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Effects of feeding three types of corn-milling coproducts on milk production and ruminal fermentation of lactating Holstein cattle

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ABSTRACT

Two experiments were conducted to determine the effects of feeding 3 corn-milling coproducts on intake, milk production, ruminal fermentation, and digestibility of lactating Holstein cows. In experiment 1, three corn-milling coproducts were fed at 15% of the diet dry matter (DM) to 28 Holstein cows averaging (±SD) 625 ± 81 kg of body weight and 116 ± 33 d in milk to determine effects on DM intake and milk production. In experiment 2, the same rations were fed to 4 ruminally fistulated, multiparous Holstein cows averaging 677 ± 41 kg of body weight and 144 ± 5 d in milk to determine the effects on ruminal fermentation and digestibility. In both experiments, cows and treatments were assigned randomly in 4 × 4 Latin squares over four 21-d periods. Treatments were formulated by replacing portions of forage and concentrate feeds with 15% coproduct and included 1) 0% coproduct (control), 2) dried distillers grains plus solubles (DDGS), 3) dehydrated corn germ meal (germ), and 4) high-protein dried distillers grains (HPDDG). Feed intake was recorded daily, and milk samples were collected on d 19 to 21 of each period for analysis of major components. Rumen fluid was collected at 10 time points over 24 h post feeding on d 21 of experiment 2. In experiment 1, DM intake was greater for the germ (24.3 kg/d) and DDGS treatments (23.8 kg/d), but DDGS was not different from the control (22.9 kg/d) and HPDDG treatments (22.4 kg/d). Milk production paralleled DM intake and tended to be greater for the germ (32.1 kg/d) and DDGS treatments (30.9 kg/d), but the DDGS treatment was not different from the control (30.6 kg/d) and HPDDG treatments (30.3 kg/d). However, yields of milk fat, milk protein, and 3.5% FCM were similar and averaged (±SEM) 1.1 ± 0.1, 0.9 ± 0.03, and 31.7 ± 1.3 kg/d. Milk urea nitrogen was greater for the HPDDG (15.9 mg/dL) and germ treatments (15.5 mg/dL) than for the control (15.0 mg/dL) and DDGS treatments (14.9 mg/dL). In experiment 2, DM intake and milk production were not different across treatments and averaged 26.1 ± 2.3 and 28.3 ± 3.9 kg/d. Ruminal pH (6.26 ± 0.08) and total concentration of volatile fatty acids (125.3 ± 4.2 m*M*) were similar. Acetate concentration was higher for the control treatment than the DDGS, germ, and HPDDG treatments (81.7 vs. 75.8, 75.0, and 78.4 m*M*). Concentrations of propionate and butyrate were not different and averaged 27.8 ± 1.2 and 14.3 ± 0.9 m*M* across treatments. The acetate:propionate ratios for the control, germ, and HPDDG treatments were greater than for the DDGS treatment (3.02, 2.88, and 2.91 vs. 2.62). Dry matter, organic matter, and neutral detergent fiber digestibilities were similar across treatments and averaged 63.5 ± 2.7, 67.3 ± 2.2, and 43.5 ± 4.2%. Milk production followed DM intake in experiment 1, and yield of major milk components was not affected. Results of these experiments indicate that dairy rations can be successfully formulated to include 15% of diet DM as corn-milling coproducts while maintaining or increasing DM intakes and yields of milk and milk components.
Key words: coproduct, dairy, milk production, ruminal fermentation

INTRODUCTION

Growth and technological advancement in the corn-ethanol production process has prompted changes in how ethanol is produced from corn grain. These changes have also resulted in changes in the nature and chemical composition of corn-milling coproducts (Ponnampalam et al., 2004; Murthy et al., 2006). For example, one process replaces the heating and cooking steps before fermentation with raw starch hydrolysis (Wang et al., 2007). An additional process separates the corn kernel into its 3 main components (germ, bran, and endosperm) before fermentation. In this process, the separated germ and bran are considered corn-milling coproducts and are used as animal feed, whereas the starch-containing endosperm enters the industrial fermentation process (Corredor et al., 2006; Murthy et al., 2008). As the fermentation process proceeds, the resulting coproduct is recovered and is highly concentrated in

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N. Each of these coproducts is unique because each has less exposure to high temperatures during processing.

Several studies have demonstrated that compared with a control diet without coproducts, feeding traditional coproducts, such as dried distillers grains plus solubles or wet corn gluten feed, results in increased intake and enhanced milk yield when fed to Holstein dairy cows (Nichols et al., 1998; VanBaale et al., 2001; Leonardi et al., 2005). However, research evaluating diets formulated to contain newly available coproducts is limited. The objectives of this research were to compare rations containing 1 of 3 corn-milling coproducts with a control ration not containing any coproducts and to evaluate the effects of diet on digestibility and milk production. Given the unique chemical composition of each of these coproducts, a different substitution strategy was used for each treatment diet; thus, the primary aim was to compare each diet containing a coproduct with the control diet not containing any.

MATERIALS AND METHODS

Experiment 1: Animals, Experimental Design, and Treatments

Twenty lactating Holstein cows averaging (±SD) 111 ± 38 DIM and 653 ± 70 kg of BW and 8 lactating Holstein heifers averaging 129 ± 12 DIM and 556 ± 65 kg of BW were randomly assigned to seven 4 × 4 Latin squares. Within a square, animals were stratified by parity and milk production, and treatments were assigned randomly according to the method of Kononoff and Hanford (2006). During each of the four 21-d periods, cows were offered 1 of 4 TMR that differed by type of corn-milling coproduct, included at 15% of diet DM. The 4 dietary treatments were as follows: first, the control included no coproducts, and second, **DDGS** included distillers dried grains plus solubles (**DG**) at 15% of the diet DM (Northstar Ethanol LLC, Lake Crystal, MN). The distillers grains plus solubles used in this treatment resulted from the corn-ethanol production process in which heating before fermentation was replaced with enzymatic digestion. The third treatment (hereafter, termed "germ") was formulated to contain corn germ meal (TCE LLC, Coon Rapids, IA) that was removed from the corn kernel before fermentation. The fourth treatment diet (**HPDDG**) was formulated to contain the corn-milling coproduct high-protein distillers dried grains (**HP**; TCE LLC, Coon Rapids, IA), resulting from fermentation of primarily endosperm. Treatments were formulated with the CPM-Dairy model (version 3.0) to meet or exceed requirements as estimated by the CPM-Dairy model (Boston et al., 2000).

A brief rationale for the formulated treatment diets follows. The control diet was formulated to be similar to a dairy diet fed in the Great Plains region of the United States. This ration did not contain any corn-milling coproducts and was largely composed of ingredients such as corn silage, ground corn, alfalfa, soybean meal, and soyhulls, which are produced locally. Given the high concentration of fiber and protein contained in corn distillers grains, DG were included at 15% of the ration DM, and this largely replaced the alfalfa and soybean meal. A portion of ground corn was also replaced to compose the DDGS treatment. The formulation of the germ treatment ration was similar, but given the lower concentration of protein and higher concentration of starch in the corn germ, more soybean meal and less corn was included. Given the high-protein content of HP, the HPDDG diet was formulated to contain less alfalfa and soy-based protein. Brome hay was added to each treatment diet in an attempt to increase the concentration of effective fiber. Treatments were mixed separately and fed to individual cows by using a small drum mixer (Data Ranger, American Calan Inc., Northwood, NH).

Experiment 2: Animals, Experimental Design, and Sample Collection

After completion of the first study, experiment 2 was conducted. Four ruminally fistulated Holstein cows averaging 144 ± 5 DIM and 677 ± 41 kg of BW were assigned randomly to 1 of 4 treatments in one 4 × 4 Latin square according to the method of Kononoff and Hanford (2006). Treatments were formulated, mixed, and fed using the same procedures as described for experiment 1. Days 1 to 17 of each period were used for dietary adaptation, and d 18 to 21 were used for data collection. On d 18 to 21, urine and fecal samples were collected at 0600 and 1800 h before milking. Urination upon stimulation and rectal grab sample techniques were used to collect urine and feces. Thirty milliliters of urine was acidified with 4 *M* HCl to pH <4 for preservation before immediately being frozen (−20°C) for later analyses. Fecal samples (approximately 200 g wet wt) were also immediately frozen (−20°C) for later analyses. On d 21 of each period, ruminal fluid samples were collected over 10 time points (0, 1, 2, 4, 6, 8, 11, 14, 18, and 23.5 h) post feeding. Ruminal grab samples were taken from the cranial, caudal, left lateral, and right lateral areas of the rumen to obtain a representative sample, were mixed to become uniform, and were strained through 4 layers of cheesecloth to obtain rumen fluid. Rumen fluid pH was measured immediately and directly by using a handheld pH electrode (model M90, Corning Inc., Corning, NY), and 30 mL of ruminal fluid

was immediately stored in plastic, screw-capped, 50-mL conical tubes and frozen (−20°C) for later analyses.

Animal Care and Measurements, Milk Collection, and Feed Sampling

All experimental procedures were approved and cows were cared for according to guidelines stipulated by the University of Nebraska Institutional Animal Care and Use Committee. During both experiments, cows were housed in individual stalls and milked at 0730 and 1930 h. On d 19 to 21 of each period, milk samples were collected during the a.m. and p.m. milkings and preserved using 2-bromo-2-nitropropane-1,3-diol. Milk samples were sent to Heart of America DHIA in Manhattan, Kansas, for laboratory analyses of fat, true protein, lactose, SNF, and MUN. Milk true protein, fat, and lactose contents were analyzed for each sample by near-infrared spectroscopy (Bentley 2000 Infrared Milk Analyzer, Bentley Instruments, Chaska, MN), and yields were reported and weighted according to milk volume and time of collection. Chemical methodology based on a modified Berthelot reaction was used to determine MUN concentration (ChemSpec 150 Analyzer, Bentley Instruments).

Cows were individually fed at 0900 h for ad libitum consumption and approximately 10% refusal. Weight of the feed offered to cows each day was recorded, and refused feed was individually removed and weighed each day at 0800 h. Daily intake was recorded on individual cows by subtracting the feed refusal amount from the total amount fed the previous day. Throughout the experiment, DM content was analyzed on corn silage and alfalfa haylage once per week by using a microwave oven (Heinrichs and Ishler, 2000). Diet ingredient proportions were adjusted accordingly if the DM of the forages changed. Total mixed ration, forage, and concentrate samples were collected on d 20 to 21 of each period. Samples of corn-milling coproducts included in the grain mixes were obtained 3 times throughout the experiment. All cows were individually weighed on d 20 to 21 immediately after the a.m. milking, and weights were averaged for each period. Cows were scored for body condition by a single trained individual on d 21 of each period by using a scale of 1 (extremely thin) to 5 (extremely fat) according to the method of Wildman et al. (1982).

Forage, Coproduct, TMR, Fecal, Urine, and Rumen Fluid Sample Analyses

Subsamples of forages, corn-milling coproducts, and diets from experiment 1 were sent to Dairy One Forage Analysis Laboratory (Ithaca, NY) for chemical analysis. The analyses reported during each period included DM (AOAC, 2000; method 930.15), CP (AOAC, 2000; method 990.06), soluble protein (Roe and Sniffen, 1990), NDF and ADF (Van Soest et al., 1991; without sodium sulfite, using an Ankom Fiber Analyzer, Ankom Technology, Fairport, NY, and with 100 μL/0.50 g of sample heat-stable α-amylase, no. A3306, Sigma Chemical Co., St. Louis, MO), lignin (AOAC, 2000; method 973.18 D), starch (Smith, 1969), ash (AOAC, 2000; method 942.05), ether extract (AOAC, 2000; method 2003.05), and minerals (Ca, P, S, Mg, K, Na, Fe, Zn, Cu, Mn, and Mo; Sirois et al., 1994). Total mixed ration samples from experiment 2 were analyzed for chemical composition (DM, CP, NDF, ADF, ash, ether extract, NFC, and starch) in the University of Nebraska Ruminant Nutrition Laboratory (Lincoln, NE). Particle size distribution of the rations were analyzed using the Penn State Particle Separator (Kononoff et al., 2003). Samples of TMR were dried for 48 h in a 60°C forced-air oven to determine DM (AOAC, 1996) and ground through a 1-mm screen (Wiley mill, Arthur H. Thomas Co., Philadelphia, PA). Fecal samples from experiment 2 were thawed and composited by cow and period before complete drying in a 60°C forced-air oven.

Laboratory DM of the TMR and fecal samples was determined in a 100°C oven for 12 h (AOAC, 1996). Percentage of ash was determined by incinerating the samples in a 600°C ash oven for 6 h (AOAC, 1996), and OM was calculated as (100 − % ash). Percentage of N was estimated for the TMR and fecal samples using the combustion method (AOAC, 1996) in a combustion N analyzer (Leco FP-528, Leco Corp., St. Joseph, MI). Neutral detergent fiber and ADF (Van Soest et al., 1991) concentrations were determined on all samples with an Ankom Fiber Analyzer (Ankom Technology). The procedure was modified not to include sodium sulfite and to include heat-stable α-amylase (no. A3306, Sigma Chemical Co.) at 100 μL/0.50 g of sample. In addition, samples of TMR were analyzed for starch (Total Starch Assay, Megazyme International, Co. Wicklow, Ireland).

The internal marker used in this experiment to determine nutrient digestibility was indigestible ADF (**IADF**; Huhtanen et al., 1994). Approximately 1.25 g of 1-mm ground subsamples of TMR and fecal samples from experiment 2 were weighed (in triplicate) into 5 × 10 cm Dacron nylon bags (Ankom Technology) possessing a pore size of 50 μm. The bags were then heat-sealed with an Ankom Heat Sealer (Vanzant et al., 1998). Fifty Dacron bags each were placed into larger nylon mesh bags (36 × 42 cm) that contained 2 secured 100-g weights before rumen incubation.

Nylon mesh bags were incubated for 12 d in the ventral sac of the rumen of a ruminally fistulated steer

fitted with a flexible ruminal cannula. The steer was of Angus-cross breeding, weighed 418 kg, and was limit-fed 7.4 kg of DM of a mixed diet containing 70% grass hay, 15% ground corn, and 15% soybean meal daily. The animal was housed in an individual pen in a temperature-controlled room and had free access to water and no access to the outside. Nylon bags were removed after 12 d, and Dacron bags were machine washed using five 3-min cycles consisting of a 1-min wash and a 2-min spin; rinsed in distilled water, forcing all residues to the bottom; rolled; and dried for 12 h at 55°C (AOAC, 1996). After drying, ADF content was determined gravimetrically (Van Soest et al., 1991) with an Ankom Fiber Analyzer (Ankom Technology). The procedure was modified not to include sodium sulfite and to include heat-stable α-amylase (no. A3306, Sigma Chemical Co.) at 100 μL/0.50 g of sample. Total fecal output was calculated by determining intake of IADF and dividing intake of IADF by IADF concentration in the feces. Whole-diet total digestible nutrient (**TDN**) concentrations were then determined (Weiss et al., 1992), and based on these values, production levels of digestible energy, ME, and NE_L were calculated as outlined by the NRC (2001).

Urine samples collected in experiment 2 were thawed and composited by cow and period. Nitrogen content was determined by using the Dumas combustion method (AOAC, 1996) in a combustion N analyzer (Leco FP-528, Leco Corp.). Urine samples were diluted with 19 parts urine diluent to 1 part urine. The urine diluent was composed of 0.202% sodium 1-heptane sulfonic acid and 0.086% ammonium dihydrogen phosphate. The solution was brought to pH 2.1 with 4 *M* HCl. Diluted urine samples were analyzed for the purine derivatives (**PD**) of allantoin, uric acid, xanthine, hypoxanthine, and creatinine by HPLC (Waters Corp., Milford, MA) according to the procedures of Shingfield and Offer (1999). The ratio of PD to creatinine has been used to illustrate relative differences in microbial CP flow to the duodenum (Gonda, 1995; Shingfield and Offer, 1998). Based on estimates of urinary excretion of PD, the microbial protein supply was estimated according to the method of Chen and Gomes (1992). Creatinine concentration was used as a marker to estimate total urine output volume (Valadares et al., 1999; Leonardi et al., 2003). Urine volume was calculated by assuming that creatinine output averaged 28 mg/kg of BW, as estimated by Whittet (2004). Similar daily creatinine outputs, ranging from 25 to 30 mg/kg of BW, have been reported previously (McCarthy et al., 1983; Jones et al., 1990).

Rumen fluid samples collected during experiment 2 were thawed and centrifuged at 5,000 × *g* for 10 min before analyses for ammonia-N and VFA concentrations. Ruminal fluid ammonia-N was determined according to procedures reported by Broderick and Kang (1980), using a SPECTRAmax 250 spectrophotometer (Molecular Devices Corp., Sunnyvale, CA). Ruminal fluid VFA concentrations were determined according to the method of Yang and Varga (1989) by using a gas chromatograph (HP5890 Series II, Hewlett-Packard Co., Palo Alto, CA).

Statistical Analysis: Experiment 1. Performance data were analyzed as a replicated 4 × 4 Latin square using the MIXED procedures of SAS (Version 9.1, SAS Institute Inc., Cary, NC). Fixed model effects included square, period within square, and treatment, and the random effect was cow within square. The linear model for this experiment is written as follows:

$$y_{ijkm} = \mu + \tau_m + \beta(\tau)_{im} + \rho(\tau)_{jm} + \alpha_k + \varepsilon_{ijkm},$$

where y_{ijkm} represents observation$_{ijkm}$; μ represents the overall mean; τ_m represents the fixed effect of square m; $\beta(\tau)_{im}$ represents the random effect of cow i within square m; $\rho(\tau)_{jm}$ represents the fixed effect of period j within square m; and α_k represents the fixed effect of treatment k. The residual term ε_{ijkm} was assumed to be normally, independently, and identically distributed, with variance σ_e^2.

Statistical Analyses: Experiment 2. Performance data were analyzed as a 4 × 4 Latin square using the MIXED procedures of SAS (Version 9.1; SAS Institute Inc.). Fixed model effects included treatment and period with cow as the random effect. The linear model for this experiment is written as follows:

$$y_{ijk} = \mu + \beta_i + \rho_j + \alpha_k + \varepsilon_{ijk},$$

where y_{ijk} represents observation$_{ijk}$; μ represents the overall mean; β_i represents the random effect of cow i; ρ_j represents the fixed effect of period j; and α_k represents the fixed effect of treatment k. The residual term ε_{ijk} was assumed to be normally, independently, and identically distributed, with variance σ_e^2.

Rumen measurements were analyzed as repeated measures by using the autoregressive repeated covariance structure in SAS (Version 9.1, SAS Institute Inc.). Model fixed effects included period, treatment, hour, and the treatment × hour interaction, with cow as the random effect. The linear model for these data is written as follows:

$$y_{ijkm} = \mu + \beta_i + \rho_j + \gamma_k + \alpha_m + \alpha\gamma_{km} + \varepsilon_{ijkm},$$

where y_{ijkm} represents observation$_{ijkm}$; μ represents the overall mean; β_i represents the random effect of cow i;

Table 1. Ingredient and chemical composition of experimental treatments (experiments 1 and 2)

	Treatment[1]			
Ingredient, % of DM	Control	DDGS	Germ	HPDDG
Distillers dried grains plus solubles	—	15.0	—	—
Corn germ	—	—	15.0	—
High-protein corn distillers grains	—	—	—	14.4
Corn silage	26.7	26.0	26.3	25.3
Alfalfa haylage	10.3	5.42	5.48	5.28
Alfalfa hay	5.56	5.42	5.48	5.28
Brome hay, chopped	6.67	15.2	15.3	14.8
Ground corn	20.7	13.9	9.42	15.2
Soybean meal, 48% CP	8.93	6.18	8.32	—
SoyPass[2]	4.44	2.82	5.91	—
Whole linted cottonseed	3.33	—	—	6.83
Soybean hulls	10.4	7.38	6.13	10.0
Urea	—	—	—	0.21
Tallow	0.44	—	—	—
Vitamin ADE[3]	0.13	0.13	0.13	0.13
Magnesium oxide	0.16	0.15	0.15	0.15
Trace mineral[4]	0.04	0.04	0.04	0.04
Sel-Plex 1000[5]	0.02	0.02	0.02	0.02
Vitamin E	0.02	0.02	0.02	0.02
Limestone	0.98	1.35	1.34	1.37
Salt	0.10	0.10	0.10	0.10
Sodium bicarbonate	1.00	0.98	0.99	0.95
Dicalcium phosphate	0.18	—	—	—

[1]Control = 0% DM coproducts; DDGS = 15% DM distillers dried grains plus solubles (DG); germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (HP; no solubles included).

[2]LignoTech (Overland Park, KS).

[3]Formulated to supply approximately 120,000 IU/d of vitamin A, 24,000 IU/d of vitamin D, and 800 IU/d of vitamin E in the total ration.

[4]Formulated to contain 1.0% Ca, 0.50% P, 0.36% Mg, and 1.3% K.

[5]Alltech Inc. (Nicholasville, KY).

ρ_j represents the fixed effect of period j; γ_k represents the fixed effect of hour k; α_m represents the fixed effect of treatment m; and $\alpha\gamma_{km}$ represents the interaction effect between hour k and treatment m. The residual term ε_{ijkm} was assumed to be normally, independently, and identically distributed, with variance σ_e^2.

Statistical significance for all treatment effects was declared with $P \leq 0.05$, and trends were discussed with $P \leq 0.10$. The PDIFF option was used to separate and compare differences of least squares means when the P-value for the treatment effect was <0.10. Treatment means are presented as least squares means, and the largest standard errors of the means are reported.

RESULTS

Forage, Coproduct, and Ration Chemical Composition

Ingredient compositions of the experimental treatment rations are listed in Table 1. Results of the chemical composition of the forages and coproducts were averaged across experimental treatments and are listed in Tables 2 and 3. Measured chemical compositions for the treatment diets fed in experiment 1 (Table 4) and experiment 2 (Table 5) are listed. The particle sizes of treatment rations are listed in Tables 6 and 7 for experiment 1 and experiment 2, respectively.

DMI, Milk Production, and Milk Composition

Feed DMI and production results are listed in Table 8 for experiment 1 and Table 9 for experiment 2. In experiment 1, only DMI of the germ treatment differed from the control treatment (24.3 vs. 22.9 ± 0.61 kg/d). The DMI observed in experiment 2 was not different and averaged 26.1 ± 2.32 kg/d across experimental treatments.

The milk production response in experiment 1 paralleled DMI, with only the germ treatment differing from the control treatment (32.1 vs. 31.5 ± 1.12 kg/d). Percentage of fat was not different among treatments and averaged 3.76 ± 0.10%. Yield of milk fat was similar and averaged 1.15 ± 0.1 kg/d across treatments. In addition, 3.5% FCM was not different across treatments and averaged 31.7 ± 1.3 kg/d. Percentage of protein was similar and averaged 3.0 ± 0.03% for all treatments. Yield of milk protein was not different and aver-

Table 2. Chemical analysis of forages included in experimental treatments[1]

	Corn silage		Alfalfa haylage		Alfalfa hay		Brome hay	
Item	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DM, %	35.0	3.11	27.9	0.77	89.8	0.61	91.5	0.58
CP, %	9.30	0.86	23.7	0.76	22.7	1.04	13.0	2.68
ADICP,[2] %	—	—	1.45	0.30	—	—	—	—
Soluble protein, % of CP	65.3	3.86	62.3	1.26	33.0	0.82	26.8	2.99
ADF, %	22.1	1.76	33.1	0.86	29.3	0.53	38.9	2.74
NDF, %	39.0	2.06	42.0	2.25	37.3	1.13	67.2	4.75
Lignin, %	2.43	0.64	7.28	1.85	6.65	0.59	5.70	1.08
Starch, %	34.4	3.12	—	—	—	—	—	—
Ether extract, %	3.65	0.47	3.75	0.31	3.03	0.29	2.80	0.61
Ash, %	5.24	0.57	15.9	0.94	13.0	0.87	10.4	0.89
Ca, %	0.29	0.04	1.32	0.06	1.50	0.08	0.37	0.05
P, %	0.30	0.02	0.43	0.03	0.35	0.04	0.32	0.02
Mg, %	0.17	0.02	0.46	0.02	0.26	0.01	0.14	0.02
K, %	1.17	0.16	5.01	0.23	3.37	0.24	2.80	0.55
Na, %	—	—	0.02	0.00	0.02	0.01	0.01	0.01
Fe, mg/kg	138.0	28.3	425.0	100.0	587.0	183.0	254.0	131.0
Zn, mg/kg	26.3	3.10	37.3	2.06	27.8	1.26	26.5	2.38
Cu, mg/kg	5.25	0.96	8.00	2.00	5.50	0.58	8.25	1.71
Mn, mg/kg	37.5	5.45	66.0	7.79	43.3	4.92	64.3	26.1
Mo, mg/kg	0.63	0.36	1.40	0.54	0.85	0.31	0.70	0.14
S, %	0.12	0.01	0.28	0.09	0.28	0.01	0.20	0.02

[1]Values determined by Dairy One Forage Testing Laboratory (Ithaca, NY).
[2]Acid detergent insoluble CP.

aged 0.90 ± 0.03 kg/d across treatments. Compared with the control diet, cows consuming HPDDG had a higher concentration of MUN (15.9 vs. 15.0 ± 0.39 mg/dL). Feed efficiency was not different and averaged 1.30 ± 0.04 across treatments.

In experiment 2, observed milk production was similar and averaged 28.3 ± 3.92 kg/d across treatments. In contrast to experiment 1, milk production in experiment 2 did not parallel DMI. Percentage of milk fat was not different and averaged 3.28 ± 0.28%. Yield of milk

Table 3. Chemical analysis of the 3 corn-milling coproducts included in experimental treatments[1,2]

	DG		DHG		HP	
Item	Mean	SD	Mean	SD	Mean	SD
DM, %	85.0	0.21	92.1	0.23	91.4	1.07
CP, %	30.9	0.72	16.6	0.17	46.1	0.55
ADICP,[3] %	1.20	0.36	—	—	4.13	0.38
Soluble protein, % CP	18.7	3.21	52.3	4.16	10.7	1.53
ADF, %	12.0	2.16	9.80	4.35	15.6	1.72
NDF, %	30.3	2.89	24.5	4.43	26.4	1.91
Lignin, %	3.07	0.59	2.37	1.40	3.77	0.55
Starch, %	7.73	0.31	26.0	3.65	9.10	0.87
Ether extract, %	12.5	1.14	18.5	0.21	4.63	0.12
Ash, %	6.30	0.19	6.07	0.24	2.54	0.53
Ca, %	0.08	0.02	0.03	0.005	0.02	0.01
P, %	0.97	0.05	1.33	0.07	0.37	0.02
Mg, %	0.42	0.03	0.52	0.04	0.09	0.00
K, %	1.25	0.07	1.53	0.24	0.37	0.04
Na, %	0.25	0.01	0.01	0.01	0.09	0.01
Fe, mg/kg	107.0	27.3	96.7	18.3	65.3	8.08
Zn, mg/kg	102.0	5.13	83.7	2.52	27.3	3.21
Cu, mg/kg	4.67	0.58	5.30	1.53	2.03	1.95
Mn, mg/kg	17.7	2.08	22.3	4.04	7.00	2.00
Mo, mg/kg	1.10	0.17	0.97	0.06	0.83	0.21
S, %	1.03	0.04	0.17	0.02	0.75	0.03

[1]Values determined by Dairy One Forage Testing Laboratory (Ithaca, NY).
[2]DG = dried distillers grains plus solubles (no heating or cooking before fermentation); DHG = dehydrated corn germ meal; HP = high-protein dried distillers grains (no solubles included).
[3]Acid detergent insoluble CP.

Table 4. Analyzed chemical composition of experimental treatments (experiment 1)

	Treatment[1,2]							
	Control		DDGS		Germ		HPDDG	
Item, %	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DM	58.7	2.29	63.2	2.40	62.9	3.28	64.4	2.54
CP	19.5	0.69	19.7	0.59	19.5	0.45	18.9	0.45
NDF	34.5	1.79	35.6	1.56	34.6	2.72	41.1	3.27
ADF	23.0	2.02	21.0	0.98	19.4	0.54	25.9	1.67
OM	91.8	0.59	91.3	0.35	91.0	0.20	92.1	0.26
Ether extract	4.50	0.51	4.50	0.17	5.50	0.20	4.80	0.39
Starch	22.9	1.67	21.8	0.69	22.3	0.17	19.9	2.42
NFC[3]	33.4	1.54	31.6	1.25	31.4	2.51	27.0	3.21

[1]Samples were collected on d 20 and 21 of each period and composited; each mean is representative of 4 composite samples.
[2]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).
[3]Calculated by difference; NFC = 100 − (CP + ether extract + ash + NDF).

fat was similar and averaged 0.95 ± 0.2 kg/d. Comparable with experiment 1, 3.5% FCM was similar across treatments and averaged 27.8 ± 4.5 kg/d. Yield of milk protein was similar among treatments and averaged 0.9 ± 0.1 kg/d. In contrast to experiment 1, MUN was not different and averaged 11.2 ± 1.10 mg/dL across treatments. Feed efficiency was not different and averaged 1.09 ± 0.10 across treatments.

Ruminal pH, VFA Concentrations, and Ammonia-N Concentration

The effects of feeding rations containing corn-milling coproducts on ruminal VFA and ammonia-N concentrations in experiment 2 are listed in Table 10. Ruminal pH was not different and averaged 6.26 ± 0.08 across treatments. Rumen ammonia-N concentrations were similar among treatments and averaged 14.1 ± 0.95 mg/dL. Total VFA concentration did not differ among treatments and averaged 125.3 ± 4.2 m*M*. The concentration of acetate in the rumen for animals consuming the control treatment (81.7 m*M*) was significantly higher than for the DDGS (75.8 m*M*), germ (75.0 m*M*), and HPDDG treatments (78.4 m*M*). Propionate concentration was similar across treatments and averaged 27.8 ± 1.2 m*M*. Concentrations of butyrate (14.4 ± 0.89 m*M*) and isobutyrate (1.53 ± 0.08 mM) were not different across treatments. Concentration of valerate was similar and averaged 2.1 ± 0.1 m*M* across treatments. Isovalerate tended to be highest for the control treatment (2.1 mM) compared with the DDGS (1.7 m*M*), germ (1.8 m*M*), and HPDDG treatments (1.7 m*M*). In addition, compared with the control treatment, the ratio of ruminal acetate to propionate was lower for the DDGS treatment (2.6 vs. 3.0 ± 0.10 for DDGS and the control, respectively).

Table 5. Analyzed chemical composition of experimental treatments (experiment 2)

	Treatment[1,2]							
	Control		DDGS		Germ		HPDDG	
Item, %	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DM	60.1	2.28	64.8	2.32	64.5	2.15	66.1	2.34
CP	18.2	0.98	19.1	0.43	19.3	0.69	19.9	0.52
NDF[3]	37.7	1.37	39.2	1.38	36.3	1.19	41.1	1.66
ADF[4]	24.0	1.32	23.4	1.57	21.1	0.69	26.4	0.58
OM	91.7	0.91	91.4	0.11	91.6	0.29	93.4	0.32
Ether extract	3.11	0.19	3.72	0.06	4.44	0.12	4.10	0.31
Starch	24.6	0.78	22.6	0.77	23.1	0.23	21.3	0.86
NFC[3]	32.7	0.60	29.5	1.51	31.5	1.58	28.1	1.44

[1]Samples were collected on d 20 and 21 of each period and composited; each mean is representative of 4 composite samples.
[2]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).
[3]Calculated by difference; NFC = 100 − (CP + ether extract + ash + NDF).

Table 6. Effects of feeding corn-milling coproducts on as-fed ration particle size distribution (experiment 1)

	Treatment[2,3]				
Particle size,[1] % retained	Control	DDGS	Germ	HPDDG	SEM[4]
>19.0 mm	12.8	12.6	12.0	16.2	0.84
>8.0 to 19.0 mm	24.5	19.5	20.3	22.1	0.48
>1.18 to 8.0 mm	41.4	36.2	46.2	34.4	0.53
<1.18 mm	20.5	30.8	20.8	26.2	0.39
1.18 to >19.0 mm	78.7	68.2	78.4	72.6	0.35

[1]Particle size determined using the Penn State Particle Separator (Kononoff et al., 2003).

[2]Samples were collected on d 20 and 21 of each period and composited; each mean is representative of 4 composite samples.

[3]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).

[4]Highest SEM of the MIXED procedure (SAS Institute Inc., Cary, NC) is reported.

Apparent Nutrient Digestibility of TMR

Major nutrient digestibility, amount digested, and energy compositions of the rations fed in experiment 2 are listed in Table 11. Dry matter digestibility was not different across treatments and averaged 63.5 ± 2.71%. Organic matter digestibility was similar and averaged 67.4 ± 2.14% across experimental treatments. Neutral detergent fiber digestibility was not different and averaged 43.5 ± 4.22%. Digestibility of N, ether extract, and NFC were similar across treatments and averaged 65.7 ± 2.73, 85.1 ± 1.9, and 96.7 ± 2.98%, respectively. When percentage of TDN was measured according to NRC (2001), the control treatment (62.7%) tended to be similar in TDN to the DDGS treatment (57.9%) but higher than the germ (55.5%) and HPDDG treatments (55.4%). Net energy for lactation values of the rations followed a pattern similar to TDN and were 1.49, 1.35, 1.27, and 1.27 Mcal/kg for the control, DDGS, germ, and HPDDG treatments.

Urine PD and Creatinine Excretion

The concentration and excretion of urinary PD and creatinine of animals fed in experiment 2 are listed in Table 12. No treatment differences were observed for concentrations of allantoin, uric acid, total PD, or creatinine. Allantoin concentration averaged 8.0 ± 0.8 m*M* across treatments. Concentration of uric acid averaged 1.0 ± 0.2 m*M*, and the sum of allantoin and uric acid concentrations averaged 9.0 ± 1.0 m*M* across treatments. Xanthine was not detected for any treatment, and compared with the control treatment (0.14 mM), concentration of hypoxanthine was higher for the DDGS (0.76 m*M*) and HPDDG treatments (0.84 m*M*). Excretion of allantoin was similar among treatments and averaged 265.2 ± 38.9 mmol/d. Total PD excretion was also similar across treatments and averaged 296.1 ± 38.5 mmol/d. In addition, excretion of creatinine was similar across treatments and averaged 174.6 ± 4.9 mmol/d. The ratio of total PD to creatinine was similar (1.69 ± 0.21) among treatments and was used to estimate differences in microbial CP production (**MCP**). Treatment estimates of MCP averaged 1,161.2 ± 182.2 g/d.

DISCUSSION

Reports of using corn-milling coproducts to replace portions of forages and concentrates in lactating dairy

Table 7. Effects of feeding corn-milling coproducts on as-fed ration particle size distribution (experiment 2)

	Treatment[2,3]				
Particle size,[1] % retained	Control	DDGS	Germ	HPDDG	SEM[4]
>19.0 mm	14.4	12.4	12.4	14.0	0.70
>8.0 to 19.0 mm	26.6	19.8	21.3	25.1	0.70
>1.18 to 8.0 mm	39.8	35.6	46.2	33.6	0.54
<1.18 mm	18.5	31.6	19.5	26.4	0.78
1.18 to >19.0 mm	80.8	67.7	79.8	72.6	0.78

[1]Particle size determined using the Penn State Particle Separator (Kononoff et al., 2003).

[2]Samples were collected on d 20 and 21 of each period and composited; each mean is representative of 4 composite samples.

[3]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).

[4]Highest SEM is reported.

Table 8. Effects of feeding corn-milling coproducts on milk yield and composition (experiment 1)

	Treatment[1]					
Item	Control	DDGS	Germ	HPDDG	SEM[2]	*P*-value[3]
DMI, kg/d	22.9[b]	23.8[ab]	24.3[a]	22.4[b]	0.61	0.02
Milk, kg/d	30.6[a]	30.9[a]	32.1[b]	30.3[a]	1.12	0.08
3.5% FCM,[4] kg/d	31.5	31.5	32.2	31.8	1.25	0.81
Fat, %	3.73	3.72	3.68	3.90	0.10	0.16
Fat, kg/d	1.13	1.13	1.15	1.17	0.05	0.76
Protein, %	2.97	2.99	2.94	2.98	0.03	0.32
Protein, kg/d	0.90	0.90	0.92	0.88	0.03	0.58
Lactose, %	4.72	4.74	4.72	4.74	0.06	0.86
Lactose, kg	1.44	1.46	1.48	1.42	0.06	0.41
SNF, %	8.59	8.60	8.57	8.63	0.08	0.60
SNF, kg/d	2.61	2.63	2.69	2.58	0.10	0.47
MUN, mg/dL	15.0[a]	14.9[a]	15.5[ab]	15.9[b]	0.39	0.04
Milk:DMI[5]	1.30	1.27	1.30	1.32	0.04	0.53
Milk energy[6]	21.3	21.4	21.8	21.4	0.85	0.85
BW, kg	648[b]	657[ab]	658[a]	657[a]	13.3	0.08
BCS[7]	3.28	3.25	3.38	3.23	0.09	0.11

[a,b]Values in the same row with different superscripts differ ($P < 0.05$).

[1]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).

[2]Highest SEM is reported.

[3]Main effect of the treatment.

[4]FCM calculated as [milk fat (kg) × 16.218] + [milk yield (kg/d) × 0.4324].

[5]Feed efficiency calculated as milk:DMI.

[6]Milk energy (Mcal/kg per day) calculated as (0.0929 × milk fat % + 0.0563 × milk protein % + 0.0395 × lactose %) × milk yield (kg/d).

[7]Cow BCS determined on a 1 to 5 scale according to Wildman et al. (1982).

Table 9. Effects of feeding corn-milling coproducts on milk yield and composition (experiment 2)

	Treatment[1]					
Item	Control	DDGS	Germ	HPDDG	SEM[2]	*P*-value[3]
DMI, kg/d	27.0	26.2	25.9	25.3	2.32	0.74
Milk, kg/d	26.9	28.9	29.6	28.0	3.92	0.85
3.5% FCM,[4] kg/d	27.2	28.3	27.7	27.9	4.47	0.99
Fat, %	3.39	3.15	3.07	3.49	0.28	0.18
Fat, kg/d	0.95	0.96	0.92	0.97	0.18	0.97
Protein, %	3.23[a]	3.15[b]	3.13[b]	3.16[b]	0.11	0.06
Protein, kg/d	0.89	0.94	0.92	0.88	0.14	0.95
Lactose, %	4.47	4.65	4.56	4.59	0.08	0.46
Lactose, kg	1.23	1.38	1.35	1.30	0.19	0.86
SNF, %	8.55	8.69	8.56	8.63	0.14	0.56
SNF, kg/d	2.36	2.58	2.54	2.42	0.36	0.90
MUN, mg/dL	10.1	11.0	11.5	12.1	1.10	0.45
Milk:DMI[5]	0.97	1.09	1.15	1.17	0.10	0.49
Milk energy[6]	18.7	19.6	19.1	19.1	3.12	0.98
BW, kg	715	700	703	697	19.7	0.46
BCS[7]	3.25	3.13	3.25	3.13	0.09	0.45

[a,b]Values in the same row with different superscripts differ ($P < 0.05$).

[1]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).

[2]Highest SEM is reported.

[3]Main effect of the treatment.

[4]Calculated as [milk fat (kg) × 16.218] + [milk yield (kg/d) × 0.4324].

[5]Feed efficiency calculated as milk:DMI.

[6]Milk energy (Mcal/kg per day) calculated as (0.0929 × milk fat % + 0.0563 × milk protein % + 0.0395 × lactose %) × milk yield (kg/d).

[7]Cow BCS determined on a 1 to 5 scale according to Wildman et al. (1982).

Table 10. Effects of feeding corn-milling coproducts on VFA and NH_4 concentrations (experiment 2)

	Treatment[1]					
Item	Control	DDGS	Germ	HPDDG	SEM[2]	*P*-value[3]
pH	6.36	6.16	6.29	6.21	0.08	0.19
NH_4, mg/dL	14.7	13.1	15.0	13.7	0.95	0.35
Total VFA, m*M*	130.3	125.0	121.6	124.5	4.17	0.30
Acetate, m*M*	81.7[a]	75.8[b]	75.0[b]	78.4[b]	2.77	0.05
Propionate, m*M*	27.5	29.7	26.6	27.3	1.24	0.27
Butyrate, m*M*	15.0	14.1	14.7	13.6	0.89	0.60
Isobutyrate, m*M*	1.72	1.44	1.50	1.46	0.08	0.11
Valerate, m*M*	2.22	2.21	2.09	1.97	0.13	0.37
Isovalerate, m*M*	2.13[a]	1.74[b]	1.78[b]	1.70[b]	0.12	0.06
Acetate:propionate	3.02[a]	2.62[b]	2.88[a]	2.91[a]	0.10	0.03

[a,b]Values in the same row with different superscripts differ ($P < 0.05$).

[1]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).

[2]Highest SEM is reported.

[3]Main effect of the treatment. $P < 0.05$ are significantly different; $P \leq 0.10$ are considered a trend.

cow rations have demonstrated that these feeds may be effectively included in rations fed to lactating cows without deleterious effects on production (Anderson et al., 2006; Kleinschmit et al., 2006). In experiment 1, cows consuming rations containing DG and HP coproducts consumed similar amounts of feed as cows consuming the control ration. In addition, these treatment rations resulted in similar milk production and composition when compared with the control ration, suggesting that the partial replacement of alfalfa, soybean meal, and ground corn with these coproducts still maintained the required supply of net energy and MP. Cows consuming

Table 11. Effects of feeding corn-milling coproducts on ration component digestibility and energy composition (experiment 2)

	Treatment[1]					
Measurement	Control	DDGS	Germ	HPDDG	SEM[2]	*P*-value[3]
Digestibility, %						
DM	68.1	63.8	61.7	60.6	2.71	0.18
OM	71.5	67.7	66.2	64.4	2.14	0.21
NDF	49.0	43.8	40.3	40.9	4.22	0.35
CP	67.5	66.9	65.2	63.1	2.73	0.64
Ether extract	84.3	86.3	86.0	83.8	1.88	0.71
NFC[4]	98.5	97.4	93.5	97.5	2.98	0.50
Digested, kg/d						
DM	18.4	16.9	16.0	15.7	2.08	0.35
OM	17.6	16.3	15.7	15.4	1.81	0.49
NDF	4.96	4.65	3.81	4.38	0.80	0.45
CP	3.33	3.38	3.26	3.21	0.40	0.94
N	0.53	0.54	0.52	0.51	0.06	0.94
Ether extract	0.71[a]	0.85[ab]	0.99[b]	0.88[ab]	0.10	0.07
NFC	8.64	7.46	7.65	6.95	0.67	0.27
Energy partition						
TDN,[5] %	62.7[a]	57.9[ab]	55.5[b]	55.4[b]	1.91	0.10
DE,[6] Mcal/kg	2.80	2.60	2.49	2.48	0.09	0.13
ME,[7] Mcal/kg	2.39	2.18	2.08	2.07	0.09	0.13
NE_L,[8] Mcal/kg	1.49	1.35	1.27	1.27	0.06	0.13

[a,b]Values in the same row with different superscripts differ ($P < 0.05$).

[1]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).

[2]Highest SEM is reported.

[3]Main effect of the treatment. $P < 0.05$ are significantly different; $P \leq 0.10$ are considered a trend.

[4]Calculated as 100 − (% CP + % ether extract + % ash + % NDF).

[5]Total digestible nutrients measured according to NRC (2001).

[6]Digestible energy content calculated according to NRC (2001), using measured TDN values.

[7]ME content calculated according to NRC (2001), using measured TDN values.

[8]Calculated according to NRC (2001), using measured TDN values.

Table 12. Effects of feeding corn-milling coproducts on daily excretion of urinary creatinine, allantoin, uric acid, and hypoxanthine and rumen microbial CP synthesis (experiment 2)

	Treatment[1]					
Item	Control	DDGS	Germ	HPDDG	SEM[2]	*P*-value[3]
Concentration, *mM*						
Creatinine	5.34	5.79	4.98	6.41	1.00	0.34
Allantoin	7.97	8.35	7.41	8.18	0.80	0.84
Uric acid	0.92	1.15	0.96	0.98	0.23	0.74
Hypoxanthine	0.14[a]	0.76[b]	0.35[a]	0.84[b]	0.16	0.001
PD[4]	8.89	9.51	8.37	9.16	0.95	0.82
Excretion, mmol/d						
Creatinine[5]	177.3	173.7	174.3	173.0	4.88	0.46
Allantoin[6]	284.9	272.9	269.5	233.5	38.9	0.41
PD[7]	315.6	305.4	303.5	259.9	38.5	0.34
A:C[8]	1.60	1.57	1.55	1.35	0.21	0.49
PD:C[9]	1.77	1.75	1.75	1.50	0.21	0.41
MCP,[10] g/d	1,251.0	1,206.0	1,196.0	990.3	—[11]	—

[a,b]Values in the same row with different superscripts differ ($P < 0.05$).

[1]Control = 0% DM coproducts; DDGS = 15% DM distillers grains plus solubles; germ = 15% DM corn germ; HPDDG = 15% DM high-protein distillers grains (no solubles included).

[2]Highest SEM is reported.

[3]Main effect of the treatment. $P < 0.05$ are significantly different; $P \leq 0.10$ are considered a trend.

[4]Total concentration of purine derivatives.

[5]Excretion of creatinine = [28 × BW (kg)/113.1].

[6]Excretion of allantoin = creatinine excretion × A:C.

[7]Excretion of total purine derivatives = creatinine excretion × PD:C.

[8]Ratio of allantion excretion to creatinine excretion.

[9]Ratio of total purine derivative excretion to creatinine excretion.

[10]Microbial CP as estimated by Chen and Gomes (1992).

[11]Statistical test of treatment on microbial CP production was not conducted because values were an estimated concentration of PD.

germ tended to consume more feed and tended to produce more milk (32.1 vs. 30.6 ± 1.12 kg/d) than those consuming the control ration. It is possible that the higher fat content of this ration resulted in a greater supply of energy and thus allowed animals to produce more milk while consuming less feed.

In the second experiment, both feed intake and milk production did not follow patterns identical to those observed in the first experiment; however, given the small sample size, treatment differences were not expected for these variables. Additionally, the average fat concentration of milk fat in the first experiment was greater than in the second experiment (3.75 vs. 3.20%). Although differences between experiments cannot be tested, it is likely that this was because the second study was conducted during warmer summer months, and it is well known that heat stress affects milk fat synthesis (West, 2003). More specifically, the main objective of the second experiment was to evaluate how the inclusion of corn-milling coproducts might affect rumen fermentation and total-tract nutrient digestibility when compared with inclusion of the control ration.

When compared with the control treatment, ruminal pH was not different with the inclusion of any coproduct and averaged 6.26 ± 0.08 across treatments. A major factor known to affect rumen pH is level of NFC (Russell et al., 1992). Although rations including coproducts contained slightly less NFC, it is likely that differences were not great enough to affect rumen pH. In addition, the NDF content and particle size were similar, thus ensuring that the level of effective fiber was similar between treatments. Although concentration of total rumen VFA was similar across treatments, the concentration of acetate was reduced when animals consumed treatments containing coproducts when compared with the control treatment. Consequently, the ratio of acetate to propionate was also lower, yielding effects similar to the observations of Sasikala-Appukuttan et al. (2008). The higher concentration of rumen acetate for the control diet compared with diets containing coproducts was likely due to its higher concentration of TDN (Table 11). This association has long been noted (Hinders and Owen, 1963). Unfortunately, in the current experiment, no significant treatment effects were observed on individual nutrient components of TDN; thus, it is difficult to determine the cause of the shift in rumen fermentation. Likely, a portion of the reduction of ration TDN in diets containing coproducts was due to the increase in the proportion of lower quality brome hay, making these treatments less digestible than the control treatment. Decreased isovalerate concentration in diets containing coproducts was consistent with

previous observations. Anderson et al. (2006) observed decreased isovalerate concentrations with diets containing 10 and 20% dry distillers grains and wet distillers grains (both containing solubles) compared with the control ration containing 0% coproducts (1.3 vs. 1.5 ± 0.11 m*M* for DG rations vs. the control). Schingoethe et al. (1999; 1.4 vs. 1.7 ± 0.06 m*M* for DG vs. control) and Nichols et al. (1998; 1.7 vs. 2.0 ± 0.09 m*M* for DG vs. soybean meal) also observed decreased isovalerate concentrations when feeding distillers grains to lactating dairy cattle. The decreased production of branched-chain fatty acids may be attributed to the overall low concentrations of branched-chain AA present in diets containing high amounts of corn products (Schingoethe et al., 1999); thus, the control ration may contain more precursors for branched-chain fatty acid synthesis (Johnson et al., 1994).

Determination of urine PD excretion is considered a noninvasive, indirect method for estimating differences in rumen microbial protein production (Moorby et al., 2006). In experiment 2, xanthine was not detected, and hypoxanthine concentrations were low across diets (less than 1 m*M*). This observation is consistent with the literature, which suggests that high activity of the enzyme xanthine oxidase, which is present in intestinal mucosal cells of cattle, oxidizes and degrades xanthine and hypoxanthine to uric acid before the molecules reach the liver for excretion (Gonzalez-Ronquillo et al., 2004). The total excretion of PD was observed to be similar and averaged 296.1 ± 38.5 mm/d across treatments. This finding would result in a predicted flow of 1160.8 g/d of MCP. Treatment effects of MCP were not tested, as recommended by Firkins et al. (2006), because they are predictions based on an algebraic equation, and this estimate contains only the error associated with measurement of urinary PD. Nonetheless, results of the current experiment suggest that compared with the control diet, the inclusion of coproducts in each diet did not affect duodenal MCP flow in lactating cows. It is interesting to note that the concentrations of hypoxanthine were higher for rations that included DDGS and HPDDG, which can be attributed to the residual yeast cells from the industrial corn-ethanol fermentation process found in these coproducts. Similar observations have been made by Janicek et al. (2008), and the higher hypoxanthine may be due to the existence of this PD in yeast cells, which were likely present in the DG and HP coproducts (Ferreira et al., 1999).

CONCLUSIONS

This experiment indicates that dairy rations can be successfully formulated to include 15% of diet DM as corn-milling coproducts while maintaining yields of milk and milk components. Diets formulated to contain coproducts at these levels did not result in major differences in rumen fermentation or digestibility. Decreases in rumen acetate concentration and TDN in diets containing coproducts were likely a result of the addition of grass hay, which was included to increase diet effective fiber levels. These experiments demonstrate that coproducts can be fed at higher levels as alternative energy and protein feed sources. With current increases in feed and production expenses in the dairy industry, coproducts may be used as cost-effective alternative sources of energy, protein, and fiber to replace more expensive feedstuffs. The ration-balancing methods used in this experiment should allow dairy producers flexibility to incorporate different corn-milling coproducts into lactating dairy rations, which may reduce ration costs.

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