Interactions Between Forage and Wet Corn Gluten Feed as Sources of Fiber in Diets for Lactating Dairy Cows

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ABSTRACT

Twelve early lactation Holstein cows (4 fistulated) were used in replicated 4 × 4 Latin squares with 4-wk periods to determine the effective neutral detergent fiber (NDF) content of wet corn gluten feed and to measure the effect of forage particle size on ruminal mat consistency and passage rate of wet corn gluten feed. Diets were 1) 23.3% NDF (17.4 percentage units of NDF from alfalfa silage), 2) diet 1 plus 11.1 additional percentage units of NDF from alfalfa silage, 3) diet 1 plus 10.7 percentage units of NDF from wet corn gluten feed, and 4) 8.6 percentage units of NDF from alfalfa silage plus 8.9 percentage units of NDF from coarsely chopped alfalfa hay and 10.7 percentage units of NDF from wet corn gluten feed. The calculated effective NDF factor for wet corn gluten feed, using change in milk fat concentration per unit change in NDF, was 0.74 compared with an assumed 1.0 for alfalfa silage. Rumination activity was measured to calculate a physically effective NDF factor for wet corn gluten feed, which was only 0.11 compared with 1.0 for alfalfa silage. Physically effective NDF also was determined for wet corn gluten feed by wet sieving; 22% of the particles were retained on the 3.35-mm screen or greater. Ruminal mat consistency increased and passage rate of wet corn gluten feed decreased with added hay. The inclusion of chopped alfalfa hay to a diet containing wet corn gluten feed increased ruminal mat consistency, rumination activity, and slowed passage rate, resulting in greater ruminal digestion of NDF from wet corn gluten feed. Depending on the response variable, the effectiveness of NDF from wet corn gluten feed varied from 0.11 to 0.74.

(**Key words:** effective fiber, fibrous coproducts, corn gluten feed, rumination)

Abbreviation key: CGF = corn gluten feed, **HF** = high fiber, **LF** = low fiber, **peNDF** = physically effective neutral detergent fiber, **WCGF** = wet CGF.

INTRODUCTION

Because of low lignin content and a large proportion of potentially digestible fiber, nonforage sources of fiber supply energy needed for lactation without the ruminal acid load caused by rapidly fermented starchy concentrates. Nonforage sources of fiber also may serve as partial replacements for forage fiber in those situations where forage availability is limited. Compared with most forages, nonforage sources of fiber typically have a smaller particle size and relatively high specific gravity which promote particle passage from the rumen (9, 18).

A coproduct of wet milling of corn, wet corn gluten feed (**WCGF**) is primarily a mixture of corn bran and fermented corn extractives (steep liquor). Although WCGF contains 40 to 45% NDF, it only contains 3% lignin and is a source of highly digestible fiber. When incorporating nonforage sources of fiber, such as WCGF, into rations for lactating dairy cows, at least two major considerations are 1) the interaction between forage and nonforage fiber for ruminal passage and digestion, and 2) the effective NDF content of the nonforage source of fiber.

Sutherland (26) described the ruminal mat as a highly effective first-stage separator. Through the processes of filtration and mechanical entanglement, the mat selectively retains potentially escapable fiber particles, thereby increasing the time allowed for fermentation (11). Welch (31) predicted that the consistency of the ruminal mat (hard or soft packed) would either promote or retard particle passage from the reticulorumen. In the only previous study with lactating dairy cows, Weidner and Grant (30) observed a 16% decrease in the fractional passage rate of soybean hulls from the rumens of cows fed coarsely chopped hay to increase ruminal mat consistency of an alfalfa and corn silage blend.

Nonforage sources of fiber do not stimulate rumination activity as effectively as dietary forage because of their small particle size (20). Therefore, it is important

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Table 1. Chemical composition and particle distribution of alfalfa silage, alfalfa hay, and wet corn gluten feed.

	Fiber Source (% of DM)		
Item	Alfalfa silage	Alfalfa hay	WCGF[1]
DM, %	46.3	88.9	62.5
CP	21.2	17.6	23.4
ADF	31.6	34.7	11.7
NDF	43.4	47.3	43.9
NE_L, Mcal/kg	1.52	1.19	1.98
Particle distribution[2]			
% ≥ 9.5 mm	27.0	44.0	1.0
3.35 mm ≤ % < 9.5 mm	22.0	24.0	21.0
1.18 mm ≤ % < 3.35 mm	8.0	15.0	10.0
0.3 mm ≤ % < 1.18 mm	3.0	3.5	8.0
0.053 mm ≤ % < 0.3 mm	3.0	1.0	6.5
% < 0.053 mm	37.0	12.5	53.5
Physically effective NDF[3], %			
≥ 1.18 mm	57.0	83.0	32.0
≥ 3.35 mm	49.0	68.0	22.0

[1]Wet corn gluten feed.

[2]Determined by wet sieving.

[3]Physically effective NDF calculated according to Mertens (20). Neutral detergent fiber content of particles retained on 1.18-mm screen and greater was: alfalfa silage, 53.5%; alfalfa hay, 66.5%; and WCGF, 76.5%.

to consider the effective NDF content of these fiber sources. Effective NDF has been estimated with three approaches 1) change in milk fat concentration (2), 2) change in rumination activity (1), and 3) sieving and particle size analysis (20). Ration formulation requires that accurate effective NDF values be determined for nonforage sources of fiber, but various methods of determining effective NDF have resulted in inconsistent values for the same feed. For example, Swain and Armentano (27) measured effective NDF of corn gluten feed (**CGF**), using milk fat percentage as the response variable, and found that in two separate trials the values differed by 56%.

The objectives of this research were 1) to evaluate the effect of altering forage particle size on ruminal mat consistency, rumination activity, passage rate of WCGF, and milk production, and 2) to determine the effective NDF content of WCGF relative to a high-fiber control diet based on response in milk fat concentration, rumination activity, and particle size distributions.

MATERIALS AND METHODS

Cows and Diets

Twelve Holstein dairy cows (8 multiparous including four ruminally fistulated) were used in a replicated 4 × 4 Latin square design with 4-wk periods. Cows averaged 71 ± 25 DIM when they were assigned to diets. Fiber sources compared were alfalfa silage, alfalfa hay, and WCGF. Chemical composition and particle distribution of dietary fiber sources are shown in Table 1. The WCGF was delivered and stored in a plastic silage bag prior to the start of this experiment. There was no visual evidence of molding during feeding.

Dietary treatments were 1) basal low-fiber alfalfa silage diet (**LF**) formulated to contain 23.3% NDF (17.4 percentage units of NDF from alfalfa silage), 2) high-fiber alfalfa silage diet (**HF**) formulated to contain 31.9% NDF (LF diet plus an additional 11.1 percentage units of NDF from alfalfa silage), 3) WCGF diet formulated to contain 31.6% NDF (LF diet plus 10.7 percentage units of NDF from WCGF), and 4) WCGF diet plus coarsely chopped alfalfa hay formulated to contain 32.0% NDF (8.6 percentage units of NDF from alfalfa silage plus 8.9 percentage units of NDF from alfalfa hay and 10.7 percentage units of NDF from WCGF). Diets were formulated to be similar in CP (18% CP, DM basis). The calculated RUP requirements (21) were met by adding Soy Pass (a nonenzymatically browned soybean meal containing 70% RUP manufactured by Lignotech USA, Rothschild, WI) to the diet to achieve 5.6 to 6.3% RUP (DM basis, Table 2). With these diets,

Table 2. Ingredient and chemical composition of dietary treatments.

	Diet[1] (% of DM)			
Item	LF	HF	WCGF	WCGFH
Ingredient				
Alfalfa silage	40.0	65.7	39.8	19.9
Alfalfa hay	. . .	. . .	. . .	18.8
WCGF	. . .	. . .	24.4	24.4
Ground corn	46.3	29.2	28.6	26.9
Soybean meal	6.5	1.7	2.1	4.8
Soy Pass[2]	3.7	. . .	1.7	1.7
Mineral and vitamin mix[3]	3.5	3.5	3.5	3.5
Composition				
DM, %	66.0	56.3	62.0	70.1
NDF	23.3	31.9	31.6	32.0
NDF from Alfalfa silage	17.4	28.5	17.3	8.6
NDF from Alfalfa hay	. . .	. . .	. . .	8.9
NDF from WCGF	. . .	. . .	10.7	10.7
ADF	15.8	22.4	17.3	17.5
CP	18.1	18.0	18.4	18.5
RUP	6.3	5.6	5.7	6.1
NE_L, Mcal/kg[4]	1.78	1.67	1.78	1.73
Particle distribution[5]				
(% of DM retained on screen)				
% ≥ 9.5 mm	10.0	9.8	7.3	11.6
% ≥ 3.35 mm	58.2	52.2	47.4	45.2
% ≥ 1.18 mm	72.3	66.4	60.1	60.3
0.053 mm ≤ % < 1.18 mm	9.8	12.8	14.0	14.1
% < 0.053 mm	17.9	21.1	25.9	25.6

[1]LF = Low fiber, HF = high fiber, WCGF = wet corn gluten feed, WCGFH = WCGF plus hay.

[2]Nonenzymatically browned soybean meal (Lignotech USA, Rothschild, WI).

[3]Supplement contained 7.9% Ca, 2.6% P, 1.8% Mg, 2.2% Na, 1,026 mg/kg of Zn, 718 mg/kg of Mn, 128 mg/kg of Cu, and 15,358, 3,072, and 94,270 IU per kilogram of Vitamin A, D, and E, respectively.

[4]Estimated using values for individual ingredients given by NRC (21).

[5]Determined by wet sieving.

an increase in milk fat concentration or rumination activity for cows fed the LF versus the HF diet would be attributable to additional NDF from alfalfa silage. Similarly, an increase in milk fat concentration or rumination activity for cows fed the LF versus the WCGF diet would be attributable to additional NDF from WCGF. The effect of increasing dietary forage particle length on ruminal mat consistency and passage kinetics of WCGF would be determined by comparing responses to the WCGF diet with or without added chopped hay.

Experimental periods were 28 d; the last 7 d were used for sample and data collection. Diets were fed once daily in amounts to ensure 10% orts. Amounts offered and orts were recorded daily. Body weight was measured each week immediately after a.m. milking. Daily milk production was recorded electronically for all cows. Composite a.m. and p.m. milk samples were collected twice during wk 4 of each period and analyzed for percentage of milk fat, protein, and lactose (3; Milko-Scan Fossomatic; Foss Food Technology Corp., Eden Prairie, MN). Calculation of milk composition was weighted according to a.m. and p.m. milk production. Cows were fistulated and housed under conditions described in animal use protocols approved by the Institutional Animal Care and Use Committee at the University of Nebraska.

Sample Collection and Analysis

Forage, concentrate, and TMR samples were composited daily during the last 7 d of each collection period for chemical analysis. Samples were oven-dried (60°C), ground through a Wiley mill (1-mm screen; Arthur H. Thomas Co., Philadelphia, PA), and analyzed for CP (3), amylase-modified (heat stable α-amylase; ANKOM Tech. Corp., Fairport, NY), ash-free NDF (28), and ADF (28). Sodium sulfite (0.5 g/sample) was added to Soy-Pass samples in an attempt to adequately solubilize all protein complexes, resulting in a more accurate determination of NDF content (15).

Particle size was determined on masticate, ruminal digesta, and fecal samples collected at approximately 4 h postfeeding on the last day of each period. Collection procedures for masticate, dorsal rumen, ventral rumen, reticulum, and fecal samples were as described by Weidner and Grant (30). Two representative subsamples of each sample type were processed and wet sieved in duplicate for 15 min with a vibrational sieve shaker (Fritsch Analysette; Worthington, OH) utilizing a continuous water spray on the top and middle sieves as described by Shaver et al. (25). Sieves were chosen to ensure that less than 2% of the sample was retained on the top screen (with the exception of the hay samples) and less than 20% on each of the subsequent screens. Nine 20-cm diameter sieves from the US Standard Series were used for masticate, digesta, and fecal samples with screen apertures of 12.5, 9.5, 6.3, 3.35, 1.18, 0.6, 0.3, 0.150, and 0.053 mm. The same technique was used to determine particle size distributions for composite TMR, forage, and WCGF samples during each period. Additionally, rumens were emptied, and digesta was weighed and sampled for DM and NDF analyses to determine ruminal fill.

Total chewing, eating, and ruminating times were determined during the last week of each collection period. The chewing action of individual cows was recorded every 5 min for 24 h. Ruminal fluid samples were collected via ruminal fistula immediately beneath the ruminal mat at 4-h intervals for 24 h during the last day of each period. Ruminal pH was determined immediately with a portable pH meter. Samples were frozen until analysis for VFA by GLC with run conditions described by Weidner and Grant (30).

The fractional passage rate of WCGF fiber from the rumen was determined with Er as a rare earth marker. Some evidence exists that rare earth markers may migrate, but this movement would likely occur postruminally and not affect the ruminal passage kinetics reported. Wet corn gluten feed NDF was soaked in a solution containing 87 mg of Er-acetate/g of DM in 7.5 ml of distilled water for 24 h and then soaked in 10 ml of 0.1 *M* acetic acid/g of DM for 6 h. Each fistulated cow was dosed with 100 g (DM basis) of labeled, undried WCGF. Ruminal digesta samples were collected at 0, 6, 12, 24, 36, 48, 72, and 96 h postdosing. Samples were dried in a forced-air oven at 60°C for 48 h and ground through a 1-mm screen (Wiley mill). Erbium was extracted from the samples by 0.1 *M* diethylenetriaminepentaacetic acid solution (17). Erbium concentrations were determined by atomic absorption spectroscopy with an air-acetylene flame. Techniques described by Llamas-Lama and Combs (19) were used to calculate the ruminal escape rate of WCGF.

To determine the fractional rate of ruminal NDF digestion of WCGF, 5-g samples of dried, unground WCGF (60°C, forced-air oven) were measured into Dacron bags by the in situ bag technique. Samples were incubated in duplicate for 0, 6, 12, 24, 36, 48, 72, and 96 h. Dacron bags were 10 × 20 cm with a mean pore size of 53 μm (ANKOM Tech. Corp., Fairport, NY). Upon removal from the rumen, bags were rinsed and dried at 60°C in a forced-air oven for 48 h (32). Bags were weighed and the residue was analyzed for amylase-modified, ash-free NDF. Kinetics of NDF digestion and apparent extent of ruminal fiber digestion, using measured rates of passage and digestion, were calculated as described by Grant (13).

The specific gravity of WCGF was determined by a flotation technique described by Weidner and Grant

(30). Duplicate samples of four treatments were analyzed: WCGF (0 h of ruminal incubation), Er-labeled WCGF (0 h of ruminal incubation), WCGF (3 h of ruminal incubation), and Er-labeled WCGF (3 h of ruminal incubation). Four solutions with specific gravities of 1.0, 1.1, 1.2, and 1.4 at room temperature (23°C) were prepared according to Hooper and Welch (16). The percentage of particles within each specific gravity fraction (DM basis) was calculated.

The effect of increasing dietary particle size on ruminal mat consistency was determined with a technique adapted from Welch (31) as described by Weidner and Grant (30). Ruminal mat consistency was measured at 3 h postfeeding. A 454-g weight was placed in the ventral rumen 1 h prior to measurement to ensure normal mat reformation. Upon release of an exterior 1500-g weight, ascension of the 454-g weight through the ruminal contents was recorded every 10 s for 120 s. The ascension rate, in centimeters per second, was considered to be an indication of ruminal mat consistency.

Data were analyzed as a replicated 4 × 4 Latin square design with model effects for square, cow within square, period, treatment, and square × treatment using the GLM procedure of SAS (24). A multiple t-test was used to determine significance among means for significant main effects (24). Significance was declared at $P < 0.10$ unless otherwise noted.

RESULTS AND DISCUSSION

Dietary Chemical Composition and Particle Size

Chemical composition and particle distribution of fiber sources is presented in Table 1. Although our goal was to have alfalfa hay and silage of similar quality, as sampled and analyzed the quality of the hay was slightly lower than the silage. The NDF of WCGF was similar to alfalfa silage, but ADF was distinctly lower at 11.7 versus 31.6%, respectively. Particle distributions from wet sieving showed that the coarsely chopped alfalfa hay had the greatest particle length; 44% of the particles were retained on the 9.5-mm screen, whereas over 50% of WCGF passed through the 0.053-mm screen. The alfalfa hay contained 63% more large particles (≥9.5-mm screen) than the alfalfa silage. The physically effective NDF (**peNDF**) for the fiber sources, as measured by wet sieving, was greatest for the alfalfa hay and least for the WCGF. Our goals were to manipulate TMR particle size by partially substituting longer particle length hay for silage and to compare the effectiveness of NDF from alfalfa and WCGF that differed substantially in particle size.

Diets LF, HF, and WCGF without hay were formulated by an approach similar to Clark and Armentano (6, 7, 8; Table 2). The LF diet contained 17.4 percentage units of NDF from forage, well below NRC (21) recommendations of approximately 21% NDF from forage. We observed a significant reduction in milk fat percentage and rumination activity for cows fed the LF diet compared with the HF diet. The HF diet contained an additional 11.1 percentage units of NDF from alfalfa silage versus the LF diet. The WCGF diet without hay contained an additional 10.7 percentage units of NDF from WCGF, relative to the LF diet, to provide a direct comparison of the effectiveness of fiber from alfalfa silage versus WCGF. The WCGF diet with 50% of the alfalfa silage replaced by hay provided a test of the effect of TMR particle length on ruminal mat consistency and WCGF passage rate. The HF and WCGF diets all contained similar NDF (31.8% of DM).

Table 3. Consumption of DM, NDF, and ADF by cows fed experimental diets.

	Diet[1]				
Item	LF	HF	WCGF	WCGFH	SE
DMI					
kg/d	24.2[ab]	22.4[b]	25.1[a]	26.1[a]	1.1
% of BW	4.2[ab]	3.9[b]	4.4[a]	4.5[a]	<0.1
NDF					
kg/d	5.7[c]	7.1[b]	8.0[a]	8.3[a]	0.3
% of BW	0.9[c]	1.2[b]	1.4[a]	1.4[a]	<0.1
ADF					
kg/d	3.8[c]	5.0[a]	4.4[b]	4.5[b]	0.2
% of BW	0.7[c]	0.9[a]	0.8[b]	0.8[b]	<0.1

[a,b,c]Means within row with unlike superscripts differ ($P < 0.10$).

[1]LF = Low fiber, HF = high fiber, H = chopped hay, WCGF = wet corn gluten feed, WCGFH = WCGF plus hay.

Table 2 provides the particle distributions of the TMR. The addition of alfalfa hay to the WCGF diet resulted in a 58% increase in particles retained on the 9.5-mm screen compared with the WCGF diet without hay. The WCGF diets with or without hay both contained a larger proportion of particles <0.053 mm than the LF and HF diets which was probably due to the small particle size of the WCGF. A greater percentage of particles was retained on the 3.35 and 1.18-mm screens for the LF diet compared with the WCGF diets. This distribution was due to the higher content of corn in the LF diet which was retained on these screens.

Nutrient Intake, Milk Production, and Composition

Cows fed the WCGF diets consumed the greatest amount of DM (Table 3). This higher DMI likely reflected the smaller particle size of the WCGF diets and the faster rate of passage for WCGF versus alfalfa silage (Table 4). Consumption of NDF in kilograms per day was greatest for the WCGF diets, intermediate for the HF diet, and least for the LF diet. The WCGF was relatively low in ADF content compared with alfalfa

Table 4. Ruminal content characteristics, passage rate of WCGF NDF, and in situ NDF digestion kinetics of WCGF.

Item	Diet[1]				SE
	LF	HF	WCGF	WCGFH	
Rumen contents					
Wet weight, kg	182.9	187.9	170.1	184.4	8.9
Dry matter, %	18.5	19.5	20.0	20.5	
Dry weight, kg	33.8	36.7	34.0	37.8	1.8
NDF, % of DM	60.0	65.0	67.5	65.0	0.3
NDF, kg	20.3[c]	24.7[a]	22.4[bc]	24.3[ab]	0.8
Rate of passage, %/h	5.20[ab]	4.20[b]	6.40[a]	4.20[b]	0.60
Digestion kinetics					
Lag, h	5.80	4.20	5.40	3.50	1.14
k_d, %/h	5.40[ab]	6.70[a]	6.40[ab]	5.10[b]	0.50
PED[2], %	92.8	92.8	92.9	92.7	0.6
AED[3], %	32.6[b]	47.4[a]	32.4[b]	44.8[a]	2.3

[a,b,c]Means within a row with unlike superscripts differ ($P < 0.10$).

[1]LF = Low fiber, HF = high fiber, WCGF = wet corn gluten feed, WCGFH = WCGF plus hay.

[2]Potential extent of ruminal NDF digestion calculated using equations in Grant (13).

[3]Apparent extent of ruminal NDF digestion calculated using equations in Grant (13).

silage (11.7 vs. 31.6% ADF, respectively); therefore, intake of ADF was highest for the HF diet when calculated both as percentage of BW and in kilograms per day. Averaged over all diets, NDF intake was 1.23% of BW which is typical of cows in this stage of lactation consuming diets containing nonforage sources of fiber (20).

Milk fat concentration was significantly less for cows fed the LF diet compared with cows fed the HF diet. This response can be attributed to inadequate amount and physical form of NDF needed for acetate production and maintenance of milk fat synthesis for cows fed the LF diet. The increase in milk fat percentage for cows fed the HF diet can be attributed to additional alfalfa silage and to additional NDF from WCGF in the WCGF plus hay diet. The change in milk fat concentration was used to calculate an effective NDF factor for WCGF.

Milk protein concentration was different among treatments (Table 5). Cows fed the WCGF diet with added hay produced significantly greater milk protein than cows fed the HF diet although the difference was small at 0.15 percentage units.

Chewing Activity, Ruminal pH, and VFA

Dairy cattle require fiber of adequate particle size to maintain a ruminal environment conducive to animal health. Chewing activity has been a measure of forage physical form since the roughage value index proposed by Balch (4). Recently, rumination activity has been used as an estimate of the physical effectiveness of fiber sources at stimulating salivary secretion and ruminal buffering (1). Table 6 summarizes chewing activity as influenced by dietary treatment. Cows fed the HF diet spent significantly more time eating and ruminating per day compared with the LF diet. The addition of chopped alfalfa hay to the WCGF diet resulted in rumination activity similar to the HF diet (475 and 504 min/d, respectively). By increasing dietary particle size with replacement of 47% of the alfalfa silage with alfalfa hay, chewing activity was increased for the WCGF diet with hay versus the same diet without hay. These results are similar to Weidner and Grant (30) who observed that chewing activity increased 24% with the addition of alfalfa hay to a 25% soybean hull diet fed to lactating dairy cows. Figure 1 illustrates the cumulative time spent ruminating for all treatments during a 24-h period. By 4 h postfeeding, rumination activity

Table 5. Lactational performance of cows as influenced by experimental diets.

Item	Diet[1]				SE
	LF	HF	WCGF	WCGFH	
Milk, kg/d	31.2	29.4	32.7	33.7	1.9
Fat					
%	2.90[b]	3.25[a]	3.15[ab]	3.14[ab]	0.11
kg/d	0.90	0.97	0.98	1.06	0.08
Protein					
%	2.97[ab]	2.85[b]	2.95[ab]	3.00[a]	0.06
kg/d	0.91[ab]	0.84[b]	0.96[ab]	1.01[a]	0.06
Lactose					
%	4.87	4.86	4.89	4.88	0.07
kg/d	1.52	1.43	1.60	1.65	0.10
4% FCM, kg/d	26.0	26.2	27.9	29.4	1.9
4% FCM/DMI, kg/kg	1.07	1.17	1.11	1.13	0.06
BW, kg	584	573	570	584	6

[a,b]Means within a row with unlike superscripts differ ($P < 0.10$).

[1]LF = Low fiber, HF = high fiber, WCGF = wet corn gluten feed, WCGFH = WCGF plus hay.

Table 6. Chewing activity as influenced by diet.

Activity	Diet[1] LF	HF	WCGF	WCGFH	SE
Eating					
min/d	190[b]	237[a]	175[b]	192[b]	17
min/kg of NDF intake	33.5[a]	34.9[a]	22.5[b]	24.1[b]	2.8
Ruminating					
min/d	339[b]	504[a]	356[b]	475[a]	23
min/kg of NDF intake	61.4[b]	73.0[a]	46.5[c]	59.2[b]	3.5
Total chewing[2]					
min/d	529[c]	740[a]	531[c]	667[b]	23
min/kg of NDF intake	94.9[b]	107.9[a]	69.0[d]	83.3[c]	4.5

[a,b,c,d]Means within a row with unlike superscripts differ ($P < 0.10$).

[1]LF = low fiber, HF = high fiber, WCGF = wet corn gluten feed, WCGFH = WCGF plus hay.

[2]Eating plus ruminating times.

Table 7. Ruminal pH and VFA as influenced by diet.

Item	Diet[1] LF	HF	WCGF	WCGFH	SE
pH	5.95[b]	6.36[a]	6.00[b]	6.14[b]	0.08
Total VFA, m*M*/L	104.5	102.7	103.8	104.5	0.9
VFA, mol/100 mol					
Acetate (A)	57.2	56.0	57.0	56.9	0.6
Propionate (P)	25.9	25.4	25.6	25.7	0.3
n-Butyrate	16.8	16.9	16.8	17.1	0.4
Isobutyrate	1.3	1.2	1.3	1.2	0.1
n-Valerate	1.8	1.7	1.6	1.9	0.2
Isovalerate	1.6	1.6	1.6	1.7	<0.1
A:P	2.2	2.0	2.2	2.2	<0.1

[a,b]Means within a row with unlike superscripts differ ($P < 0.10$).

[1]LF = Low fiber, HF = high fiber, WCGF = wet corn gluten feed, WCGFH = WCGF plus hay.

was already significantly greater for cows fed the HF and WCGF plus hay diets compared with cows fed the LF and WCGF diet without hay.

Ruminal pH was greatest for the HF diet (6.36; Table 7). Because rumination activity stimulates salivary secretion of bicarbonate and phosphate buffers (1), ruminal pH would be expected to be higher for diets that stimulate greater rumination. Ruminal pH was numerically higher for the WCGF plus hay diet versus the WCGF diet. Furthermore, the pH values for the LF, HF, and WCGF diets resulted in a calculated effectiveness factor for NDF from WCGF of approximately 13%. Allen (1) has suggested the use of ruminal pH as an accurate estimate of the physical and chemical characteristics of fiber from nonforage sources of fiber.

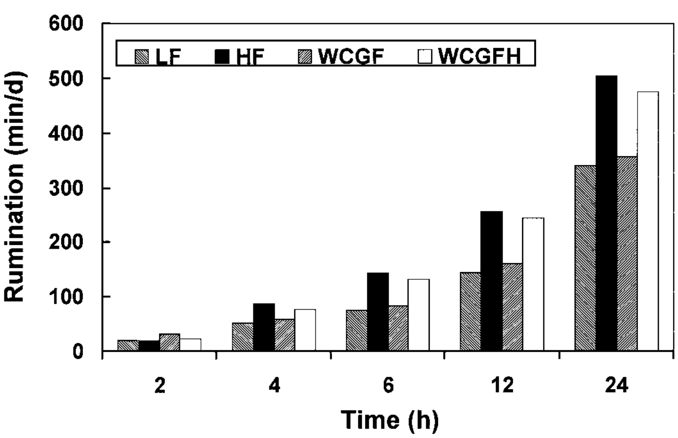

Figure 1. Rumination activity by diet at 2, 4, 6, 12, and 24 h after morning feeding. By 4 h postfeeding, rumination was significantly ($P < 0.10$) greater for cows fed the high fiber (HF) and wet corn gluten feed plus hay (WCGFH) diets compared with the low fiber (LF) and wet corn gluten feed without hay (WCGF) diets. Pooled SE for all treatments was 16 min/d.

Increased dietary NDF for the HF and WCGF diets did not result in greater acetate to propionate ratios which averaged 2.15 for all diets (Table 7). In contrast, Weidner and Grant (30) observed a significant increase in acetate to propionate ratio when alfalfa hay replaced a portion of the silage in a diet containing 25% soybean hulls fed to lactating dairy cows.

Ruminal Mat Consistency, Passage Rate, and In Situ Digestion Kinetics

Specific gravity and particle size account for 88% of the variation in particle passage from the rumen (18). The influence of dietary particle size on ruminal mat consistency has been documented by Weidner and Grant (30) in lactating dairy cows, Welch (31) in sheep and beef steers, and Sutherland (26) in sheep. Nonforage sources of fiber often have both a high specific gravity and small particle size, resulting in decreased ruminal retention time and lowered NDF digestibility. Therefore, the addition of alfalfa hay to the WCGF diet allowed a comparison of the effects of increasing dietary particle length on ruminal mat consistency, particle retention time, and ruminal NDF digestibility. At 3 h postfeeding, the WCGF diet with chopped hay had a significantly slower rate of ascension (centimeters per second) than the WCGF diet (Table 8) reflecting a more consistent, hard-packed ruminal mat. The total distance traveled in 120 s was also greater for the WCGF diet compared with the WCGF diet plus hay. Adding alfalfa hay decreased the ascension rate similar to the HF diet, whereas the WCGF diet was similar to the LF diet (0.26 versus 0.28, cm/s, respectively). These results reinforce the conclusions of Weidner and Grant (30); replacement of 75% of an alfalfa and corn silage mixture with 25% soybean hulls and 20% coarsely chopped alfalfa hay resulted in increased ruminal mat consistency and decreased ascension rate from 9.9 cm/min to 7.6

Table 8. Ruminal mat consistency as influenced by dietary treatment.

	Diet[1]				
Item	LF	HF	WCGF	WCGFH	SE
Distance traveled, cm					
10 s	8.3[a]	3.0[b]	7.3[a]	4.0[b]	1.2
120 s	34.0[a]	17.0[c]	31.4[a]	23.4[b]	1.4
Ascension rate, cm/sec					
10 s	0.80[a]	0.30[c]	0.70[ab]	0.40[bc]	0.10
120 s	0.28[a]	0.14[c]	0.26[a]	0.19[b]	<0.10

[a,b]Means within a row with unlike superscripts differ ($P < 0.10$).

[1]LF = Low fiber, HF = high fiber, WCGF = wet corn gluten feed, WCGFH = WCGF plus hay.

cm/min for a 25% soybean hull minus hay and a 25% soybean hull plus hay diet, respectively.

Table 4 contains the rate of passage and in situ digestion data for the diets. The HF diet resulted in the greatest amount of ruminal NDF, and the LF diet resulted in the least amount of NDF. The rate of ruminal passage of soybean hulls has varied considerably depending on the source and amount of the forage fed (12). By altering ruminal mat consistency with the addition of chopped hay, Weidner and Grant (30) showed a 15% decrease in ruminal rate of passage of soybean hulls. Passage rate of dry CGF has been reported to vary from 0.027 to 0.048/h (22). We observed that passage of WCGF from the rumen was significantly decreased for the WCGF diet plus hay compared with the WCGF diet (0.042 vs. 0.068/h, respectively).

The apparent extent of ruminal NDF digestion was calculated as described by Grant (13) and combined both NDF digestion and passage. By decreasing ruminal rate of passage, the addition of alfalfa hay resulted in an increased extent of digestion for the WCGF diet versus the WCGF diet without added hay (47.4 vs. 32.4%, respectively). These results are similar to research summarized by Grant (14), in which addition of hay to an all soybean hull or soy flake diet increased NDF digestibility from 58.7 or 68.5%, respectively, to 84.1% when fed to sheep, steers, or cows.

Particle Distributions

Evans et al. (11) observed that specific gravity and particle size differed at various sampling sites within the rumen. Table 9 presents particle distributions of masticate, ruminal digesta, and fecal samples by dietary treatment. For masticate samples, the HF diet had the greatest percentage of particles retained on the 9.5-mm screen, the WCGF diet with hay was intermediate, and the WCGF and LF diets were least.

Sampling of the dorsal ruminal contents indicated that the HF and WCGF diet plus hay had the greatest percentage of particles retained on the 9.5-mm or greater screen. For both the dorsal and ventral ruminal contents, the HF and WCGF plus hay diets contained the greatest percentage of smaller particles (0.053 ≤ % <1.18 mm). Samples collected near the reticulo-omasal orifice contained fewer small particles for the WCGF diet with hay than the WCGF diet suggesting greater particle entrapment. A more developed ruminal mat for the WCGF diet plus hay did would presumably increase particle entrapment, resulting in slower passage, greater extent of digestion, and more particle breakdown from increased rumination activity versus the WCGF diet.

Particle distributions for fecal samples indicate that LF and WCGF without hay diets had a significantly greater percentage of particles retained on 1.18-mm screens (30.8 and 27.9%, respectively) compared with the HF (22.7%) and WCGF plus hay diets (20.9%). Grant and Weidner (30) speculated that lower rumination time per unit of fiber intake as a result of increased intake (as in the LF diet) may be responsible for the increased mean size of fecal particles. This response in fecal particle size could also be due to a reduced ruminal mat, rumination, and particle retention in the rumen.

Specific Gravity of Wet Corn Gluten Feed

Specific gravity accounts for 59% of variation in mean retention of plastic particles in the rumen of sheep (18). Optimal functional specific gravity for particle passage from the rumen is between 1.2 and 1.5 (5). Most nonforage sources of fiber have a small enough particle size so that ruminal passage would be dictated by functional specific gravity and particle entrapment in the ruminal mat. Passage and functional specific gravity of particles may be altered if forages are mordanted with a rare-earth marker used to measure passage rate (10).

Therefore, specific gravity of WCGF was determined at 0 or 3-h ruminal incubation with or without Er labeling. Table 10 shows the specific gravity of WCGF as influenced by fermentation and labeling with Er. At 0-h ruminal incubation, 57.6% of Er-labeled WCGF had a specific gravity of >1.4, whereas no Er label resulted in the greatest percentage of particles between 1.2 and 1.4 specific gravity. Therefore, 60% of WCGF particles were at a specific gravity that would not restrict passage. When exposed to ruminal fermentation for 3 h, with or without the Er label, a similar percentage of particles were >1.4 specific gravity (32.5 and 34.8%, respectively). Therefore, extent of digestion of WCGF may be compromised if particles do not become entrapped in the ruminal mat. Bhatti and Firkins (5) measured functional specific gravity of CGF at 4 h of ruminal incubation to be 1.13, but at 0.5 h of ruminal incubation functional specific gravity was 1.33. There-

Table 9. Influence of diet on particle size distributions of masticates, ruminal digesta, and feces as determined by wet sieving.

Sample site		Diet[1] (% of DM retained on screen)				
Source	Screen size (mm)	LF	HF	WCGF	WCGFH	SE
Diet	% ≥ 9.5	10.0	9.8	7.3	11.6	1.8
	% ≥ 3.35	58.2[a]	52.2[ab]	47.4[b]	45.2[b]	2.9
	% ≥ 1.18	72.3[a]	66.4[ab]	60.1[b]	60.3[b]	2.3
	0.053 ≤ % < 1.18	9.8	12.8	14.0	14.1	2.1
	% < 0.053	17.9[b]	21.1[ab]	25.9[a]	25.6[a]	2.1
Masticate	% ≥ 9.5	9.3[b]	14.4[a]	10.5[b]	11.6[ab]	1.6
	% ≥ 3.35	36.5	34.5	35.0	36.1	2.4
	% ≥ 1.18	56.8[a]	51.0[b]	50.7[b]	55.1[ab]	2.2
	0.053 ≤ % < 1.18	16.6[b]	17.6[ab]	15.4[b]	20.1[a]	1.3
	% < 0.053	26.6	31.4	31.3	28.8	2.6
Dorsal	% ≥ 9.5	7.7[c]	10.2[ab]	8.8[bc]	11.7[a]	1.0
	% ≥ 3.35	26.3	27.9	26.7	27.5	1.8
	% ≥ 1.18	44.1[a]	40.4[b]	42.8[ab]	44.9[a]	1.3
	0.053 ≤ % < 1.18	23.1[b]	26.7[a]	22.2[b]	25.6[a]	1.0
	% < 0.053	32.8	33.0	31.2	29.5	1.9
Ventral	% ≥ 9.5	9.0	11.2	11.0	9.0	1.2
	% ≥ 3.35	26.1[b]	24.7[b]	29.6[a]	23.3[b]	1.5
	% ≥ 1.18	44.7[b]	41.4[b]	48.9[a]	41.4[b]	1.7
	0.053 ≤ % < 1.18	25.1[ab]	27.7[a]	23.1[b]	26.3[a]	1.3
	% < 0.053	30.2	30.9	28.0	32.4	2.5
Reticulum	% ≥ 9.5	3.2	4.1	3.6	2.9	0.5
	% ≥ 3.35	10.5	11.2	11.3	8.5	1.4
	% ≥ 1.18	24.7[a]	22.0[ab]	23.7[ab]	19.1[b]	2.3
	0.053 ≤ % < 1.18	30.0[a]	28.0[ab]	25.6[ab]	24.3[b]	2.2
	% < 0.053	45.3[b]	47.8[b]	50.7[ab]	56.6[a]	3.6
Feces	% ≥ 9.5	0.9[ab]	1.6[a]	0.6[b]	0.9[b]	0.3
	% ≥ 3.35	21.1[a]	11.1[c]	14.9[b]	9.3[c]	1.5
	% ≥ 1.18	30.8[a]	22.7[b]	27.9[a]	20.9[b]	1.4
	0.053 ≤ % < 1.18	25.4[c]	30.7[a]	27.1[bc]	28.9[ab]	1.1
	% < 0.053	44.3[b]	47.6[ab]	45.0[b]	50.2[a]	1.4

[a,b,c]Means within a row with unlike superscripts differ ($P < 0.10$).

[1]LF = Low fiber, HF = high fiber, WCGF = wet corn gluten feed, WCGFH = WCGF plus hay.

fore, the fast rate of digestion of WCGF could potentially increase buoyancy of particles within the rumen.

Effective NDF of Wet Corn Gluten Feed

Three methods have been used to determine effective NDF 1) change in milk fat concentration, 2) change in rumination activity, and 3) evaluation of particle size distributions. Clark and Armentano (6, 7, 8) estimated effective NDF by change in milk fat concentration by the slope-ratio technique. Because milk fat is dependent on fiber digestion and production of fermentation acids in the rumen, it is thought to be the most complete measure of effective NDF (2). In our study, an effective NDF value based on change in milk fat concentration was calculated by the slope-ratio technique as shown in Table 11. Milk fat increased in HF and WCGF diets compared with the LF diet to yield an effective NDF factor of 0.74 for WCGF if alfalfa silage is assumed to be 1.0. Therefore, WCGF contained 32.9% effective NDF based on change in milk fat percentage. Using the same technique to calculate peNDF based on change in rumination activity, the peNDF factor for WCGF was 0.11 compared with an assumed value of 1.0 for alfalfa silage. An effective NDF factor based on change in ruminal pH (Table 7) of 0.13 was similar to the peNDF value for rumination activity. The large range in values may reflect the chemical and physical attributes of WCGF as a highly digestible fiber that is capable of diluting

Table 10. Percentage of particles at varying specific gravities for wet corn gluten feed (WCGF) at 0 and 3 h of ruminal incubation with or without erbium label.

Specific gravity fractions	Treatment[1]				SE
	0 h	0 h+Er	3 h	3 h+Er	
% ≤ 1.0	3.4[b]	5.4[ab]	8.6[a]	3.9[b]	1.5
1.0 < % ≤ 1.1	12.6[ab]	5.5[c]	18.4[a]	9.2[bc]	2.1
1.1 < % ≤ 1.2	23.1[a]	9.0[b]	15.4[ab]	20.1[a]	3.4
1.2 < % ≤ 1.4	40.5[a]	22.4[b]	22.9[b]	34.3[ab]	5.5
% > 1.4	20.4[b]	57.6[a]	34.8[b]	32.5[b]	7.5

[a,b,c]Means within row with unlike superscripts differ ($P < 0.10$).

[1]0 h = WCGF at 0 h ruminal incubation, 0 h+Er = erbium labeled WCGF at 0 h ruminal incubation, 3 h = WCGF at 3 h ruminal incubation, and 3 h+Er = erbium-labeled WCGF at 3 h ruminal incubation.

Table 11. Calculation of effective NDF and physically effective NDF based on change in milk fat concentration and rumination activity as influenced by dietary treatment.

	Fiber source	
Item	Alfalfa silage	WCGF[1]
Milk fat[2]		
Increase in milk fat %, a	0.35	0.25
Added NDF %, b	11.00	10.70
Slope, a/b	0.03	0.02
eNDF factor[3]	1.00	0.74
Chemical NDF, %	43.40	43.90
Effective NDF, %	43.40	32.90
Rumination activity[4]		
peNDF factor	1.00	0.11
Physically effective NDF, %	43.40	4.80
Ruminal pH[5]		
eNDF factor	1.00	0.13
Effective NDF, %	43.40	5.71

[1]WCGF = Wet corn gluten feed.

[2]Based on data in Table 5.

[3]Effectiveness of alfalfa assumed to be 1.0.

[4]Based on data in Table 6.

[5]Based on data in Table 7.

dietary NFC and slowing the rate of fermentation acids production, yet is only 11% as effective as alfalfa silage at maintaining rumination activity due to its small particle size.

A major assumption in determination of effective NDF and peNDF values based on animal response is their ability to replace the standard forage used in each separate trial. If the alfalfa silage that was used in our trial was not 100% effective (as we assumed), values calculated for WCGF would be different. Mertens (20) proposed comparing fiber sources to a hypothetical long grass hay as the standard forage. To date, most reported values based on animal responses have used alfalfa as the standard forage (1, 6, 7, 8, 27).

Mertens (20) proposed using the laboratory technique of particle sieving based on research by Poppi et al. (23). In our study, particle distributions were determined for each fiber source (Table 1). Particles retained on the 1.18-mm screen and greater were 57, 83, and 32% for alfalfa silage, alfalfa hay and WCGF, respectively. These larger particles require rumination and reduction in size for passage from the reticulorumen to occur. Shaver et al. (25) concluded that particles retained on the 3.35-mm screen and greater were more applicable to larger ruminants. Therefore, the peNDF factor for WCGF would be 0.22 compared with alfalfa silage at 0.49. This result suggests that the alfalfa silage used in our experiment was not 100% effective, emphasizing the need to standardize effective NDF values based on one fiber source.

Another assumption inherent in the slope-ratio technique to calculate effectiveness factors is that the HF diet results in milk fat concentration still in the linear range and that milk fat has not reached a plateau at a lower dietary forage NDF concentration. The milk fat concentration versus dietary NDF relationship varies enough to be justified in assuming that milk fat concentration from the HF diet was still within this range for our experiment. If, in fact, milk fat had reached a plateau at a lower NDF from forage, then the calculated effective NDF value based on milk fat in our study would be smaller (due to a steeper slope), falling more in line with predicted values based on rumination activity, ruminal pH, and particle size. To date, all reported values (2) have relied on two points to calculate the slope of the response line; future research to determine the effectiveness of fiber sources using the slope-ratio approach should use more points to eliminate this concern when interpreting the data.

CONCLUSIONS

Incorporation of WCGF into the diet resulted in increased DMI, increased NDF intake, sustained milk composition, and reduced rumination, but had little effect on ruminal pH and VFA. It appeared that WCGF provided sufficient fermentable carbohydrates to maintain milk protein and not depress milk fat synthesis. Coarsely chopped hay decreased passage rate of WCGF, increased rumination activity, and increased ruminal extent of NDF digestion compared with the WCGF diet without hay. Effective NDF values can vary substantially depending on the response variable chosen to calculate the effectiveness factor. To be conservative, a smaller peNDF value should be used, which would avoid a situation in which ruminal acidosis could occur. More research is needed to confirm if some nonforage sources of fiber, such as WCGF, have effectiveness factors greater than 50%. Quantitating the impact of dietary forage on utilization of nonforage sources of fiber will allow us to define accurately the peNDF requirement of lactating dairy cows.

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