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Physically Effective Fiber: Method of Determination and Effects on Chewing, Ruminal Acidosis, and Digestion by Dairy Cows

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ABSTRACT

A study was conducted to investigate the effects of physically effective neutral detergent fiber (peNDF) content of dairy cow diets containing corn silage as the sole forage on intake, chewing, ruminal pH, microbial protein synthesis, digestibility, and milk production. A second objective was to compare current methods of measuring peNDF to determine the most suitable approach for use in ration formulation. The experiment was designed as a replicated 3 × 3 Latin square using 6 lactating dairy cows with ruminal cannulas. Diets varied in peNDF content (high, medium, and low) by altering the particle length of corn silage. The physical effectiveness factors (pef) and peNDF contents of the corn silage and diets were determined based on the original (19- and 8-mm sieves) and new Penn State Particle Separator (PSPS; 19-, 8-, and 1.18-mm sieves). A dry-sieving technique that measures the proportion of particles retained on a 1.18-mm sieve was also used. The new PSPS and the 1.18-mm sieve produced similar estimates of pef and peNDF of diets but gave higher values than the original PSPS. There was a much smaller range in pef of corn silage when 3 sieves, rather than 2, were used with the PSPS (range of 0.93 to 0.96 vs. 0.41 to 0.72, respectively). Consequently, increased forage particle length in the diets increased dietary peNDF content and its intake when using the original PSPS; however, the new PSPS and the 1.18-mm sieve failed to detect changes in dietary peNDF and peNDF intake. The peNDF values estimated based on fractional NDF rather than the total NDF content were higher, but the ranking of diets was not changed. Increased intake of peNDF linearly increased digestibility of CP and tended to linearly increase digestibility of fiber in the total tract. As a result, milk yield tended to linearly increase with no effect on milk composition. Ruminal microbial protein synthesis and microbial efficiency were higher with the medium peNDF than with the high or low peNDF diets. Total chewing time and ruminating time were linearly increased with increasing dietary peNDF, whereas influence of dietary peNDF on ruminal pH and fermentation was minimal. This study showed that increasing peNDF content of diets improved fiber digestion. Of the systems used to measure peNDF, the original PSPS provided a good description of dietary particle length and its effects on chewing time and rumen pH, whereas the new PSPS provided a more consistent chewing index, the ratio of total chewing activity to peNDF, across diets varying in chop length of corn silage.

Key words: physically effective neutral detergent fiber, chewing, digestion, dairy cow

INTRODUCTION

Providing sufficient physically effective fiber (**peNDF**) in diets fed to high-producing dairy cows is necessary to prevent subclinical ruminal acidosis and the resulting depressions in milk fat, DMI, and fiber digestion, and increase in lameness (NRC, 2001). The concept of peNDF incorporates information on dietary particle length and the chemical NDF content of the diet in a manner that predicts the physical effectiveness of the diet (Mertens, 1997). However, the most appropriate means of measuring peNDF content of the forage or diet is uncertain. A laboratory method was proposed by Mertens (1997) that determines peNDF as the proportion of DM retained on a 1.18-mm sieve multiplied by dietary NDF content ($\mathbf{peNDF_{1.18}}$). Lammers et al. (1996) developed a practical device, known as the Penn State Particle Separator (**PSPS**), for routine on-farm use to measure the peNDF of forages and TMR. The proportion of DM retained by the 19- and 8-mm sieves of the PSPS multiplied by dietary NDF is $\mathbf{peNDF_{ps\text{-}2s}}$. Kononoff et al. (2003a) added an additional 1.18-mm sieve to the PSPS, so that it determines peNDF as a proportion of DM retained by 19-, 8-, and 1.18-mm sieves of the PSPS multiplied by dietary NDF ($\mathbf{peNDF_{ps\text{-}3s}}$). The additional sieve was added to be consistent with the system developed by Mertens (1997) and because 1.18 mm is considered to be a critical length governing retention of particles in the reticulorumen (Poppi and Norton, 1980). Because NDF content varies

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among PSPS fractions, peNDF is sometimes determined as the amount of NDF retained by the PSPS, multiplied by the respective DM percentage of the individual sieves (Einarson et al., 2004).

It is unclear which measure of peNDF and what peNDF contents provide the most accurate estimation of chewing activity and ruminal pH in dairy cows, although a number of studies have been conducted in recent years (Yang et al., 2001; Krause et al., 2002b; Beauchemin et al., 2003; Kononoff et al., 2003b; Yansari et al., 2004; Beauchemin and Yang, 2005). These different methods of peNDF estimation result in very different values (Yang et al., 2001; Beauchemin et al., 2003; Einarson et al., 2004). Yansari et al. (2004) showed that chewing activity per unit intake of peNDF was consistent across diets varying in particle length when estimated using systems that incorporated a 1.18-mm sieve (i.e., $peNDF_{1.18}$ or $peNDF_{ps\text{-}3s}$). A consistent ratio of chewing activity to peNDF is desirable in terms of predicting chewing time based on peNDF intake. However, in some studies, $peNDF_{ps\text{-}3s}$ did not differentiate diets that differed in forage particle length (Kononoff and Heinrichs, 2003b).

Increased chewing activity as a result of increased peNDF intake can increase ruminal pH, and help minimize ruminal acidosis in dairy cows (Krause et al., 2002b; Yansari et al., 2004). However, this is not always the case; chewing activity can also increase with increasing intake of peNDF without affecting ruminal pH, particularly when diets contain highly fermentable carbohydrate sources (Kononoff et al., 2003b; Kononoff and Heinrichs, 2003a; Beauchemin and Yang, 2005). Thus, it is not clear whether systems of measuring peNDF are useful for predicting both chewing and ruminal pH.

A number of studies on the effects of peNDF on feed intake, digestibility, and milk production and composition have also been conducted (Krause et al., 2002a; Kononoff et al., 2003a; Plaizier, 2004; Yansari et al., 2004; Yang and Beauchemin, 2005). However, the results have been inconclusive due to differences in measuring peNDF.

The objectives of the present study were to determine the effect of increasing the peNDF content of a diet containing CS on feed intake, chewing activity, ruminal pH and fermentation, microbial protein synthesis, digestibility, and milk production in lactating dairy cows. The second objective was to determine the most appropriate method of determining peNDF for use in diet formulation to promote chewing and prevent ruminal acidosis. Thus, the peNDF content of the diets was determined using the PSPS with 2 and 3 sieves, and by expressing the values as a proportion of DM and NDF, and using a dry sieving technique as particles retained on a 1.18-mm sieve (Mertens, 1997).

MATERIALS AND METHODS

Corn Silage

Whole plant corn (hybrid 39T68, Pioneer Hi-Bred International, Des Moines, IA) was harvested at a moisture content of 60% from a single field using a self-propelled forage harvester (model FX58, New Holland, PA) set to obtain a theoretical cut length (**TCL**) of 28.6, 15.9, and 4.8 mm for long, medium, and short, respectively, with kernel processing at a 2-mm roll clearance. The chopped forages were ensiled on the same day in large silo bags (200-tonne capacity) for 2 mo before being used. Fermentation characteristics of the silage as sampled from the silo before starting the experiment are presented in Table 1. These analyses were conducted commercially by Cumberland Valley Analytical Service, Inc. (Maugansville, MD).

Cows and Diets

Six multiparous lactating Holstein cows fitted with ruminal cannulas, averaging 664 ± 62 kg of BW and 120 ± 63 DIM, were assigned randomly to two 3 × 3 Latin squares balanced for carryover effects. The 2 squares were conducted simultaneously. Cows were housed in individual tie stalls and offered a TMR 3 times daily at 0600, 1500, and 1800 h for ad libitum intake. Cows were cared for according to the Canadian Council on Animal Care Guidelines (Ottawa, ON, Canada).

Cows were offered 1 of 3 diets, which were chemically identical with approximately 54% of concentrate and 46% of corn silage (CS; Table 2), but differed in peNDF level: high, medium, and low. The 3 dietary peNDF levels were obtained using CS differing in particle length: long silage (high), medium silage (medium), and short silage (low) (Table 3). The diets were formulated using the Cornell-Penn-Miner System (CPMDairy, Version 3.0.4a; Cornell University, Ithaca, NY; University of Pennsylvania, Kennett Square, PA; and William H. Miner Agricultural Research Institute, Chazy, NY) to supply adequate ME and MP for a 650-kg cow producing 35 kg/d of milk containing 3.5% fat and 3.2% protein. Each period consisted of 11 d for adaptation to diets and 10 d for experimental measurements.

Feed offered and orts were measured for each cow and recorded daily during the last 10 d of the period to calculate feed intake. Samples of CS and each TMR were collected once weekly, and orts were collected daily and composited weekly by cow for particle distribution