Lactation performance and digestibility of forages and diets in dairy cows fed a hemicellulose extract

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ABSTRACT

Inclusion of hemicellulose extract (HE) in cattle diets have shown potential for improving fiber digestibility and production efficiency. The objective of this research was to evaluate production and digestibility effects of a HE on midlactation cows. Twelve multiparous Holstein cows (142 ± 44 d in milk, 685 ± 19 kg of body weight) including 4 with ruminal fistula were used in a 2×2 Latin square design with 21-d periods. Cows were fed a control (CON) diet containing 55% forage [dry matter (DM) basis, 2/3 corn silage and 1/3 alfalfa hay] or a similar diet where 1.0% of the diet DM was replaced with HE (TRT). Dry matter intake averaged 27.1 and 26.9 kg/d, for CON and TRT respectively, and was not affected by addition of extract. The percentage of milk protein (3.40 vs. 3.29%) was greater, whereas the percentage of milk fat (3.91 vs. 3.80%) tended to be greater, for cows fed the CON compared with the TRT diet. Because of numerically greater milk production (38.8 vs. 39.2 kg/d) for cows fed the TRT diet, no differences were observed in component yields other than lactose (1.86 vs. 1.94 kg/d), which tended to be greater for cows fed the TRT ration. Treatment improved neutral detergent fiber (NDF) digestibility (38.6 vs. 48.1%) for the TRT diet compared with the CON diet but did not affect apparent total-tract DM (67.8 vs. 68.5%), crude protein (67.2 vs. 67.9%), acid detergent fiber (ADF; 37.1 vs. 43.3%), or starch (92.8 vs. 92.2%) digestibility. For in situ determinations, Dacron bags containing corn silage, alfalfa hay, and either the CON or TRT ration were incubated in triplicate in the rumens of the cannulated cows at 0, 3, 6, 9, 12, 24, and 48 h on d 18 of each period. Each total mixed ration was incubated only in cows assigned to the corresponding diet. For corn silage, the rate of disappearance of NDF (1.70 vs. 4.27%) and ADF (1.79 vs. 4.66%) increased for cows fed the TRT diet. For alfalfa hay, the disappearance

of fraction A of DM, NDF, and ADF decreased and fraction B of DM and NDF increased with treatment. The rate of disappearance for DM (8.03 vs. 11.04%), NDF (6.30 vs. 10.28%), and ADF (5.52 vs. 9.19%) increased for the alfalfa hay in rumens of treated cows. For the total mixed ration, the disappearance of the A fraction of NDF and ADF increased for cows fed the TRT diet. Supplementing diets of lactating dairy cows with an HE has beneficial effects on fiber degradation characteristics and provides opportunities for improving animal performance.

Key words: dairy cow, digestibility, forage, hemicellulose extract

INTRODUCTION

Sugars have effectively been used in dairy cow diets to offer alternatives to more expensive feed ingredients or to promote performance (Hall et al., 2010). It is believed that some of the improvement observed from sugar supplementation can be attributed to optimizing microbial growth by synchronizing protein and carbohydrate degradation (Kim et al., 1999). Researchers have demonstrated an effect of sugars on fermentation patterns and performance when readily fermentable carbohydrates are fed with different protein sources that vary in ruminal degradation characteristics (Broderick and Radloff, 2004; Golombeski et al., 2006; Penner and Oba, 2009). Furthermore, Hoffman and Bauman (2003) reported increased DMI, milk production, and component yield when lactating cows being fed red clover silage were supplemented with 4.2% dextrose. Much of this early work focused on including sugars in the diets at a relatively large percentage (>4.0% of diet DM). Additional research needs to be conducted to further understand the effects of supplementing sugars at lower inclusion amounts similar to other feed additives.

Previous research demonstrated that individual sugars have different effects on ruminal molar proportions of VFA, supply of microbial nitrogen to the small intestine, and ruminal ammonia (Chamberlain et al., 1993). Additionally, differences have occurred in rumen

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protozoa population when lactating dairy cows were fed either starch or a source of readily fermentable sugars (Abou Akkad et al., 1969). This response has led research to commercially available sources of sugars, such as hemicellulose extracts (**HE**) that could be used by the dairy industry to enhance performance. Hemicellulose extracts were found to contain a dilute amount of xylooligosaccharides and acetic acid as the major components, and many minor components including other organic acids, lignin-derived phenolics, and sugar degradation products (Walton, 2005). Early heifer research with yearling Holsteins demonstrated that HE treated with ammonia allowed similar performance as soybean meal (Magruder et al., 1953). Some of the first HE research as a feed ingredient in dairy cow diets dates back over 40 yr to when researchers at Kansas State University (Manhattan) compared substituting hemicellulose extract for liquid molasses at an inclusion rate of 10% of the grain ration in lactating dairy rations (Bartley et al., 1968). The researchers did not detect any differences in milk production or milk components and concluded that hemicellulose extract had a feeding value similar to cane molasses when included at a rate of 10% of the grain component. These results were substantiated when Crawford et al. (1978) found no difference in performance of beef steers when 2 types of HE were compared against cane molasses. Additionally, *in vitro* work by Hartnell and Satter (1978) reported that an HE derived from masonite board production had the ability to protect soybean meal from degradation by rumen microbes.

Much of this research was conducted several decades ago and was done using animals with vastly different production characteristics than modern dairy cattle. Furthermore, characteristics of HE vary depending upon source of woody biomass and method of hemicellulose extraction (Tunc and van Heiningen, 2008). The objective of this work was to evaluate the digestive and production characteristics in midlactation Holstein dairy cows supplemented with Temulose (Temple Inland Inc., Austin, TX), which is a specific HE coproduct from the forestry industry.

MATERIALS AND METHODS

Production Experiment

Animal care and use was approved by the South Dakota State University (Brookings) Institutional Animal Care and Use Committee. Twelve Holstein cows (8 multiparous and 4 primiparous with rumen cannulas) averaging 142 (± 46) DIM and 41.9 (± 5.56) kg/d milk yield were used in a 2 $\times$ 2 replicated Latin Square design with 21-d periods. Cows were blocked according

to production and parity and randomly assigned within block to 1 of 2 treatment diets. The control diet (**CON**) contained 55% forage DM (2/3 corn silage, 1/3 alfalfa hay) and was formulated to contain 30.0% NDF, 18.6% ADF, 17.8% CP, and 39.5% NFC on a DM basis. The treatment diet (**TRT**) was similar to CON except that HE (Temulose; Temple Inland Inc.) was added at 1.0% of diet DM (Table 1). Temulose HE is a natural product manufactured by steam extraction of select species of wood. It consists of approximately 70% sugars, 4% ash, and less than 1% protein or fat (DM basis). This HE contains a total dietary nutrient content (78%) and net energy values (NE_M 1.85 Mcal/kg) similar to cane molasses, but possesses a distinct sugar composition contrasted with the sucrose in molasses. Mannose is the predominant sugar (36.4%) in HE, followed by xylose (13.2%), glucose (11.5%), galactose (7.32%), arabinose (0.13%), fucose (0.08%), and rhamnose (0.04%). Sixty to 70% of the sugars are present in oligomeric form (Faber et al., 2011).

All cows were housed in a freestall barn at the South Dakota State University Dairy Teaching and Research Center (Brookings). Forages were premixed in a vertical mixer and blended with concentrates in a Calan Data Ranger (America Calan Inc., Northwood, NH). Diets were individually fed as a TMR for *ad libitum* intake once daily (0800 h) using Calan Broadbent individual animal feeders (American Calan Inc.). Orts were weighed once daily and the diet offered was adjusted to ensure 10% feed refusal. Cows were trained to the Calan gates for a week before initiating the experiment and individual milk production and DMI was recorded daily for the entire study. Weeks 1 and 2 of each period were allowed for adjustment to the diet, whereas data collection for each period occurred during wk 3.

Samples of the TRT and CON diets and individual orts from each cow were collected at the end of each period for 3 consecutive days, composited for period and animal, and immediately frozen at -20°C until analysis. All feed samples and orts were dried in duplicate at 55°C for 48 h in a Despatch oven (style V-23; Despatch Industries Inc., Minneapolis, MN), and then ground to a 2-mm particle size (Wiley mill, model 3; Arthur H. Thomas Co., Philadelphia, PA). Samples were then further ground to a 1-mm particle size using an ultracentrifuge mill (Brinkman Instruments Co., Westbury, NY) and analyzed for DM, NDF, ADF, CP, starch, and titanium dioxide as described in the Laboratory Analyses section.

Cows were milked 3 times daily at 0600, 1400, and 2100 h. Milk samples were collected from each cow for each milking for 3 consecutive days (d 17–19) of each period. Milk samples from each milking and cow were sent to Heart of America DHIA Laboratory (Manhat-

Table 1. Ingredient and nutrient composition of control (CON) and treatment (TRT) diets

Composition	Diet	
	CON	TRT
Ingredient (% of DM)		
Corn silage	36.7	36.2
Alfalfa hay	18.3	18.1
Soybean meal, 44%	11.8	11.8
Corn grain, high moisture	9.85	9.71
Corn grain, dry ground	6.57	6.57
Cottonseed, whole	7.55	7.45
Dried distillers grains with solubles	5.26	5.26
Limestone	1.14	1.14
Rumen inert fat ¹	0.81	0.81
Sodium bicarbonate	0.49	0.49
Salt, white	0.41	0.41
Potassium carbonate ²	0.36	0.36
Ca 17%:P 21%	0.24	0.24
Magnesium oxide	0.19	0.19
Urea	0.18	0.18
Vitamin/trace minerals pack ³	0.13	0.13
Trace minerals ⁴	0.02	0.02
Hemicellulose extract ⁵	0.00	0.98
DM (% as fed)	56.3	56.6
Nutrient composition (% of DM)		
CP	17.5	17.8
RUP ⁶	5.81	5.91
NDF	30.6	30.9
ADF	18.1	17.8
NFC ⁶	39.5	39.4
Starch	21.4	21.1
NE _L ⁶ (mcal/kg)	1.65	1.67

¹Energy Booster 100 (Milk Specialties Co., Dundee, IL).

²DCAD Plus (Church and Dwight Co., Princeton, NJ).

³BioSel Dairy Forti-P, (Vita Plus Corp., Madison, WI).

⁴Zinpro 4-Plex (Zinpro Corp., Eden Prairie, MN).

⁵Temulose (Temple Inland Inc., Austin, TX).

⁶Calculated according to NRC (2001) using analyzed feed values.

tan, KS) for analysis. Mid-infrared spectroscopy (Bentley 2000 Infrared Milk Analyzer; Bentley Instruments, Chaska, MN; AOAC, 2002) was used to analyze milk fat, protein, and lactose, whereas MUN concentration was determined using chemical methodology based on a modified Berthelot reaction (ChemSpec 150 Analyzer; Bentley Instruments). Somatic cell counts were determined using a flow cytometer laser (Somacount 500; Bentley Instruments; AOAC, 2002). Energy-corrected milk was calculated using the following equation: $\{[0.327 \times \text{milk yield (kg)}] + [12.95 \times \text{fat yield (kg)}] + [7.2 \times \text{protein yield (kg)}]\}$ (Orth, 1992).

Rumen fluid was collected from the 4 cannulated cows on d 20 of period 1 and d 23 of period 2 at 0, 3, 6, 9, and 12 h relative to feeding. Feeding of both CON and TRT was extended to d 23 of period 2 to facilitate collection of rumen fluid. Samples of rumen fluid were taken from the cranial, central, and caudal portions of the rumen via a filtered probe and tube attached to a 50-mL syringe. Ten milliliters of rumen fluid was added

to a vial containing 2 mL of 25% (wt/vol) metaphosphoric acid and immediately frozen at -20°C until VFA analysis. An additional 10 mL of rumen fluid to be used for ammonia analysis was added to a separate vial containing 200 μL of 50% (vol/vol) H_2SO_4 and frozen at -20°C .

Body weights and BCS were recorded over 3 consecutive days at the beginning of the experiment, at the end of the first period, and then again at the end of the experiment. Body condition scores were recorded independently by 3 individuals on a scale of 1 to 5, where 1 represented emaciated and 5 represented obese (Wildman et al., 1982).

Digestibility Experiment

The 8 cows without rumen cannulas were used in a digestibility study to determine the effects of TRT on total-tract digestibility estimates of DM, NDF, ADF, CP, and starch. From d 13 to 20 in each period, 20 g of titanium dioxide was added to each cow's TMR immediately after feeding and hand mixed with the upper portion of the TMR to guarantee consumption. A total of 12 fecal samples were collected on d 18 to 20. Sampling times were staggered such that the entire 24-h day was represented to avoid diurnal variation. A similar volume of feces on a wet basis was collected from each cow for each time point and composited for each cow and stored at -20°C until analysis. Fecal composites were thawed and samples were placed in duplicate containers for freeze drying before analysis. After freeze drying, the fecal samples were ground to pass a 2-mm screen (Wiley mill; Arthur H. Thomas Co.) and then further ground to a 1-mm particle size using an ultra-centrifuge mill. Ground samples were analyzed for DM, NDF, ADF, CP, starch, and titanium dioxide.

In Situ Experiment

Four primiparous cannulated cows were used in an in situ study to determine rumen disappearance characteristics of alfalfa hay (AH), corn silage (CS), CON, and TRT in cows fed either the CON or TRT diets. Samples of AH, CS, CON, and TRT from each period were dried at 55°C for 48 h in a Despatch oven and then ground to a 2-mm particle size (Wiley mill). Triplicate Dacron bags containing approximately 5 g of AH, CS, and either CON or TRT were weighed into nylon bags (10×20 cm, 53 ± 10 - μm pore size; R1020; Ankom Technology Corp., Macedon, NY), heat sealed, and incubated in the rumens for 0, 3, 6, 12, 24, and 48 h. Sample bags with CON were placed only in those cows receiving the CON diet and, likewise, samples of TRT were only incubated in those cows receiving the

TRT diet. Before incubation, all bags were soaked in water (39°C) for 15 min and then placed in a larger, weighted mesh bag (36 × 42 cm) that was suspended below the particulate mat layer in the ventral sac of the rumen. Bags were inserted in reverse order and all were removed at the same time. After removal, the bags were immediately immersed in cold water to arrest bacterial growth and then hand washed to remove any external particulate material. Bags were allowed to air dry for a period of 24 h and then placed in a 55°C Despatch oven for 48 h. Bags were individually weighed and composited for each time point for each cow. Samples of CS, AH, CON, and TRT were analyzed for DM, NDF, ADF, CP, and starch.

Laboratory Analyses

Dry matter content was determined at 105°C for 3 h (Shreve et al., 2006). Concentrations of NDF (Van Soest et al., 1991) and ADF (Robertson and Van Soest, 1981) were determined sequentially using an Ankom fiber analyzer (Ankom Technology Corp.). Sodium sulfite and α -amylase were added during NDF extraction. Nitrogen concentration was determined according to AOAC (2002; method 968.06) using an automated N combustion analyzer (Rapid N cube; Elementar Analysensysteme GmbH, Hanau, Germany). Crude protein concentration was reported as 6.25 multiplied by the nitrogen concentration. Starch concentration was determined using an amylase assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland; AOAC, 2002; method 996-11).

Titanium dioxide was chosen as a marker to estimate total-tract digestibility (Glindemann et al., 2009). The concentration of titanium dioxide was measured according to the procedure of Myers, et al. (2004) with a few modifications (P. A. Ludden, University of Wyoming, Laramie, personal communication, 2010). Briefly, 250 mL macro-Kjeldahl digestion tubes were washed in a 10% (vol/vol) HCl bath and weighed. Standards were prepared by accurately weighing 0, 2, 4, 6, 8, and 10 mg of titanium dioxide into the macro-Kjeldahl digestion tubes. Standards and samples of feed and feces were treated in the same manner except that duplicate 0.5-g samples were used for the feed and fecal samples. Samples of feces and feed devoid of titanium dioxide were used as a baseline. Approximately 3.5 g of K_2SO_4 , 0.4 g of $CuSO_4$, and 13 mL of concentrated H_2SO_4 were added to each tube containing the samples or standards. The tubes were vortexed and placed in a Kjeldahl digestion block preheated to 420°C. The temperature was allowed to return to 420°C and the samples were digested for 2 h. Following digestion, the tubes were removed from the digestion block, allowed

to cool, after which 15 mL of 30% H_2O_2 was added to each tube. The tubes were once again allowed to cool and distilled water was added to each digestion tube to bring the total liquid weight to 100 g. The samples were vortexed and filtered through Whatman 54 filter paper into a 250-mL Erlenmeyer flask. Just before reading, approximately 5 drops of 30% H_2O_2 were added to each flask and gently swirled. Samples were read using a sipper attachment on a Cary 50 Bio UV Visible Spectrophotometer (Varian Inc., Palo Alto, CA) with a wavelength of 410 nm. The 0 standard was used to zero the instrument. The concentration of titanium dioxide was calculated according to the equation generated from the standard curve and the average absorbance of 3 readings from each sample. The baseline titanium dioxide concentration of feed and feces was subtracted from the corresponding samples to obtain a final titanium dioxide concentration. To validate the procedure, 4 and 8 mg of titanium dioxide was spiked to 0.5 g of both fecal and TMR sample. The recovery of titanium dioxide was 95.0% for the TMR sample and 90.4% for the fecal sample.

Rumen fluid samples containing H_2SO_4 were thawed, centrifuged for 20 min at $30,000 \times g$ and analyzed for ammonia N according to Chaney and Marbach (1962). Rumen fluid samples containing metaphosphoric acid were thawed, centrifuged at $30,000 \times g$ for 20 min and analyzed for acetate, propionate, butyrate, isobutyrate, isovalerate, and valerate. Concentrations of VFA were measured using an automated gas-liquid chromatograph (model 6890; Hewlett-Packard Co., Palo Alto, CA) using a flame-ionization detector. Volatile fatty acids were separated on a capillary column (15 m × 0.25 mm i.d.; Nukol, 17926-01C; Supelco Inc., Bellefonte, PA) using 2-ethylbutyrate as an internal standard. The split ratio of 100:1 in the injector port was at a temperature of 250°C with flow rate of 1.3 mL/min of helium. The column and detector temperature were maintained at 140°C and 250°C, respectively.

Mathematical and Statistical Analyses

All data were analyzed by the MIXED procedure in SAS (version 9.2; SAS Institute, 2008). Milk production and feed intake were averaged over the final week of each period. Means for the remaining variables were calculated from the data gathered during the collection time for each period. The model for feed intake, milk yield, milk composition, and apparent digestibility variables was $Y = \text{period} + \text{treatment} + \text{block} + (\text{treatment} \times \text{period}) + (\text{treatment} \times \text{block})$, where Y was the variable of interest and the random effect was cow. The same model was used for BW change and BCS change. The model for VFA, rumen pH, and

rumen ammonia was $Y = \text{period} + \text{time} + \text{treatment} + (\text{time} \times \text{treatment}) + (\text{period} \times \text{treatment} \times \text{time})$, where Y was the variable of interest and the random effect was cow. Time was considered a repeated measure. The variance-covariance error structure was ante-dependence covariance, which was selected based on the lowest Akaike information criterion fit statistic.

Nonsignificant interactions were sequentially dropped from the model. Significant interactions are identified in the results and tables. Least squares means are reported for each variable and statistical significance of main effects was declared at $P \leq 0.05$ and tendencies were discussed at $0.05 \leq P \leq 0.10$.

In situ degradation curves for DM, NDF, ADF, and starch were fitted to a nonlinear model (Ørskov and McDonald, 1979) without a lag phase as described by the following equation:

$$Y = A + B \left(1 - e^{-K_d(t)} \right),$$

where Y = ruminal disappearance (%); A = fraction that disappeared at 0 h after the rinsing procedure; B = potentially degradable fraction; e = base for the natural logarithm; K_d = constant rate of degradation of fraction B ; and t = time of incubation (h). The undegradable fraction C was calculated as $100 - (A + B)$. Effective degradability was determined by the equation

$$\text{effective degradability} = A + B [K_d / (K_d + K_p)],$$

where A , B , and K_d are the degradation constants described previously (Ørskov and McDonald, 1979). The rate of disappearance (K_p) from the rumen (%/h) was calculated using the NRC (2001) equations for wet forages, dry forages, and concentrates. The passage rate for CS was calculated using the equation

$$K_p = 3.054 + 0.614X_1,$$

where X_1 = DMI as a percentage of BW.

The passage rate for AH was calculated using the equation

$$K_p = 3.362 + 0.479X_1 - 0.007X_2 - 0.017X_3,$$

where X_1 = DMI as a percentage of BW, X_2 = concentrate as a percentage of diet DM, and X_3 = NDF of AH as a percentage of DM.

The passage rate for CON and TRT was calculated using the equation

$$K_p = 2.904 + 1.375X_1 - 0.020X_2,$$

where X_1 = DMI as a percentage of BW and X_2 = concentrate as a percentage of diet DM.

Energy values were calculated as follows using equations from NRC (2001):

$$\begin{aligned} \text{milk NE}_L \text{ (Mcal/kg)} &= 0.0929 \times (\text{fat } \%) + 0.0547 \\ &\times (\text{protein } \%) + 0.0395 \times (\text{lactose } \%); \end{aligned}$$

$$\begin{aligned} \text{milk NE}_L \text{ (Mcal/d)} &= \text{milk yield (kg)} \\ &\times [0.0929 \times (\text{fat } \%) + 0.0547 \times (\text{protein } \%) \\ &+ 0.0395 \times (\text{lactose } \%)]; \end{aligned}$$

$$\text{NE}_M = 0.080 \times \text{BW}^{0.75}.$$

In situ degradation constants (A , B , C , and K_d) and effective degradability were analyzed using the MIXED procedure of SAS (version 9.2; SAS Institute, 2008) for each feed ingredient, with cow as a random variable. The model for all variables was $Y = \text{treatment} + \text{period} + \text{treatment} \times \text{period}$, where Y was the variable of interest. Mean comparisons were performed using the Tukey test. Least squares means are reported for each variable and statistical significance was declared at $P \leq 0.05$ and tendencies were discussed at $0.05 \leq P \leq 0.10$.

RESULTS AND DISCUSSION

Production Experiment

Production measures did not differ except for a tendency for greater lactose yield for the TRT diet ($P = 0.08$), a tendency for less milk fat percent for the TRT diet ($P = 0.06$), and a significant decrease in milk protein percent for the TRT diet ($P = 0.03$; Table 2). This is in agreement with the results of several other researchers who observed no differences in milk yield and milk components when feeding sugar (Golombeski et al., 2006; Broderick et al., 2008; Penner and Oba, 2009) or molasses (Broderick and Radloff, 2004). It should be emphasized that the current research was conducted with a product that contains a variety of sugars and varies considerably in composition compared with the previously mentioned research.

Penner and Oba (2009) supplemented early lactation cows with either 0 or 4.7% sucrose to provide either 4.5 or 8.7% total soluble carbohydrates. In that research, no significant differences were observed between the 2 treatments for yield of milk, fat, CP, and lactose. Milk production was numerically greater (34.4 vs. 33.0 kg) for the high-sugar diet as compared with the low-sugar treatment. Similarly, Broderick et al. (2008) reported

Table 2. Milk production and composition in dairy cows fed a control (CON) diet or treatment (TRT) diet containing a hemicellulose extract

Item	CON	TRT	SEM	<i>P</i> -value ^{1,2}
DMI (kg/d)	27.1	26.9	0.80	0.86
Yield (kg/d)				
Milk	38.8	39.2	0.64	0.55
Fat	1.52	1.48	0.04	0.39
Protein	1.31	1.29	0.03	0.58
Lactose	1.86	1.94	0.06	0.08
SNF	3.54	3.55	0.10	0.97
MUN	5.78	5.99	0.35	0.61
FCM, 4.0%	38.3	38.0	0.86	0.77
ECM	41.9	41.3	0.87	0.68
Milk composition (%)				
Fat	3.91	3.80	0.03	0.06
Protein	3.40	3.29	0.08	0.03
Lactose	4.78	4.95	0.11	0.17
SNF	9.12	9.06	0.12	0.37
SCC ($\times 1,000$ cells/mL)	308	44	192	0.35
MUN (mg/dL)	14.9	15.3	0.74	0.66
4.0% FCM/DMI	1.49	1.47	0.12	0.89

¹Trends were observed for interactions between period and treatment for DMI ($P = 0.07$) and protein percentage ($P = 0.10$), and a significant interaction for fat percentage ($P < 0.01$).

²Trends were observed for period effect for milk ($P = 0.09$), intake ($P = 0.10$), and fat percentage ($P = 0.08$), and significant effects for MUN ($P = 0.05$), MUN yield ($P = 0.05$), and lactose yield ($P = 0.02$).

no differences in yield of milk, protein, or lactose when early lactation cows were fed diets with increasing amounts of sucrose (0, 2.5, 5, and 7.5%) substituted for starch. However, the authors did report greater concentration and yield of milk fat as the amount of sucrose in the diet increased. This is in contrast to the results from the current study, which demonstrated that milk fat concentration had a tendency ($P = 0.06$) to decrease with HE treatment. These differences are likely related to differences in the sugar composition and types of forages in the basal diet.

Golombeski et al. (2006) reported an increase in milk fat concentration when 8.6% of diet DM was replaced with a source of fermentable sugars fed with either urea or a source of slow-release urea. In agreement with results from the current research, those authors observed a tendency for lower yield of milk true protein ($P = 0.07$) for cows fed the fermentable sugar. However, the authors also reported less yield of lactose and concentration of lactose for the fermentable sugar treatments. This is contradictory to the response observed from the current study in which yield of lactose tended to be greater ($P = 0.08$) for the TRT diet.

A portion of these differences could be explained by milk yield. Although milk production difference was not significant for this study, a numerical difference existed. This is probably a result of the tendency for greater milk lactose yield ($P = 0.08$) for the TRT diet, which could have resulted in a dilution effect on the milk fat and protein concentration (Akers, 2002). Several trends and differences also occurred for period

effects and interactions between period and treatment. This was most likely explained by the change in environmental conditions between the first and second collection periods. The average temperature during the first collection period was 12.0°C, with high temperatures approximately 15.5°C. The second collection period high temperatures were approximately 32.2°C, with an average temperature of 20.0°C.

Digestibility Experiment

Apparent total-tract digestibility values are shown in Figure 1. Dry matter, ADF, CP, and starch apparent total-tract digestibility were not affected by treatment with HE; however, significant improvement in NDF digestibility occurred in the TRT diet. This is in agreement with the results of several other researchers who reported improvement in digestibility characteristics with sugar substitution or addition (Wiedmeier et al., 1992; Broderick and Radloff, 2004; Broderick et al., 2008).

Wiedmeier et al. (1992) fed a sugar product manufactured from a unique extraction process of molasses to cannulated beef cows. These authors reported a 4.46% improvement in NDF digestibility when a high-grain diet (33.7% NDF) was fed. Broderick and Radloff (2004) replaced high-moisture shell corn with increasing amounts of dried or liquid molasses to increase total sugar concentration up to 10% of diet DM in midlactation Holstein cow diets. These authors observed a linear improvement in DM, OM, NDF, and ADF digestibility

Figure 1. Apparent total-tract digestibilities from cows fed a control (Con; dark bar) or treatment (Trt; light bar) TMR.

with dried molasses substitution up to 7.2% total sugar in the diet. They also reported a cubic response for these same parameters when liquid molasses instead of dried molasses was used as a substitute for high-moisture shelled corn up to 10% total sugar in the diet. Digestibility values were greatest when liquid molasses was added at 6% of the diet to increase the total sugar content to 7.4% of diet DM. Broderick et al. (2008) added sucrose to early lactation Holstein cows and replaced corn starch at increasing amounts up to 7.5% sucrose of dietary DM. Digestibility values, based on nutrient flow from and digestion in the rumen, for DM and ADF were not affected by treatment. However, a quadratic response in rumen NDF digestibility values occurred with the diet that contained the 5.0% sucrose having the greater response. Some authors have reported no differences in digestibility parameters related to sugar supplementation (Penner and Oba, 2009). Penner and Oba (2009) replaced 4.7% cracked corn with sucrose in postpartum transition cow diets and reported no change in apparent total-tract digestibility for DM, NDF, or starch when cows were fed a low-sugar or high-sugar diet in early lactation.

It is of interest to note that in this research, NDF digestibility increased when HE was supplemented at a rate of only 1.0% of diet DM. Previous research has not demonstrated a strong relationship between sugar supplementation and NDF digestibility when supplemented or substituted at lower inclusion amounts (Broderick and Radloff, 2004; Broderick et al., 2008).

The only responses in lactating cows came when the concentration of sugars was greater than 5.0% of the diet DM. These experiments were conducted using molasses as a sugar source. This would support previous research that demonstrated a change in rumen parameters when individual sugars were fed to sheep (Chamberlain et al., 1993).

Neutral detergent fiber disappearance for the TMR was 9.5% greater for the TRT TMR than the CON TMR. Previous research has suggested that for each 1-U increase for in vitro or in situ forage NDF digestibility positively equates to 0.17 kg of DMI or 0.23 kg of milk production (Oba and Allen, 1999). Those authors also suggested that NDF digestibility estimates from in vivo data would be approximately 40% of this value because of changes in rumen retention time and passage rate. Taking this into consideration and assuming that a similar response would be expected with TMR digestibility, the change in NDF disappearance from the current study would then be 3.8%. This should equate to an increase in milk production of 0.874 kg and an increase in DMI of 0.646 kg. However, the milk response and DMI response was +0.4 and -0.2 kg/d respectively. A portion of this difference could be explained by the shorter 21-d feeding period not providing enough time for adaptation. Additionally, as was discussed previously, the cows used in the current experiment may have been at a level of production or stage of lactation that allowed for BW gain (Table 3) rather than increased milk production.

Table 3. Body weight, condition, and energy partitioning for cows on control (CON) or treatment (TRT) diets

Item	CON	TRT	SEM	<i>P</i> -value ^{1,2}
Initial BW (kg)	690	687	19	0.51
Final BW (kg)	714	722	17	0.37
BW change (kg/d)	1.1	1.7	0.31	0.27
Initial BCS	3.30	3.30	0.05	0.99
Final BCS	3.28	3.32	0.05	0.29
BCS change	-0.02	0.02	0.05	0.55
Milk NE _L ³ (Mcal/kg)	0.72	0.73	0.01	0.56
NE _L intake ⁴ (Mcal/d)	40.1	41.8	1.72	0.33
NE _L intake (Mcal/kg of DMI)	1.59	1.66	0.12	0.46
Milk NE _L (% NE _L intake)	65.9	64.1	1.39	0.34
NE _M (% NE _L intake)	27.6	26.3	1.09	0.22

¹A significant period effect was observed for initial BW ($P < 0.01$) and final BW ($P < 0.01$).

²A significant block effect was observed for initial BW ($P = 0.01$) and final BW ($P < 0.01$).

³NE_{L(milk)} (Mcal/kg) = $(0.0929 \times \text{fat}\%) + (0.0547 \times \text{protein}\%) + (0.0395 \times \text{lactose}\%)$ (NRC, 2001).

⁴NE_{L(intake)} = NE_{L(milk)} + NE_{L(maintenance)} + NE_{L(BW gain)}, where NE_{L(maintenance)} = $0.08 \times \text{BW}^{3/4}$ (NRC, 2001).

In Situ Experiment

Effective degradability, disappearance rate, and fractions of DM, NDF, ADF, and CP for TMR, AH, and

CS are shown in Tables 4, 5, and 6, respectively. Effective degradabilities of all nutrients were not affected by treatment. Likewise, the potentially degraded fraction (fraction B) or the undegraded fraction (fraction C)

Table 4. In situ disappearance characteristics for a control (CON) and treated (TRT) TMR incubated in cows fed a control (CON) or treated (TRT) diet containing hemicellulose extract

Item ¹	CON	TRT	SEM	<i>P</i> -value
DM (%)				
A	37.7	36.4	0.92	0.38
B	46.4	41.6	2.86	0.24
C	15.9	21.9	3.05	0.19
K _d	5.03	6.96	0.69	0.11
Effective degradability ²	56.0	56.8	1.26	0.69
NDF (%)				
A	9.6	20.2	1.16	<0.01*
B	47.1	36.1	7.78	0.14
C	43.3	43.7	8.01	0.94
K _d	6.29	5.21	1.01	0.40
Effective degradability ²	28.3	34.0	1.80	0.15
ADF (%)				
A	11.3	17.1	0.83	0.03*
B	47.0	33.6	10.4	0.14
C	41.5	49.3	10.8	0.36
K _d	6.47	5.35	1.18	0.57†
Effective degradability ²	27.5	29.5	1.71	0.44
CP (%)				
A	32.0	27.9	1.52	0.20
B	66.2	59.3	3.74	0.32
C	1.8	12.7	2.44	0.09
K _d	3.37	6.07	0.61	0.09
Effective degradability ²	53.5	54.5	1.86	0.73
Starch (%)				
A	54.2	43.6	5.19	0.08
B	45.2	56.4	5.03	0.06
C	0.5	0	0.50	0.24
K _d	8.03	10.06	2.12	0.43
Effective degradability ²	79.3	76.9	0.86	0.10*

¹A = immediately soluble fraction; B = potentially degraded fraction; C = undegraded fraction; K_d = disappearance rate.

²Calculated as $A + B(K_d/K_d + \text{passage rate})$, where K_d = disappearance rate and the passage rates were calculated for each cow and feed based on individual BW and DMI.

*Significant period effects ($P < 0.10$); †significant period $\times$ treatment effects ($P < 0.10$).

Table 5. In situ disappearance characteristics for alfalfa hay incubated in cows fed a control (CON) or treatment (TRT) diet containing hemicellulose extract

Item ¹	CON	TRT	SEM	P-value
DM (%)				
A	32.4	26.7	0.89	0.04*†
B	35.2	41.6	1.15	0.06†
C	32.4	31.7	1.26	0.64*
K _d	8.03	11.04	0.83	0.05*
Effective degradability ²	55.6	56.7	1.30	0.57
NDF (%)				
A	9.4	3.6	0.69	0.02*†
B	33.1	38.9	1.93	0.06
C	57.5	57.5	2.22	0.99
K _d	6.30	10.28	0.83	<0.01*†
Effective degradability ²	29.4	29.9	1.67	0.84
ADF (%)				
A	8.0	3.1	0.54	0.02*†
B	35.5	39.4	2.03	0.13
C	26.5	57.5	2.24	0.70
K _d	5.52	9.19	0.91	<0.01*
Effective degradability ²	28.2	28.5	1.76	0.90
CP (%)				
A	35.7	27.9	2.23	0.13†
B	45.7	53.5	2.85	0.16
C	18.7	18.6	1.72	0.98
K _d	7.99	11.92	1.61	0.18
Effective degradability ²	64.9	67.4	1.94	0.45

¹A = immediately soluble fraction; B = potentially degraded fraction; C = undegraded fraction; K_d = disappearance rate.

²Calculated as $A + B(K_d/K_d + \text{passage rate})$, where K_d = disappearance rate and the passage rates were calculated for each cow and feed based on individual BW and DMI.

*Significant period effects ($P < 0.10$); †significant period $\times$ treatment effects ($P < 0.10$).

was not affected, except for trends for greater DM and NDF disappearance of fraction B for AH. The greatest response was observed with the disappearance of the immediately soluble fraction (fraction A) and the disappearance rate. Fraction A for AH and CS incubated in cows fed the TRT diet had less disappearance than those cows fed the CON diet, whereas fraction A for the TRT TMR had greater disappearance.

Interestingly, an increase in NDF (20.1 vs. 9.8%) and ADF (17.5 vs. 12.1%) disappearance was observed at the 0-h time point for TRT TMR compared with CON TMR. The 0-h time point in situ samples were never placed in the rumens of the cows. The TMR samples for each diet were collected before the start of the in situ portion of the experiment, dried, and weighed into Dacron bags. The fact that an increase in disappearance was observed at this time point would suggest an effect of HE separate from any rumen effect. It would seem likely that some fermentation occurred between collection of the TMR and processing before weighing into the bags that affected NDF and ADF disappearance.

The in situ results support the observations from the digestibility experiment that HE supplementation affects fiber digestibility. Although effective degrad-

ability was not changed because of supplementation, the immediately soluble fraction was degraded to a larger extent and at a faster rate, especially for AH and TMR supplemented with HE. This would support the hypothesis that HE provides a source of sugars that optimizes rumen function. Corn silage would generally have a greater source of fermentable carbohydrates than AH, and as a result, less of a response would be expected for the CS treatment.

Rumen Measures

Treatment did not affect most measurements of rumen parameters (Table 7). This is consistent with results from other researchers feeding sugars (Chamberlain et al., 1993). A significant reduction in acetate concentration occurred with the TRT diet. Chamberlain et al. (1993) also observed this type of response when individual sugars were being fed to sheep. Interestingly, the pattern of VFA change was quite different between TRT and CON. Although the average VFA concentrations and proportions throughout the 12-h period were not different, the VFA concentration for TRT increased much earlier than CON. Total VFA concentration (mM) was maximized between 3 and 6

Table 6. In situ disappearance characteristics for corn silage incubated in cows fed a control (CON) or treatment (TRT) diet containing hemicellulose extract

Item ¹	CON	TRT	SEM	P-value
DM (%)				
A	37.1	38.1	1.26	0.65
B	35.2	34.9	1.26	0.90*
C	27.6	26.9	1.49	0.74*
K _d	4.75	6.34	0.76	0.28*
Effective degradability ²	53.5	56.0	1.19	0.17
NDF (%)				
A	7.1	6.1	1.94	0.78
B	79.5	63.3	7.02	0.24*
C	13.5	30.5	7.41	0.25*
K _d	1.70	4.27	0.43	0.05*†
Effective degradability ²	25.1	28.3	1.97	0.24
ADF (%)				
A	6.3	4.8	1.96	0.63
B	78.7	61.9	8.03	0.28
C	14.9	33.2	8.18	0.25
K _d	1.79	4.66	0.41	0.04*†
Effective degradability ²	24.8	27.8	2.01	0.22
CP (%)				
A	60.4	53.2	2.74	0.20
B	13.8	30.9	14.11	0.48
C	25.8	15.8	13.03	0.61
K _d	22.29	6.38	11.62	0.40
Effective degradability ²	55.4	59.7	3.05	0.34
Starch (%)				
A	63.1	64.1	7.02	0.93
B	36.8	35.9	7.02	0.94
C	0.06	0.02	0.05	0.65
K _d	16.53	16.88	3.87	0.96
Effective degradability ²	91.1	91.6	0.54	0.58

¹A = immediately soluble fraction; B = potentially degraded fraction; C = undegraded fraction; K_d = disappearance rate.

²Calculated as $A + B(K_d/K_d + \text{passage rate})$, where K_d = disappearance rate and the passage rates were calculated for each cow and feed based on individual BW and DMI.

*Significant period effects ($P < 0.10$); †significant period × treatment effects ($P < 0.10$).

h for TRT, whereas CON did not reach maximum concentration until 9 h postfeeding. Furthermore, by 9 h, it appeared as though VFA concentration for TRT had returned to the prefeeding concentration.

Acetate concentration numerically decreased with HE addition. Although the change was not significant, the difference along with a numerical increase in propionate concentration resulted in an acetate-to-propionate ratio that was less for the TRT diet. This is in agreement with other in vivo experiments that reported a linear decrease in the ruminal acetate-to-propionate ratio with increasing sugar concentration in the diet (Broderick et al., 2008). In mixed culture studies, fermentation of soluble starch in the presence of sugars and malate decreased the acetate-to-propionate ratio (Martin et al., 2000). Those authors also reported greater concentrations of acetate, propionate, and total VFA. However, that was an in vitro study and the current in vivo experiment may have provided an environment that promoted short-chain VFA utilization or absorption (Gäbel et al., 2002).

CONCLUSIONS

Hemicellulose extract supplementation positively affected fiber digestibility, particularly NDF digestibility. This response was observed both in situ as well as in total-tract apparent digestibility. Despite the increase in digestibility and potential energy, milk production was not increased. Supplementation of HE did not alter the majority of milk components. Additional research needs to be conducted to determine at what stage of lactation or level of production that dairy cows can benefit most from HE supplementation. It can be concluded that feeding HE is an effective feed additive to improve fiber digestibility in midlactation Holstein cows.

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Table 7. Least squares means of rumen fluid measures from cows fed a control diet (CON) or treatment diet (TRT) containing a hemicellulose extract

Item	CON					TRT					CON average	TRT average	SEM of TRT means	<i>P</i> -value ^{1,2}		
	Hours after feeding					Hours after feeding								Trt	Time	Period
	0	3	6	9	12	0	3	6	9	12						
VFA (mM)																
Acetate	56.2	55.5	65.9	74.6	66.1	58.8	67.3	66.1	57.9	53.3	63.6	59.9	1.71	0.01	0.39	<0.01
Propionate	20.2	21.4	25.5	28.6	26.9	20.7	25.8	28.2	24.2	25.4	24.5	24.9	1.88	0.42	0.07	0.90
Butyrate	9.2	11.7	12.6	13.5	12.6	8.6	12.7	13.1	10.6	10.5	11.9	11.1	0.45	0.47	0.01	0.01
Isobutyrate	1.06	0.85	0.86	0.83	0.82	1.06	0.96	0.82	0.69	0.69	0.88	0.84	0.03	0.73	<0.01	0.01
Valerate	1.21	1.31	1.40	1.45	1.34	1.17	1.53	1.61	1.37	1.35	1.34	1.41	0.05	0.72	0.30	0.08
Isovalerate	1.65	1.42	1.43	1.40	1.35	1.68	1.64	1.51	1.29	1.24	1.45	1.47	0.07	0.34	0.01	0.03
Total	89.5	92.1	107.7	120.4	109.1	92.1	109.9	111.3	92.1	92.6	103.8	99.6	2.25	<0.01	0.03	<0.01
VFA (mol/100 mol)																
Acetate (A)	62.9	60.2	61.1	61.9	60.5	64.1	60.9	59.4	57.8	58.1	61.4	60.1	0.77	0.14	<0.01	0.04
Propionate (P)	22.4	23.2	23.6	23.7	24.8	22.3	23.7	25.3	26.9	27.1	23.5	25.1	1.47	0.11	<0.01	0.16
Butyrate	10.3	12.7	11.9	11.2	11.5	9.3	11.6	11.7	11.5	11.2	11.5	11.1	0.26	0.08	0.08	0.31
Isobutyrate	1.20	0.92	0.81	0.69	0.75	1.19	0.88	0.73	0.76	0.74	0.87	0.86	0.04	0.86	<0.01	0.86
Valerate	1.34	1.42	1.30	1.20	1.23	1.24	1.43	1.44	1.51	1.44	1.30	1.41	0.05	0.23	0.23	0.23
Isovalerate	1.87	1.54	1.35	1.18	1.24	1.88	1.51	1.37	1.43	1.34	1.43	1.51	0.08	0.98	<0.01	0.98
A:P	2.85	2.69	2.64	2.67	2.49	2.91	2.61	2.43	2.22	2.20	2.67	2.47	0.17	0.20	<0.01	0.14
NH ₃ -N (mM)	10.2	13.7	8.6	10.3	9.7	7.6	13.5	9.2	8.8	9.5	10.6	9.7	0.08	0.14	0.22	0.14
pH	6.89	6.52	6.29	6.43	6.39	6.81	6.65	6.21	6.50	6.41	6.50	6.52	0.04	0.79	<0.01	0.79

¹Significant ($P < 0.01$) treatment (Trt) $\times$ time interactions for mmol of acetate, total VFA, and mol/100 mol of valerate.²Significant ($P < 0.05$) Trt $\times$ period interactions for mmol of butyrate, valerate, and pH.

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