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Effects of Physically Effective Fiber on Digestive Processes and Milk Fat Content in Early Lactating Dairy Cows Fed Total Mixed Rations

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ABSTRACT

Data from recent research studies were analyzed quantitatively, and the random effect of experiment was assessed to define the physiological responses of dairy cows in early lactation to intake of physically effective neutral detergent fiber (peNDF). All studies were conducted with lactating Holstein cows (84.8 ± 3.54 days in milk) in Latin square designs, and feeds were offered ad libitum as total mixed rations (TMR). The peNDF was estimated by 2 measurement techniques, the NDF content of TMR multiplied by amount of dry matter (DM) retained on a 1.18-mm screen ($peNDF_{>1.18}$) and NDF content of TMR multiplied by the proportion of DM retained by 19- and 8-mm Penn State Particle Separator screens ($peNDF_{>8}$). Other factors, including concentrations of NDF, forage NDF, nonfiber carbohydrates, the amount of digestible organic matter of forages (FDOM), and the intake of ruminally degradable starch (RDSI) from grain in the diet were also investigated. The studied animal response variables included feed intake, ruminal fermentation, chewing activity, fiber digestibility, and milk production and composition. The ruminal pH (day mean) in this study ranged from 5.30 to 6.59. Using $peNDF_{>1.18}$ approach, the requirements for physically effective fiber in high-yielding dairy cows fed TMR in an ad libitum intake were estimated to be about 19% of ration DM or 4.1 kg/d or 0.6 kg/100 kg of body weight to maintain a ruminal pH of about 6.0. When peNDF was measured as $peNDF_{>8}$, ruminal pH responded in a quadratic fashion but the confidence of estimation was lower (R^2 = 0.27) compared with the $peNDF_{>1.18}$ approach (R^2 = 0.67). Results of these data analyses showed that $peNDF_{>1.18}$ provided a satisfactory estimation of the mean ruminal pH (R^2 = 0.67) and NDF digestibility (R^2 = 0.56). Furthermore, $peNDF_{>1.18}$ was poorly, although positively, correlated to daily chewing (R^2 = 0.17), and rumination (R^2 = 0.24) activity. On the other hand, results from these analyses showed that milk parameters are less sensitive to the effects of dietary peNDF than other variables, such as ruminal pH, chewing activity, and fiber digestibility. Dietary FDOM correlated positively (moderately) to ruminal pH (R^2 = 0.24), daily chewing (R^2 = 0.23), and rumination (R^2 = 0.29) activity, whereas the daily RDSI from grain correlated negatively to ruminal pH (R^2 = 0.55) and positively to total volatile fatty acids (R^2 = 0.27). Inclusion of FDOM and RDSI from grain along with $peNDF_{>1.18}$ in the models that predict rumen pH further improved the accuracy of prediction. This approach appeared to further complement the concept of peNDF that does not account for differences in ruminal fermentability of feeds.
Key words: physically effective fiber, dairy cow, rumen pH, chewing activity

INTRODUCTION

High-concentrate diets for high-yielding dairy cows must contain sufficient physically effective fiber (i.e., fiber that stimulates rumination, saliva production, and rumen buffering) to prevent ruminal dysfermentation and subacute ruminal acidosis (**SARA**). The concept of physically effective fiber was created to amalgamate the chemical characteristics and particle size of forages, and to quantify its value to rumen function (Mertens, 2000). According to Lammers et al. (1996), physically effective NDF (**peNDF**) could be measured as a proportion of DM retained by the 19- and 8-mm Penn State Particle Separator (**PSPS**) screens multiplied by dietary NDF content ($\mathbf{peNDF_{>8}}$). Mertens (1997) determined peNDF as the proportion of DM retained by a 1.18-mm screen multiplied by dietary NDF ($\mathbf{peNDF_{>1.18}}$) using a dry-sieving technique. It is, however, unclear which measure of peNDF provides the most accurate estimate of chewing, saliva production, and rumen buffering (Einarson et al., 2004). Although a number of recent studies have been conducted to investigate the effects of peNDF on rumen fermentation, feed intake, milk production, chewing activity, and nutrient digestibility in high-yielding, early lactation dairy cows, the results obtained from these studies are not conclusive. Differences in measurement and definition of dietary peNDF and interactions between levels

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of concentrate inclusion, forage and grain sources, and animal-response variables among studies make peNDF recommendations difficult. The NRC (2001) does not give requirements for peNDF due to lack of a standardized, validated method for measuring effective fiber in feeds and to establish requirements for effective fiber.

Part of the difficulty in assigning fiber requirements for high-yielding dairy cows related to the interpretation of response variables. Despite the fact that milk fat percentage is an easily measured parameter, low fiber in the diet can detrimentally affect animal health without significant milk fat depression (Mertens, 1997). Ruminal pH may be a better indication of ruminal health and optimal function, and a better basis for determining fiber requirements of dairy cows in early lactation than the maintenance of milk fat production (Allen, 1997; Mertens, 1997).

However, Beauchemin and Yang (2005) concluded that the models used to predict rumen pH should include both peNDF and fermentable OM intake. Because the peNDF concept relates only to the physical properties of fiber, inclusion of forage and grain fermentability characteristics in the models to predict animal response and to evaluate physical effectiveness of dairy cow diets would likely increase the estimation accuracy. Results from several studies showed that increasing the amount of digestible fiber of hay or corn silage in dairy cow diets increased digesta stratification, particle breakdown in the rumen as well as digesta turnover, forage intake, and fiber digestibility without compromising the physical effectiveness at stimulating chewing (Oba and Allen, 2000b; Tafaj et al., 2004b, 2005b). Krause et al. (2002b) found that replacing dry cracked corn with high-moisture corn in a TMR fed to dairy cows significantly reduced ruminal pH. Furthermore, Beauchemin and Rode (1997) reported that rapidly digested starch sources such as barley grain increase the need for effective fiber, suggesting an interaction between ruminal fermentability and physical characteristics of the ration.

This quantitative study aimed to define the physiological responses of high-yielding dairy cows in early lactation to peNDF when estimated as $peNDF_{>1.18}$ and $peNDF_{>8}$. Furthermore, based on the most sensitive animal response variable, an optimization of peNDF concentration in TMR fed ad libitum to this category of dairy cows was also intended. Possible interactions between dietary peNDF, NFC, the amount of digestible OM of forages (**FDOM**), and intake of ruminally degradable starch (**RDSI**) from grains composing TMR were also investigated.

MATERIALS AND METHODS

Description of the Database

To conduct this quantitative study, an independent data set with data on animal characteristics, detailed ration components, and an evaluation of physical structure of the ration was generated. The data file containing 131 treatment means was generated from 33 experiments published from 1997 to 2005 (Table 1). Animals were lactating Holstein cows (84.8 ± 3.54 DIM) (mean ± SE) weighing between 570 and 886 kg and producing 23.1 to 49.3 kg of milk/d. Feeds were offered ad libitum as TMR. The level of DMI ranged from 16.9 to 28.3 kg/d, and the percentage of forage in TMR ranged from 27 to 75% of DM (49.2 ± 0.87%). Dietary NDF ranged from 18.2 to 48.1% of DM (30.9 ± 0.51%) and forage NDF (**FNDF**) ranged from 15.5 to 35.8% of DM (21.3 ± 0.36%). The $peNDF_{>1.18}$ content in TMR ranged from 4.2 to 37.4% of DM (21.1 ± 0.64%) and the content of $peNDF_{>8}$ ranged from 2.0 to 29.5% (15.2 ± 0.73%). The main characteristics of the database, including animal characteristics, investigated dietary factors, and animal response variables (hereafter referred to as response variables) are listed in Table 2. The response variables included data on feed intake, ruminal fermentation, chewing activity, fiber digestibility, and milk production and composition. All experiments included in this study were conducted in Latin square design.

Ruminal fermentation was investigated based on the response of total VFA, molar proportion of individual VFA, acetate to propionate ratio, and pH value in the ruminal fluid. For VFA measurement through GLC, ruminal fluid was collected several times after morning feeding via cannula from the ventral sac of the rumen. Some studies measured pH from ruminal fluid in spot samples collected from the ventral sac of the rumen, whereas in others, ruminal pH was continuously measured (during 24 h) using an industrial electrode placed in the ventral rumen sac. However, in all cases, the measurements of ruminal pH covered at least a period from 8 to 10 and, in several cases, up to 12 h postfeeding. In the present study, values of ruminal pH, total and individual molar amounts of VFA, and the acetate to propionate ratio reported from studies were analyzed as treatment means.

Estimation of peNDF of Diets

As a prerequisite for inclusion in this literature study, articles were expected to give complete information on the components and chemical composition of rations, as well as on the physical evaluation of experimental diets (vertical dry-sieving technique). The $peNDF_{>8}$ content of TMR was determined by multiplying the proportion of DM retained by the 19- and 8-mm screens of PSPS by dietary NDF content (DM basis; Lammers et al., 1996).