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Physically adjusted neutral detergent fiber system for lactating dairy cow rations. I: Deriving equations that identify factors that influence effectiveness of fiber

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ABSTRACT

Physically effective neutral detergent fiber (peNDF) is the fraction of neutral detergent fiber (NDF) that stimulates chewing activity and contributes to the floating mat of large particles in the rumen. Multiplying dietary NDF by particle size has been used as an estimate of peNDF. In re-evaluating the concept of peNDF, we compared the use of peNDF as dietary NDF × particle size with the use of individual NDF and particle size descriptors (physically adjusted NDF; paNDF) when used with other physical and chemical diet descriptors to predict dry matter (DM) intake (DMI), rumination time, and ruminal pH in lactating dairy cows. The purpose is to ultimately use these equations to estimate diet adequacy to maintain ruminal conditions. Each response variable had 8 models in a 2 (peNDF, paNDF) × 2 (diet, diet and ruminal factors) × 2 (DM, as fed basis) factorial arrangement. Particle size descriptors were those determined with the Penn State Particle Separator. Treatment means (n = 241) from 60 publications were used in backward elimination multiple regression to derive models of response variables. When available, peNDF terms entered equations. Models containing peNDF terms had similar or lower unadjusted concordance correlation coefficients (an indicator of similar or lower accuracy and precision) than did models without peNDF terms. The peNDF models for rumen pH did not differ substantially from paNDF models. This suggests that peNDF can account for some variation in ruminal pH; however, overt advantages of peNDF were not apparent. Significant ($P < 0.05$) variables that entered the models included estimated mean particle size; as fed or DM proportions retained on 19- and 8-mm sieves of the Penn State Particle Separator; DMI; dietary concentrations of forage; forage NDF; CP; starch; NDF; rumen-degraded starch and rumen-degraded NDF; and the interaction terms of starch × mean particle size, acid detergent fiber/NDF, and rumination time/DMI. Many dietary factors beyond particle size and NDF were identified as influencing the response variables. In conclusion, these results appear to justify the development of a modeling approach to integrate individual physical and chemical factors to predict effects on factors affecting rumen conditions.
Key words: chewing activity, effective fiber, particle size, ruminal pH

INTRODUCTION

Dairy cattle are grass and roughage eaters (Hofmann, 1989) and consequently require coarse roughage to maintain normal rumen function and overall health (Cole and Mead, 1943). The positive relationship between particle size and chewing activity has long been proposed as part of a method for assessing the effect of coarse roughage in diets (Balch, 1971; Sudweeks et al., 1981; Nørgaard, 1989). Several investigators have sought to quantify coarseness of roughage so that these measures could be adopted into feeding recommendations (Santini et al., 1983; Mertens, 1997). At the 1995 American Dairy Science Association Annual Meeting, a symposium titled "Meeting the Fiber Requirements of Dairy Cows" was held, and companion papers from this symposium were published (Allen, 1997; Armentano and Pereira, 1997; Firkins, 1997; Mertens, 1997). These works collectively outline the need for fiber by dairy cattle.

The concept of physically effective NDF (**peNDF**) as a means for measuring the ruminal effects of coarse roughage was also introduced and was defined as the fraction of NDF that stimulates chewing activity and contributes to the floating mat of large particles in the rumen (Mertens, 1997). Mertens (1997) proposed

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that the peNDF of individual feedstuffs could be estimated by multiplying the NDF content of a feed by the proportion of material retained on a 1.18-mm sieve, though this approach assumes that NDF is uniformly distributed over all particles regardless of size. When updating the nutrient recommendations and after considering the merits of published mechanistic approaches, NRC (2001) chose not to include a peNDF system. The basis of this decision was a lack of studies available that validated and standardized any proposed methods and the lack of experimentally measured effectiveness coefficients among feeds. Instead, guidelines outlining minimum concentrations of NDF, forage NDF (**fNDF**), and maximum concentrations of NFC were published and have been used widely throughout the dairy industry (Table 4-3 in NRC, 2001).

Quantitative assessments of the physical characteristics of feed have been made using several different sieving methods (Murphy and Zhu, 1997). Historically, this most commonly has been done according to 1 of 2 methods. First, a Ro-Tap particle separator (W. S. Tyler, Mentor, OH) equipped with a set of wire cloth sieves (ASABE, 2013) has been used for dry sieving and sometimes modified for wet sieving, especially of silages. Second, a mechanically driven forage particle separator device was engineered specifically to determine the particle size distribution of chopped forage (ASABE, 2017). Given the cost, weight, and size of the equipment and the need for electricity (or standardized water spray for wet sieving) to operate, these methods are not practical for on-farm evaluations of feed particle size (Maulfair and Heinrichs, 2012).

The Penn State Particle Separator (**PSPS**) is a portable and manually operated device that is widely used on farm to measure the particle size of both forages and TMR (Lammers et al., 1996; Heinrichs and Kononoff, 2002). Since its introduction in 1996, researchers have used it to evaluate the effects of TMR particle size on milk production, composition, chewing activities, and rumen fermentation. Zebeli et al. (2012) proposed a method for estimating peNDF by multiplying the sum of DM retained on 19- and 8-mm sieves of the PSPS by the NDF concentration of the diet and combining these measurements into a system that integrates chewing activity with ruminal pH and ruminal digestibilities of starch and NDF. Although this approach represents a major advancement in quantifying peNDF, several limitations in this system remain. First, sieving results are assumed to be equivalent whether expressed on an as-fed (**AF**) basis or a DM basis, and NDF is assumed to be distributed equally across particle sizes. These assumptions are not well supported by data because moisture affects particle size proportion; moisture has been reported to affect particle size measures and NDF concentration not uniformly distributed across sieves (Ranathunga et al., 2010). Second, the digestibility or fragility of forages has not been considered, although these factors are known to affect rumination times (Mertens, 1997). Third, few studies in the Zebeli et al. (2012) database had objectives of evaluating diets with large concentrations of nonforage fiber sources; several studies are now available that seek to replace both starch and forages with nonforage fiber sources (Bradford and Mullins, 2012). Fourth, wet (silage) and dry (hay) forages were not differentiated, although forage DM influences rumination activities (Beauchemin et al., 1997) and saliva production (Beauchemin et al., 2008). Fifth, in situ methods were used to determine rumen-degraded starch (**dStarch**), which may be poorly estimated in feeds containing either slowly or rapidly degradable starch (Offner and Sauvant, 2004), and rumen-degraded NDF (**dNDF**) was not considered; both have major effects on rumen fermentation and can be predicted from dietary nutrient composition (White et al., 2016). If these limitations are overcome, feeding recommendations for coarse particles and fiber could be standardized and included in a more robust system. For example, models might be made more accurate and responsive if they (1) recognize that dietary factors can affect eating and rumination times (Beauchemin, 1991), (2) consider eating and ruminating separately rather than combining these factors into total chewing time (sum of eating plus ruminating times), (3) use optimization routines that might be more appropriate than mathematical integration (Mayer et al., 1998), and (4) avoid the use of forced broken-line models because these may be too simplistic to describe a more complex, multifactorial system that is more dynamic over a variety of dietary conditions. Hence, the prior advances made with peNDF should first be challenged by comparing equations with peNDF (i.e., particle size multiplied by NDF) with similar equations in which peNDF is separated into its core components (i.e., particle size distinguished from NDF but potentially including other dietary nutrients).

The objective of this work was to re-evaluate the concept of peNDF by quantitatively summarizing the body of literature reporting physical and chemical characteristics of total diets and deriving equations that relate these to DMI, chewing behavior, and ruminal pH. Data generated using the PSPS were used to enhance the potential for the system to be used in on-farm situations. We hypothesized that (1) particle size can be separated from the peNDF calculation and instead be included separately in a multiple regression that includes fNDF but also potentially other dietary composition factors; (2) dietary factors will improve accuracy and precision of predictions if total chewing is