recently become interested in evaluating alternative means for manipulating gastrointestinal microflora in livestock. Their motivations come from increasing public scrutiny about the use of antibiotics in the animal feed industry. However, compared with the efforts to detail the effects of antimicrobial compounds on ruminal fermentation, little research has been conducted to evaluate alternatives to antimicrobial compounds. In the past 10 years, interest has increased in direct-fed microbial (DFM) products, and research has been conducted to examine the effects of DFM on ruminant performance. Some of these products have shown promise in favorably altering ruminal fermentation and improving animal performance, in these circumstances the effects have been variable and inconsistent. Organic acids stimulate rather than inhibit some specific ruminal bacterial populations (Castillo *et al.*, 2004). Organic acids that are currently being evaluated as feed additives are malic acid, fumaric acid, and aspartic acid. Malic acid and fumaric acid are four-carbon dicarboxylic acids that are found in biological tissues (e.g. plants) as intermediates of the citric acid cycle and are intermediates in the succinate-propionate pathway of ruminal bacteria, such as *Selenomonas ruminantium* (Castillo *et al.*, 2004). Aspartic acid is an alpha amino four-carbon dicarboxylic acid. In the above study, it was found that the organic acids can stimulate the growth of the prominent ruminal bacterium, *Selenomonas ruminantium*, can favorably alter the mixed ruminal microorganism fermentation, and can improve the performance of feedlot steers (Martin and Streeter, 1995; Callaway and Martin, 1996, 1996a; Martin *et al.*, 1999). Earlier studies investigating the antimicrobial compounds are routinely incorporated into ruminant diets to improve production efficiency (Callaway and Martin, 1996, 1996a). However, in recent years there has been an increasing concern regarding the use of antibiotics in ruminant feeding and the potential for selection of antibiotic-resistant pathogenic microorganisms. On the contrary, the organic acids (aspartate, fumarate, malate) potentially provide an alternative to currently used antimicrobial compounds (Newbold *et al.*, 1996). Thus, malate supplementation in ruminant diets has been shown to increase nitrogen retention in sheep and steers, and to improve average daily gain and feed efficiency in bull calves (Satacup,

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Table 1: Summary of *in vitro* studies with mixed ruminal microorganisms that evaluated the response to supplemental malic acid

Culture system	Treatment	Response to supplementation of malate								References	
		pH	Total VFA	Acetate	Propionate	Butyrate	Lactate	CH ₄	NH ₃ -N		Digestibility
Batch (steer) ^a	0, 4, 8, 12 mM ^b	↑	↑		↑						Martin and Streeter, 1995
Bach (steer)	0, 4, 8, 12 mM ^b	↑	NE ^d	NE	NE	↑	↓	NE	↑		Callaway and Martin, 1996
RUSTIEC (sheep)	0, 5.62 mmol ^b	NE	↑	NE	↑	NE	↓	↑	↑	DM,NDF	Carro <i>et al.</i> , 1999
Bach (sheep)	0, 8 mM ^b	NE	NE	NE	↑	NE	NE	↑	NE		Jaic & Ceresnakova, 2002
Bach (sheep)	0, 4, 7, 10 mM ^c	↑	↑	↑	↑	↑	↓				Carro & Ranilla, 2003
Bach (dairy cows)	0, 10, 20 mM	↑	↑	NE	↑	↑		↓	NE		Mohammed <i>et al.</i> , 2004
RUSITEC (sheep)	0, 6.55 mM ^b	NE	↑	NE	↑	↑		NE	↑	DM,NDF,ADF	Gomez <i>et al.</i> , 2005
Continuous (dairy cow)	0, 50, 100 g/h/d	NE	NE	NE	NE	NE	↓, NE	NE	↑	DM,NDF	Sniffen <i>et al.</i> , 2006

^aInoculum source; all animals fed a mixed (forage and concentrate) diet. ^bDisodium salt. ^cDisodium + calcium malate.

^dNo effect of malic acid ($p > 0.10$). Source: Modified from Dann (2005).

1979; Sanson and Stallcup, 1984). In addition, a positive response in milk production by dairy cows fed diets supplemented with malate were obtained (Stallcup, 1979; Kung *et al.*, 1982). As a consequence, the malate altered the *in vitro* fermentation of soluble starch by mixed ruminal microorganisms or cracked corn resulting in changes in final pH, CH₄ and VFA that are analogous to ionophore effects (Martin and Streeter, 1995; Callaway and Martin, 1996). However, the mode of action of malate appears to be completely different, and in contrast with antimicrobial compounds, it appears to stimulate rather than inhibit some specific ruminal bacterial populations (Nisbet and Martin, 1993). In the same way, ionophores, such as monensin, are added routinely to beef cattle diets to increase the efficiency of production (Russell and Strobel, 1989). Ionophores decrease lactate and methane production by ruminal microorganisms, and these effects lead to increased ruminal pH and propionate concentrations. Recent research showed that a combination of organic acids (i.e., malate) and monensin was more effective at reducing lactate concentrations and increasing pH in mixed ruminal microorganism fermentation than the addition of organic acid or monensin alone (Callaway and Martin, 1996).

Manipulation of rumen fermentation by malate supplementation: In theory, malate is a four-carbon dicarboxylic acid that is commonly found in biological tissues because it is an intermediate of the citric acid cycle (Lehniger, 1975). Even though only aerobic bacteria are capable of respiration possess a functional

citric acid cycle (oxidative), some strictly anaerobic bacteria use a reductive or reverse citric acid cycle known as the succinate-propionate pathway to synthesize succinate and (or) propionate (Gottschalk, 1986). Moreover, malate is also a key intermediate in the succinate-propionate pathway, and the predominant ruminal bacterium *Selenomonas ruminantium*, uses this pathway which, it could stimulate propionate production (Gottschalk, 1986).

In fact, propionate production has been increased by adding malate to *in vitro* cultures which the malate might act as an electron sink for hydrogen. However, the mechanism of action is not completely known. *Selenomonas ruminantium* is a common gram-negative ruminal bacterium that can account for up to 51% of the total viable bacterial counts in the rumen (Nisbet and Martin, 1991). Surprisingly, this bacterium can grow under a variety of dietary conditions and ferment many different soluble carbohydrates (Hungate, 1966). When *S. ruminantium* is grown in batch culture with glucose, homolactic fermentation occurs (Hobson, 1965). However, after the glucose is depleted from the medium, *S. ruminantium* then utilizes lactate as a carbon and energy source (Scheifinger *et al.*, 1975). Only some strains of *S. ruminantium* (subspecies *lactilytica*) are able to ferment lactate (Stewart and Bryant, 1988).

Several studies have shown that adding malate to *in vitro* fermentation of mixed ruminal microorganisms resulted in changes in pH, CH₄, and volatile fatty acids (VFA) analogous to the addition of ionophores (Table 1). In batch cultures, pH was increased typically (Martin and Streeter, 1995; Callaway and Martin, 1996; Carro and

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Table 2: Summary of *in vivo* studies that evaluated the response to supplemental malic acid in dairy cattle

		Response to supplementation malic acid									
Animal	Treatment	DMI	Milk	Milk Comp.	Gain	Ruminal pH	Ruminal VFA ^a	Ruminal NH ₃ -N	Ruminal CH ₄	Digestibility	References
Dairy cattle											
Holstein cows	0, 70, 105, 140g		↑	↑ fat							Alferez, 1978
Holstein cows	0, 28, 70g	↑ grain	↑								Stallcup, 1979
Holstein cows	0, 100g	↑	↑	↑ fat							Stallcup, 1979
Holstein cows	0, 70, 105, 140g			NE							Kung <i>et al.</i> , 1982
Holstein cows	0, 4g	NE	NE	NE		NE	↑ total, A,B,NE,P	NE			Vicini <i>et al.</i> , 2003
Holstein cows	0, 84g	↑ grain	↑	NE							Devan & Bach, 2004
Holstein cows	0, 50g		↑	NE		NE				NE DM, CP,ADF,NDF	Sniffen <i>et al.</i> , 2006
Holstein cows	10, 20g ^c	↑	↑	↑ fat		↑	↑ total P	↑	↑	↑ DM,CP, NDF,ADF	Khampa <i>et al.</i> , 2006

^aA=acetate, P= propionate, B = butyrate. ^bNo effect of malic acid (p>0.01). ^cDisodium salt Source: Modified from Dann (2005).

Ranilla, 2003; Mohammed *et al.*, 2004). This effect was not observed in semi-continuous (RUSITEC) (Carro *et al.*, 1999; Gomez *et al.*, 2005) or continuous culture systems (Sniffen *et al.*, 2006) due to the use of artificial saliva and its high buffering capacity. Martin (1998) suggested that supplementing beef cattle finishing diets or high-producing dairy cow diets with malate might be effective in reducing subclinical ruminal acidosis. Typically, total VFA and propionate production increased (Martin and Streeter, 1995; Carro *et al.*, 1999; Carro and Ranilla, 2003; Mohammed *et al.*, 2004) and lactate production decreased (Callaway and Martin, 1996; Carro *et al.*, 1999; Carro and Ranilla, 2003) with the addition of malate. Methanogenesis was reduced (Carro and Ranilla, 2003). Digestibility of dry matter (DM), acid detergent fiber (ADF), and neutral detergent fiber (NDF) increased in most studies (Carro *et al.*, 1999; Gomez *et al.*, 2005; Sniffen *et al.*, 2006). Recently, Gomez *et al.* (2005) and Sniffen *et al.* (2006) observed an increase in microbial N production with the addition the malate to semi-continuous and continuous culture systems, respectively. There was a numerical increase in efficiency of microbial synthesis (unit microbial N/unit DM digested) with the addition of malate. There were no differences among treatments for NH₃-N, non-ammonia N, or non-ammonia, nonmicrobial N. The inconsistent results observed with supplemental malic acid (Table 1) can partially be explained by the diet or substrate incubated and experimental conditions.

Based on earlier studies, it was found that growth of *S. ruminantium HD4* in a lactate-salts medium was

stimulated by L-aspartate and the requirement for L-aspartate could be replaced with L-malate or fumarate Linehan *et al.*, 1978). More recent research showed that L-lactate uptake by *S. ruminantium HD4* was increased in the presence of 10 mM L-aspartate, fumarate, or L-malate and L-malate elicited the greatest response, especially uptake of lactate by *S. ruminantium* was increased fourfold by aspartate and fumarate and tenfold by malate (Fig. 2) (Nisbet and Martin, 1990). In addition, different concentrations (0.03 to 10 mM) of L-malate stimulated L-lactate uptake by *S. ruminantium* in a dose-response fashion. It also seems that both L-malate and Na⁺ are involved in stimulating L-lactate utilization by *S. ruminantium HD4* (Nisbet and Martin, 1991). Lactate uptake and utilization by the predominant ruminal bacterium *Selenomonas ruminantium* was increased in presence of the dicarboxylic acid malate (Nisbet and Martin, 1990, 1991, 1994). For example, the addition of DL-malate to soluble starch and cracked corn fermentation with mixed ruminal microorganisms resulted in changes in final pH, methane, and VFA that are analogous to ionophore effects (Martin and Streeter, 1995). In some cases, it was demonstrated that dl-malate and monensin had an additive effect on these mixed ruminal microorganism fermentations (Callaway and Martin, 1996). Limited *in vivo* research has been conducted to evaluate the effects of malate on ruminant performance. In other studies, it was revealed that feeding 140 g of malate per day resulted in an increased milk persistency in lactating cows and increased total VFA during early lactation (Kung *et al.*, 1982). Other

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Table 3: Summary of *in vivo* studies that evaluated the response to supplemental malic acid in beef cattle and small ruminants

		Response to supplementation malic acid									
Animal	Treatment	DMI	Milk	Milk Comp.	Gain	Ruminal pH	Ruminal VFA ^a	Ruminal NH ₃ -N	Ruminal CH ₄	Digestibility	References
Beef cattle											
Holstein steers	0, 100, 200 mg/kg BW	NE					↑ total, P ↑ NE A,B	NE		NE DM, ADF,CP	Kung <i>et al.</i> , 1982
Holstein steers	0, 200 mg/kg BW						↑				Kung <i>et al.</i> , 1982
Crossbred steers	0, 27, 57, 80g				↑		↑				Martin <i>et al.</i> , 1999
Crossbred steers	0, 40, 80g	NE			↑						Martin <i>et al.</i> , 1999
Angle steers	0, 60, 120g	NE			NE						Martin <i>et al.</i> , 1999
Beef cattle	0, 100g	NE			NE						Martin <i>et al.</i> , 1999
Holstein steers	0, 80g					↑	NE		NE		Montano <i>et al.</i> , 1999
Holstein steers	0, 9, 18, 27gc	↑				↑	total, P	↑	NE	↑ DM,CP, NDF,ADF	Khampa <i>et al.</i> , 2006
Small ruminants											
Dairy goats	0, 0.32%	NE	NE	NE							Salama <i>et al.</i> , 2002
Lambs	0, 0.2%	↓			↑	↑				↑ DM,CP, ADF, NDF	Flores <i>et al.</i> , 2003

^a A=acetate, P= propionate, B = butyrate. ^b No effect of malic acid (p>0.01). ^c Disodium salt Source: Modified from Dann (2005).

variables, including ruminal pH, were not altered by malate treatment, however, ruminal fluid samples were collected by stomach tube and lactate concentrations were not reported. Feeding malate to Holstein bull calves improved average daily gain and feed efficiency but had little effect on blood serum constituents (Sanson and Stallcup, 1984). Even though *in vitro* studies have shown that dl-malate favorably alters ruminal fermentation which little information is available that details the effects of dl-malate on beef cattle performance (Martin and Streeter, 1995). In a later study it was also found that supplementation of malate concentrations between 0.3 and 10 mM increased lactate uptake in a dose-response manner. In addition, when mixed ruminal microorganisms were incubated in medium that contained cracked corn or soluble starch, malate treatment decreased lactate concentrations and increased final pH. This probably indicated that increasing dietary concentrations of malate might help to reduce problems associated with ruminal acidosis by stimulating lactate utilization by *S. ruminantium* (Martin *et al.*, 1999).

In vivo studies: Although *in vitro* studies have shown positive effects of malic acid on ruminal fermentation, there are limited *in vivo* studies available to evaluate the effects of malic acid on dairy cow performance (Table 2, 3). Alferez (1978) fed early lactation Holstein cows an

alfalfa hay, corn silage, and steam-rolled barley-based diet that was supplemented with malate (0, 70, 105, or 140 g supplemental malate per cow per day). Cows fed 105 g of malate had higher milk yield, fat-corrected milk yield, and fat yield and were more efficient in converting DM into milk than cows fed 0 or 70 g malate. Feeding malate above 105 g did not increase productivity or feed efficiency. Stallcup (1979) fed Holstein cows a sorghum-sudan forage and corn grain-based diet with 0, 28, or 70 g supplemental malate per cow per day. Cows fed 70 g of malate had higher milk yield than cows fed 0 g malate. In a second trial (Stallcup, 1979), cows fed an alfalfa grass hay and sorghum silage-based diet with 100 g supplemental malate had higher solids-corrected milk and milk fat content than cows fed the diet with no supplemental malate.

More recently, Vicini *et al.* (2003) observed no difference in milk yield between cows fed a corn-based control diet or the control diet supplemented with a commercial product containing soluble sugars and malate (estimated 4 g malate per cow per day). Martin *et al.* (1999) previously determined that the malate concentration in the commercial product was not high enough to stimulate lactate utilization by *S. ruminantium*, a predominant ruminal microorganism that utilizes lactic acid. In addition, Castillo *et al.* (2004) suggested that dietary factors, such as forage to concentrate ratio and forage type, are important in determining responses to

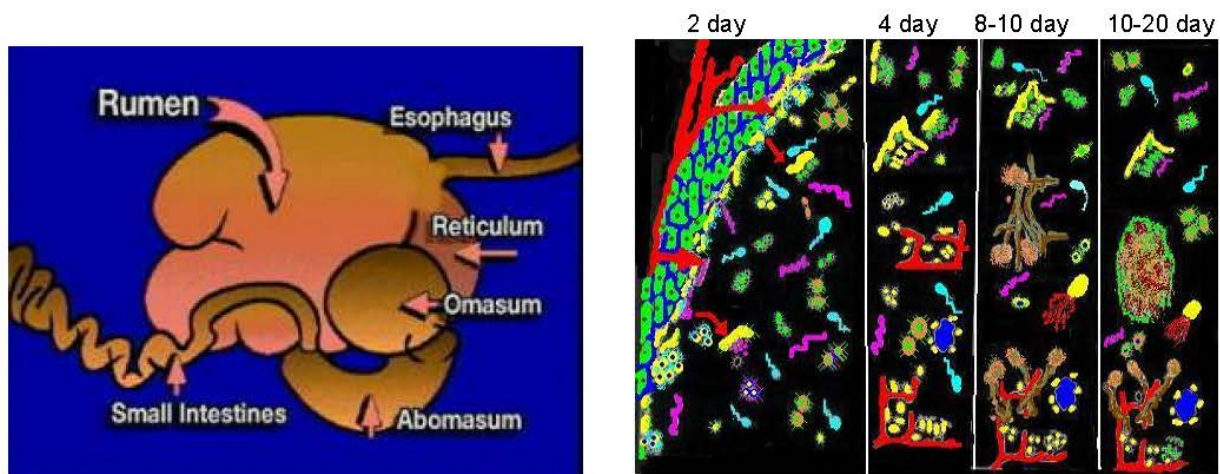


Fig. 1: Showing ruminant digestive tract component as well as rumen microbes (bacteria, protozoa and fungi).

malic acid supplementation because the content of malic acid in the basal diet will vary. The malic acid content of forage varies with forage type (legumes > grasses), forage variety, maturity (immature > mature), and processing (fresh > hay or pelleting; Callaway *et al.*, 1997). In a study with dairy goats (Salama *et al.*, 2002), supplementation with yeast and malate was not beneficial for lactational performance because of the high concentration of malic acid in the forages (high proportion of alfalfa) in the basal diet.

In early lactating cows fed a diet containing 84 g supplemental malate compared to cows fed a controlled diet had increased milk yield during peak lactation, consuming more concentrate, but had similar ruminal pH (Devan and Bach, 2004). In a similar design, supplementation of malic acid at 50 g/cow/day would be effective in *in vivo* in altering ruminal fermentation and microbial efficiency; in addition, malic acid supplementation in lactating cow diets was effective in increasing microbial nitrogen production and microbial efficiency measured *in vitro* and milk yield (Sniffen *et al.*, 2006). A recent study by Khampa *et al.* (2006) supplementation of sodium dl-malate with concentrates containing a high level of cassava chip increased ruminal pH, and altered rumen fermentation by increasing propionate production and decreasing of acetate to propionate ratio. Moreover, the high level of cassava chip in the diet resulted in increased populations of bacteria and fungi, decreased protozoal populations, and improved rumen microbial N supply and efficiency microbial nitrogen. These results suggest that the combined use of concentrates containing high level of cassava chip with supplementation of sodium dl-malate at 18 g/hd/d could improve rumen ecology and subsequent performance in dairy steers. In a subsequent study it was found that the combined use of concentrate containing high level of cassava chip at 75

% DM with urea at 4 % in concentrate and sodium dl-malate at 20 g/hd/d with urea-treated rice straw as a roughage could improved rumen ecology and microbial protein synthesis efficiency in lactating dairy cows (Khampa *et al.*, 2006a).

Implications: The rumen is an essential fermentation vat in which fermentation end-products are being prepared for the biosynthetic processes of the ruminant hosts. As could be seen in practical scale, ruminants raised in the tropics largely depend on seasonal feed resources that are relatively low in quality. Therefore, the manipulation of rumen efficiency through the use of organic acids especially malate with local feeds would be an advantage. Indeed, organic acids potentially provide an alternative to currently used antimicrobial compounds by stimulating rather than inhibiting specific ruminal microbial populations. Moreover, local feed resources especially cassava chip or other energy sources with high ruminal degradation could be used effectively at high level as an energy source with NPN (urea) for ruminants especially for fattening beef and lactating cows. Moreover, the high level of cassava chip in the diet resulted in increased population of bacteria and fungi, decreasing protozoal populations, and improving microbial protein synthesis and efficient microbial nitrogen supply in rumen. The use of malate was also effective in reducing the drop in ruminal pH. Therefore, supplementing high-producing dairy cows diets with malate might be effective in reducing subclinical acidosis. However, by selecting for and incorporating forage varieties that are high in malate into the ruminant diets, could be an alternative approach. Supplementation of organic acid, like malate, would be a desirable alternative because there is no risk of developing antibiotic resistance or having unwanted residues appear in either meat or milk products. Most

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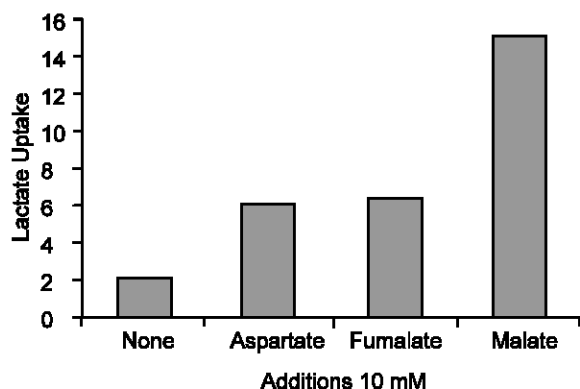


Fig. 2: Effects of aspartate, fumarate, and malate on lactate uptake (nmol/mg protein per min) by *S. ruminantium* (Nisbet and Martin, 1990).

importantly, any researches and development should be based on simplicity, availability of local feed resources, the cost-profit of production and the sustainability of ruminant production systems in the tropics particularly in fattening and lactating ruminants.

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