Particle Size, Fragmentation Index, and Effective Fiber: Tools for Evaluating the Physical Attributes of Corn Silages

David R. Mertens
U.S. Dairy Forage Research Center, Madison, WI

Nutritive evaluation of corn silage provides a unique challenge because it contains variable proportions of grain and stover that differ in chemical and physical characteristics. Although it can vary from 30 to 70%, most corn silage contains about 50% corn grain. Grain contributes more of the total digestible nutrients (**TDN**) in corn silage than the stover because it contains relatively digestible starch. The stover in corn silage is relatively mature and high in neutral detergent fiber (**NDF**) at harvest. Stover is a source of energy from digestible NDF and, depending on the length of chop, it can provide physically effective NDF (**peNDF**) to stimulate chewing activity and ruminal function.

The variable characteristics and proportions of grain and stover in of corn silage create problems when estimating energy value using chemical composition. In most forages, fiber is the major determinant of TDN or dry matter digestibility (**DMD**) because the non-fiber fraction of these feeds is almost completely digested. Van Soest (1967) developed the first simple summative equation to estimate DMD, which was the sum of digestible neutral detergent solubles and neutral detergent fiber. Because neutral detergent solubles digestibility was relatively constant at 98%, the most important factors affecting the DMD of grass and legume forage is NDF concentration and its digestibility.

The simple summative equation of Van Soest (1967) is less accurate in estimating TDN in feeds that contain significant proportions of fat, heat-damaged protein, or starch. These constituents of neutral detergent solubles vary in energy density (fat) or digestibility (heat-damaged protein and starch) from other soluble matter. Conrad et al. (1984) proposed that digestible neutral detergent fiber should be partitioned into digestible crude protein, fat, and non-fiber carbohydrates **(NFC)**. Weiss et al. (1998) updated this complex summative equation, which was adopted by the NRC (2001) with the addition of a processing adjustment factor that adjusts NFC for differences in starch digestibility. Shaver (2002) proposed dividing NFC in corn silage into starch and non-starch NFC, and related the digestibility of starch to silage DM (as an index of kernel maturity) and kernel processing. These equations have potential to be more accurate, but require additional chemical analyses and information about the processing of the starch.

Processing of corn silage through rollers during chopping typically increases starch digestibility (Rojas-Bourrillon et al., 1987; Bal et al., 2000; Weiss and Wyatt, 2000; Andrae et al., 2001; Schwab et al., 2002), but the response is variable. Cooke and Bernard (2005) observed that starch digestibility for corn silage processed with an 8-mm clearance between rollers was 12% lower compared to corn silage processed with a 2-mm clearance. Johnson et al. (2003) suggested that the lack of response in starch digestibility to kernel processing might be related lack of difference in the proportion of intact corn kernels between some processed and unprocessed corn silages.

Both chopping length and processing alter physical characteristics that not only affect starch utilization and energy value of corn silage, but also affect mean particle size and effective fiber. My objectives in this presentation are to review the physical factors affecting corn silage nutritive value and describe a laboratory method for simultaneously measuring the particle size, extent of kernel fragmentation, and physically effective fiber of corn silages.

Materials

Thirty-two corn silages were obtained from a commercial feed analysis laboratory (Dairyland Laboratories, Inc., Arcadia, WI), which were diverse in chemical and physical characteristics. All silages were selected from an initial set of 51 corn silages. Six corn silages were selected for fine, medium and coarse particle size based on visual appraisal. The remaining corn silages were selected, based on the amount of available material and on diversity on DM, CP, NDF, ADF and starch concentrations. No information regarding genotype or harvesting procedures was obtained, but visual appraisal (e.g., broken cobs and fractured kernels in silages that were coarsely chopped), indicated that a majority of the silages had been processed.

Chemical Analysis

Dry matter concentration was determined by drying the samples in a forced-air oven for 24 h at 55 °C. Concentrations of ADF, ADL and ash were measured as described by AOAC (1990). Concentration of amylase-treated NDF **(aNDF)** was determined using both amylase and sodium sulfite (Mertens, 2002a). Concentration of CP was measured as N ´ 6.25 after analysis with combustion N analyzer. Non-fiber carbohydrate was calculated as (NFC = 100 – Ash – CP – EE - aNDF), where aNDF was not corrected for CP or ash and ether extract (EE) was considered constant for all silages and equal to 3.2% (NRC, 2001). Concentrations of starch were measured using an YSI Biochemistry analyzer (Yellow Springs Instrument Inc., Yellow Springs, OH) by Dairyland Laboratories, Inc., Arcadia, WI.

Recommended Method for Measuring Particle Size, Fragmentation Index and Effective Fiber

Vigorous, vertical shaking of dried silages is needed to dislodge fine particles of starch that adhere to larger particles in silage when the sample is moist. Mean particle size **(MPS)** is calculated as described by ANSI (1993), except the square instead of the diagonal dimension of apertures were used. This method of sieving results a determination MPS that measures the smallest cross-sectional dimension of particles, as will be explained later. To measure corn silage MPS, fragmentation index **(CSFI)** and peNDF:

1) Mix the undried silage sample thoroughly and dry a representative sample of 600 ±100 mL volume for particle size separation and a separate complete sample of 100 to 200 g wet weight for routine analysis. Dry under conditions that will not affect starch or fiber analyses (55 to 60 °C).
2) Record the tare weight of a set of sieves with square apertures of 19.00, 13.20, 9.50, 6.70, 4.75, 3.35, 2.36, 1.18, 0.60 and 0.30 mm, in addition to the bottom pan. Stack sieves in ascending order of aperture. Use 20-cm diameter brass or stainless steel sieves with 5-cm height for apertures of 4.75 mm and above and 2.5-cm height for all other apertures (ATM Corporation, Milwaukee, WI). Using a large number of sieves prevents accumulation and bridging of material on any one sieve and allows shorter shaking times.
3) Transfer the entire 600 ml of dried test sample on the top sieve of a stacked series of sieves, cover with lid, and place on a vertical shaker (RoTap or equivalent, W.S. Tyler Incorporated, Mentor, OH).
4) Shake for 10 min and record the weight of retained material plus sieve for each sieve in the series.
5) Composite all retained residues on sieves with apertures of 4.75 and larger. Grind the >4.75-mm composite and complete samples suitable for starch analysis. Determine starch concentrations of the >4.75-mm composite and total samples using an appropriate method.
6) Composite all residues passing through the sieve with 1.18-mm aperture and analyze the <1.18-mm composite and total samples for aNDF.
7) To determine MPS (minimal cross-sectional dimension) of corn silage calculate the weight of residue retained on each sieve and determine geometric mean particle size as described by ANSI (1993) using the square dimension of sieve apertures (Table 1).
8) Calculate CSFI = 100 × [(Total sample starch concentration) – (fraction of total particle size sample retained on >4.75-mm compos-

ite sample sieves) × (>4.75-mm composite sample starch concentration)] / (Total sample starch concentration) (Table 2).

9) Calculate peNDF (NDF distribution) = (Total sample aNDF concentration) – (fraction of total particle size sample passing through the 1.18-mm sieve) × (<1.18-mm composite sample aNDF concentration) (Table 2) or Calculate peNDF (DM distribution) = (Total sample aNDF concentration) × (fraction of DM passing through the 1.18-mm sieve)

Results and Discussion

Chemical Composition

The range in minimum and maximum chemical and physical characteristics of the 32 selected materials indicate that they represent a wide diversity of corn silages (Table 1). Average chemical composition was similar to that reported by NRC (2001) for normal corn silage, except for ash which was higher than that reported by NRC (5.1 versus 4.0%). Four silages exceeded 7.0% ash and without these samples the average ash was 4.7%, which still exceeded the average reported by NRC (2001). The concentrations of aNDF and ADF were highly correlated (r = 0.92). The regression coefficient relating ADF to NDF was similar (0.62 versus 0.61) to that reported by NRC (2001); however our intercept not different from zero. High negative correlations were observed between aNDF and NFC and starch (-0.96 and -0.89, respectively). This suggests that the primary determinant of fiber concentration in corn silage is the proportion of grain in the crop, which dilutes the forage stover contribution. It also suggests that NFC and starch can be estimated from aNDF concentration in corn silage with reasonable accuracy:

% NFC = 87.5 - 1.03*(% aNDF); $R^2 = .93$, SE of regression = ±1.9

and

% Starch = 60.0 - .79*(% aNDF); $R^2 = .77$, SE of regression = ±2.7.

Table 1. Calculation of mean particle size, fragmentation index and physically effective NDF in corn silage.

Aperture Dimension[a]	**Sieve weight**	**Sieve + Sample weight**	**Sample weight**	**Fraction retained[b]**	**Log (GM)[c]**	**Fraction × Log(GM)[d]**
(mm)	**(g)**	**(g)**	**(g)**	**(%)**	**($\log_{10}$)**	
26.400[e]						
19.000	568.77	570.28	1.51	0.020	1.350	0.027
13.200	502.87	504.98	2.11	0.028	1.200	0.034
9.500	492.95	498.30	5.35	0.071	1.049	0.075
6.700	473.32	481.78	8.46	0.113	0.902	0.102
4.750	771.73	784.46	12.73	0.169	0.751	0.127
2.360	450.42	467.58	17.16	0.228	0.525	0.120
1.180	337.49	347.34	9.85	0.131	0.222	0.029
.600	288.42	297.04	8.62	0.115	-0.075	-0.009
(Pan) .038[f]	255.95	265.29	9.34	0.124	-0.821	-0.102
Totals **MPS[h]**			75.13	1.000		0.403[g] 2.528[h]

[a] Square dimension of sieve aperture.

[b] (Sample weight / Total sample weight).

[c] Logarithm (base 10) of the geometric mean dimension of particles retained by the sieve. Log(GM) = $\log_{10}$ [•(aperture dimension of sieve above × aperture dimension of the sieve retaining particles)].

[d] Fraction retained × Log(GM) for each sieve.

[e] To calculate the geometric mean dimension of particles on the top sieve (19000 nm) it is assumed they would have passed through the aperture of the next largest geometric progression of apertures. To minimize error associated with this assumption the top sieve should contain < .05 of the total sample weight.

[f] To calculate the geometric average dimension of particles in the pan it is assumed they have minimum size of 38 nm. To minimize error associated with this assumption the pan should contain < 10% of the total sample weight.

[g] Weighted logarithmic normal mean = Average Log(GM) of particles.

[h] Mean particle size in mm (minimal cross-sectional dimension) = $10^{[\text{Average Log(GM)}]}$.

Table 2. Calculation of corn silage fragmentation index (CSFI) and physically effective NDF (peNDF).

Fraction	Aperture size	Fraction of Total[a]	Starch	aNDF
Coarse composite	>4.75 mm	.401	20.90	
Medium composite	1.18-4.75 mm	.360		
Fine composite	<1.18 mm	.239		37.50
Complete corn silage		100.00	27.02	42.06
CSFI[b]			68.95	
peNDF[c] (NDF dist.)				33.09
pef[d] (NDF dist.)				0.79
pef[e] (DM dist.)				0.76
peNDF[f] (DM dist.)				32.00

[a] Sums of percentage retained on sieves from Table 1.

[b] CSFI =100 × [(Total starch concentration) – (fraction retained on sieves >4.75-mm) × (coarse composite starch concentration)] / (Total sample concentration).

[c] peNDF (NDF distribution) = (Total aNDF concentration) – (fraction passing through the 1.18-mm sieve) × (<1.18-mm composite sample aNDF concentration).

[d] Physical effectiveness factor (pef) = 100 × [(Total aNDF concentration) – (fraction passing through the 1.18-mm sieve) × (<1.18-mm composite aNDF concentration)] / (Total sample aNDF concentration).

[e] Physical effectiveness factor (pef) based on DM distribution = 100 – (Fraction <1.18 mm).

[f] peNDF (DM distribution) = (Total aNDF concentration) × (fraction passing through the 1.18-mm sieve).

Table 3. Chemical and physical characteristics of 32 diverse corn silages.

Characteristics	Average	StandardDeviation[a]	CV[b]	Minimum	Maximum
DM, %	34.7	±7.8	22.5	19.2	48.1
ANDF[c], % DM	44.2	±6.4	14.5	30.0	56.3
NFC[d], % DM	41.6	±7.1	17.1	27.4	57.7
Starch, % DM	25.2	±5.7	22.5	12.2	36.2
Crude Protein, % DM	7.8	±1.4	17.4	5.7	12.5
Ash, % DM	5.1	±1.5	29.9	3.1	9.6
MPS[e], mm	4.2	±1.4	33.5	2.1	7.3
DM <1.18 mm, %	86.2	±8.0	9.3	67.5	96.5
PeNDF[f], % DM	38.3	±7.1	18.5	25.8	50.9
CSFI[g], % of starch	47.8	±20.6	43.1	0.0	91.3

[a] The range of average minus one standard deviation to average plus one standard deviation will include about 2/3 of the samples.

[b] Coefficient of variation = 100*Standard deviation / Average.

[b] Amylase-treated NDF.

[c] Nonfibrous carbohydrates = 100 – ash – CP – EE – aNDF (EE estimated to be 3.2% of DM).

[d] Mean particle size of the minimal cross-sectional dimension.

[e] Physically effective NDF estimated from DM particle size distribution.

[f] Corn silage fragmentation index, percentage of starch retained on sieves with apertures >4.75.

Both NFC and starch are used in current summative equations to estimate total digestible nutrients (NRC, 2001; Shaver, 2002) and these equations can be used to evaluate analytical results and generate values when they are not determined analytically.

In the early 1980s, Mertens proposed the calculation of NFC from routine analyses as an estimate of rapidly available carbohydrate and used it to validate starch analyses (which must be less than NFC as a portion of DM) and to insure that feed inputs for rumen models would sum to 100% of DM. Calculated NFC differs from nonstructural carbohydrates, which are measured analytically as starch and soluble sugars, and the terms should not be used interchangeably

(Mertens, 1988). Although NFC consists of a mixture of sugars, starch, pectins, soluble fibers and organic acids, it is a crude estimate of available carbohydrate, which is often used to define maximum recommendations for rapidly fermentable matter in dairy rations. In corn silage, the major NFC is starch, which can be predicted more reliably from NFC than from aNDF:

% Starch = -6.0 + .76*(% NFC); $R^2 = .87$, SE of regression = ±2.1.

This equation indicates that most of NFC is starch. Because corn silage would be expected to have little non-fermented sugar, the remainder of NFC is probably organic acids, soluble fiber and cumulative errors associated measured components in the equation, such as not correcting aNDF for protein or ash contamination or crude protein for non-protein nitrogen.

In most forages, maturity is highly and positively correlated with fiber concentration, but in corn silage the accumulation of grain dilutes the fiber concentration as the crop matures. In corn, both stover and grain dry with advancing maturity, but at different rates (Cummins, 1970; Hunt et al., 1989). Thus, DM concentration may be the best chemical indicator of maturity in corn silage. Although maturity in corn silage should be positively correlated with grain and starch, and negatively correlated with fiber concentration, these relationships were relatively poor because they are also affected by grain yield. The DM concentration of these silages was positively correlated with NFC concentration (r = 0.55) and starch concentration (r = 0.48) and negatively correlated with aNDF concentration (r = -0.49).

Mean Particle Size

Mean particle size provides a quantitative measure of how thoroughly materials are chopped. It will vary with the chopper setting for theoretical length of cut (**TLC**), the sharpness of the knives and the orientation of material as it enters the cutter head. Chopping reduces the chewing required by the cow during eating and ruminating (Sudweeks et al., 1979) and may increase intake of low quality forages when chewing time is the constraint for passing poorly digested residues out of the rumen. Particle size may also affect packing density and indirectly affect silage fermentation characteristics.

There are numerous methods of measuring particle size in feeds and forages. Although they are correlated, they generate different estimates of MPS because the method of separation and calculation of results differ. It is crucial to know the method for determining MPS when interpreting the results. For example, separation of undried feeds with gentle shaking is often incomplete because small particles adhere to large particles and this is especially true for small starch particles. In addition, the particle size distribution of undried forages and total mixed rations can be biased if larger and smaller particles have different DM concentrations.

The duration and type of shaking motion can also affect results. The time needed to obtain complete separation is obtained by determining the shaking time needed to reach the maximum plateau weight of residue in the bottom pan. This varies with the dryness and amount of sample, number of sieves, and shaking motion and intensity. With our vertical shaker and dried samples it typically takes 15 to 20 minutes to obtain maximum separation. However, >90% of the separation occurs in the first 10 minutes and this time was selected for the recommended method to maximize sample throughput while obtaining repeatable separation. We observed that a 600 ml volume was adequate to obtain a representative test sample and minimize bridging of particles on sieves with 5-cm heights and 20-cm diameters. Volume is used to standardize the mass being separated because the density of chopped materials varies too greatly. Too minimize bridging of material on sieves, no sieve should retain more than 25% of the total sample and additional sieves in the geometric progression should be added to meet this restriction.

Type and intensity of shaking action and the design of the sieve surface also affect the determination of MPS. Gentle, horizontal shaking keeps particles in a length-wise plane and separates them by the length (largest cross-sectional dimension). If the distance between openings in the sieve is slightly greater than 50% of the diameter of the opening and the thickness of the mesh increases with the size of the opening, the tipping of long particles through the opening will be minimized. Conversely, vigorous, vertical shaking of particles tends to bounce them on end and they pass through sieve apertures based on their width or diameter. When combined with sieves made of wire mesh, which have minimal distance between openings and maximum open space, particles are separated by their smallest cross-sectional dimension. The shape of the opening in the sieve also affects separation and calculation of results. Most sieves are made of mesh with square openings. Depending on the orientation of the particle, square openings will retain particles that range in size from the square dimension to the diagonal dimension of the opening.

The net effect of differences in duration, intensity, and motion of shaking and in the design and shape of openings in sieves is that MPS is dependent on the method used for separation. The method that is recommended is based on the one we have used during the last 20 years and compared to chewing activity when investigating fiber effectiveness in ruminant diets (Mertens, 1997). Because it is based on vigorous, vertical shaking of dried materials with wire mesh sieves with square openings and uses a sample size that minimizes bridging and a time that optimizes separation, the recommended method will separate particles based on their width or diameter (smallest cross-sectional dimension). Mertens et al. (1984) reported that the length of sieved corn silage particles were about 3.4 times their width. The ANSI (1993) method uses horizontal shaking and the diagonal dimension of the square opening (which is $\surd 2$ times the square dimension) for determining mean particle length. Multiplying the MPS by 4.8 should approximate the mean particle length, which varied from 3/8 to 1 3/8 inches with an average of 3/4 inch for the 32 diverse silages. Visual appraisal indicated that several of these silages were chopped very coarsely.

Corn Silage Fragmentation Index

Given that not all processed corn silage results in complete or similar kernel disruption (Shinners et al., 2000; Cooke and Bernard, 2005), it is obvious that methods are needed to quantitatively describe the actual extent of kernel fragmentation in corn silage during processing so its effect on starch digestibility in corn silage can be evaluated. It is also evident that processing of corn silage through rollers is not the only method by which corn kernels can be fragmented. Very fine chopping of corn also fragments kernels, so it may be misleading to refer to the result in terms of "processing." Both chopping and rolling are processes, but the desired result is fragmentation of corn kernels and large particles of cobs and stalks in the stover. To the cow, it is irrelevant how the kernels were fragmented, only that they are broken open so that more complete digestion can occur under production levels of intake. Thus, the term "fragmentation" will be used to more clearly indicate the result that is measured and important in determining the nutritive value of corn silage.

Although processing can reduce the starch excreted in feces (Johnson et al., 1996, Dhiman, 2000), not all silage processing is equally effective in enhancing starch digestibility (Johnson et al., 2003; Cooke and Bernard, 2005). Extent of processing is affected not only by roller clearance and roller wear, but also by the forage particle size and rate of flow of chopped material through the processor. Although the nominal clearance may be set to 1 mm, the operating clearance is larger as the mass of silage spreads the rollers apart. Longer lengths of cut generate larger particles of cobs and stalks, which also force the rollers apart. As the rolls separate, the shear exerted by the differential speed of the rollers is decreased. Thus, there is a direct conflict between chopping length and fragmentation of kernels by roller processing. There is also a conflict between maximum kernel fragmentation and greater flow rate through a processor with a given width, roller diameter, and tension. Given the variation in chopping and processing that can occur, it is evident that a method for quantifying fragmentation of kernels is needed.

We observed that sieves with square apertures of 6.25 mm and larger retained most whole corn kernels in corn silage and those with apertures of 4.75 mm retained kernel fragments bigger than one fourth of a kernel. The kernels and large kernel fragments retained on sieves with apertures >4.75 were collected manually and analyzed for starch and in vitro dry matter disappearance (IVDMD). In the 32 diverse corn silages, the concentration of kernels and large kernel fragments was highly variable (coefficient of variation = 47%) and ranged from 4.2 to 48.4% of corn silage DM. There was no correlation between mean particle size (MPS) and the proportion of kernel and large fragments in silage DM because total kernels in corn silage is a function of grain yield, which is independent of harvesting conditions.

The IVDMD of the kernels and fragments retained on the sieves > 4.75 mm was about 30% of that obtained when these kernel fragments were finely ground. This suggests that the starch in these kernels and fragments would be incompletely fermented in the rumen and poorly digested by the animal unless they are chewed adequately. It was concluded that starch in particles that are less than ¼ of a kernel would be readily digested, and that the proportion of total starch that is in fragments < 4.75 mm could be used as a corn silage fragmentation index (CSFI) to provide a quantitative measure of kernel fragmentation in corn silage. Expressing the fragmentation index as a percentage of total starch in the corn silage, instead of percentage of DM, minimizes the effects of grain yield on the index and focuses on the proportion of starch that is fragmented. We observed that CSFI was positively correlated with IVDMD of whole, unground silages, which confirms that fermentation of starch in small fragments would be digested without chewing by the animal. Ferreira (2002) observed 5.6% greater total tract starch digestibility for cows consuming diets containing processed corn silage (CSFI = 90%) than for cows consuming diets containing unprocessed corn silage (CSFI = 50%).

For our diverse set of corn silages, the CSFI ranged from 0 to 91% and was negatively correlated with MPS (r = -0.46). The low correlation between CSFI and MPS is related to different degrees of kernel disruption within the same chop length (Roberge et al., 1998; Shinners et al., 2000), although other factors, such as maturity (Shinners et al., 2000) and differences in grain fragility may alter kernel fragmentation at a given MPS. It is clear from Figure 1 that there is a relationship between MPS and CSFI. We are planning an experiment to confirm these relationships by varying TLC and processor setting and measuring CSFI and MPS. Although we have no information about the chopping length and processing of the selected corn silages other than visual appraisal, we speculate that the upper-right and lower-left boundaries of the data in Figure 1 represent corn silages that were maximally processed or unprocessed, respectively, at a given MPS.

It is logical to expect silage that more coarsely chopped and not processed will have less kernel fragmentation than silage which is finely chopped. However, Figure 1 also suggests that longer chopping lengths will also result in less fragmentation with processing, which indicates there is a conflict between chopping length and CSFI. Currently we can speculate that a CSFI of 70% would require a MPS of 2.4 mm (about 7/16 inch particle length) without processing, but could be achieved with maximal processing at a MPS of 4.7 mm (about 7/8 inch particle length). The merging of these lines at a MPS of about 1.5 mm indicates the point at which corn processing has minimal

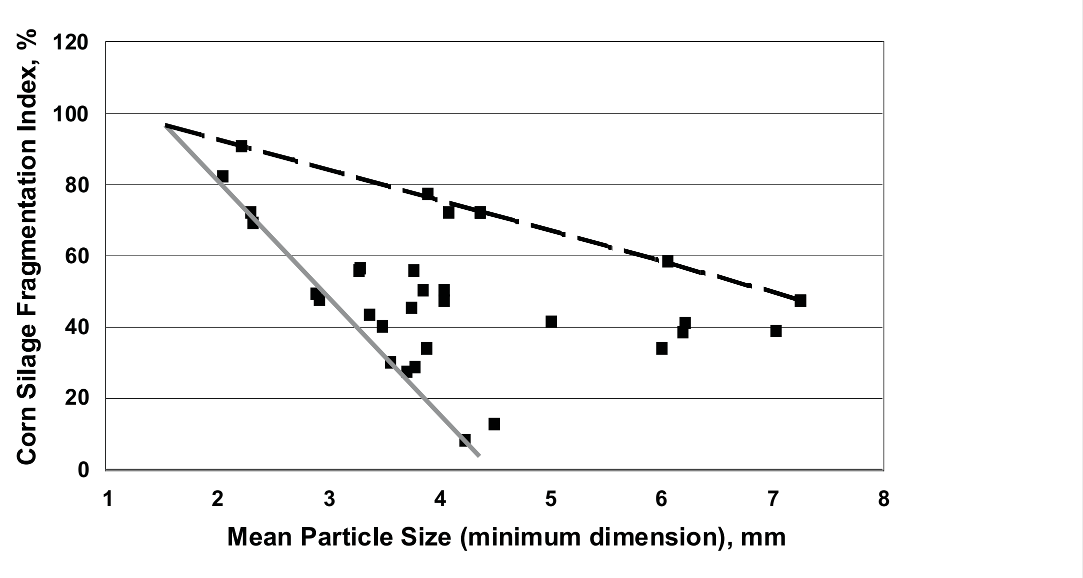

Figure 1. Relationship of corn silage fragmentation index to the mean particle size of corn silages. Upper dashed line is the proposed boundary of maximally processed corn silages at each mean particle size and the lower solid line is the proposed boundary of unprocessed corn silages.

impact because fine chopping already fragments kernels. The high variation in CSFI at a given mean particle size, especially at large MPS, confirms the importance of having a quantitative index of kernel fragmentation in corn silage.

Physically Effective Neutral Detergent Fiber

It is well know that dairy cows require a minimum amount of insoluble dietary fiber that is of adequate particle size. Actually the cow's physiological requirement is for a ruminal environment that minimizes digestive upsets and optimizes fermentative digestion. Both the chemical and physical natures of fiber are important in describing its effectiveness in generating a desirable ruminal environment. Because NDF and NFC are inversely related in most diets, it is difficult to attribute the ruminal environment exclusively to one or the other. However, the ruminant stomach is designed to digest fiber via microbial fermentation by selectively retaining and ruminating large fiber particles. Although NFC and especially starch concentrations and characteristics can affect the minimal fiber requirement, it is fiber that provides the mechanical properties in the diet that allow the rumen to function effectively. Although ruminal pH, volatile fatty acid concentrations and microbial population characteristics provide the best indicator of ruminal health, chewing activity is one of the most readily available indicators of ruminal health and function and of fiber effectiveness.

Mertens (1997) related chewing activity to both NDF concentration and particle size and proposed the concept of physically effective NDF (peNDF) to combine these properties in a single measurement. A database of chewing activity information was developed to estimate physical effectiveness factors for NDF from a variety of forages and physical forms. Based on the stimulation of chewing per unit of NDF intake, Mertens (1997) reported that the physical effectiveness of coarse, medium and finely chopped corn silage ranged from .90 to 1.00, .85 to .95, and .80 to .90, respectively. The variation in physical effectiveness within and among chopping lengths indicates that a quantitative method for measuring the peNDF of corn silage directly would be useful.

Based on the published observations that particles retained on sieves with apertures of 2.0 mm or less passed rapidly from the rumen and on the reports that the median particles in the feces of lactating cows are retain on sieves with apertures of .4 to 1.2 mm, Mertens (1997) concluded that particles passing through a 1.18-mm sieve would not stimulate chewing. He proposed that a simple laboratory method for measuring particle size distribution using vigorous vertical shaking could be used to estimate physical effectiveness factors for feeds. By assuming that NDF is evenly distributed among particles, the fraction of DM retained on sieves with apertures of 1.18 mm and larger could estimate the physical effectiveness factor. Thus, peNDF (based on DM distribution) would equal aNDF X (fraction of DM retained on >1.18-mm sieves). Using this approach, the physical effectiveness factors (DM distribution) of the 32 diverse corn silages ranged from .675 to .965 (Table 3). The average physical effectiveness factor was .862, which compares favorably with the average standardized value of .85 estimated from chewing activity (Mertens, 1997).

Because fiber is the feed component that requires extensive chewing, it would be most accurate to estimate peNDF based on the distribution of NDF in particles. This approach could easily be adopted by collecting the residue passing through the 1.18-mm sieve and analyzing it for aNDF. Then peNDF based on NDF distribution could be calculated as total aNDF minus NDF passing through the 1.18-mm sieve. Note in Table 2 there is a slight difference in peNDF determined by DM or NDF distributions; therefore the method of determining peNDF should be indicated when results are reported.

It is likely that physical effectiveness of fiber in stimulating chewing activity and ruminal function is related to many factors including fiber composition, particle size, ease of breakdown, moisture of the feed, preservation method, and dry matter intake. It appears that particle size is the major factor determining the physical effectiveness of NDF. However, adding additional long fiber that animals sort out and do not eat will not solve the problem. The animals must consume the longer fiber to alleviate the problem. Although processing corn silage reduces MPS compared to the same TLC that is unprocessed because grain, cobs and stalks are crushed into smaller particles, it often reduces the selectivity of cows and they tend to eat all the fibrous portions processed corn silage.

Summary

The proposed method for simultaneously measuring MPS, CSFI and peNDF provides a tool for assessing the physical properties of corn silage that are important in ensiling, starch utilization and ruminal health and function. Mean particle size is probably related to potential density of the silage and provides information about the relative impact of chopping length and processing on kernel fragmentation. Corn silage fragmentation index provides a quantitative measure of the extent of kernel disruption, which should be related to the rate of fermentation and total digestion of starch in corn silage. Given the important contribution that grain in corn silage makes to total dry matter digestion, information about starch utilization should be a valuable tool in adjusting the energy value of corn silage. When corn silage is a major contributor of fiber in dairy rations, it is important that its physical effectiveness be measured and taken into account when formulating diets that are borderline in fiber. Simultaneous measurement of particle size, fragmentation index and effectiveness of fiber offers valuable tools for fine-tuning rations and diagnosing potential problems. Additional animal experiments are needed to relate these measures to the nutritive evaluation of corn silage and to the health and productivity of lactating cows.

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