Substitution of Neutral Detergent Fiber from Forage with Neutral Detergent Fiber from By-Products in the Diets of Lactating Cows

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ABSTRACT

Four lactating dairy cows that were ruminally and duodenally cannulated were used in an experiment with a 4 × 4 Latin square design to determine the effects of the substitution of neutral detergent fiber (NDF) from forage with NDF from wheat middlings, corn gluten feed, or a blend of distillers dried grains and hominy. Dietary crude protein and NDF averaged 18 and 31%, respectively, for the diet with 71.2% of the NDF from forage (control diet) and for diets with 55% of the NDF from forage (by-product diets). The substitution of NDF from these by-products for forage NDF did not affect dry matter intake (20.1 kg/d) or digestibility of organic matter. Total tract digestibility of acid detergent fiber was lower for cows fed the diet containing a blend of distillers dried grains and hominy than for cows fed the diet containing corn gluten feed. Microbial crude protein synthesis, milk production (23.9 kg/d), and milk fat percentage were similar for all cows, regardless of diet. Cows fed the diets containing wheat middlings or a blend of distillers dried grains and hominy had reduced ruminal pH compared with that of cows fed the diet containing corn gluten feed or the control diet. Diets containing 55% of total NDF from forage with 31% of total NDF from corn gluten feed, wheat middlings, or a blend of distillers dried grains and hominy can supply sufficient effective fiber to maintain normal ruminal function.

(**Key words**: by-products, forage, neutral detergent fiber)

Abbreviation key: **CGF** = corn gluten feed, **DDGH** = blend of distillers dried grains and hominy, **NSC** = nonstructural carbohydrate, **WM** = wheat middlings.

INTRODUCTION

Interest in by-product feeds, such as corn gluten feed (**CGF**), distillers dried grains, wheat middlings (**WM**), and hominy, as alternative feeds for dairy cows has increased over the past several years. By-products of the milling industry have a combination of energy sources for ruminal microbes including both nonstructural carbohydrate (**NSC**; approximately 25%) and a readily digestible NDF fraction (19). A balance in availability of carbohydrate and CP from the by-products and the availability of the rest of the diet may optimize ruminal fermentation and microbial protein synthesis (16); however, the NDF of by-products has physical and chemical properties that differ from the NDF of forage, which may reduce cow performance. A minimum of 26 to 28% NDF in total dietary DM with 75% of the NDF from forage is recommended (8). Few data are available to document the effect of the substitution of by-product NDF for forage NDF. Our objective was to determine the effects of the substitution of forage NDF with NDF from by-products [CGF, WM, and a blend of distillers dried grains and hominy (**DDGH**)] on DMI, ruminal digestion of nutrients, microbial CP synthesis, and lactation.

MATERIALS AND METHODS

Four multiparous Holstein cows were fitted with duodenal cannulas [2.5 cm i.d., T-type rigid cannulas (6); Ankom Tech. Corp., Fairport, NY] 70 d prior to calving and were maintained on grass hay until calving. At 1 wk postpartum, each cow was fitted with a ruminal cannula, and experimental diets were introduced at 56 d into lactation. Four diets (Table 1), which were designed to be isocaloric (1.63 Mcal of NE_L/kg of DM) and isonitrogenous (18.2% CP), were fed in a 4 × 4 Latin square design. The control diet contained a ratio of forage to concentrate of 46:54; 71.2% of the NDF was from forage. For the diets containing WM, CGF, and DDGH, 54.7, 54.5, and 54.3%, respectively, of the NDF was from forage. The

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diet containing DDGH had a ratio of distillers dried grains to hominy of 1.4:1 and was designed to have a starch content that was similar to that of the other by-product diets. Diets were fed as a total mixed diet for ad libitum intake (>10% orts) at 0600 and 1800 h. Experimental periods were 18 d in length; 12 d were used for adaption to the diets, and 6 d were used for sample collection.

Feed intakes were measured daily, and diets were sampled weekly. Samples were dried in a forced-air oven (55°C) to determine DM. Orts were obtained daily during the last 6 d of each period, composited for each cow on a proportional basis, and dried (55°C) for subsequent analysis. Composite samples were ground through a Wiley mill (1-mm screen; Arthur H. Thomas, Philadelphia, PA) and analyzed for DM, OM, and CP (1); ADF and NDF (18); and NSC [(12); modified to use ferricyanide as a colorimetric agent]. Milk production was recorded daily at each milking (two a.m. samples and two p.m. samples). Samples were collected on d 15 and 18 of each period. Milk samples were composited by day according to milk production and stored at 4°C. Samples were analyzed for protein (N × 6.38) by the standard Kjeldahl method (1) and for fat by the Babcock method (1).

On d 3 to 16 of each period, 10 g of chromic oxide were dosed intraruminally twice daily prior to each feeding as a marker to measure nutrient digestibilities. On d 13 to 16, duodenal digesta and fecal grab samples were collected at 12-h intervals starting at 0600 h; collection times were postponed 3 h daily. Approximately 500 ml of duodenal digesta were collected and composited at each sampling time and frozen (–20°C) until analysis. After thawing, 100 ml of duodenal sample were centrifuged at 1000 × *g* for 10 min at 0°C and analyzed for ammonia (1). The remaining portion was dried at 55°C and ground through a 1-mm screen. Fecal samples were frozen at the time of collection, thawed, and composited for each cow on an equal wet weight basis before analysis. Fecal composites were dried at 55°C and ground as described previously. Fecal and duodenal samples were analyzed for DM, OM, CP, ADF, NDF, and NSC using the methods described for feed analysis. Chromium content was determined by spectrophotometry as described by Fenton and Fenton (4). Duodenal samples were also analyzed for purines using the method of Zinn and Owens (21).

Cobalt-EDTA (2 g) was dosed intraruminally on d 17 of each period at 0600 h to determine the fractional dilution rate (20). Ruminal fluid samples were obtained at 3, 6, 9, 12, 18, 22, and 24 h postdosing. The procedure was repeated on d 18 with sampling at 0, 3, 6, 9, and 12 h postdosing. Samples were squeezed through three layers of cheesecloth, and pH was determined immediately. One-half (140 ml) of the sample was added to a composite vessel containing saline-formalin as a preservative for bacterial harvesting (21). The remainder of the sample was acidified (final pH <2) with 50% sulfuric acid and frozen (–20°C) for subsequent analysis. After thawing, the acidified sample was divided for analyses of ammonia, Co (15), and VFA concentrations. To calculate the fractional dilution rate, the concentration of Co on d 18 was corrected for residual Co on d 17. Dilution rates of the ruminal fluid fraction were calculated from the slopes of the natural logarithms of

TABLE 1. Ingredient and chemical composition of diets.[1]

Composition	Diet[2]			
	Control	WM	CGF	DDGH
Ingredient, % of DM				
Alfalfa haylage	21.4	14.0	5.0	21.0
Corn silage	25.0	26.0	35.0	19.0
Ground corn	31.4	20.3	15.0	20.6
WM	. . .	22.0	. . .	. . .
CGF	. . .	. . .	33.0	. . .
Dried distillers grains	. . .	. . .	. . .	17.0
Hominy	. . .	. . .	. . .	12.0
Soybean meal (44% CP)	17.6	10.0	5.5	6.7
Meat and bone meal	1.6	5.0	3.8	1.5
Mineral and vitamin mix[3]	2.3	2.0	2.0	1.5
Sodium sesquicarbonate	0.7	0.7	0.7	0.7
Chemical				
NE_L,[4] Mcal/kg of DM	1.7	1.6	1.7	1.7
CP, % of DM	18.8	18.1	17.5	18.6
Total carbohydrate, % of DM	65.7	68.8	66.0	66.5
% from By-product	. . .	55.5	55.3	58.7
NSC,[5] % of DM	30.3	30.4	26.2	29.9
NDF, % of DM	28.9	32.2	31.8	32.2
% from Forage	71.2	54.7	54.5	54.3
% from By-product	. . .	29.4	32.4	30.5
ADF, % of DM	16.7	16.0	15.6	16.5
% from Forage	82.2	71.1	67.1	73.3
% from By-product	. . .	16.1	24.3	17.7
F:C[6]	46:54	40:60	40:60	40:60

[1]Balanced to meet NRC (8) requirements for a 600-kg cow producing 35 kg of milk (3.5% fat).

[2]In the experimental diets, the NDF from forage (corn and soybean meal) in the control diet was substituted with NDF from by-products [wheat middlings (WM), corn gluten feed (CGF), or a blend of distillers dried grains and hominy (DDGH)].

[3]Mineral and vitamin mix included limestone, dicalcium phosphate, Dynamate® (Mallinckrodt Veterinary, Inc., Mundelein, IL), trace minerals, and a vitamin A, D, and E premix. The premix supplied 1.0% Ca and 0.45% P, had a N:S of 10:1, and meet NRC (8) requirements.

[4]Calculated using NRC (8) values.

[5]Nonstructural carbohydrate based on enzymatic analysis of alfalfa haylage, corn silage, and a concentrate mixture fed during the trial.

[6]Ratio of forage to concentrate.

the Co concentrations over time for d 17 and 18; the mean fractional dilution rate was used for statistical analysis. Ammonia concentrations in ruminal fluid were determined by distillation of samples treated with MgO according to the AOAC (1) method. Ruminal fluid VFA were determined according to the procedures described by Erwin et al. (2) with an automated GLC (model 940; Varian Chromatography Systems, Walnut Creek, CA). Microbes were harvested from the saline-formalin collection using the differential centrifugation technique described by Smith and McAllan (13). Harvested microbes were dried at 55°C and ground through a 1-mm screen. The bacterial samples were analyzed for DM, OM, CP, and purines by the methods described previously. The ratio of N to purine was used to calculate the flow of bacterial N to the duodenum.

Mean values for milk production from d 13 to 18 of each period and milk composition on d 15 and 18 were used to test the effects of diet. Data were analyzed by the general linear models procedure of SAS (10). Sources of variation included in the model were diet (treatment), cow, and period. If treatment effects were significant, means were compared using Scheffe's multiple range test (10). Significance was declared at $P < 0.05$.

RESULTS AND DISCUSSION

The four experimental diets and their compositions are described in Table 1. The contributions of forage NDF to total dietary NDF for diets containing WM, CGF, or DDGH averaged 54.5%; a mean 30.7% of NDF was supplied from the by-products.

Intakes of OM and NSC did not differ across diets (Table 2). Apparent and true ruminal digestibilities of OM (corrected for microbial OM) and NSC were also similar across diets.

Diet did not affect intake or apparent ruminal digestion of ADF (Table 2). Cows fed the diet con-

TABLE 2. Intake and digestibility of OM, nonstructural carbohydrate (NSC), ADF, and NDF in response to diet.

	Diet[1]				
Item	Control	WM	CGF	DDGH	SEM
OM					
Intake,[2] kg/d	19.0	17.3	18.2	18.5	1.3
Apparent ruminal OM digestion, % of intake	46.6	45.8	45.0	39.1	3.3
True ruminal OM digestion,[3] % of intake	56.6	55.4	55.9	50.8	2.9
Apparent total tract OM digestion, % of intake	63.3	67.1	66.3	66.1	1.7
NSC					
Intake,[2] kg/d	6.0	5.5	4.8	5.8	0.4
Apparent ruminal NSC digestion, % of intake	63.8	59.6	57.1	63.7	4.0
Apparent total tract NSC digestion, % of intake	94.9	96.5	96.3	94.8	0.9
ADF					
Intake,[2] kg/d	3.3	3.0	3.3	3.2	0.2
Apparent ruminal ADF digestion, % of intake	33.3	27.4	33.7	30.4	3.5
Apparent total tract ADF digestion, % of intake	33.4[ab]	33.1[ab]	42.5[a]	30.3[b]	3.4
NDF					
Intake,[2] kg/d	5.6	5.8	6.3	6.5	0.4
Apparent ruminal NDF digestion, % of intake	33.7	32.6	39.7	37.9	2.4
Apparent total tract NDF digestion, % of intake	33.3	35.7	43.4	39.5	2.6

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

[1]In the experimental diets, the NDF from forage (corn and soybean meal) in the control diet was substituted with NDF from by-products [wheat middlings (WM), corn gluten feed (CGF), or a blend of distillers dried grains and hominy (DDGH)].

[2]Adjusted for composition of orts.

[3]True ruminal OM digestion corrected for microbial OM.

taining DDGH had markedly lower apparent total tract ADF digestion than did those fed the diet containing CGF. Apparent ruminal digestibilities of ADF were similar to apparent total tract digestibilities of ADF for cows fed the control diet or the diet containing DDGH. Higher apparent ruminal digestion than apparent total tract digestion of ADF has been reported by Kerley et al. (5). Lund and Smoot (7) reported that certain dietary phenolics can form polyphenolic oxidation products (artifact fiber), resulting in insoluble protein complexes that may increase ADF concentrations measured in the duodenum.

Intake of NDF was unaffected by diet (Table 2). Apparent ruminal and total tract digestibilities of NDF were similar across diets. Again, this result might have been caused by artifact fiber formed in the digestive tract (7). The apparent total tract digestibilities of NDF of by-product diets were similar to those reported by Sarwar et al. (9).

Nitrogen intake and daily passage of total N to the duodenum were not affected by diet (Table 3). Flows of ammonia; NAN; nonammonia, nonmicrobial N; and bacterial N to the duodenum were not affected by diet. Efficiency of bacterial growth, expressed as grams per kilogram of OM truly digested in the rumen, was not significantly different across diets. Stern and Hoover (14) reported that efficiencies of bacterial protein synthesis ranged from 17.1 to 37.0 g of N/kg of OM apparently digested in the rumen. The mean efficiency of bacterial protein synthesis in this study, 30.6 g of N/kg of OM apparently digested in rumen, was consistent with the results from previous observations (14). Apparent digestion of N in the total track was similar across diets.

Total concentrations and molar percentages of VFA in ruminal fluid were unaffected by diet (Table 4). The ratios of acetate to propionate were also similar across diets. The pH of ruminal fluid was lower for cows fed the diets containing WM and DDGH than for cows fed the control diet or the diet containing CGF. Fellner and Belyea (3) found that ruminal fluid pH decreased when cows were fed diets containing 39% CGF; however, Sarwar et al. (9) noted that ruminal pH was only affected at 3 h postfeeding when cows were fed diets containing up to 28.9% CGF. Ruminal pH did not decrease when cows were fed CGF in the present study. The mean values of ruminal pH were <6.0 when cows were fed diets containing WM or

TABLE 3. Digestibility of N and efficiency of bacterial growth in response to diet.

	Diet[1]				
Item	Control	WM	CGF	DDGH	SEM
N Intake,[2] g/d	583.3	519.9	531.4	580.0	36.2
Ruminal N digestion,[3] % of intake	46.3	50.4	47.5	44.0	1.3
Flow to duodenum					
Total N, g/d	529.7	467.7	508.4	552.3	34.3
Ammonia, g/d	23.4[a]	16.5[b]	15.9[b]	16.6[b]	2.0
NAN,[3] g/d	506.3	451.2	483.5	535.7	33.2
Bacterial N, g/d	221.4	211.2	226.8	228.0	16.6
NANMN,[4] g/d	284.9	240.0	256.8	307.7	18.5
% of intake	49.9	46.7	49.8	53.2	1.3
Efficiency of bacterial growth					
g of N/kg of OMADR[5]	26.5	29.3	31.1	35.5	3.0
g of N/kg of OMTDR[6]	21.0	22.7	23.5	24.9	1.3
N Digested postruminally, % of N passing to the duodenum	64.6	65.5	65.7	68.1	1.1
Apparent total tract N digestion, % of intake	66.9	67.6	68.8	70.0	1.1

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

[1]In the experimental diets, the NDF from forage (corn and soybean meal) in the control diet was substituted with NDF from by-products [wheat middlings (WM), corn gluten feed (CGF), or a blend of distillers dried grains and hominy (DDGH)].

[2]Adjusted for composition of orts.

[3]Calculated using RNA analysis of microbial OM.

[4]Nonammonia, nonmicrobial N.

[5]OM apparently digested in rumen.

[6]OM truly digested in rumen.

TABLE 4. Ruminal VFA, pH, ammonia, and dilution rates of the ruminal fluid fraction in response to diet.

Item	Diet[1]				SEM
	Control	WM	CGF	DDGH	
Total VFA,[2] m*M*	116.7	106.7	101.5	106.0	3.2
VFA, mol/100 mol					
Acetate (A)	66.0	65.6	66.3	64.6	1.3
Propionate (P)	22.1	22.2	22.2	22.6	1.1
Butyrate	8.9	8.8	8.7	10.0	0.6
Isobutyrate	0.9	1.0	0.8	0.9	0.04
Isovalerate	1.1	1.4	1.0	0.9	0.1
Valerate	1.1	1.1	1.1	1.0	0.1
A:P	3.2	3.1	3.2	2.9	0.2
pH[2]	6.1[a]	5.9[b]	6.1[a]	6.0[b]	0.05
Ammonia,[2] mg/dl	16.8	16.1	10.9	11.8	1.6
Fractional dilution rate, %/h	9.6	11.0	9.7	12.9	0.9

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

[1]In the experimental diets, the NDF from forage (corn and soybean meal) in the control diet was substituted with NDF from by-products [wheat middlings (WM), corn gluten feed (CGF), or a blend of distillers dried grains and hominy (DDGH)].

[2]Mean of 12 sampling times over a 36-h period.

DDGH. Terry et al. (17) proposed that cellulose digestion could be inhibited when ruminal pH was <6.0. Ruminal pH in the present study was 5.94 and 5.98 for cows fed diets containing WM and DDGH, respectively. This decrease in ruminal pH did not depress cellulose digestion, because ruminal ADF and NDF digestibilities did not differ across diets. Ruminal ammonia concentrations were 16.8, 16.1, 10.9, and 11.8 mg/dl for cows fed the control diet and diets containing WM, CGF, and DDGH, respectively. Ammonia concentrations for all diets were greater than the 5 mg/dl suggested to be optimal for maximizing microbial growth (11). The fractional dilution rates of ruminal fluid were similar across diets.

Dry matter intake (Table 5) did not differ across diets. Milk and FCM production were also similar across diets. Milk fat percentage was not affected by diet and ranged from 3.02 to 3.20% (Table 5); however, all milk fat contents were low. The ratio of acetate to propionate was similar across diets (2.93 to 3.18). Milk protein content was high in the present study and ranged from 3.6 to 3.9% (Table 5). An amino acid standard was analyzed to test the method of milk protein analysis. Recovery of the amino acid standard averaged 99.4%.

TABLE 5. Dry matter intake, milk production, and milk composition in response to diet.

Item	Diet[1]				SEM
	Control	WM	CGF	DDGH	
DMI,[2] kg/d	20.7	19.0	20.3	20.3	1.4
Milk, kg/d	24.3	24.1	22.5	24.8	1.4
4% FCM, kg/d	21.6	20.6	20.4	20.6	1.4
Milk fat					
%	3.2	3.0	3.2	3.0	0.1
kg/d	0.8	0.7	0.7	0.7	0.1
Milk protein					
%	3.9	3.6	3.7	3.7	0.1
kg/d	1.0	0.9	0.9	0.9	0.1

[1]In the experimental diets, the NDF from forage (corn and soybean meal) in the control diet was substituted with NDF from by-products [wheat middlings (WM), corn gluten feed (CGF), or a blend of distillers dried grains and hominy (DDGH)].

[2]Adjusted for composition of orts.

CONCLUSIONS

Results of the present study indicate that replacing forage NDF with NDF from by-products (CGF, WM, or DDGH) supported short-term milk production and milk fat content in a manner similar to that of a control diet containing soybean meal. Dry matter intake, OM digestion, and efficiency of microbial protein synthesis were unaffected by the substitution of forage NDF with NDF from by-products. Although ruminal pH was slightly depressed when cows were fed diets containing WM or DDGH, ruminal fiber digestion did not differ among diets. Diets containing CGF, WM, or DDGH apparently supplied sufficient fiber to maintain normal ruminal function when forage NDF accounted for 55% of total NDF with 31% of the total NDF from by-products.

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