CHARACTERIZING EFFECTIVE FIBER WITH PARTICLE SIZE AND FIBER CONCENTRATION INTERACTIONS

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ABSTRACT

Both physical form and chemical nature of fiber is important to ruminant animals. A recently developed method for determining particle size distribution was used to characterize typical distributions for forages and total mixed rations (TMR) from the Mid-Atlantic region of the U.S. An effective fiber index (EFI) and modified effective fiber index (MEFI) are proposed which link physical and chemical characteristics. The EFI and MEFI are computed by weighting NDF concentrations by particle size distribution and effectiveness for contribution towards a rumen mat and rumination.

KEYWORDS

Effective fiber, forage, neutral detergent fiber, particle size, total mixed ration

INTRODUCTION

Cows have a requirement for fiber in addition to other nutrients. When the minimum fiber levels are not met, cows often show one or more of the following metabolic disorders: reduced total DM digestibility, reduced milk fat percentage, displaced abomasum, and increased incidence of rumen parakeratosis, laminitis, acidosis, and fat cow syndrome (Sudweeks *et al*., 1981). Cows consuming sufficient NDF with a finely chopped forage can also exhibit the same metabolic disorders as cows fed a diet deficient in fiber (Fahey and Berger, 1988).

Under conditions with insufficient forage particle length, the cows spend less time chewing, decreasing the volume of saliva produced needed to buffer the rumen (Grant *et al*., 1990a). Small ration particle size decreases the rumen acetate to propionate ratio and the pH which lowers milk fat percentage (Santini *et al*., 1983). Reduced forage particle size increases DMI which decreases retention time in the rumen and hence, reduces digestibility (Jaster and Murphy, 1983; Welch and Smith, 1978).

The mean particle size and the variation in particle size are important nutritionally to the cow and, under normal circumstances, the cow consumes particles of many different sizes, which allows for a steadier rate of digestion in the rumen and passage out of the rumen (Van Soest, 1982). A description of the distribution of the length of feed particles (rather than only the mean) is needed for proper nutritional management (Mertens *et al*., 1984). Furthermore, a method of integrating fiber concentration and particle size as a feedstuff characteristic is needed since insufficient amounts of either one can lead to similar animal responses and symptoms.

The objectives of this work were to illustrate typical particle size distributions for forages and total mixed rations, determine NDF concentrations of different particle size fractions in forages, and introduce a concept for effective fiber index.

METHODS

Until recently, there was no simple, cost effective method to determine forage and TMR particle length. One standard method and associated device (ASAE, 1995) for determining the particle size distribution in chopped forages is not practical for on-farm evaluations. Using the ASAE device as a model and standard for comparison, a simplified separator (Penn State Forage and TMR separator) was developed (Lammers *et al.*, 1996). The Penn State separator fills the need for nutritionists and farmers to have a practical method that is rapid, accurate, and inexpensive. The device uses two sieves and a bottom pan to separte forage and TMR samples into 3 size fractions (>19 mm, 8 to 19 mm, and < 8 mm).

Convenience samples were collected at a commercial forage quality laboratory. Most samples were received from farms in the Mid-Atlantic (PA, MD, VA) United States. Two sets of samples are discussed herein. A summary of the first set (367 TMR, 2104 corn silage, and 1252 mixed mostly legume (MML) silage samples) are presented later to illustrate typical particle size fractions. The second set (21 corn silage, 22 mixed mostly grass (MMG), and 39 MML samples) were separated into 3 fractions with NDF concentration of each fraction determined (Van Soest, 1982).

RESULTS AND DISCUSSION

Even though the complete distribution of particle sizes is important nutritionally (Van Soest, 1982; Welch, 1982), much of the current research focus and recommendations regard providing enough ìlongî effective fiber to stimulate rumination (Lammers *et al*., 1996). The large set of convenience samples of feeds was evaluated for particle size distribution (Figure 1).

For the 367 TMR samples, the average amount on the top sieve of the Penn State device (particles longer than 19 mm) was 6.14%. Very few samples had more than 12% on the top sieve. For the 2104 corn silage samples, the average percentage of particles longer than 19 mm was 6.62%. The mixed mostly legume silage samples were harvested with a considerably coarser chop length; an average of 19.0% was longer than 19 mm. Because these distributions were not associated with any nutritional study, they cannot be used to generate recommendations. They are however, indicative of forages and TMR being fed on Mid-Atlantic U.S. farms.

Effective fiber involves an interaction between particle size and chemically determined fiber attributes of the feed (Fahey and Berger, 1988). Development of a cost-effective, rapid, accurate method for particle size determination should facilitate much more research in this area (Lammers *et al*., 1996). The small convenience sample set was analyzed for particle size distribution, for whole sample NDF, and for NDF of each particle size fraction from the Penn State (3 fraction) separator.

Table 1 includes the range and mean NDF concentrations for the whole samples. The mean NDF concentrations for the separated fractions are also given. Paired t-tests for NDF of separated fractions indicated significantly higher NDF in particles >19 mm than particles <19 mm for all three types of forages (p<.001). Furthermore, for the MML silage, the NDF of particles 8-19 mm in size was significantly higher (p<.001) than NDF of particles <8 mm. These differences suggest that an ideal method of characterizing effective fiber should embelish both the particle size distribution of a forage as well as the NDF concentration of each particle size fraction.

One proposed method of linking particle size distribution with NDF concentration is an effective fiber index:

$$EFI = \frac{E_{>19mm} \cdot NDF_{>19mm} \cdot X_{>19mm} \cdot E_{8\text{-}19mm} + E_{<8mm} \cdot NDF_{<8mm} \cdot X_{<8mm}}{X_{>19mm} + X_{8\text{-}19mm} + X_{<8mm}}$$

where:

EFI = effective fiber index

E = relative effectiveness of particles in each size range

NDF = neutral detergent fober concentraction of each size range, fraction of DM

X=fraction of total mass in each size range

Here, the relative effectiveness coefficients (E) reflect the effectiveness of each particle length range to stimulate rumination and contribute to a rumen mat. Research is needed to establish these coefficients, but for illustrative purposes, index results for the convenience feed samples were generated with coefficients of E>19mm = 2, E8-19mm = 1, and E<8mm = .2. These coefficients imply that the top sieve material is twice as effective for stimulating rumination and contributing to a rumen mat as lower sieve material, and that the particles < 8 mm are 20% as effective for contributing to a rumen mat and stimulating rumination as lower sieve material (Van Soest, 1982; Welch, 1982). While the coefficients used may need to be refined with further research, the concept of weighting NDF concentration for particle size is valid.

Illustrative EFI values are included in Table 1. Important for any index is sufficient range so differences can be detected. The EFI ranges (maximum - minimum) were approximately equal to the mean, so this proposed index is sufficiently varying. Determination of EFI in this proposed manner requires 3 NDF analyses per sample. A simplified expression which does not account for varying NDF concentration among fractions, but which integrates whole sample NDF and particle size distribution is:

$$MEFI = \frac{NDF_{sample}(E_{>19mm} \cdot X_{>19mm} + E_{8\text{-}19mm} \cdot X_{8\text{-}19mm} + E_{8mm} \cdot X_{<8mm})}{X_{>19mm} + X_{8\text{-}19mm} + X_{<8mm}}$$

where:
MEFI = modified (simplified) effective fiber index

Illustrative values for the same effectiveness coefficients are included in Table 1. On average, MEFI was 4% higher, 2% higher, and 4% higher than EFI for corn, MMG, and MML silage, respectively. The maximum differences between EFI and MEFI were -23%, 11%, and 15% for corn, MMG, and MML silage respectively.

As methods for dairy ration formulation and feeding become more refined, it is clear that effective fiber will become increasingly important. The proposed methods (EFI and MEFI) of linking physical measures (particle size distribution) and chemical measures (NDF or acid detergent fiber) into one index inherently contains more information and more accurately reflects effects on animal function than expressing mean particle length with fiber concentration.

Table 1
Neutral detergent fiber and particle size interactions for corn, mixed mostly grass, and mixed mostly legume silages.

	Corn silage	Mixed mostly grass silage	Mixed mostly legume silage		
Number of samples	26	22	43		
Whole samples					
Minimum NDF	29.8	37.4	32.3		
Mean NDF	41.5	53.5	46.1		
Maximum NDF	54.2	65.2	57.7		
Means for separated fractions					
NDF of particles > 19 mm		64.0	59.0	52.9	
NDF of particles 8 to 19 mm			40.8	53.6	47.3
NDF of particles < 8 mm		39.4	52.9	44.6	
Effective fiber index (EFI)					
Minimum EFI	15.4	21.8	22.5		
Mean EFI	31.4	35.0	35.9		
Maximum EFI	49.6	54.2	54.0		
Modified effective fiber index (MEFI)					
Minimum MEFI	15.3	21.8	19.1		
Mean MEFI	29.8	35.2	34.9		
Maximum MEFI	44.6	55.7	50.5		

NDF = neutral detergent fiber concentration, % of DM
EFI = effective fiber index as defined in the text ($E_{>19mm} = 2$, $E_{8\text{-}19mm} = 1$, $E_{<8mm} = .2$)
MEFI = modified effective fiber index as defined in the text ($E_{>19mm} = 2$, $E_{8\text{-}19mm} = 1$, $E_{<8mm} = .2$)

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Figure 1
Frequency plots illustrating typical fractions of long (>19 mm) particles in (a) total mixed ration, (b) corn silage, and (c) mixed mostly legume silage samples.