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Use of indirect calorimetry to evaluate utilization of energy in lactating Jersey dairy cattle consuming common coproducts

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ABSTRACT

The use of coproducts as an alternative feed source is a common practice when formulating dairy rations. A study using 12 multiparous (79 ± 16 d in milk; mean ± standard deviation) lactating Jersey cows was conducted over 5 mo to evaluate the effects of dried distillers grains with solubles (DDGS) or canola meal on milk and gas production. A replicated 4 × 4 Latin square design was used to compare 4 dietary treatments. Treatments comprised a control (CON) containing no coproducts, a treatment diet containing 10% (dry matter basis) low-fat DDGS (LFDG), a treatment diet containing 10% high-fat DDGS (HFDG), and a 10% canola meal (CM) treatment. The crude fat content of the LFDG, HFDG, and CM treatments was 6.05 ± 0.379, 10.0 ± 0.134, and 3.46 ± 0.085%, respectively. Coproducts were included in partial replacement for corn and soybean meal. Indirect headbox-style calorimeters were used to estimate heat production. Dry matter intake and milk yield were similar between all treatments, averaging 17.4 ± 0.56 kg/d and 24.0 ± 0.80 kg, respectively. Milk urea N was affected by treatment and was highest in CON (20.6 mg/dL; 18.0, 19.9, and 18.1 ± 0.62 mg/dL in LFDG, CM, and HFDG, respectively). Heat production per unit of metabolic body weight tended to be affected by treatment and was lowest for CON, and diets containing coproducts were not different (192, 200, 215, and 204 ± 5.91 kcal/kg of metabolic body weight for CON, LFDG, CM, and HFDG, respectively). The concentration of metabolizable energy was affected by dietary treatment; specifically, HFDG did not differ from CON but was greater than LFDG and CM (2.58, 2.46, 2.29, and 2.27 ± 0.09 Mcal/kg for HFDG, CON, LFDG, and CM, respectively). The concentration of net energy balance (milk plus tissue) tended to be affected by dietary treatment; HFDG did not differ from either CON or LFDG, but it was higher than CM (1.38, 1.36, 1.14, and 1.06 ± 0.11 Mcal/kg for HFDG, CON, LFDG, and CM, respectively). Results of this study indicate that milk production and dry matter intake were not affected by feeding common coproducts and that differences may result in whole-animal energy use; fat content of DDGS is a major factor affecting this.
Key words: dairy cow, coproduct, energy utilization, indirect calorimetry

INTRODUCTION

Feed coproducts are defined as secondary products that are produced in addition to a principal product (AAFCO, 2016). An array of feed coproducts is produced from the food, fuel, and beverage industries, and these are widely available and used by the dairy industry (Crawshaw, 2004). Often soybean meal is the preferred protein supplement for dairy cattle. This is because it is widely available and high in CP content (Huhtanen et al., 2011). Solvent-extracted soybean meal contains approximately 54% CP and 10% NDF (DM basis). The RUP content is approximately 43%, and this rumen bypass protein is highly digestible (93%; NRC, 2001). In comparison, the RUP content and intestinal digestibility of RUP of canola meal is lower than that of soybean meal (36 and 75%, respectively). Interestingly, despite these differences, recent meta-analyses have suggested that milk production and composition may frequently respond positively when canola meal is added to the diet (Huhtanen et al., 2011; Martineau et al., 2013). In contrast, the RUP content and digestibility of RUP in dried distillers grains with solubles (**DDGS**; 51 and 85%, respectively) are higher than that in either soybean meal or canola meal (NRC, 2001). In a study in which canola meal or DDGS replaced soybean meal, yield of FCM and protein was maintained; however, a

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reduction in milk fat yield in cattle consuming DDGS was observed and may have been due to an increased intake of PUFA and, in turn, increased rumen outflow of CLA isomers that suppressed milk fat synthesis (Christen et al., 2010; Ramirez-Ramirez et al., 2016).

The concentration and digestibility of protein may vary in feedstuffs; the concentration of energy is also different. Although measuring energy concentration can be laborious, the Dairy NRC (2001) estimates that the NE_L concentration for soybean meal, DDGS, and canola meal is 2.38, 1.97, and 1.76 Mcal/kg, respectively. Recently, the DDGS available to the dairy feed market often contain less fat. This is because the corn ethanol industry has adopted technology to extract a portion of the fat from the coproduct stream. Although differences in the concentration of energy from DDGS likely exist, direct measure of energy utilization in cows consuming DDGS different in fat content has not been conducted (Ramirez-Ramirez et al., 2016). In general, nutrient availability of ruminant feeds can be determined by laboratory-scale in vitro or in situ procedures or by in vivo feeding studies. Each of these provides an informative way to evaluate the feeding value of particular feeds (Flatt et al., 1969). To date, very few energy balance experiments have been carried out on modern coproducts with lactating dairy cattle. Without such studies, it is difficult to know whether observed differences in milk production or composition are a result of differences in digestibility or nutrient utilization. The objective of this study was to test the effects of feeding canola meal or DDGS on feed intake, milk production and composition, total-tract digestibility, and energy utilization in lactating dairy cows. We hypothesized that rations containing byproduct will maintain milk production without altering energy utilization; however, we predict that canola meal will have less total-tract digestibility of protein and that this may have a negative effect on milk production and composition.

MATERIALS AND METHODS

All animal care and experimental procedures were approved by the University of Nebraska–Lincoln Animal Care and Use Committee. Multiparous Jersey cows (n = 12) averaging 79 ± 16 DIM and weighing 450 ± 11.5 kg were used in this study. Cows were housed in the temperature-controlled barn at the Dairy Metabolism Facility in the Animal Science Complex of the University of Nebraska–Lincoln. Each stall was equipped with rubber mats and a water bowl. Cows were milked twice daily at 0700 and 1800 h and fed once daily at 0900 h.

The experimental design was a replicated 4 × 4 Latin square in which each cow was randomly assigned to 1 of 4 dietary treatments that alternated over 4 periods, and cows were assigned a treatment structure according to Kononoff and Hanford (2006). Each experimental period was 28 d in length, with 23 d for ad libitum diet adaptation followed by 5 d of urine, fecal, milk, and gas collections, during which time animals were fed 95% ad libitum intake in an attempt to limit the amount of orts remaining. Animals were blocked into squares by milk production and DIM. Treatments comprised a zero control (**CON**) not containing feed coproducts, a treatment diet containing 10% (DM basis) low-fat DDGS (**LFDG**), a 10% canola meal (**CM**) treatment, and a 10% DDGS treatment with high-fat distillers grains (**HFDG**). The DDGS also differed in method of production; specifically, the LFDG were produced by a method that used lower temperatures for starch hydrolysis (Gutierrez et al., 2014). In the production of LFDG, centrifugation was also used to remove a portion of corn oil, resulting in a low-fat DDGS. Complete diet compositions and nutrient analysis of the TMR and individual ingredients are presented in Tables 1, 2, 3, and 4. Coproducts were included in partial replacement for corn and soybean meal. All diets contained corn silage, alfalfa hay, brome hay, and a concentrate mix specific to that diet, which were mixed into a TMR. Diets were mixed using a Calan Data Ranger (American Calan Inc., Northwood, NH).

Laboratory Analysis

During the 5-d collection period, milk production was recorded and milk samples were collected from each cow at each a.m. and p.m. milking. During each milking, 3 milk samples were collected. Two 50-mL conical tube (model 430829, Corning Centristar, Corning, NY) samples were frozen at −20°C. The third sample was preserved using 2-bromo-2-nitropropane-1,3-diol and sent to Heart of America DHIA (Kansas City, MO). These samples were analyzed for protein, fat, lactose, SNF, MUN, and SCC using a Bentley FTS/FCM infrared analyzer (Bentley Instruments, Chaska, MN). One of the two 50-mL conical tubes was stored at −20°C. The other sample was lyophilized and composited by cow number and period. Milk samples were then analyzed at the University of Nebraska–Lincoln for laboratory-corrected DM (100°C oven for 24 h), gross energy (**GE**; 6400 calorimeter, Parr, Moline, IL), and N (FlashSmart N/protein analyzer CE, Elantech Inc., Lakewood, NJ).

Total fecal and urine output was collected from each cow during the 5-d collection period (d 23–28 of the experimental period). A 137- × 76-cm rubber mat (Snake River Supply, Idaho Falls, ID) was placed behind each cow to aid in fecal collections. During the collection pe-

Table 1. Diet composition of control (CON), low-fat distillers grains with solubles (LFDG), canola meal (CM), and high-fat dried distillers grains with solubles (HFDG)

	Treatment			
Item, % of DM unless noted	CON	LFDG	CM	HFDG
Ingredient				
Corn silage	40.5	40.5	40.5	40.5
Alfalfa hay	13.3	13.3	13.3	13.3
Brome hay	1.15	1.15	1.15	1.15
Ground corn	16.8	15.0	15.8	15.0
Soybean meal	13.7	5.50	4.70	5.50
Low-fat DDGS	—	10.1	—	—
High-fat DDGS	—	—	—	10.1
Canola meal	—	—	10.1	—
Soybean hulls	2.52	2.52	2.52	2.52
Expellers soybean meal[1]	4.58	4.58	4.58	4.58
Calcium carbonate	1.37	1.37	1.37	1.37
Animal fat	1.95	1.95	1.95	1.95
Blood meal	1.53	1.53	1.53	1.53
Ca salts of LCFA[2]	0.80	0.80	0.80	0.80
Magnesium oxide	0.32	0.32	0.32	0.32
Sodium bicarbonate	0.57	0.57	0.57	0.57
Dicalcium phosphate	0.34	0.34	0.34	0.34
Salt	0.25	0.25	0.25	0.25
Vitamin-mineral premix[3]	0.05	0.05	0.05	0.05
Trace mineral premix[4]	0.04	0.04	0.04	0.04
Rumen-protected lysine[5]	0.05	0.05	0.05	0.05
Rumen-protected methionine[6]	0.05	0.05	0.05	0.05
Formulated chemical composition[7]				
CP	18.6	17.1	18.1	16.9
Crude fat	5.5	5.8	5.7	6.0
NDF	28.7	31.0	30.5	31.0
Lignin	2.90	3.00	3.60	3.0
Ash	8.40	8.40	8.60	8.40
Starch	28.3	27.2	27.7	27.2
NFC[8]	41.7	40.6	40.8	40.6
ME, Mcal/kg	2.71	2.73	2.71	2.73
NE_L, Mcal/kg	1.74	1.76	1.74	1.76

[1]Soypass (LignoTech, Overland Park, KS).

[2]Calcium salts of long-chain fatty acids marketed as Megalac by Church & Dwight Co. Inc. (Princeton, NJ).

[3]Formulated to supply approximately 148,500 IU/d of vitamin A, 38,500 IU/d of vitamin D, and 902 IU/d of vitamin E in total rations.

[4]Formulated to supply approximately 2,300 mg/kg of Co, 25,000 mg/kg of Cu, 2,600 mg/kg of I, 1,000 mg/kg of Fe, 150,000 mg/kg of Mn, 820 mg/kg of Se, and 180,000 mg/kg of Zn in total rations.

[5]AjiPro-L (Ajinomoto Heartland Inc., Chicago, IL).

[6]SmartamineM (Adisseo Inc., Antony, France).

[7]Values formulated from the Cornell-Penn-Miner Dairy model (Boston et al., 2000).

[8]Calculated as 100 − (% NDF + % CP + % fat + % ash).

riod, personnel were present at all times to collect feces, which were deposited into rubber trash cans (87.1 L, Rubbermaid, Wooster, OH). A garbage bag was placed over the trash can to prevent N loss before sampling. Feces were subsampled consecutively every day of the 5-d collection period at 1000 h and immediately dried at 60°C in a forced-air oven for 48 h and then composited by weight of DM excreted, cow number, and period. Samples were ground through a 1-mm screen (Wiley mill, Arthur H. Thomas Co., Philadelphia, PA) and analyzed at the University of Nebraska–Lincoln for DM (100°C oven for 24 h), N (FlashSmart N/protein analyzer CE, Elantech Inc.), ash-corrected NDF (with sodium sulfite and α-amylase; Van Soest et al., 1991), GE (Parr 6400 calorimeter), starch (Hall, 2009), and ash.

Urine was collected by inserting a 30-mL French Foley catheter (REF 0166L30; Bard Catheters, Covington, GA) into each cow's bladder with a stylus (Tamura et al., 2014). The balloon was inflated with 50 mL of physiological saline to keep the catheter in place for the duration of the 5-d collection. Urine drained from the catheter into a plastic carboy (14.2 L, Midwest Can Co., Melrose Park, IL) behind the cow using Tygon tubing (Saint Gobain, La Defense, Courbevoie, France). Urine was deposited in a 55-L plastic container 4 times

Table 2. Chemical composition of forages and concentrates [low-fat dried distillers grains with solubles (LFDG), canola meal (CM), and high-fat dried distillers grains with solubles (HFDG); DM basis][1]

Item, % of DM unless noted	Corn silage		Alfalfa hay		Brome hay		Control concentrate		LFDG concentrate		CM concentrate		HFDG concentrate	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DM, %	95.8	0.507	95.2	0.616	93.7	0.804	96.2	0.287	96.3	0.311	95.9	0.330	96.3	0.173
CP	8.15	0.436	14.6	1.086	7.83	0.419	28.5	1.374	25.6	0.450	26.6	0.263	25.8	0.638
Soluble protein	4.68	0.877	6.35	0.889	2.40	0.594	5.48	1.159	6.90	0.523	7.13	1.063	6.10	1.116
ADICP[2]	0.87	0.388	1.92	0.297	1.18	0.319	0.62	0.327	1.11	0.361	1.41	0.877	1.31	0.194
NDICP[3]	0.94	0.361	3.50	0.326	2.23	1.291	2.12	0.318	2.20	0.079	2.98	0.141	2.62	0.129
ADF	23.0	2.651	45.8	2.048	41.9	0.520	5.63	0.759	7.28	0.929	9.50	1.169	8.35	0.473
NDF	37.3	3.612	55.2	2.865	60.9	8.592	13.5	1.079	17.68	0.991	17.9	0.768	18.0	0.968
Lignin	3.36	0.400	10.1	0.553	5.92	0.915	0.92	0.336	1.47	0.159	2.73	0.145	1.98	0.453
NFC[4]	47.1	4.685	20.0	1.726	20.8	8.802	40.5	3.289	39.23	1.350	38.59	0.872	39.1	1.602
Sugar	0.78	0.206	3.35	0.545	7.33	0.822	6.30	0.356	4.53	0.340	5.18	0.287	5.25	0.695
Starch	35.6	3.559	0.85	0.580	0.78	0.918	27.5	2.640	27.38	0.568	27.1	0.497	26.4	0.594
Crude fat	2.79	0.198	0.75	0.185	1.22	0.212	6.65	0.225	7.49	0.386	7.08	0.095	8.23	0.367
Ash	4.61	0.744	9.41	0.502	9.19	0.261	10.9	1.555	10.04	0.798	9.78	0.655	8.91	0.369
Ca	0.21	0.021	0.89	0.087	0.36	0.019	2.19	0.484	1.99	0.040	2.14	0.209	1.81	0.127
P	0.23	0.029	0.35	0.008	0.27	0.010	0.64	0.047	0.72	0.096	0.70	0.048	0.69	0.022
Mg	0.15	0.025	0.20	0.014	0.12	0.006	0.59	0.066	0.62	0.033	0.65	0.019	0.61	0.053
K	1.08	0.082	3.96	0.099	2.33	0.085	1.36	0.074	1.21	0.048	1.14	0.045	1.24	0.048
S	0.13	0.006	0.16	0.016	0.15	0.031	0.34	0.005	0.47	0.034	0.42	0.008	0.44	0.005
Na	0.02	0.000	0.03	0.000	0.02	0.000	0.67	0.135	0.86	0.282	0.62	0.058	0.69	0.038
Cl	0.14	0.040	0.11	0.006	0.28	0.010	0.45	0.130	0.64	0.405	0.35	0.038	0.40	0.021
Fe, mg/kg	157	45.29	187	42.51	182	26.61	383	126.9	468	41.26	425	35.98	437	65.88
Zn, mg/kg	27.5	3.697	20.5	1.291	19.5	1.915	194	34.61	252	142.3	206	40.72	181	16.42
Cu, mg/kg	9.50	5.686	8.00	0.000	7.00	0.816	34.0	5.354	45.3	14.84	31.5	3.109	36.8	2.986
Mn, mg/kg	31.5	3.873	24.5	2.646	49.8	1.258	116	23.26	157	44.44	120	13.19	112	25.79

[1]Values determined by Cumberland Valley Analytical Services (Hagerstown, MD).

[2]Acid detergent insoluble CP.

[3]Neutral detergent insoluble CP.

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

daily and acidified with 50 mL of HCl at 1730 h. Urine was then subsampled at 1000 h every day of the 5-d collection period using two 100-mL bottles. One bottle was dried at 60°C in a forced-air oven to determine DM. The other was frozen at −20°C until analysis, which included thawing and boiling before lyophilization. To decrease water content of the urine before N analysis, the urine was boiled. To boil, 5 thawed 100-mL bottles were poured into a 600-mL beaker and placed into a heated water bath (Ankom Technology, Macedon, NY) located underneath a fume hood. The water bath was turned on in the morning and off in the afternoon, approximately 6 h each day, to avoid overheating and burning of the sample. After much of the water was removed from each sample, the remaining residue was composited by cow number and period and lyophilized (VisTis Freezemobile 25ES, SP Scientific, Gardiner, NY). Urine samples were then analyzed for laboratory-corrected DM (100°C oven for 24 h), N (FlashSmart N/protein analyzer CE, Elantech Inc.), and GE (Parr 6400 calorimeter).

Total mixed rations were sampled (500 g) on the first day of each collection period and frozen at −20°C. Samples were analyzed at the University of Nebraska–Lincoln for particle size (Heinrichs and Kononoff, 2002), DM (100°C oven for 24 h), N (FlashSmart N/protein analyzer CE, Elantech Inc.), ash-corrected NDF (with sodium sulfite and α-amylase; Van Soest et al., 1991; Whatman filter papers, GE Healthcare Bio-Sciences, Pittsburgh, PA), starch, and ash. Feed ingredients were sampled (500 g) on each day of each collection period and were frozen at −20°C. The samples were then composited by period and treatment. A subsample was sent to Cumberland Valley Analytical Services Inc. (Waynesboro, PA) for complete nutrient analysis of DM (AOAC International, 2000), N (Leco FP-528 N combustion analyzer, Leco Corp., St. Joseph, MO), ash-corrected NDF (with sodium sulfite and α-amylase; Van Soest et al., 1991), ADF (method 973.18; AOAC International, 2000), lignin (Goering and Van Soest, 1970), NFC [100 − (% NDF + % CP + % fat + % ash)], sugar (DuBois et al., 1956), starch (Hall, 2009),

Table 3. Chemical composition of coproducts[1,2]

Item, % of DM unless noted	LFDG		CM		HFDG	
	Mean	SD	Mean	SD	Mean	SD
DM, %	89.8	0.698	89.7	0.071	89.7	0.071
CP	30.8	0.538	41.1	0.354	32.2	0.495
Soluble protein	8.53	0.695	13.3	0.636	7.65	0.217
RUP,[3] % of CP	94.3	2.376	58.3	0.000	74.2	0.000
dRUP,[3] % of RUP	83.7	1.658	71.8	0.000	77.3	0.000
ADICP[4]	2.01	0.155	2.39	0.106	2.90	0.127
NDICP[5]	2.69	0.549	4.28	0.078	3.83	0.078
ADF	11.7	1.748	19.3	0.283	11.9	0.141
NDF	32.2	2.171	27.5	0.495	31.8	0.990
Lignin	3.40	0.132	9.02	0.170	3.59	0.764
NFC[6]	24.5	3.23	17.9	0.120	20.1	1.499
Sugar	5.15	0.404	10.9	0.354	5.20	0.283
Starch	6.68	1.684	0.30	0.141	2.60	0.141
Crude fat	6.05	0.379	3.46	0.085	10.0	0.134
Ash	6.40	1.008	10.3	0.177	5.85	0.120
Ca	0.08	0.062	2.01	0.092	0.05	0.000
P	0.91	0.077	1.17	0.000	0.97	0.014
Mg	0.35	0.010	0.70	0.000	0.38	0.000
K	1.44	0.123	1.41	0.120	1.48	0.028
S	1.14	0.055	0.81	0.007	1.09	0.035
Na	0.35	0.089	0.12	0.007	0.22	0.000
Cl	0.46	0.552	0.06	0.000	0.20	0.007
Fe, mg/kg	104	22.17	207	14.14	142	2.121
Zn, mg/kg	59.0	5.944	92.5	7.778	64.5	3.536
Cu, mg/kg	2.75	0.500	26.5	0.707	5.00	0.000
Mn, mg/kg	17.3	2.630	92.5	3.536	19.5	0.707

[1]Values determined by Cumberland Valley Analytical Services (Hagerstown, MD).

[2]LFDG = low-fat dried distillers grains with solubles; CM = canola meal; HFDG = high-fat dried distillers grains with solubles.

[3]Values determined at Cumberland Valley Analytical Services Inc. (Waynesboro, PA) according to Ross et al. (2013).

[4]Acid detergent insoluble CP.

[5]Neutral detergent insoluble CP.

[6]Calculated as 100 − (% NDF + % CP + % fat + % ash).

crude fat (method 2003.05; AOAC International, 2006), ash (method 943.05; AOAC International, 2000), and minerals (method 985.01; AOAC International, 2000). In addition to the assays previously described, coproducts were analyzed at Cumberland Valley Analytical Services Inc. (Waynesboro, PA) for rumen and intestinal protein degradability (Ross et al., 2013).

Heat production by cattle was determined through headbox-type indirect calorimeters based on those used by Birkelo et al. (2004) and described by Foth et al. (2015) and Freetly et al. (2006). Before collections, 5 headboxes were used to test the rate of recovery of gas by burning 100% concentration of ethyl alcohol in the sealed headbox and comparing this measure with calculated gas concentrations. These calculations were based on weight of alcohol burned and a measured volume of gas sample. Five lamp runs were conducted. Recovery rates of oxygen (O_2) and carbon dioxide (CO_2) averaged 101.0 ± 0.04 and 100.8 ± 0.04%, respectively. For each cow and within each period, heat production was estimated using the Brouwer equation (Brouwer, 1965). To do so, O_2 consumption and CO_2 and methane (CH_4) production were measured and adjusted for a 24-h period. The design of the headboxes allowed for feed to be placed in the bottom of the box, and ad libitum access to water was available for the cows from a water bowl located inside the headbox. Water meters (model 11 010805, DLJ Meters, Hackensack, NJ) were attached to the water bowl to record water usage. Within the headbox, temperature and dew point were recorded every minute using a probe (model TRH-100, Pace Scientific Inc., Moorseville, NC) that was connected to a data logger (model XR440, Pace Scientific Inc.). Fifteen minutes before the start of the collection, the doors were closed and the motor was turned on to allow for several air turnovers before gases were collected. Line pressure was measured using a manometer (item no. 1221-8, United Instruments, Westbury, NY). Barometric pressure of the room was also recorded using a barometer (Chaney Instruments Co., Lake Geneva, WI) and uncorrected for sea level. Total volume of gas that passed through the headbox during each run was measured using a dry gas meter (model AL425, American Meter, Horsham, PA). From the headbox, continuous samples of outgoing and incoming air were diverted to 2 different collection bags (61 × 61 cm LAM-Japcon-NSE, 44 L; PMC, Oak Park, IL) using glass tube rotameters (model 1350E Sho-Rate 50, Brooks Instruments, Hatfield, PA). Collection bags

Table 4. Chemical composition (% of DM unless noted) and particle size (mm) of treatment diets differing in coproducts based on the feed ingredients

	Treatment[1,2]							
	CON		LFDG		CM		HFDG	
Item	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Chemical composition								
DM, %	70.6	1.219	70.7	1.072	70.8	1.237	70.5	1.137
CP	18.2	0.789	16.8	0.095	17.3	0.292	17.0	0.405
Soluble protein	5.23	0.270	5.87	0.496	5.97	0.643	5.51	0.766
ADICP[3]	0.90	0.248	1.12	0.352	1.26	0.440	1.21	0.130
NDICP[4]	1.82	0.154	1.86	0.133	2.21	0.094	2.05	0.116
ADF	18.4	1.298	19.1	0.962	20.1	1.422	19.6	1.114
NDF	29.2	1.083	31.1	1.779	31.2	1.620	31.2	0.985
Lignin	3.18	0.206	3.43	0.240	3.99	0.260	3.66	0.258
NFC[5]	40.2	1.867	39.7	2.082	39.4	2.089	39.6	1.110
Sugar	3.68	0.222	2.88	0.163	3.17	0.201	3.21	0.357
Starch	26.9	1.886	26.9	1.367	26.8	1.246	26.5	1.365
Crude fat	4.24	0.175	4.61	0.116	4.43	0.112	4.95	0.213
Ash	8.12	0.776	7.74	0.615	7.63	0.334	7.24	0.122
Particle size[6]								
>19.0	3.46	0.574	3.67	0.951	4.04	1.411	4.29	1.406
8.0–19.0	26.7	3.052	28.4	1.544	29.6	1.624	28.3	1.379
1.18–8.0	51.2	3.850	44.7	2.708	46.7	4.136	45.7	2.004
<1.18	18.7	2.540	23.2	2.743	19.6	2.775	21.7	2.128

[1]Values determined by Cumberland Valley Analytical Services (Hagerstown, MD).

[2]CON = control; LFDG = low-fat dried distillers grains with solubles; CM = canola meal; HFDG = high-fat dried distillers grains with solubles.

[3]Acid detergent insoluble CP.

[4]Neutral detergent insoluble CP.

[5]Calculated as 100 − (% NDF + % CP + % fat + % ash).

[6]Determined using the Penn State Particle Separator on an as-fed basis (Heinrichs and Kononoff, 2002).

with gas samples inside were analyzed at the University of Nebraska–Lincoln laboratory according to Nienaber and Maddy (1985). Heat production was estimated through calculation of O_2 consumption and CO_2 and CH_4 production with correction for urinary N loss according to Brouwer (1965). Respiratory quotient was calculated using the ratio of CO_2 produced to the O_2 consumed and was not corrected for N. Volume of CH_4 produced was multiplied by a constant of 9.45 kcal/L to estimate the amount of energy formed from the gaseous products (Blaxter and Clapperton, 1965). Energy use was calculated for each cow and adjusted for excess N intake according to Freetly et al. (2006) according to the following equations:

$$\text{HP (Mcal/d)} = 3.866 \times \text{O}_2\text{ (L)} + 1.200 \times \text{CO}_2\text{ (L)} - 0.518 \times \text{CH}_4\text{ (L)} - 1.431 \times \text{N (g)}; \quad [1]$$

$$\text{ME (Mcal/d)} = \text{GE intake (Mcal/d)} - \text{fecal energy (Mcal/d)} - \text{urinary energy (Mcal/d)} - \text{methane energy (Mcal/d)}; \quad [2]$$

$$\text{Recovered energy (Mcal/d)} = \text{ME} - \text{HP}; \quad [3]$$

$$\text{Tissue energy (Mcal/d)} = \text{recovered energy} - \text{milk energy (Mcal/d)}; \text{ and} \quad [4]$$

$$\text{Tissue energy in protein (g/d)} = \text{N balance (g/d)} \times (5.88 \text{ kg of protein/kg of N}) \times (5.7 \text{ Mcal/kg of protein})/1{,}000. \quad [5]$$

Tissue energy in protein describes the energy used for tissue protein synthesis. A total of 48 observations were collected. Two animals were removed from all 4 periods of the data set because one cow suffered from an injured teat and the second cow failed to consume feed while in the headbox. This resulted in a total of 40 energy balances.

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Treatment, square, and period were modeled as fixed effects, whereas cow within square was modeled as a random effect. The LSMEANS option was used to generate least squares means of treatments listed in this study, and means were separated using the DIFF option. Significance was declared at $P \leq 0.05$, and trends were declared at $0.05 < P \leq 0.10$.

RESULTS

Diet Composition

Chemical composition of the diets is listed in Table 4. The CP content of the control was slightly greater than that of the diets containing coproducts. Neutral detergent fiber content was similar across treatments, and, as expected, crude fat was greatest in the HFDG treatment and least in CON (4.95 ± 0.21, 4.61 ± 0.12, 4.43 ± 0.11, and 4.24 ± 0.17% for HFDG, LFDG, CM, and CON, respectively).

Feed Intake, Milk Production, and Composition

Results of milk production and composition are listed in Table 5. Dry matter intake was not different ($P = 0.437$) across treatments, averaging 17.4 ± 0.56 kg/d. Milk yield ($P = 0.552$) and ECM ($P = 0.762$) were also similar between treatments, averaging 24.0 ± 0.80 and 33.3 ± 1.2 kg/d, respectively. Similarly, the percentage of milk fat ($P = 0.937$) and fat yield ($P = 0.868$) was not affected by treatment, averaging 6.19 ± 0.17% and 1.5 ± 0.06 kg/d, respectively. The percentage of milk protein ($P = 0.423$) and protein yield ($P = 0.826$) was not different across treatments, averaging 3.64 ± 0.04% and 0.87 ± 0.03 kg/d, respectively. Milk urea N was affected by treatment ($P = 0.001$; SEM = 0.62); it was greatest in CON (20.6 mg/dL) and CM (19.9 mg/dL) and lowest in the DDGS treatments (18.0 and 18.1 mg/dL for LFDG and HFDG, respectively). Body weight ($P = 0.169$) and BCS ($P = 0.316$) were not different between all treatments and averaged 458 ± 11.5 kg and 3.16 ± 0.09, respectively.

Oxygen Consumption, Carbon Dioxide, Methane, and Heat Production

Results of oxygen consumption, gas production, and heat production are listed in Table 6. Oxygen consumption did not differ across treatments ($P = 0.132$), averaging 4,058 ± 135 L/d. Carbon dioxide production tended ($P = 0.085$) to be affected by treatment; specifically, the control produced the lowest CO_2. This was similar to cows consuming 2 treatments containing DDGS, but the greatest production was observed in cows consuming CM. Methane production was not affected by treatment ($P = 0.542$) and averaged 340 ± 19.6 L/d across treatments. The respiration quotient averaged 1.01 ± 0.01 L/L and was not different across treatments ($P = 0.748$). Heat production was not different across treatments ($P = 0.118$) and averaged 20.3 ± 0.67 Mcal/d. However, when expressed as a function of metabolic BW (**MBW**), heat production tended to be affected by treatment ($P = 0.058$). This was low-

Table 5. Dry matter intake, milk production and components, BW, and BCS of lactating Jersey cows fed treatments differing in coproducts

	Treatment[1]					
Item	CON	LFDG	CM	HFDG	SEM[2]	*P*-value
DMI, kg/d	17.5	17.4	17.6	17.0	0.558	0.437
Milk yield, kg/d	23.4	24.2	24.2	24.4	0.804	0.552
ECM,[3] kg/d	32.7	33.3	33.4	33.8	1.234	0.762
Fat, %	6.23	6.11	6.20	6.17	0.167	0.937
Fat yield, kg/d	1.46	1.48	1.49	1.50	0.063	0.868
Protein, %	3.67	3.63	3.60	3.64	0.045	0.423
Protein yield, kg/d	0.86	0.87	0.87	0.89	0.030	0.826
Lactose, %	4.71	4.69	4.70	4.71	0.033	0.878
MUN, mg/dL	20.6[a]	18.0[b]	19.9[a]	18.1[b]	0.620	0.001
SCC, cells/mL	43.5	190	91.8	66.6	66.14	0.346
BW, kg	461	460	454	459	11.50	0.169
BCS[4]	3.23	3.21	3.03	3.19	0.088	0.316

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]CON = control; LFDG = low-fat dried distillers grains with solubles; CM = canola meal; HFDG = high-fat dried distillers grains with solubles.

[2]Lowest SE of treatment means is shown.

[3]Calculated as 0.327 × milk yield (kg) + 12.95 × fat (kg) + 7.20 × protein (kg) adjusted for 3.5% fat and 3.2% total protein (DRMS, 2014).

[4]Scale of 1 to 5 according to Wildman et al. (1982).

est in CON (192.4 kcal/MBW), similarly higher in the DDGS treatments (200 and 204 kcal/MBW for LFDG and HFDG, respectively), and highest in CM (215 kcal/kg of MBW).

Energy Utilization

Intake, use, and output of energy results are listed in Table 7. Gross energy intake was not different between treatments ($P = 0.697$) and averaged 76.8 ± 2.6 Mcal/d. Digestible energy (**DE**; $P = 0.357$) and ME ($P = 0.351$) also did not differ between treatments and averaged 48.5 ± 2.2 and 41.7 ± 2.2 Mcal/d, respectively. As a percentage of GE intake, DE ($P = 0.141$) and ME ($P = 0.166$) were not affected by treatment. As a percentage of GE intake, fecal loss ($P = 0.142$) and urine loss ($P = 0.700$) were not affected by treatment, averaging 36.8 ± 1.24 and 4.65 ± 0.34%, respec-

Table 6. Daily consumption of oxygen and production of carbon dioxide and methane in lactating Jersey cows fed treatments differing in coproducts

	Treatment[1]					
Item	Control	LFDG	CM	HFDG	SEM[2]	*P*-value
O_2 consumption, L/d	3,873	4,007	4,262	4,092	135	0.132
CO_2 production, L/d	3,932[b]	4,041[ab]	4,342[a]	4,141[ab]	132	0.085
CH_4 production, L/d	335	329	360	337	19.6	0.542
RQ,[3] L/L	1.01	1.01	1.02	1.01	0.007	0.748
CH_4/ECM,[4] L/kg	10.3	10.2	10.8	10.0	0.695	0.780
CH_4/DMI, L/kg	19.3	19.0	20.5	19.9	1.27	0.787
Heat production,[5] Mcal/d	19.2	19.9	21.2	20.3	0.668	0.118
Heat production,[6] kcal/MBW	192.4[b]	200.0[ab]	214.9[a]	203.8[ab]	5.91	0.058

[a,b]Means within rows with different superscripts differ ($P < 0.05$).

[1]CON = control; LFDG = low-fat dried distillers grains with solubles; CM = canola meal; HFDG = high-fat dried distillers grains with solubles.

[2]Lowest SE of treatment means is shown.

[3]Respiratory quotient; CO_2 production/O_2 consumption.

[4]Energy-correct milk = 0.327 × milk yield (kg) + 12.95 × fat (kg) + 7.20 × protein (kg) adjusted for 3.5% fat and 3.2% total protein (DRMS, 2014).

[5]Heat production calculated with Brouwer's (1965) equation from oxygen consumption (L), carbon dioxide production (L), methane production (L), and urine N (g); heat production = 3.866 × O_2 + 1.200 × CO_2 − 0.518 × CH_4 − 1.431 × N.

[6]Heat production, kcal/d per unit of metabolic BW (MBW = $BW^{0.75}$).

tively. Net energy balance (milk plus tissue) was similar across treatments ($P = 0.217$) and averaged 21.6 ± 2.3 Mcal/d. No differences in milk energy were detected between treatments ($P = 0.260$) and when expressed as a percentage of GE intake ($P = 0.267$) averaged 23.2 ± 1.0 Mcal/d and 30.6 ± 1.2%, respectively. Tissue energy did not differ across treatments ($P = 0.164$) and averaged −1.62 ± 2.0 Mcal/d. Net energy balance when expressed as a percentage of GE intake was not affected by treatment ($P = 0.117$) and averaged 27.9 ± 2.27%. The concentration of GE was affected by treatment ($P = 0.014$; SEM = 0.07); it was greatest in HFDG (4.62 Mcal/kg of DM), not different from diets containing coproducts in CON (4.40 Mcal/kg of DM), and least in LFDG and CM (4.31 and 4.34 Mcal/kg of DM, respectively). Digestible energy was affected by treatment ($P = 0.018$; SEM = 0.08) and followed the same pattern as GE: greatest in HFDG (2.98 Mcal/kg of DM), not different from diets containing coproducts in CON (2.98 Mcal/kg of DM), and least in LFDG and CM (2.83 and 2.67 Mcal/kg of DM, respectively). Metabolizable energy was affected by treatment ($P = 0.034$; SEM = 0.09) and again displayed a similar pattern as GE and DE: greatest in HFDG (2.58 Mcal/kg of DM), not different from diets containing coproducts in CON (2.46 Mcal/kg of DM), and least in LFDG and CM (2.29 and 2.27 Mcal/kg of DM, respectively). Net energy balance (milk plus tissue) also tended to be affected by treatment ($P = 0.062$; SEM = 0.11) and was greatest in CON and HFDG (1.36 and 1.38 Mcal/kg of DM, respectively), not different from CON, HFDG, and CM in LFDG (1.14 Mcal/kg of DM), and lowest in CM (1.06 Mcal/kg of DM).

N Utilization

Nitrogen intake, use, and excretion are listed in Table 8. Total N intake was affected by treatment ($P = 0.045$) and was greatest in cows consuming CON (539 g/d) and least in cows consuming DDGS treatments (481 and 495 g/d for LFDG and HFDG, respectively). Fecal N was also affected by treatment ($P = 0.044$) and was greatest in CM (181 g/d), not different from diets containing coproducts in CON (172 g/d), and lowest in

Table 7. Energy utilization in lactating Jersey cows consuming treatments differing in coproducts

	Treatment[2]					
Item[1]	Control	LFDG	CM	HFDG	SEM[3]	*P*-value
Mcal/d						
GE intake	76.8	75.1	76.6	78.5	2.58	0.697
DE	49.4	46.8	47.1	50.7	2.20	0.357
ME	42.9	40.1	40.0	43.9	2.23	0.351
Component						
Feces	27.4	28.3	29.6	27.8	1.09	0.371
Urine	3.30	3.59	3.68	3.67	0.238	0.639
Methane	3.16	3.11	3.40	3.18	0.185	0.542
Heat	19.2	19.9	21.2	20.3	0.668	0.118
Milk	22.0	23.8	22.7	24.5	1.05	0.260
Tissue	1.76	−3.52	−3.81	−0.90	1.99	0.164
Balance[4]	23.7	20.2	18.9	23.6	2.27	0.217
% of GE						
Feces	35.7	37.7	38.4	35.6	1.24	0.142
Urine	4.30	4.81	4.80	4.70	0.34	0.700
Methane	4.17	4.17	4.46	4.06	0.27	0.621
Heat	25.1	26.6	27.8	25.9	1.04	0.292
Milk	29.1	32.0	29.8	31.5	1.19	0.267
Tissue	0.16	−0.05	−0.05	−0.02	0.03	0.168
Balance[4]	30.7	26.6	24.6	29.7	2.27	0.117
DE	64.3	62.2	61.6	64.4	1.24	0.141
ME	55.8	53.3	52.3	55.6	1.48	0.166
Mcal/kg of DM						
GE	4.40^{ab}	4.31^{b}	4.34^{b}	4.62^{a}	0.068	0.014
DE	2.83^{ab}	2.68^{b}	2.67^{b}	2.98^{a}	0.082	0.018
ME	2.46^{ab}	2.29^{b}	2.27^{b}	2.58^{a}	0.089	0.034
Balance[4]	1.36^{a}	1.14^{ab}	1.06^{b}	1.38^{a}	0.111	0.062

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]GE = gross energy; DE = digestible energy.

[2]CON = control; LFDG = low-fat dried distillers grains with solubles; CM = canola meal; HFDG = high-fat dried distillers grains with solubles.

[3]Lowest SE of treatment means is shown.

[4]Balance = milk energy + tissue energy.

DDGS diets (165 and 160 g/d for LFDG and HFDG, respectively). As a percentage of N intake, fecal N was affected by treatment ($P = 0.038$) and was greatest in CM (35.6%), not different from CON, CM, and HFDG in LFDG (34.3%), and lowest in CON and HFDG (31.9 and 32.4%, respectively). Total urine N was not affected by treatment ($P = 0.768$) and averaged 230 ± 16.0 g/d. Total N excretion did not differ between treatments and averaged 399 ± 18.4 g/d ($P = 0.449$). Milk N was not affected by treatment ($P = 0.477$) and averaged 161 ± 8.34 g/d. Nitrogen balance was not affected by treatment ($P = 0.651$) and averaged −59.7 ± 26.1 g/d. Tissue energy in protein was not different between treatments ($P = 0.632$) and averaged −1.87 ± 0.89 g/d. As a percentage of N intake, urine N was not affected by treatment ($P = 0.840$) and averaged 45.6 ± 3.54%. As a percentage of N intake, milk N was not affected by treatment ($P = 0.188$), averaging 32.1 ± 1.49%. When expressed as a percentage of N intake, N balance was not affected by treatment ($P = 0.514$) and averaged −12.3 ± 5.19% across treatments.

Nutrient Digestibility

Nutrient digestibility is listed in Table 9. Dry matter digestibility was affected by treatment ($P = 0.050$; SEM = 1.09) and was greatest in CON and HFDG (66.7 and 66.0%, respectively), not different from CON, CM, and HFDG in LFDG (64.2%), and lowest in CM (63.3%). Organic matter digestibility tended to be affected by treatment ($P = 0.062$; SEM = 1.02) and followed the same pattern as DM digestibility: it was greatest in CON and HFDG, not different from CON, CM, and HFDG in LFDG, and least in CM. Crude protein digestibility was affected by treatment ($P = 0.038$; SEM = 1.25) and was greatest in CON and HFDG (68.1 and 67.6%, respectively), not different from CON, CM, and HFDG in LFDG (65.6.%), and lowest in CM (64.3%). Starch digestibility was not affected by treatment ($P = 0.292$) and averaged 92.7 ± 0.29%. Neutral detergent fiber digestibility was affected by treatment ($P = 0.002$; SEM = 1.70) and was greatest in CON and HFDG (47.0 and 45.0%, respectively) and lower in LFDG and CM (41.4 and 39.5%, respectively).

DISCUSSION

Coproducts have historically played an important role in dairy feeding practices by providing a cost-effective source of protein and fiber for dairy farmers (Bradford and Mullins, 2012). The use of these coproducts has also been predicted to increase overall efficiency and productivity of the dairy industry as a whole by utilizing a product that would have been considered waste in the primary production process (VandeHaar and St-Pierre, 2006). The purpose of our research was to compare 2 of the more popular coproducts today, canola meal and DDGS, and analyze their effect on digestibility, energy utilization, and milk production.

Diet Composition

As expected, treatments containing high-fat DDGS had the highest concentration of fat. Both DDGS

Table 8. Nitrogen utilization in lactating Jersey cows fed treatments differing in coproducts

	Treatment[1]					
Item	CON	LFDG	CM	HFDG	SEM[2]	*P*-value
Mass, g/d						
N intake	539[a]	481[b]	508[ab]	495[b]	17.97	0.045
Fecal N	172[ab]	165[b]	181[a]	160[b]	7.142	0.044
Urine N	234	216	236	233	15.70	0.768
Total N excretion[3]	406	381	417	393	18.42	0.449
Milk N	168	163	150	163	8.34	0.477
N balance[4]	−34.0	−81.1	−61.2	−62.7	26.15	0.651
Tissue energy in protein	−0.97	−2.62	−1.82	−2.08	0.8943	0.632
N intake, %						
Fecal N	31.9[b]	34.3[ab]	35.6[a]	32.4[b]	1.246	0.038
Urine N	43.1	45.3	46.6	47.3	3.539	0.840
Milk N	31.5	34.0	29.6	33.2	1.493	0.188
N balance[4]	−6.30	−17.4	−12.2	−13.3	5.188	0.514

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]CON = control; LFDG = low-fat dried distillers grains with solubles; CM = canola meal; HFDG = high-fat dried distillers grains with solubles.

[2]Lowest SE of treatment means is shown.

[3]Fecal N + urine N.

[4]Nitrogen balance = intake N − fecal N − urine N − milk N.

treatments were included at the same rate in the diet (10.1%), and this explains the increased fat content of the HFDG diet. Historically, heat damage has been estimated by considering the acid detergent insoluble CP (**ADICP**) content of a feed (Kajikawa et al., 2012). The DDGS used in this study were produced differently; specifically, the LFDG were exposed to less heat than the HFDG. Therefore, differences in the ADICP were expected. Indeed, lower concentrations of ADICP were observed in the LFDG diet (1.12% DM) compared with the HFDG diet (1.21% DM). Additionally, the low-fat DDGS in the LFDG diet contained lower concentrations of ADICP (2.01% DM) compared with the DDGS used in the HFDG diet (2.90%). Although increasing ADICP of a feed may not necessarily lead to reduced N digestibility (Nakamura et al., 1994), the implications of this characteristic on N digestibility are described in further detail below.

Nutrient Digestibility

Previous research conducted using in vitro or in situ methods has reported intestinal RUP digestibility values for DDGS to be greater than those for canola meal (NRC, 2001; Paz et al., 2014). However using an in vitro technique, Lawrence and Anderson (2018) estimated the intestinal digestibility of CP to be greatest in soybean meal (81%) and, in contrast with Paz et al. (2014), reported digestibility to be similar between canola meal (71%) and DDGS (63%). In the current study and according to the in vitro assay used (Ross et al., 2013), the RUP and digestibility of RUP were greatest for low-fat DDGS (94 and 84%, respectively), lower in high-fat DDGS (74 and 77%, respectively), and lowest in canola meal (58 and 72%, respectively). Total-tract digestibility of CP was observed to be lower in cattle consuming canola meal (64.3%) compared with cattle consuming LFDG (65.6%) or HFDG (67.6%). Similar to previous research (Shingfield et al., 2003; Huhtanen et al., 2011), we observed lower NDF digestibility for cattle consuming the canola meal diet compared with the control. We suggest that this relates to a greater lignin content of the CM treatment compared with the CON diet (3.99 and 3.18% of DM, respectively). This increased lignin content of canola meal is an artifact of the hard seed coat of canola seeds, and this property may contribute to resistance of degradation by rumen microbes (Bell, 1993).

As noted above, we also hypothesized that the LFDG may have a higher CP digestibility than the HFDG. Drying the product at higher temperatures or drying for a longer duration may increase the chance for heat damage and could damage the protein, making it unavailable for the animal (Kleinschmit et al., 2007). Previous research has observed that ADICP may be used to estimate the extent of heat damage (Kajikawa et al., 2012). Considering that LFDG contained a lower content of ADICP compared with HFDG, it could suggest that digestibility of this treatment would be greater than that of HFDG. However, somewhat unexpectedly, HFDG, which were produced in a corn ethanol process that uses more heat, resulted in a greater digestibility of CP. The reason for this observation is not apparent; however, these results support the suggestion that unless the feeds have experienced extensive heat damage, ADICP is not an accurate predictor of the digestibility of protein (Nakamura et al., 1994).

Table 9. Apparent digestibility of nutrients in lactating Jersey cows consuming treatments differing in coproducts

	Treatment[1]					
Item, %	CON	LFDG	CM	HFDG	SEM[2]	*P*-value
DM	66.7[a]	64.2[ab]	63.3[b]	66.0[a]	1.094	0.050
OM	68.8[a]	66.3[ab]	65.7[b]	68.2[ab]	1.025	0.062
Ash	34.5	34.9	31.3	32.9	3.425	0.786
CP	68.1[a]	65.6[ab]	64.3[b]	67.6[a]	1.246	0.038
Starch	92.5	92.8	92.3	93.2	0.430	0.292
NDF[3]	47.0[a]	41.4[b]	39.5[b]	45.0[a]	1.701	0.002

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]CON = control; LFDG = low-fat dried distillers grains with solubles; CM = canola meal; HFDG = high-fat dried distillers grains with solubles.

[2]Lowest SE of treatment means is shown.

[3]Ash-corrected NDF.

Milk Production and Composition

Previous research comparing DDGS and canola meal treatments have reported similar DMI (Mulrooney et al., 2009; Mutsvangwa et al., 2016). However, this is in contrast with Chibisa et al. (2012), who reported increasing DMI when wheat DDGS replaced canola meal. In the current study, the addition of coproducts to the diet did not affect DMI. This may be because of the comparatively low inclusion rate of coproducts (10%) in the current study. Chibisa et al. (2012) reported differences in DMI with wheat DDGS inclusion rates of up to 20%. In addition, Janicek et al. (2008) reported that dairy diets containing as much as 30% of DDGS might result in an increase in DMI.

Substituting coproducts in diets with high starch concentrations has been reported to have positive associate effects such as increased milk fat (Weiss, 2012), NDF digestibility (Allen and Grant, 2000), and feed efficiency (Boddugari et al., 2001). In the current study, the starch content was similar across all diets, ranging from 26.5 to 26.9% of DM. Perhaps the low inclusion rate of coproducts in the current study did not displace

enough starch to display the positive associate effects that are described by previous research.

In the current study, differences in the concentration of energy content and digestibility did not translate into differences in milk production or composition. Milk yield and ECM were similar between the canola meal and DDGS treatments, which is similar to several previous studies (Maxin et al., 2013; Acharya et al., 2015; Mutsvangwa et al., 2016).

Dried distillers grains have been reported to contain rumen-available UFA, which can contribute to milk fat depression (Hippen et al., 2010). Weiss et al. (2015) reported milk fat to linearly increase from 3.28 to 3.34% when canola meal in the diet was increased from 3.9 to 13.9% and fed to Holstein dairy cattle. The results of our study suggest that milk fat can be maintained when DDGS containing varying crude fat levels and canola meal are replace corn and soybean meal at 10% of the diet. The inclusion of DDGS in diets has been shown to negatively affect milk protein, presumably due to an unbalanced supply of AA, particularly lysine (Carvalho et al., 2006). In the current study, ruminally protected lysine and methionine were supplemented to ensure that AA requirements were met. Although milk protein was maintained across treatments, MUN was reduced when coproducts were added to the diets compared with the control. This is surprising because CP digestibility and N balance were greatest in the control, possibly predicting that less N would be translated into milk. This small difference may be due to the greater protein content in the CON treatment (18.2%) versus the coproducts treatments; therefore, the cows excreted more N.

Energy Utilization

The ratio of CO_2 produced to O_2 consumed is commonly known as the respiratory quotient (**RQ**). In the current study, RQ was not affected by treatment and on average was observed to be 1.01 L/L. These observations are similar to those of Aubry and Yan (2015), who summarized data from 987 cattle and observed an average RQ of 1.00 ± 0.09 L/L. Although cattle in the current study were fed 95% ad libitum and restriction of feed intake is known to have a reducing effect on RQ (Yan et al., 1997), our observations appear to be within normal ranges expected for dairy cattle. Given that the heat of combustion is higher for fat than for any other nutrient (Maynard et al., 1979) and that the crude fat content was greatest in the HFDG diet (4.95%) compared with the LFDG or CM diets (4.61 and 4.43%, respectively), it was expected that HFDG would contain the greatest concentration of GE. Although the concentration of GE of HFDG was not different from the control, it was greater than either LFDG or CM. These differences were also observed in the concentration of DE and ME. Net energy balance (milk plus tissue energy) tended to be affected by treatment. Specifically, net energy balance was lowest for diets containing canola meal. When replacing high-protein DDGS with canola meal and a rumen-inert fat, Swanepoel et al. (2014) observed a curvilinear response in milk production. In that study, milk yield increased when the inclusion of canola meal increased from 0 to 5.5 and 13.5% of the diet DM and then decreased when canola meal was included at 20% of the diet DM. In the current study, no attempts were made to keep the fat content similar across treatments, and, despite the fact that no effects were observed on milk production or composition, the inclusion of canola meal reduced tissue energy. We suggest that the lower energy supply observed is attributable to the fact that canola meal contains less fat and the protein is less digestible. Over approximately the last 10 yr, the corn ethanol industry has identified new markets for corn oil and as a result has used technology to remove it from DDGS. Results of this study indicate that this practice may reduce the overall supply of energy; however, it should be noted that the source of the DDGS was different and, as a result, this observation may be explained by other factors related to corn used by that production plant. As was the case with canola meal, this reduction in energy did not affect either milk yield or composition; however, compared with HFDG, feeding LFDG resulted in a reduction in energy supply that was measured in less tissue energy. These results are consistent with those reported by Havlin et al. (2015) that supplementation of fat in diets containing reduced-fat DDGS is needed to maintain the supply of energy equivalent to that of the original full-fat DDGS.

The pattern of energy utilization when expressed as megacalories per day or percentage of GE did not differ between treatments and is generally comparable with other energy balance studies. As a percentage of GE, energy lost as feces averaged 37%, compared with values corresponding to control diets fed to lactating dairy cattle of 31% (Tine et al., 2001) and 33% (Birkelo et al., 2004; Foth et al., 2015). Urine energy as a percentage of GE averaged 4.6%, which is slightly greater than that reported by Tine et al. (2001), Birkelo et al. (2004), and Foth et al. (2015), who reported urine losses to be 3.9, 3.7, and 3.6%, respectively. This observation may be a result of catabolized protein from body stores that were used for energy and excreted as urea in urine (Maltz and Silanikove, 1996), which is discussed in further detail along with N utilization below.

N Utilization

In the current study, N intake was affected by treatment and was specifically greatest for CON, lower in CM, and similarly lowest in LFDG and HFDG. Total fecal N output was also affected by treatment, with the greatest output from CM, lower in CON, and similarly lowest in LFDG and HFDG. The greater fecal N output in canola meal is likely a result of the lower CP digestibility. Greater N outputs may result in environmental consequences such as nitrate leaching into water, which leads to eutrophication (Arriaga et al., 2009). Overall, N balance was not affected by treatment but was numerically negative for all treatments. Nitrogen balance is the N remaining after subtracting N lost in milk, feces, and urine. Negative N balances have been associated with negative energy balances, where catabolized protein from body stores are used for energy and excreted as urea in urine (Maltz and Silanikove, 1996). This may have been the case for the current study, as LFDG contained a low energy content and for all treatments N loss was greatest through the urine. Additionally, in the current study, cows placed in the indirect calorimeters were fed at 95% ad libitum; this may have contributed to the negative plane of energy.

CONCLUSIONS

The results of the current study support previous research showing that the addition of coproducts such as DDGS and canola meal maintain milk production and composition in lactating dairy cattle. Metabolizable energy and DE were increased in the DDGS containing the highest concentrations of crude fat. As hypothesized, digestibility of CP was lowest in the cattle consuming canola meal; this, along with less fat in canola meal, resulted in a reduction in energy supply. Furthermore, the fat content of DDGS is a major factor that contributed to energy supply. Future research should be conducted to gather a better understanding of how the digestibility of CP in canola meal could be improved.

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