Effects of varying rates of tallgrass prairie hay and wet corn gluten feed on productivity of lactating dairy cows

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ABSTRACT

Productivity of lactating dairy cows fed diets with wet corn gluten feed (WCGF, Sweet Bran, Cargill Inc., Blair, NE) as the primary energy substrate and prairie hay as the primary source of physically effective neutral detergent fiber (peNDF) was assessed relative to a control diet. Forty-eight Holstein cows, 100 to 250 d in milk, were randomly assigned to 1 of 6 pens and pens were randomly assigned to treatment sequence in a replicated 3×3 Latin square. Treatments were a control diet with 18% alfalfa, 18% corn silage, 33% WCGF, and 15% forage NDF (CON); a diet with 20% tallgrass prairie hay, 46% WCGF, and 13% forage NDF (TPH20); and a diet with 14% tallgrass prairie hay, 56% WCGF, and 9% forage NDF (TPH14). Midway through period 2, TPH14 was discontinued due to the high prevalence of diarrhea among cows on that treatment. Data from period 2 for TPH14 pens were discarded, and the pens that had been assigned to TPH14 for period 3 were randomly assigned to the other 2 treatments. Pen-level data were analyzed using linear mixed models, including the random effects of period and pen and the fixed effect of treatment. For animal-level data, additional random effects were introduced to account for subsampling. No evidence for treatment effects was apparent on dry matter intake. Least squares mean milk yields were 36.2, 34.6, and 35.2 kg/d for CON, TPH20, and TPH14, respectively, and were not significantly different. Milk fat concentration was higher for CON and TPH20 than for TPH14, with means of 3.48, 3.41, and 2.82%, respectively. Fat yield was significantly greater for CON compared with TPH20 and TPH14. Milk urea nitrogen was greatest for TPH20 and TPH14 and least for CON, consistent with differences in dietary protein content. Efficiencies, expressed as energy-corrected milk divided by dry matter intake, were 1.47, 1.42, and 1.24 for CON, TPH20, and TPH14, respectively, and were

not significantly different. These data indicate that TPH14 did not provide adequate peNDF to support normal rumen function in mid lactation dairy cows; instead, TPH20 may be a feasible diet for use on dairies where high-NDF grass hay and WCGF are available.

Key words: wet corn gluten feed, dairy cow, physically effective fiber

INTRODUCTION

Low milk prices or small profit margins lead dairy farmers to search for opportunities to reduce input costs. Often the first area of focus is feed cost, because this represents the largest cost for dairy producers, accounting for about 50% of the total operating and ownership costs for dairies in the US heartland (Short, 2004). Novel diet formulation methods using atypical feedstuffs or uncommon inclusion rates may be a way to decrease ration costs. Additionally, in circumstances in which supplies of typical feedstuffs may not be sufficient for a production year, a diet that includes alternative feed ingredients that are readily and locally available may help dairy producers to maintain acceptable productivity without the cost of purchasing forages from distant sources.

Wet corn gluten feed (WCGF), a co-product of the wet-milling process, is a high-fiber, low-lignin feedstuff that has been repeatedly demonstrated to be a viable option for inclusion into lactating dairy cattle rations (Wickersham et al., 2004; Mullins et al., 2009). Although the fiber in WCGF is highly digestible, its effective NDF content can be variable depending on the method used to estimate it. Allen and Grant (2000) calculated the effective NDF (eNDF) of WCGF to be 32.9 or 5.71% based on change in milk fat concentration and ruminal pH, respectively, and physically effective NDF (peNDF) of WCGF to be 4.8%, based solely on rumination activity. Regardless of which figure is used, peNDF must be supplied by other fiber sources to prevent ruminal acidosis or milk fat depression. However, WCGF is also quite low in rapidly fermentable carbohydrates (such as starch) compared with other high energy feedstuffs, so the risk of ruminal acidosis is

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decreased (Wickersham et al., 2004). Considering this, it may be possible to formulate a diet with a high inclusion rate of WCGF and lower peNDF.

Dietary sources of peNDF have traditionally been forages such as alfalfa or corn silage. In a survey conducted in the summer of 1995 by Mowrey and Spain (1999), 62% of the lactating dairy cattle across the United States were fed alfalfa hay and 61% were fed some type of corn forage. Tallgrass prairie hay (TPH), a mixture of many grass species native to the central plains region, is a relatively inexpensive forage fiber source that is typically fed to beef cattle or far-off dry dairy cows with low energy requirements. According to Olson et al. (2008), TPH contains an average of 67.4% NDF, 15.2% acetyl bromide lignin, and 3.9% CP. Thus, TPH may provide a low-cost, physically effective source of NDF in rations.

Taken together, the unique characteristics of TPH and WCGF may serve to complement each other in lactating dairy cow rations. However, no published research has shown the effects of such a diet compared with one containing common ingredients such as alfalfa hay and corn silage. Our objectives were to compare diets containing varying amounts of TPH and WCGF to a control diet and observe effects on productivity of lactating dairy cows.

MATERIALS AND METHODS

Animals, Design, and Diets

Twenty-one primiparous and 27 multiparous lactating Holstein cows (167 ± 47 DIM, 1.8 ± 0.97 lactations, mean $\pm$ SD) were selected from the Kansas State University Dairy Teaching and Research Center herd and randomly assigned to 1 of 6 freestall pens. Experimental procedures were approved by the Institutional Animal Care and Use Committee at Kansas State University. Pens were assigned to treatment sequence in a replicated 3×3 Latin square design that was balanced for carryover effects of treatments. Treatment periods were 21 d, with 17 d of diet adaptation and 4 d of sampling; feeding of treatments began in September and continued through November 2009. Cows were fed fresh TMR blended in a TMR wagon daily at 0930 h and milked 3 times daily at 0600, 1300, and 2000 h.

Treatments were a diet containing 18% of DM alfalfa hay and 18% of DM corn silage (control, **CON**), a diet containing 20% of DM TPH (**TPH20**), and a diet containing 14% of DM TPH (**TPH14**; Table 1). Diets were formulated to be isocaloric and isonitrogenous, with varying amounts and sources of forage NDF; however, chemical analysis after the experiment showed that diets were not completely isonitrogenous. Water

was added to TPH20 and TPH14 diets to target a DM concentration of 60%, with the goal of limiting ration sorting.

Cows fed TPH14 during period 1 had loose stools, but no health problems were observed, and no animals were considered to have diarrhea. However, midway through period 2, feeding of TPH14 was discontinued due to visual observations of diarrhea in $>25\%$ of cows consuming that diet, across both pens. The 2 pens on TPH14 were switched to the CON diet for the remainder of period 2 (data were not collected), and pens allocated to TPH14 in period 3 were instead assigned to either TPH20 or CON. The resulting treatment allocations are represented in Table 2. The statistical models fitted to the data (see later) recognize periods as incomplete blocks (i.e., all treatments were present in period 1 but TPH14 was missing in periods 2 and 3). Fitting period as a random effect using a mixed model approach effectively borrows information across periods to allow for inference on treatment effects for CON, TPH20, and TPH14. The smaller number of observations available for TPH14 translates into increased inferential uncertainty for this treatment, as demonstrated by the magnitude of the estimated standard errors of the least squares means estimates associated with TPH14, as well as the estimated standard errors of estimated pairwise treatment differences involving this treatment.

Data and Sample Collection and Analysis

Feed offered and refused for each pen was recorded on the final 4 d of each treatment period. Samples of the TMR were also gathered on these days and composited by period; particle size was analyzed using a 4-compartment Penn State Particle Separator (Kononoff et al., 2003). After separation, each fraction was dried for 48 h in a 55°C forced-air oven, and then weighed to determine particle size distribution on a DM basis. Physically effective NDF was calculated as the proportion of particles retained on the top 2 sieves multiplied by the NDF content of the diet (**peNDF_{8,0}**; Table 1; Yang and Beauchemin, 2009).

Samples of corn silage, alfalfa hay, TPH, WCGF, cottonseed, and grain mixes were gathered on d 18 and 21 of each period, composited, and then dried for 48 h in a 55°C forced-air oven before laboratory analysis. All samples were ground to pass through a 1-mm screen utilizing a Wiley mill (Arthur H. Thomas, Philadelphia, PA), and DM content was determined by drying at 105°C in a forced-air oven for 12 h. Crude protein content was estimated by determination of elemental nitrogen content (Leco Analyzer, Leco Corp., St. Joseph, MI). Neutral detergent fiber concentration was quantified according to Van Soest et al. (1991; method

Table 1. Ingredient and nutrient composition of experimental diets

Item	Treatment ¹		
	CON	TPH20	TPH14
Ingredient, % of DM			
Corn silage	17.6	—	—
Alfalfa hay	17.7	—	—
Tallgrass prairie hay	—	19.2	13.8
WCGF ²	33.0	46.1	56.0
Cottonseed	7.3	7.5	7.5
Corn grain	16.6	17.5	15.6
Soybean meal, 48% CP	1.0	2.6	—
Expeller soybean meal ³	4.1	4.2	4.2
Limestone	1.2	1.6	1.7
Magnesium oxide	0.1	0.1	0.1
Sodium bicarbonate	0.8	0.8	0.8
Trace mineral salt	0.5	0.1	0.1
Salt	0.03	—	—
Micronutrient premix ⁴	0.13	0.13	0.13
Nutrient, % of DM			
DM, % as fed	62.7	60.7	61.5
CP	16.5	18.0	18.6
NE _L , ⁵ Mcal/kg	1.65	1.60	1.59
NDF	34.5	38.3	37.0
Forage NDF	15.3	12.9	9.3
Ether extract	3.6	4.1	3.7
Starch	20.8	13.9	12.1
NFC ⁶	34.5	30.7	31.2
Ash	10.9	8.9	9.5
Physically effective fiber, ⁷ % of DM			
peNDF _{8.0}	15.9 ± 2.8	11.8 ± 2.5	10.7 ± 4.3
peFNDF _{8.0}	7.3 ± 0.9	3.9 ± 0.9	1.1 ± 1.1

¹CON = control, TPH20 = tallgrass prairie hay 20%, TPH14 = tallgrass prairie hay 14%.
²Wet corn gluten feed (Sweet Bran, Cargill Inc., Blair, NE).
³SoyBest (West Point, NE).
⁴Micronutrient premix consisted of 30.2% Se premix (0.06% Se), 34.9% 4-Plex (Zinpro Corp., Eden Prairie, MN), 23.3% vitamin E premix (44 IU/g), 9.3% vitamin A premix (30,000 IU/g), and 2.32% vitamin D premix (20,000 IU/g).
⁵Calculated according to NRC (2001).
⁶Calculated as DM – (ash + ether extract + NDF + CP).
⁷peNDF_{8.0} (physically effective NDF) was calculated as the proportion of particles retained on the top 2 sieves of a Penn State Particle Separator multiplied by the total dietary NDF concentration (Yang and Beauchemin, 2009); peFNDF_{8.0} (physically effective forage NDF) was calculated as the proportion of particles retained on the top 2 sieves of a Penn State Particle Separator multiplied by the total dietary forage NDF concentration.

A) by using an Ankom Fiber Analyzer (Ankom Technology, Fairport, NY) with sodium sulfite and amylase. Crude fat was determined by ether extraction (AOAC, 2000; method 920.9). Ash content was measured following 8 h of incineration at 500°C by a muffle furnace. Results of nutrient analyses for key ingredients are shown in Table 3.

Milk samples were collected from each cow at every milking during the last 4 d of each period. Samples were composited over a 48-h period and analyzed for fat, true protein, and lactose with a B2000 Infrared Analyzer (Bentley Instruments, Chaska, MN), somatic cells were counted using a flow cytometer laser (Soma-count 500; Bentley Instruments), and urea N was determined using chemical methodology based on a modified Berthelot reaction (ChemSpec 150 analyzer; Bentley

Instruments) at Heart of America DHIA (Manhattan, KS). Body weight was measured on d 21 of each period immediately following the milking at 1300 h.

Table 2. Treatments assigned to each pen throughout the study¹

Pen	Period		
	1	2	3
1	TPH20	CON	TPH20
2	CON	Treatment ended	TPH20
3	TPH14	TPH20	CON
4	CON	TPH20	CON
5	TPH20	Treatment ended	CON
6	TPH14	CON	TPH20

¹CON = control, TPH20 = tallgrass prairie hay 20%, TPH14 = tallgrass prairie hay 14%.

Table 3. Composition of corn silage, alfalfa hay, wet corn gluten feed (WCGF), and tallgrass prairie hay¹

Nutrient	Ingredient			
	Corn silage	Alfalfa hay	WCGF	Tallgrass prairie hay
DM	36.9 ± 1.8	89.5 ± 1.7	58.5 ± 0.5	88.5 ± 4.1
NDF	43.2 ± 3.5	43.6 ± 1.4	37.5 ± 0.7	67.5 ± 5.3
CP	8.0 ± 0.8	18.3 ± 1.4	22.9 ± 0.5	6.6 ± 0.9
Ether extract	2.9 ± 0.8	1.1 ± 0.2	2.6 ± 0.5	1.7 ± 0.2
Ash	5.2 ± 0.6	11.4 ± 1.3	5.8 ± 0.1	7.3 ± 0.2

¹All nutrients except DM are expressed as a percentage of diet DM. Values are means ± SD, representing 1 sample analysis per period (n = 3).

Statistical Analysis

During period 2, two cows were removed from the study due to health problems associated with TPH14. Two additional cows were removed from the study because of health issues unrelated to treatment. Dry matter intake was adjusted using the number of cows within each pen to account for inequality of animal numbers within pen. Milk yield and composition data were averaged across the 4-d collection period for each cow before statistical analysis. Data were analyzed using JMP (version 8.0, SAS Institute, Cary, NC) according to the following statistical models. The model for pen-level data was

$$Y_{ilk} = \mu + T_i + P_j + N_k + e_{ijk},$$

where μ is the overall mean, T_i is the fixed effect of treatment ($i = 1$ to 3), P_j is the random effect of period ($j = 1$ to 3), N_k is the random effect of pen ($k = 1$ to 6), and e_{ijk} is the pen-level residual error. Pen-level data included DMI, feed efficiency, and particle size analyses.

The model for cow-level data was

$$Y_{ijkl} = \mu + T_i + P_j + N_k + C_l(N_k) + TN_{ik} + e_{ijkl},$$

where μ is the overall mean, T_i is the fixed effect of treatment ($i = 1$ to 3), P_j is the random effect of period ($j = 1$ to 3), N_k is the random effect of pen ($k = 1$ to 6), $C_l(N_k)$ is the random effect of cow ($l = 1$ to 8) nested within pen, TN_{ik} is the random effect of treatment-by-pen combination intended to recognize pen as the experimental unit for treatment, and e_{ijkl} is the cow-level residual error. Cow-level data included milk and milk component yields, milk composition, and BW change. In this model, treatment by pen interaction was the error term for fixed effect tests, ensuring that pen served as the experimental unit.

For all variables, values with a Studentized residual $> |4|$ were determined to be outliers and were removed before final analysis; no more than 2.5% of values were

designated as outliers for any analysis. Significant effects were declared at $P < 0.05$.

RESULTS AND DISCUSSION

Diet Composition and Particle Size

Physically effective NDF_{8.0} values, calculated according to Yang and Beauchemin (2009), were 15.6, 11.8, and 10.7% of diet DM for CON, TPH20, and TPH14, respectively (Table 1). As described in the methods, TPH14 was discontinued midway through period 2 because of high prevalence of diarrhea and gastrointestinal tract abnormalities, common symptoms of clinical acidosis, which is often attributed to a lack of adequate peNDF in the diet (Blowey and Weaver, 2003). However, peNDF_{8.0} values for TPH20 and TPH14 were very similar, suggesting that this metric was not a good predictor of effectiveness of fiber for these diets.

Table 4 shows particle size separation for the treatments. Particles >19 mm were 21.6, 14.8, and 13.3% of DM for CON, TPH20, and TPH14, respectively, but were not significantly different. The proportion of particles retained on the middle screen was greatest for CON and least for TPH20 (24.3 vs. 16.2%; $P < 0.05$). The proportion of particles retained on the lower sieve was greatest for TPH20 and least for CON ($P < 0.05$). Guidelines for particle size distributions in TMR as proposed by Heinrichs and Kononoff (2002) are to target 2 to 8% of particles on the upper sieve, 30 to 50% on the middle sieve, 30 to 50% on the lower sieve, and $\leq 20\%$ in the pan. These targets were not met by any of the dietary treatments, but CON most closely resembled the recommended distribution. Interestingly, the proportion of particles >19 mm greatly exceeded that of the guidelines, even for TPH14.

DMI and Performance

No evidence for any difference in DMI was apparent between treatments ($P = 0.24$; Table 5). This obser-

Table 4. Particle size distribution (% of DM)

DM retained on sieves, %	Treatment ¹		
	CON	TPH20	TPH14
19.0 mm	21.6 ± 4.9	14.8 ± 4.7	13.3 ± 7.1
8.0 mm	24.3 ^a ± 2.9	16.2 ^b ± 2.8	17.5 ^{ab} ± 3.8
1.18 mm	46.7 ^b ± 6.9	61.5 ^a ± 6.4	64.1 ^{ab} ± 10.3
Pan	7.6 ± 0.7	7.6 ± 0.7	7.8 ± 1.1

^{a,b}Means within a row with different superscripts differ by Tukey's honestly significant difference test ($P < 0.05$).

¹CON = control, TPH20 = tallgrass prairie hay 20%, TPH14 = tallgrass prairie hay 14%.

vation was consistent with Schroeder (2003), who observed no change in DMI when WCGF was increased in the diet. Dry matter intake is controlled by a complex set of factors, and mechanisms that limit DMI may differ based on the nature of the diet being consumed. Dry matter intake of diets with greater amounts of peNDF is more likely to be limited by physical regulation mechanisms (Allen, 2000). However, in the case of TPH20 and TPH14, where peNDF_{8.0} was lower, a significant increase in intake was not observed. This may be explained by the differences in retention time of the forage included in the diet. Allen (2000) suggests that, compared with perennial grasses such as those found in tallgrass prairie, alfalfa particles possess a much higher fragility and a shorter buoyancy period, both of which would decrease retention time and therefore distention and satiety.

Milk yield was not significantly altered by treatment ($P = 0.25$; Table 5). Milk fat yield was greater for CON than for TPH14 and TPH20 (Table 6). Likewise, milk fat concentration was greatest for CON and least for TPH14 ($P < 0.05$); however, TPH20 milk fat concentration was not significantly different from CON. The decrease in milk fat yield for TPH20 was driven by a combination of small, nonsignificant decreases in both milk yield and fat content. Consistent with treatment

effects on milk fat yield, ECM yield was lower for TPH20 and TPH14 than for CON ($P < 0.05$; Table 5). Although diets were formulated to be isocaloric, inclusion of prairie hay in TPH20 and TPH14 decreased the energy content by ≈ 50 kcal/kg of DM compared with CON (Table 1). To assess whether ECM responses were driven by differences in energy intake, milk energy output per unit of NE_L intake was determined. As shown in Table 5, the efficiency of energy use for milk production was not significantly altered by treatment ($P = 0.27$). The almost identical efficiencies for CON and TPH20, in particular, suggest that ECM yield differences between these diets were likely a product of differences in dietary energy density. Likewise, no treatment effects on production efficiency (quantified as ECM/DMI) were detected ($P = 0.14$).

Diets containing as little as 9.6% peNDF_{8.0} have maintained milk component yield and concentration equivalent to that of a diet containing 12.7% peNDF_{8.0} (Yang and Beauchemin, 2007). In contrast, the TPH14 diet failed to maintain milk fat concentration with a peNDF_{8.0} content of 10.7%. A recent meta-analysis suggested the peNDF_{1.18} was a better predictor of ruminal pH and NDF digestibility than peNDF_{8.0} (Zebeli et al., 2008). Although this may be true for traditional dairy rations, this metric would have been of little use in the

Table 5. Effects of treatments on DMI and performance

Item	Treatment ¹			<i>P</i> -value
	CON	TPH20	TPH14	
No. of observations ²	53	53	15	
DMI, kg/d	24.9 ± 0.86	24.8 ± 0.86	27.1 ± 1.32	0.24
Milk yield, kg/d	36.0 ± 1.1	34.6 ± 1.1	35.2 ± 1.4	0.25
ECM yield, kg/d	36.3 ± 0.71 ^a	34.7 ± 0.71 ^b	33.5 ± 1.26 ^b	0.04
ECM/DMI	1.47 ± 0.06	1.42 ± 0.06	1.24 ± 0.10	0.14
Milk energy/NE _L intake ³	0.628 ± 0.026	0.626 ± 0.026	0.554 ± 0.043	0.27
BW change, kg/21 d	7.2 ± 3.8	13.4 ± 4.3	6.0 ± 5.0	0.71

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹CON = control, TPH20 = tallgrass prairie hay 20%, TPH14 = tallgrass prairie hay 14%.

²Number of cow-level observations for milk production and BW variables.

³Diet NE_L density predicted by NRC (2001); see Table 1.

Table 6. Effects of treatments on milk component yield and concentration

Item	Treatment ¹			<i>P</i> -value
	CON	TPH20	TPH14	
Milk fat, kg/d	1.23 ± 0.04 ^a	1.16 ± 0.04 ^b	1.03 ± 0.06 ^b	0.02
Milk fat, %	3.48 ± 0.14 ^a	3.41 ± 0.14 ^a	2.82 ± 0.21 ^b	0.02
Milk protein, kg/d	1.22 ± 0.02 ^a	1.16 ± 0.02 ^b	1.24 ± 0.04 ^{ab}	0.03
Milk protein, %	3.38 ± 0.05	3.38 ± 0.05	3.42 ± 0.07	0.69
Milk lactose, kg/d	1.73 ± 0.05	1.68 ± 0.05	1.74 ± 0.08	0.25
Milk lactose, %	4.87 ± 0.02	4.86 ± 0.02	4.89 ± 0.04	0.78
SCC, 10 ³ cells/mL	260 ± 74	195 ± 74	218 ± 155	0.72
MUN, mg/dL	13.8 ± 0.83 ^b	17.0 ± 0.83 ^a	17.2 ± 1.10 ^a	<0.01

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹CON = control, TPH20 = tallgrass prairie hay 20%, TPH14 = tallgrass prairie hay 14%.

current experiment; all 3 diets had approximately 92% of particles >1.18 mm in length. In fact, because dietary NDF content increased in the TPH20 and TPH14 diets, $\text{peNDF}_{1.18}$ increased in these diets even as milk fat depression occurred in cows fed TPH14.

These observations support the definitions of peNDF and eNDF as proposed by Mertens (1997); not all eNDF is peNDF . Effective NDF relates to the ability of a feed to replace forage or roughage in a diet so that the concentration of fat in milk produced by cows eating the ration is maintained, whereas peNDF relates solely to the ability of the fiber to stimulate chewing and influence the consistency of the ruminal mat. By this definition, eNDF of CON and TPH20 did not differ because milk fat concentration did not differ significantly, and differences in fat yield were driven by the difference in milk yield. In contrast, the effectiveness of NDF was clearly lower for TPH14 based on the observed milk fat depression, despite the minimal differences in calculated peNDF for TPH20 and TPH14. The differences in eNDF and peNDF in these diets may be explained by the increased amount of WCGF in the TPH14 diet and its attributes as a highly digestible fiber source that promotes a moderate fermentation rate but provides little physical effectiveness to the diet because of its small particle size (Allen and Grant, 2000). The ability of the TPH20 diet to maintain acceptable milk fat production may also be related to its low starch content. Independent of effects on pH, starch substrate was shown to promote the alternative biohydrogenation pathway (Maia et al., 2009) that leads to the absorption of milk-fat-depressing fatty acid isomers (Peterson et al., 2003).

Although milk fat response is perhaps the most unequivocal approach to measure the effectiveness of fiber in production settings, it is a post hoc method of determination and thus is not feasible for evaluating novel diet formulations without the loss of revenue resulting from milk fat depression. A more real-time method for predicting dietary effects on milk fat content may be

the use of formulas that include particle size distributions as well as NDF concentrations of diets. Given that $\text{peNDF}_{8.0}$ and $\text{peNDF}_{1.18}$ had little predictive value in this study, physically effective NDF was alternately calculated using only forage NDF ($\text{peFNDF}_{8.0}$) values in an attempt to uncover a greater disparity between the diets and to account for the limited physical effectiveness of nonforage fiber (Table 1). If $\text{peFNDF}_{8.0}$ is a useful measure, the breakpoint for decreased rumen function would lie somewhere between the $\text{peFNDF}_{8.0}$ values for the diets: 3.9 and 1.0% for TPH20 and TPH14, respectively. However, it is unlikely that any single measure of diet characteristics would consistently predict rumen function and milk fat responses without including an estimate of fiber digestibility. For example, milk fat content was dramatically decreased when brown midrib corn silage replaced conventional corn silage, despite the fact that particle sizes and NDF concentrations were very similar across diets (Holt et al., 2010).

We found no evidence for any effect of treatment on milk lactose concentrations ($P = 0.78$). Likewise, no significant differences in protein concentration were observed among the 3 treatments ($P = 0.69$). However, TPH20 decreased milk protein yield compared with CON ($P < 0.05$, Table 6), again driven in part by the numerical decrease in milk yield for this treatment. Diets were formulated to be isocaloric and isonitrogenous; however, CP concentrations fluctuated between diets because of deviations in CP concentration of the respective grain mixes (Table 1). Milk urea nitrogen was greater for cows that consumed TPH20 and TPH14 than for those fed CON ($P < 0.01$, Table 6). Not surprisingly, these differences coincided with the differences in dietary CP; however, minimum target values for MUN of 10 mg/dL (Jonker et al., 1999) were met, suggesting that dietary protein was not likely a primary limitation for milk production in this study. The MUN concentrations observed for TPH20 and TPH14 also suggested that CP concentrations exceeding 18% of DM provided

substantially more protein than required by the late-lactation cows used in this experiment (Jonker et al., 1999).

Only a few published studies have evaluated responses of lactating dairy cattle to diets containing more than 50% corn gluten feed (Ohajuruka and Palmquist, 1989; Fellner and Belyea, 1991). Boddugari et al. (2001) tested 3 different strategies for incorporating a modified WCGF product, pushing inclusion rates as high as 70% of DM. The approach of these investigators was different from that of the present study; the modified WCGF was used to replace all dietary concentrate, and the most extreme diet still contained 15% corn silage and 15% alfalfa, resulting in a diet with 41% NDF and only 27% NFC (Boddugari et al., 2001). Perhaps not surprisingly, this formulation strategy was more successful at preventing MFD than the TPH14 diet. Nevertheless, our goal was to address a scenario when supplies of traditional forages run low on a dairy farm, and alternative approaches to formulation are required. In such a circumstance, the TPH20 diet appears to be a viable option, in spite of the mild decrease in ECM yield caused by this treatment.

CONCLUSIONS

Although TPH14 apparently did not supply adequate physically effective fiber to maintain rumen health, TPH20 may be a feasible option for lactating dairy cows because it resulted in production efficiencies and milk fat concentrations that were not significantly different from that of CON. Use of a diet similar to TPH20 may sometimes be economically feasible in locations where WCGF and TPH are readily available, such as the US central plains region, where numbers of dairy cows are increasing. Determining the risk threshold for disrupted rumen function remains difficult, but ideally, metrics to predict rumen function should include estimates of fiber digestibility and dietary starch content in addition to particle size and NDF content of a diet.

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