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Limited chewing takes place when a cow grazes or eats chopped forage, and a more thorough mastication will occur later when she "chews her cud."

Rumination, of which cud chewing is a part, is the process by which the contents of the rumen (the first chamber of the stomach) are thoroughly mixed and where the larger, less digested particles are redirected upward, to be regurgitated, chewed, and swallowed again. This process is repeated over and over until the feed particles attain a small enough size with relatively greater surface areas that enable bacteria and protozoa in the rumen to more efficiently feed and digest the particles. In time the feed leaves the reticulo-rumen and enters the omasum, on its way to the true stomach, the abomasum.

In addition to mechanically breaking the forage into smaller particles, chewing also stimulates the production of saliva, rich in bicarbonate. The saliva is essential to buffer the continuous production of volatile fatty acids produced by microbes in the rumen. These fatty acids are responsible for the acidity of the rumen contents.

Structural carbohydrates (the fiber in forage) are the physical stimulus that initiates rumination, thus playing an important role in maintaining the health and function of the rumen. Forage particles are covered by a cuticle on all surfaces except the ends that were chopped. In the field, cuticle protects the leaves and stems from excessive water loss and from the entry of various disease organisms. During rumination, cuticle-covered surfaces are macerated, allowing rumen microbes to colonize the digestible plant cell contents.

When, however, particle size in the diet is too small, rumination is disrupted, resulting in a reduction in buffering capacity and activity in the rumen. This may result in associated metabolic problems.

Cows, rumen fermentation, and effective fiber

Genetic improvements in milk production goes hand in hand with the nutritional challenge of dairy cows.

In forage-based diets, energy tends to be diluted. As a result, diets have changed—from predominantly forages in the past to high grain, more energy-dense rations today. Maintaining adequate nutrient intake has been addressed by chopping forages and by including more concentrates and byproducts.

As a result of these changes, nutritionists have resorted to the use of additives to stabilize rumen conditions. Sodium bicarbonate, magnesium oxide, and sodium sesquicarbonate have all been used alone or in combination to buffer rumen pH when high grain-to-forage rations are fed to dairy cows.

The addition of buffers alone does not solve the decrease in motility observed when particle size is deficient in the diets of lactating dairy cows. Motility is the successive waves of contractions in the rumen wall that mix the feed, aid in eructation of gas (burping) and send feed on to the cow's other stomachs.

What would then be the right kind and size of fiber that would maintain a healthy and functional rumen without the need of buffers? The answer involves two closely interrelated aspects of ruminant biology: rumen pH and motility.

Some fermentable fibers, such as those in soy hulls and beet pulp, have some of the characteristics of effective fiber. They change the pattern of fermentation in the rumen, increase the molar proportions of acetate, do not excessively acidify rumen pH, and promote milk fat production. But they do not have the fiber effectiveness that results in the rumen "scratch factor" that promotes rumination. There may be less regurgitation of cud or eructation of gas; consequently there may be less buffering of the rumen contents via saliva production. Nevertheless, soy hulls and beet pulp are excellent feeds for dairy cows.

When the rumen pH drops below 6, the growth of fiber-fermenting bacteria is depressed, propionate producing bacteria increase, and milk fat percentage drops.

In addition, protein percentage usually increases, creating a milk fat to protein inversion (when the protein level becomes equal to or greater than the fat level). Inversion could be an early warning sign of acidosis and laminitis.

Dietary neutral detergent fiber (NDF) concentration is poorly related to "fiber effectiveness." What really matters is not how much NDF concentration is present in the diet but the particle size of the forage source of that NDF.

A reduction in particle size also impairs the formation of the rumen mat. The rumen mat could be compared to a "forage sieve" that slows particles in the rumen long enough for them to be degraded by the microorganisms. In the absence of an adequate mat, rumen retention time decreases, and so does total tract digestibility of the diet. In general, the reason why animal performance is often not affected by decreased digestibility is because feed intake increases and this more than compensates for the decrease in digestibility.

Recommended fiber intake

Research suggests cows eat a maximum amount of NDF that is close to 1.2% of their body weight. This has been demonstrated to be the result of the "fill effect" regulated by rumen distension. A 1,350-lb cow will thus eat 16 lb NDF or approximately 50 lb of dry matter of a diet containing 32% NDF. When only forage NDF is considered, the gut-fill limit seems to be set a little lower, at 0.75 to 1.1% of the animal's body weight.

Intake of mature forages, those high in fiber content, will be limited when compared to forages offered in the early vegetative state. Decreased forage particle size can modify this rule to a certain extent, as it allows for a more rapid turnover of feed from the rumen and allows feed intake to resume faster.

However, if the forage or the total mixed ration is chopped too fine, a minimum NDF intake of greater than 0.85% of the body weight should be used. As diet NDF decreases, there is a need to increase the amount of forage NDF in the diet together with more non-fibrous carbohydrates to be able to sustain high levels of milk production (Table 1).

Table 1. Neutral detergent fiber, acid detergent fiber, and non-fibrous carbohydrates recommended for high producing dairy cows.

Forage NDF	Diet NDF	Diet NFC	Diet ADF
--------- Minimum---------		--------Maximum--------	
19	25	44	17
18	27	42	18
17	29	40	19
16	31	38	20
15	33	36	21

Source: NRC 2001

The challenge with high producing cows is the compromise between the need for energy-dense rations that also provide enough effective fiber. An example of one such contradiction is the need to include straw or other fibrous residues in order to balance rations that include highly digestible forage varieties.

Other factors that affect particle size

At times, feeding management might prevent cows given an otherwise adequately formulated diet from milking to their potential. Rations can look very good on paper but as it's usually said, there are three rations: one formulated on paper, another one delivered to the cows, and a third one that the cows actually eat.

Ration formulation is as accurate as the nutrient content of the feeds. Moisture, protein, and fiber as well as other nutrients will vary for the same crop when harvested from different fields or when harvest is delayed for a few days.

Even when the ration is adequately formulated and the feeds are analyzed and weighed properly, inadequate mixing can have an impact on particle size. Weighing, loading sequence, delivery of the ingredients, and mixer design can all have an effect on ration homogeneity. Under-mixing can result in uneven distribution of feed particles in the total mixed ration. Over-mixing can have similar results or, depending on the type of mixer used, can decrease even further the particle size.

Variations in moisture content might affect mixing and increase sorting of the feed by the cows once it is delivered to the feed bunk. Drier rations in particular are prone to sorting, which results in decreased homogeneity of the ration consumed. Bunk space plays a very important role in the characteristics of the diet the cows will eat. Competition at the feed bunk leads to uneven total dry matter intake as well as differences in the composition of the ration consumed by the animals.

Evaluating particle size

The Penn State particle size evaluator has proven to be a useful field tool to assess particle size. The original Penn State Particle Separator contained two sieves and a bottom pan. A recent update adds a third and lower sieve before the bottom pan (Heinrichs and Kononoff, 2002).

The first sieve retains those particles greater than 0.75 inches. These particles are those that form the rumen mat and that have the greatest effect in stimulating rumination. The second sieve separates those particles that measure between 0.75 and 0.31 inches, and that have moderate rate of digestion and flow. The new third sieve separates those particles that measure between 0.31 and 0.07 inches. This sieve was added to better characterize the small feed particles. The bottom pan collects the remaining particles, smaller than 0.07 inches. These particles digest or pass rapidly from the rumen.

The particle-size guidelines depend on what is being assessed, straight forages or total mixed rations (Table 2). When corn silage is the only forage in the ration, slightly longer particle size is suggested. In this case at least 8% of the corn silage particles should be retained in the upper sieve, whereas if other forages are included in the ration (such as alfalfa hay), a minimum of 3% of the corn silage particles in the upper sieve may be adequate.

If the corn silage is processed, the percentage retained on the top sieve can be increased. The middle sieve should contain 45 to 65%, the lower sieve 30 to 40%, and the bottom pan < 5% of the corn silage particles.

The particle size of alfalfa silage can vary depending on the type and use of machinery, the density of the sward, and the dry matter of the crop. Current guidelines are 10 to 25% of the particles in the upper sieve, 45 to 75% in the middle sieve, 20 to 30% in the lower sieve, and < 5% in the bottom pan.

Of the total mixed rations (TMR), ideally between 2 and 8% of the particles should be larger than 0.75 inches (upper sieve) in diets for high producing dairy cows. Less than that could lead to problems related to shortness of effective fiber in the diet, such as decreased milk fat production, displaced abomasums, acidosis, and lameness.

The middle and lower sieves should contain 30 to 50% of the particles, whereas the bottom pan should have no more than 20% (Table 2). If you're using the three-pan separator, the lower sieve and bottom pans will be combined.

Consequences of inadequate effective fiber in the diet

Increased dietary forage NDF increases rumen pH as a result of increased chewing activity and saliva production. It has long been demonstrated that as rumen pH decreases so does milk milk fat. Research has shown that with rumen pH above 6.0, milk fat percent in Holsteins was 3.5 or greater. The same was true when effective fiber was equal or greater than 20% of the ration (Table 3).

Measuring rumen pH has been used as a diagnostic tool. The only constraint of this approach is that it provides one pH point in time without showing its evolution or how much time the rumen was under acidic conditions (Fig 1). Normally, rumen pH will drop significantly after meals and will increase while the cow is resting and ruminating. While it is not unusual for rumen pH to drop below 6.0 for a period of time during the day, average rumen pH for the day should be greater than 6.0. If ruminal pH remains under pH of 6.0 for longer periods of time, subclinical acidosis may result.

Table 2. Recommended particle size for forages and total mixed rations (TMR).

	Corn silage	Alfalfa silage	TMR
Upper sieve[1] < 0.75 inch	8% if sole forage 3% if not the sole forage 10-15% if chopped/rolled	10-15% in sealed silo 15-25% if in bunker silo	2-8%
Middle sieve[1] 0.31 - 0.75 inch	45-65%	45-75%	30-50%
Lower sieve[1] 0.07 - 0.31 inch	30-40%	20-30%	30-50%
Bottom pan[1] <0.07 inch	< 5%	< 5%	≤ 20%

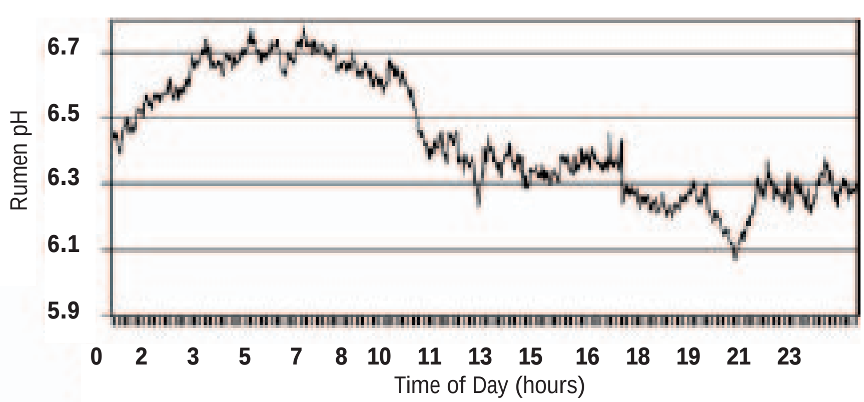
[1] Portion remaining on the screen
Source: Heinrichs, J. and P. Kononoff, 2002.

Table 3. Effects of forage particle size on rumen pH and milk fat.

	Fine	Medium	Coarse
Rumen pH	5.40	5.80	6.25
Acetate/propionate	2.08	3.20	3.89
Milk fat	3.20	3.50	3.80

Source: Grant et al., 1990.

Fig 1. Changes in rumen pH over the course of a day.



Source: Duffield et al. 2004

Take home messages

Whenever the opportunity arises, check to see how many animals are ruminating at a certain point in time. Recommendations suggest that approximately 50% of the cattle should be chewing their cud when they are resting.

Check also for any changes in dry matter intake. Sudden drops may be an indication that some cows might be going off-feed due to sub-clinical rumen acidosis beause of inadequate particle size or effective fiber in the ration.

Check manure regularly for consistency and undigested feed particles. If there is a problem with fiber effectiveness there will be cows with firm and cows with loose manure in the same pen. Make sure you check those same cows again the next day to verify any changes in manure consistency.

Other indications of the presence of acidosis would be bubbles in the manure and/or mucus casts. This mucus is secreted by the intestine to protect itself from the acid load that might damage its lining. During this time, particle size in the feces may actually increase. This results from an inadequate rumen fermentation, which in turn increases the passage rate of particles out of the rumen and allows larger fiber particles to reach the intestines intact.

Providing effective fiber is critical to maintain normal rumen function and overall animal health. As a result, milk production will be maximized and milk fat percentage will not be depressed. If particle size of the diet is reduced, forage NDF in the diet should be increased.

Although the addition of buffers to the diet can increase rumen pH and improve rumen fermentation, they should not be a substitute for maintaining an adequate particle size in the diet.

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