Ruminal Acidosis in Dairy Cows: Balancing Effective Fiber with Starch Availability

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Introduction

Dairy cows require high energy diets to meet the increasing demands placed on them for high levels of milk production. High energy diets are rapidly fermented in the rumen because they are low in neutral detergent fiber (NDF), high in starch, and contain finely chopped, highly digestible forages. These types of diets increase the risk of ruminal acidosis, which can reduce profit margins. While it is critical to meet the energy requirements of high producing cows, ruminal acidosis must be avoided to ensure high milk production and efficient use of feed.

Subacute Ruminal Acidosis

Diets that are rapidly fermented in the rumen lead to rapid production of volatile fatty acids (VFA). When VFA production exceeds the ability of the rumen environment to neutralize or absorb them, subacute ruminal acidosis occurs (Fig. 1).

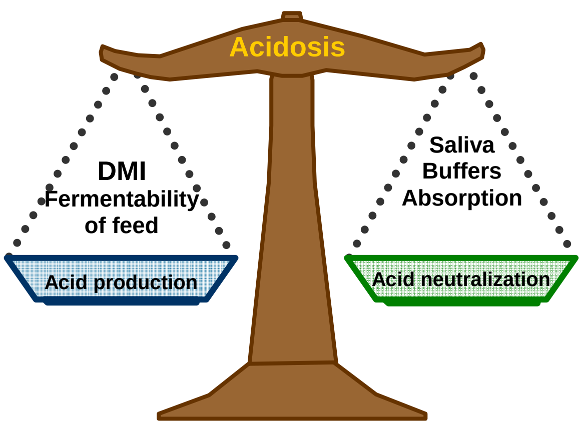

Fig. 1. Prevention of ruminal acidosis depends on balancing the production of VFA and the neutralization/removal of VFA. High feed intake and rapidly fermentable carbohydrates, such as starch, increase acid production. Neutralization occurs through buffers (mainly saliva), absorption through the rumen wall, and passage from the rumen.

An episode of ruminal acidosis occurs when the pH in the rumen drops below a threshold value. A threshold value of 5.5 to 5.8 is normally used to define subacute ruminal acidosis depending upon the researchers and method of determining pH. In our laboratory ruminal pH < 5.8 is used to denote acidosis because cellulolytic ruminal bacteria do not grow below pH 6.0 (Russell and Wilson 1996) causing a decrease in fiber digestion and feed efficiency. Subacute ruminal acidosis is not to be confused with acute acidosis, the latter more common in feedlot cattle. Lactic acid rarely accumulates in the rumen fluid of dairy cows experiencing subacute ruminal acidosis and, when the lactic acid concentration does increase, the increase is often short lived.

Mean pH versus pH < 5.8

Many studies report mean rumen pH as affected by diet, and often mean pH is determined from spot samples taken from the rumen several times during the day. While this information is useful, it does not provide information on episodes of ruminal acidosis. Recently developed systems that continuously monitor rumen pH have enabled researchers to more effectively characterize the pH profiles within the rumen and the risk of acidosis (Dado and Allen 1993; Penner et al. 2006a). Diets can result in similar mean rumen pH, but vary in subacute ruminal acidosis, or the time that pH < 5.8. For example, we fed two diets consisting of 21% forage NDF with one of two barley varieties that differed in ruminal starch degradability; low vs. high (Silveira, Oba, Yang, and Beauchemin, unpublished data). Mean rumen pH was 6.15 vs 6.05 (P = 0.09), while pH < 5.8 was 4.7 vs 8.2 h/d (P = 0.03). Thus, differences in fermentability doubled the duration of ruminal acidosis, even though mean pH was considered acceptable for optimum rumen function. Rumen pH changes throughout the day in relation to feeding with a variation of ±1.5 pH units over the course of the day. Characterizing ruminal pH profiles allows us to understand the incidence and impact of ruminal acidosis. A typical pH profile for a dairy cow is shown in Fig. 2.

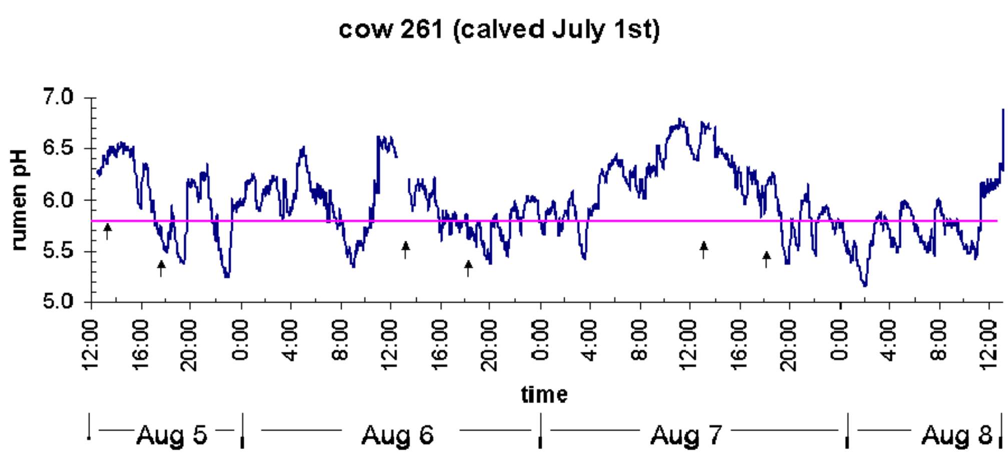

Fig. 2. Ruminal pH measured in a dairy cow over a 72-h period. Subacute ruminal acidosis (pH < 5.8) occurred for 6.4, 6.5 and 11.8 h/d and dry matter intake was 16.0, 15.6 and 14.1 kg/d on Aug 5/6, 6/7 and 7/8, respectively. Arrows show feeding times at 1330 and 1600 h; the solid line indicates the ruminal acidosis threshold of pH 5.8.

Variability in Acidosis Among Cows

The risk of acidosis is not equal for all cows. Fig. 3 shows ruminal pH profiles for two fresh cows fed the same diet. Ruminal pH in the cow with the "best" profile remained very high throughout the day, whereas the cow with the "worst" profile had a pH < 6.0 for the entire day. Factors accounting for the variation among cows are many, including dry matter intake (DMI), eating rate, sorting of feed, salivation rate, rate of passage, and other aspects of cow physiology and behavior. The goal is to minimize the number of cows that experience ruminal acidosis, and the duration and intensity of each episode of acidosis for individual cows.

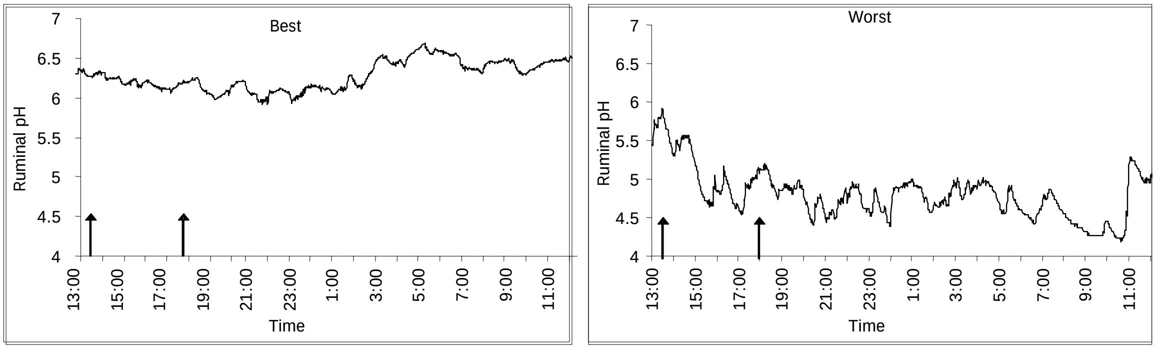

Fig. 3. Ruminal pH measured 5 days after calving in two different cows (best and worst-case acidosis cows) fed the same lactation diet (Penner, Beauchemin and Mutsvangwa, unpublished data).

Impact of Ruminal Acidosis

Ruminal acidosis is a major problem for the North American dairy industry (Krause and Oetzel 2006) costing between $500 million to $1 billion a year (Donovan 1997). Stone (2004) calculated $400 to $475 lost income per cow per year due to ruminal acidosis because of decreased milk production. In one US study, one-third of the herds tested had an incidence rate of ruminal acidosis greater than 40% (Garrett et al. 1999).

Low ruminal pH damages the surface of the rumen wall causing ulceration of the epithelium (Krause and Oetzel 2006). Once the ruminal epithelium is damaged, bacteria enter portal circulation, causing liver abscesses and an inflammatory response (Gohzo et al. 2005) that can cause lameness (Nocek 1997). Additionally, excessive keratinization of the ruminal epithelium occurs as a consequence of ruminal acidosis resulting in reduced absorptive capacity lasting up to 6 months (Krehbiel et al. 1995). Cows experiencing acidosis often display clinical symptoms such as diarrhea, body weight loss, reduced milk production, and increased susceptibility to a host of other metabolic disorders. In addition to the obvious financial losses attributed to health problems and reduced productivity, feed costs increase due to poor fiber digestion and lower feed efficiency.

Feed Intake

Ruminal acidosis can cause erratic fluctuations in feed intake (Fig. 4). Low ruminal pH causes the cow to go “off-feed”, which reduces the production of VFA, allowing the pH to recover. The cow then resumes a high feed intake that causes excessive production of acids, and the cycle is repeated.

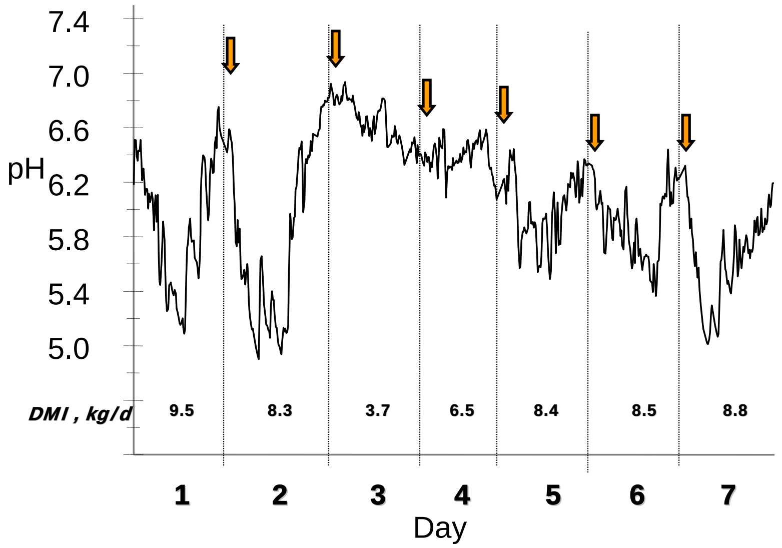

Fig. 4. Ruminal pH and dry matter intake (DMI) of a feedlot steer fed once daily (feeding indicated by arrows) measured for 7 d.

Feed Conversion Efficiency

Ruminal acidosis decreases the digestibility of fiber in the rumen, which decreases feed conversion efficiency and increases feed costs. Studies conducted at the Lethbridge Research Centre using ruminally and duodenally cannulated cows indicate a substantial decline in fiber digestion when cows experience ruminal acidosis. Ruminal NDF digestion declined from 52% for cows with a mean ruminal pH of 6.4 to 44% for cows experiencing repeated episodes of ruminal acidosis with a mean ruminal pH of 5.8. This reduction in potential fiber digestion and is equivalent to a loss of 2.5 kg/d of milk produced.

Microbial Protein Synthesis

Ruminal acidosis lowers the efficiency of microbial protein production in the rumen (i.e., the amount of microbial protein produced per unit of carbohydrate digested in the rumen). A decrease in microbial efficiency will decrease the yield of microbial protein (g/d), unless more fermentable carbohydrate is supplied. Decreased microbial protein synthesis increases the need for supplemental feed protein in the diet. Reduced microbial protein yield due to ruminal acidosis occurs mainly when forages are finely chopped. This effect is shown in a study in which we fed cows diets consisting of 60% concentrate and 40% forage made up of 50% alfalfa silage and 50% alfalfa hay (DM basis; Yang et al. 2002, Beauchemin et al. 2003). The alfalfa hay was fed chopped or ground to alter the intake of long particles without changing the NDF content of the diet. Reducing forage particle size reduced chewing time, increased the amount of organic matter fermented in the rumen, and caused mean rumen pH to drop (Table 1). Microbial efficiency was reduced, which reduced the total amount of microbial protein that was produced. In addition, the amount of undegraded feed protein flowing to the duodenum was reduced. The implication is that the undegradable protein content of the diet would need to be increased to offset the reduction of microbial and feed protein flowing to the intestine. In most cases, this means an increase in feed costs.

Table 1. Effects of forage particle size on digestion and protein metabolism (from Yang et al. 2002 and Beauchemin et al. 2003).

Item	Coarsely Chopped Hay	Finely Ground Hay
Total chewing time, h/d	12.1 *a*	10.4 *b*
Mean rumen pH	5.97	5.78
pH < 5.8, h/d	7.5 *b*	13.0 *a*
Ruminally fermentable OM (RFOM), kg/d	10.9	12.0
Ruminal NDF digestibility, % of intake	39.1	37.0
Total tract NDF digestibility, % of intake	51.1 *a*	41.7 *b*
Efficiency of microbial synthesis, g N/kg RFOM	24.9 *a*	18.2 *b*
Microbial CP, kg/d	1.71	1.41
Feed and endogenous CP (bypass protein), kg/d	2.01	1.89

a,b ($P < 0.05$)

Preventing Ruminal Acidosis

Rumen Adaptation

Abrupt fluctuations in the amount of feed offered from day-to-day and/or increased fermentability of the diet predisposes cows to ruminal acidosis. In fact, Krause and Oetzel (2005) have developed a protocol to induce and study acidosis using these factors. On day 1 they deliver 50% less TMR and then on day 2 an additional 4 kg of pelleted wheat and barley is provided with the TMR. Similarly, on the farm, an abrupt change in the amount of feed delivered or the quality of feed can increase the risk of acidosis. Changes in diet must be made gradually to allow the cow and the rumen to adapt. The drastic change in diet composition that occurs at parturition increases the risk of ruminal acidosis for “fresh” cows.

Absorption of VFA from the rumen occurs passively through papillae (finger-like projections) located on the rumen wall. These papillae increase gradually in length when cows are exposed to a “close-up” diet that contains more grain than the far-off dry cow diet (Penner et al., 2006c). Increased surface area and absorptive capacity of the rumen protects the cow from accumulation of VFA in the rumen which is the main driver of ruminal pH depression. Because the papillae may not have attained their full potential size by calving, fresh cows are susceptible to ruminal acidosis.

We studied the occurrence of acidosis pre- and post-calving using 14 ruminally cannulated primiparous cows fed a “close-up” diet, followed by a lactation diet containing adequate fiber. Ruminal pH was measured continuously before and after calving using a stand-alone ruminal pH measurement system placed within each cow’s rumen (Penner et al. 2006a). Mean ruminal pH dropped abruptly from an average of 6.32 before calving, to an average of 5.98 after calving (Table 2). The pH remained consistently low during the first 60 d after calving. Each day, pH was < 5.8 for about 6 to 9 h, with severest acidosis occurring 3 weeks after calving.

Table 2. The effect of day relative to parturition on ruminal acidosis in primiparous Holstein cows (Penner et al. 2006b).

	Day relative to parturition				
Variable	-5 to -1	1 to 5	17 to19	37 to 40	58 to 60
Minimum pH	5.74[a]	5.38[b]	5.37[b]	5.32[b]	5.37[b]
Mean pH	6.32[a]	5.96[b]	5.95[b]	5.96[b]	6.03[b]
Acidosis, h/d					
Total (pH < 5.8)	1.1[c]	7.3[ab]	9.0[a]	8.3[ab]	6.1[b]
Mild (pH < 5.8 but > 5.5)	0.9[c]	3.6[b]	5.4[a]	4.8[ab]	3.9[b]
Moderate (pH < 5.5 but > 5.2)	0.3[c]	2.4[ab]	3.2[a]	2.7[ab]	1.7[b]
Acute (pH < 5.2)	0.0[c]	1.4[a]	0.4[bc]	0.9[ab]	0.6[bc]

[abc] $P < 0.05$

Decreasing the Fermentability of the Diet

The quantity of feed fermented in the rumen drives VFA production with rapidly digestible feeds such as grains and high quality forages resulting in rapid production of VFA. The carbohydrate fractions within the diet differ in their rate of digestion, with sugars and starches digested faster than fiber. Dietary starch is supplied mainly by grains and its rate of digestion in the rumen depends on the type of grain and how it is processed. For starch, wheat is generally more rapidly digested than barley, but barley is generally more rapidly digested than corn grain, although the kinetics of digestion of all grains is altered with processing.

The incidence of ruminal acidosis is generally higher when diets are based on wheat or barley rather than corn grain. Barley should be processed to optimize ruminal digestion due to the protective nature of its hull. However, once it is processed, digestion is very rapid (Yang et al. 2000). With corn, the rate of digestion increases with heat treatment (steam-rolling, steam-flaking) and with decreased particle size (Callison et al. 2001). Starch digestion within the rumen is greater for barley than corn when these grains are processed similarly. Consequently, barley diets result in a rumen pH that is about 0.2 units lower than for corn diets, when diets are formulated to contain the same amount of forage fiber (Yang et al. 1997).

One approach to slowing the rate of fermentation is to replace a portion of the grain with non-forage sources of fiber such as beet pulp, soybean hulls, alfalfa meal, distillers grains, brewers grains, and corn gluten feed (Grant 1997). Use of non-forage fiber sources reduces the amount of starch digested in the rumen.

However, the most effective strategy to slowing fermentation rate in the rumen is to increase the proportion of forage in the diet. For example, 1 kg of alfalfa hay (40% NDF) supplies about 390 g of fermentable carbohydrate, whereas 1 kg of barley grain supplies about

430 g of fermentable carbohydrate. Thus, digestion of good quality forage only produces about 10% less total VFA than the digestion of barley grain. But, more importantly, forage is digested much more slowly than grain. After 2 h of digestion, 22% of the alfalfa hay compared to 36% of the barley would be digested. After 3h, 27% of the alfalfa hay and 46% of the barley would be digested. After 12 h, only 45% of the alfalfa hay compared with 72% of the barley would be digested. Thus, more VFA are produced right after a meal in the case of grain compared with forage which explains the large depressions in ruminal pH following concentrate meals. Adding forage to the diet not only increases chewing time and saliva secretion, but it evens out VFA production throughout the entire day.

Feeding Enough Physically Effective Fiber (peNDF)

Long forage particles in the diet promote chewing and salivary secretion, which helps buffer the acids resulting from feed digestion. Thus, particle length of forages and the amount of forage fiber in the diet can have a significant impact on rumen pH through the provision of salivary buffers. In addition, long forage fiber creates a floating mat in the rumen, which stimulates reticuloruminal contractions. Without these mixing motions the rumen can become a stagnant pool, and removal of VFA via absorption and fluid passage from the rumen declines, thereby increasing the risk of acidosis. Fiber is more slowly digested than starch and sugar, so including fiber in the diet slows the rate of carbohydrate digestion in the rumen. Decreasing the rate of carbohydrate digestion reduces the rate of VFA production, thereby preventing large drops in rumen pH. Feeding long particle fiber can also shift the site of starch digestion from the rumen to the intestine, which reduces the potential for ruminal acidosis (Yang and Beauchemin 2006b).

There are several ways of characterizing physical fiber. Physically effective fiber relates to the physical characteristics of a feed and is an indication of the potential of a feed to stimulate chewing (Mertens 1997). A limitation to using chewing time to indicate the physical effectiveness of feeds is the need to rely on book values to adjust the values for individual feed samples. Thus, laboratory approaches to measuring physical effectiveness of feeds based on particle length have been developed. The pef values determined by sieving are based on the concept that long particles (>1.18 mm) retained on sieves represent particles that require chewing. One limitation to this system is the many ways of measuring particle length of feeds.

Use of the Penn State Particle Separator to Measure peNDF

The Penn State Particle Separator (PSPS) is one method of measuring particle length of feeds that is gaining in popularity (Lammers et al. 1996). The physical effectiveness factor of a feed or TMR can be determined using the PSPS, which consists of two sieves (19- and 8-mm openings), and a collection pan. The pef_{2s} (the 2s denotes two sieves were used) of a feed is the total proportion of material (DM) retained on both sieves. Using the long corn silage in Table 3 as an example, 10.2% of corn silage DM was retained on the 19-mm screen and 61.3% of the DM was retained on the 8-mm screen, so pef_{2s} is 0.72 (ie., 0.102 + 0.613 = 0.72). That corn silage contained 49.3% NDF, so its $peNDF_{2s}$ is 35.5% (49.3% × 0.72).

The pef should be determined on fresh samples, with the pef expressed as a proportion of the total sample DM content retained on each sieve. This requires performing a DM analysis for the original sample and the material retained on each sieve. The correction for DM is important because moisture content of the sample affects the pef value (Kononoff et al. 2003). For example, the pef_{2s} of alfalfa haylage at 43% DM was 0.87 versus 0.77 at 100% DM. Similarly, the pef_{2s} of corn silage was 0.88 at 42% DM versus 0.65 at 100% DM. Physical effectiveness factors will be overestimated by up to 30% if not corrected for DM.

The PSPS now includes an additional third screen with 1.18-mm openings (Kononoff et al. 2003). Using three sieves results in higher pef_{3s} (3s denotes three sieves were used) values than when two sieves are used (Table 3). The advantage of using three sieves is the values are more closely in line with the values used in the current versions of CNCPS and CPM models. The peNDF values used in those models are based on sieving using a 1.18-mm screen.

Table 3. Example of physically effective NDF (peNDF) values determined for some feeds using the Penn State Particle Separator with two (2s) or three sieves (3s) (Yang and Beauchemin 2006a).

Feed	Proportion of DM retained on each sieve				Physically effectiveness factor[1]		peNDF[2] (% of DM)	
	Top (19-mm)	Middle (8-mm)	Bottom (1.18 mm)	Pan	pef_{2s}	pef_{3s}	$peND_{2s}$	$peNDF_{3s}$
Corn silage								
Coarse	10.2	61.3	24.0	4.5	.72	.96	35.5	47.3
Medium	8.3	59.8	27.6	4.3	.68	.96	31.5	44.5
Fine	2.7	38.7	51.5	7.2	.41	.93	19.6	44.5
TMR containing corn silage								
Coarse	7.6	47.9	33.8	10.7	.56	.89	17.7	28.1
Medium	4.8	43.7	38.6	12.9	.49	.87	15.0	26.6
Fine	2.3	29.9	52.8	15.0	.32	.85	10.0	26.5

[1]Determined using the Penn State Particle Separator. pef_{2s} = determined using two sieves (19-, 8-mm); pef_{-3s} = determined using three sieves (19-, 8-, 1.18-mm).

[2]peNDF = % NDF × pef

The disadvantage of using three sieves is that the pef_{3s} values for forages with differing chop lengths are not very different, as shown in Table 3 for corn silage of various chop lengths. With two sieves, the pef_{2s} ranged from 0.41 to 0.72, but with three sieves the pef_{3s} ranged from 0.93 to 0.96, with no difference between long and medium chopped silages. Furthermore, a lot of the grain in a TMR is trapped on the 1.18-mm sieve, thereby inflating the pef_{3s} values of TMR. For the TMRs in Table 3, which contained 45.8% corn silage (DM), the pef_{3s} of the grain would have had to be 0.84 to 0.92 to account for the pef_{3s} values obtained for the TMR, given the pef_{3s} values of the corn silages by themselves. Thus, pef_{3s} values overestimate the physical effectiveness of TMRs, especially the grain component. In contrast, when two sieves are used, there is only a small difference between using the TMR itself or the component forages to measure $peNDF_{2s,}$ except when the TMR contains very coarse grains or large pellets. Although each system of measuring peNDF has its disadvantages, the PSPS with two sieves is the most useful of the systems available for measuring peNDF because it differentiates feeds based on particle length and it is correlated with chewing and rumen pH.

peNDF and Chewing Activity

The average dairy cow spends 2 to 6 h/d eating, 3 to 9 h/d ruminating, and a maximum of about 14 h/d chewing depending upon the diet (Fig. 5). Increasing the physically effective fiber content of the diet either by 1) increasing the NDF content (i.e., including more forage), or 2) increasing the chop length of forages, increases chewing, with greatest increases in chewing for low fiber diets.

Increasing the $peNDF_{2s}$ content of the diet increases chewing time and, consequently, salivary secretion. With diets low in peNDF, each additional kilogram of $peNDF_{2s}$ will increase chewing time by up to 7 h/d. With diets containing adequate peNDF, each kilogram of $peNDF_{2s}$ promotes only 2 h/d of chewing (Fig. 6). Thus, a small increase in the peNDF content of the diet can be very effective when diets are low in fiber.

Increasing the peNDF content of the diet can increase chewing time, but the increase in saliva output due to increased chewing is not as great as often assumed. This is because the increased flow of saliva during chewing is accompanied by a decrease in resting saliva secretion. The net increase in total salivary secretion due to 1 h/d more chewing is about 7 L (Maekawa et al. 2002). The buffering capacity supplied by the additional saliva would adequately buffer the digestion of about 0.5 kg of ground barley. Thus, the net effect of this incremental saliva production on mean rumen pH is relatively small. However, an increase in saliva secretion, particularly if secreted during eating, can help reduce the extent to which pH drops below 5.8 following meals, even though mean rumen pH is not greatly affected.

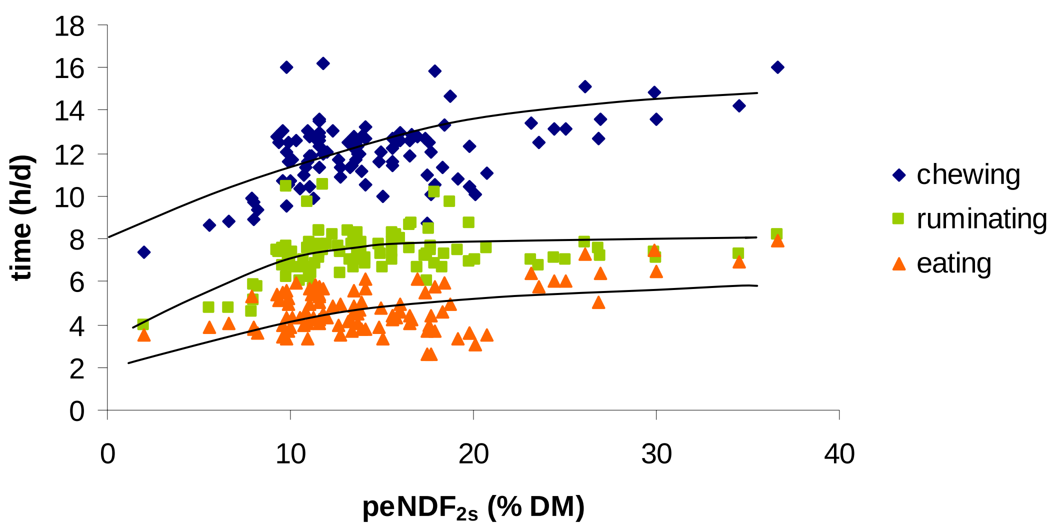

Fig. 5. Relationship between physically effective fiber ($peNDF_{2s}$) content of the diet and chewing time. Each point represents a treatment mean summarized from 24 studies published in the literature.

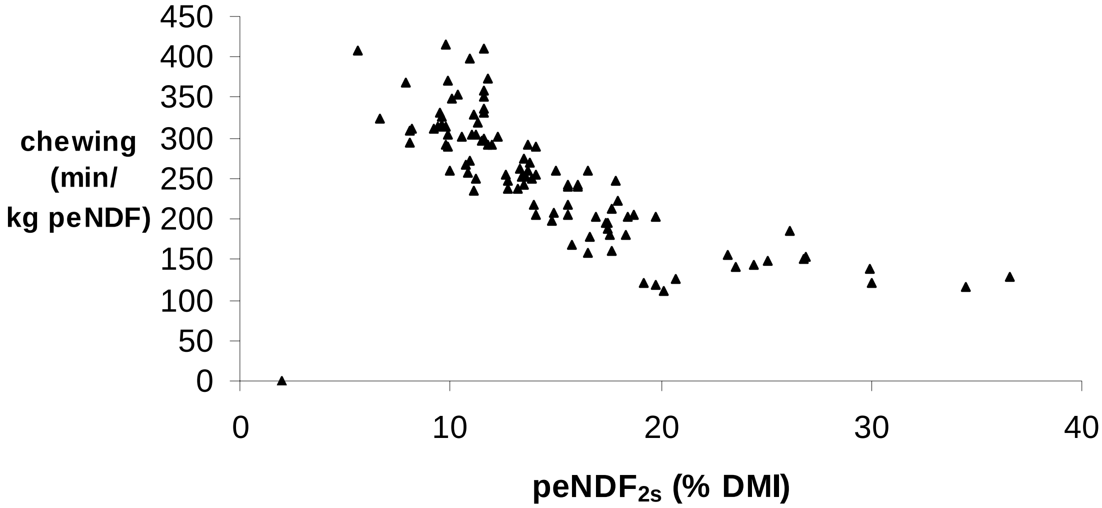

Fig. 6. Chewing time promoted by each kilogram of physically effective fiber for diets varying in physically effective fiber ($peNDF_{2s}$) content. Each point represents a treatment mean summarized from 24 studies published in the literature.

How Much peNDF Is Needed In Dairy Rations?

NRC (2001) recommends a minimum of 25% NDF in the diet, with 75% of this fiber coming from forage sources (i.e., 19% NDF from forages). The amount of NDF from forage sources can be decreased to as low at 15% if total dietary NDF is increased and the non-fiber carbohydrate levels are lowered from 44% to 36%. These recommendations are based on diets containing alfalfa or corn silage and dry ground corn grain as the starch source. When more highly fermentable sources of grain are used (e.g., barley, high moisture corn), we recommend a minimum of 21 to 23% NDF from forages and a maximum of 38% non-fiber carbohydrates.

Minimum fiber recommendations assume that the silages are coarsely chopped. When forage particle size is fine and diets are formulated to contain minimum levels of NDF, then intake of physically effective fiber will be less than required. In that case, intake of physically effective fiber can be increased by increasing the NDF content of the diet and/or by increasing the physically effectiveness (pef) of the forage.

The relationship between $peNDF_{2s}$ content of the diet and rumen pH is shown in Fig. 7. The high degree of variability in the prediction of rumen pH from peNDF is caused by the many other uncontrolled variables that affect rumen pH, such as fermentability of the carbohydrate sources. From Fig. 7 it appears that about 14% $peNDF_{2s}$ is required in the diet to maintain a mean pH of 6.0. Thus, for a diet formulated to supply the minimum NRC requirement of 25% NDF, the pef_{2s} of the TMR would need to be 0.56 (i.e., 14%/25% = 56% of the TMR captured on the two sieves of the PSPS). If 75% percent of the NDF is from forages, the pef_{2s} of the forage would need to be > 0.70. If three sieves are used with the PSPS, then a minimum of 19% $peNDF_{3s}$ is required (Zebeli et al. 2006). However, it is important to understand that the concept of physically effective fiber does not account for differences in fermentability of feeds, and does not predict differences in rumen pH due to fermentability of the diet.

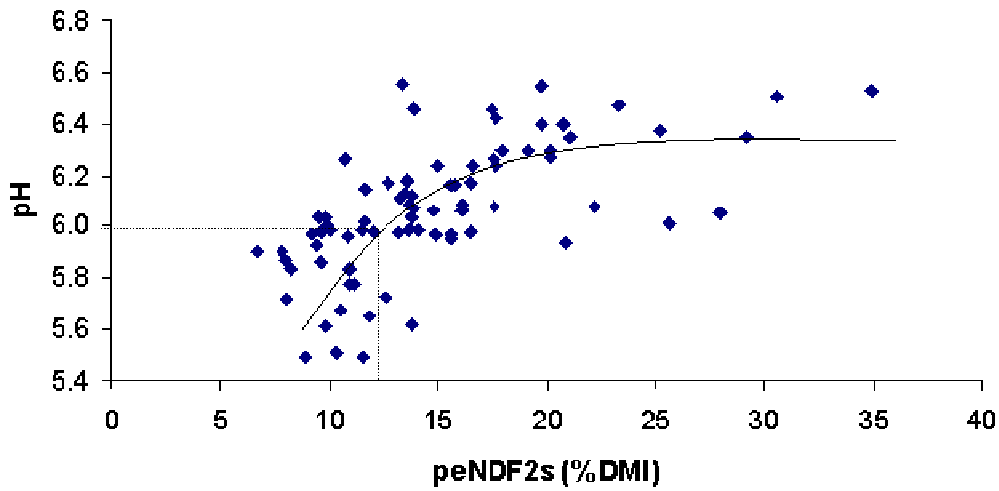

Fig. 7. Relationship between increasing the physically effective fiber ($peNDF_{2s}$) content of the diet and rumen pH. Each point represents a treatment mean summarized from 23 studies published in the literature.

It is important to understand that mean rumen pH values are means for groups of cows, and therefore don't reflect the variation in pH among cows, or the extent of diurnal fluctuations in rumen pH for individual cows. Thus, minimum recommendations (as in Fig. 7) do not include a margin of error to account for the variability among cows or the fermentability of the diet. As diets are formulated closer to the minimum level of physically effective fiber, a greater portion of the cows will experience ruminal acidosis. Formulating diets for the average cow is acceptable for cows in mid and late lactation, but diets for early lactation cows should be formulated above the minimum requirement because of their higher risk for acidosis. How far above the minimum depends on the other risk factors for acidosis, as well as the producer's tolerance for risk.

Good Bunk Management

In addition to providing adequate fiber, good feedbunk management is critical to prevent acidosis. In particular, limited bunk space, infrequent TMR push-up, high competition at the bunk, component feeding (feeding grains separately from forages), abrupt changes in diet composition, and variation in the amount of feed allocated from day-to-day, all increase the risk of acidosis. Furthermore, diets with excessive (> 15% of the DM on the 19-mm sieve) long forage particles can paradoxically increase the risk for acidosis. Cows can easily sort out and refuse to eat these long particles (Leonardi and Armentano 2003), thereby decreasing the amount of peNDF consumed.

Conclusion

The concept of physically effective fiber offers a means of balancing diets to promote healthy rumen function of dairy cows, which reduces the risk of acidosis and promotes improved feed conversion efficiency. Other factors that affect rumen pH, such as the fermentability of the diet and feeding management practices, need to be considered in addition to physically effective fiber to prevent ruminal acidosis. Use of high quality forages helps cushion against the risk of ruminal acidosis, because a greater proportion of forage can be included in the diet without lowering its digestible energy content.

Our recommendations for minimum levels of dietary physically effective fiber are based on the average cow, and do not include a margin of error to account for the variability among cows or the differences in the fermentability of the diet. As diets are formulated closer to the minimum level of physically effective fiber, a greater portion of the cows will experience ruminal acidosis. Formulating diets for the average cow may be acceptable for cows in mid and late lactation, but diets for cows in early lactation should be formulated above the minimum requirement because of their higher risk for acidosis.

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