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Increasing dietary sugar concentration may improve dry matter intake, ruminal fermentation, and productivity of dairy cows in the postpartum phase of the transition period

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ABSTRACT

The current study was undertaken to investigate the effect of feeding diets varying in sugar concentration to postpartum transition cows on productivity, ruminal fermentation, and nutrient digestibility. We hypothesized that the high-sugar diet would increase dry matter intake and lactation performance. The secondary objective was to characterize changes in ruminal fermentation and nutrient digestibility over the first 4 wk of lactation. Fifty-two Holstein cows, including 28 primiparous and 24 multiparous cows, 10 of which were previously fitted with a ruminal cannula, were assigned to the experimental diets containing either high sugar (HS = 8.4%) or low sugar (LS = 4.7%) immediately after calving, based on their expected calving date. Data and samples were collected on d 5.2 ± 0.3, 12.2 ± 0.3, 19.2 ± 0.3, and 26.1 ± 0.3 relative to parturition for wk 1, 2, 3, and 4 respectively. Cows fed HS had increased dry matter intake compared with those fed LS (18.3. vs. 17.2 kg/d). Further, cows fed HS sorted for particles retained on the pan of the Penn State Particle Size Separator to a greater extent than cows fed LS. Feeding HS tended to increase nadir (5.62 vs. 5.42), mean (6.21 vs. 6.06), and maximum pH (6.83 vs. 6.65). The duration (h/d) and area (pH × min/d) that ruminal pH was below pH 5.8 were not affected by treatment. Ruminal volatile fatty acid concentration and molar proportions of individual volatile fatty acids were not affected by treatment. The digestibility of dry matter, organic matter, neutral detergent fiber, and starch were not affected by treatment, averaging 63.3, 65.2, 43.2, and 93.5%, respectively. Feeding HS decreased plasma glucose concentration compared with feeding LS (51.3 vs. 54.0 mg/dL), but concentration of plasma insulin was not affected by treatment, averaging 4.17 μIU/mL. Cows fed HS had higher concentrations of plasma β-hydroxybutrate (17.5 vs. 10.5 mg/dL) and nonesterified fatty acids (344 vs. 280 μEq/L). Milk yield and milk composition were not affected by treatment, but a tendency for increased milk fat yield was observed for cows fed HS compared with LS (1.44 vs. 1.35 kg/d). The results of the current study imply that replacing cracked corn grain with sucrose may improve dry matter intake, ruminal pH status, and lactation performance.

Key words: postpartum, rumen pH, sucrose, transition period

INTRODUCTION

The onset of lactation imposes a considerable metabolic challenge to dairy cows because energy intake lags behind the energy expenditure required to achieve and sustain high levels of milk production (NRC, 2001). As a result, cows show a homeorhetic response, in which extensive mobilization of peripheral tissues, including muscle and adipose tissue, occurs (Chibisa et al., 2008) to support lactation (Bauman and Currie, 1980). Although numerous studies have been conducted to evaluate the carryover effects of the prepartum diet on postpartum performance (Dann et al., 1999; Rabelo et al., 2003; Penner et al., 2007), there is a paucity of data on nutritional strategies during the postpartum phase of the transition period to improve nutrient intake and lactation performance.

Conventional strategies to improve nutrient intake and performance focus on increasing the dietary energy density. For example, Rabelo et al. (2003) increased the energy density of diets (1.63 and 1.57 Mcal/kg of NE_L) by substituting the proportion of ground corn and soybean meal in diets for alfalfa and corn silage. They found that feeding the higher energy diet did not improve milk yield or energy balance but decreased ruminal pH during a time when cows were already at risk for ruminal acidosis (Penner et al., 2007). Dann et al. (1999) increased the energy density of diets by replacing cracked corn grain with steam-flaked corn, and reported increased milk yield for cows fed steam-flaked corn during the first 63 d of lactation without a change in energy balance. However, it is not clear whether the

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responses observed by Dann et al. (1999) were due to increased dietary energy density or the proportion of ruminally fermentable carbohydrate.

The replacement of starch with sugar has been shown to increase DMI and milk yield for Holstein cows in midlactation (Broderick and Radloff, 2004). Moreover, Vallimont et al. (2004) observed a quadratic increase in NDF digestibility when sucrose replaced corn starch in continuous culture, and Ribeiro et al. (2005) showed that bacterial OM production in continuous culture increased linearly from 12.3 to 14.4 g/d as the concentration of sucrose increased from 0 to 8%. The potentially greater risk for ruminal acidosis must be considered with inclusion of sugar in the diets for postpartum transition cows because they are susceptible to ruminal acidosis (Penner et al., 2007). However, a recent study by Penner et al. (2009a) demonstrated that replacement of cracked corn with sucrose did not decrease ruminal pH. As such, the replacement of starch with sucrose may have the potential to improve nutrient supply and digestibility to transition cows without negatively affecting ruminal fermentation.

The current study was undertaken to investigate the effect of feeding diets containing low or high sugar content to postpartum transition cows on productivity, ruminal fermentation, and nutrient digestibility. We hypothesized that a diet high in sugar would increase DMI and improve lactation performance. The secondary objective was to characterize changes in sorting behavior, ruminal fermentation, and diet digestibility over the first 4 wk of lactation.

MATERIALS AND METHODS

This experiment was conducted from November 2006 to August 2007 at the University of Alberta Dairy and Research Technology Centre. All experimental procedures were preapproved by the Faculty Animal Policy and Welfare Committee at the University of Alberta and were performed in accordance to the guidelines of the Canadian Council of Animal Care (Ottawa, Ontario, Canada).

Experimental Design

Fifty-two Holstein cows (28 primiparous and 24 multiparous cows), free of clinical metabolic disorders, were used in this study beginning on d 1 of lactation. Twelve additional cows were originally assigned to treatments but were removed from the study because of displaced abomasum (n = 6), mastitis (n = 1), metritis (n = 2), and low feed intake (<3 kg/d, as fed basis, n = 3). For cows on the high-sugar (**HS**) treatment, reasons for removal from the study were displaced abomasum (n = 2), mastitis (n = 1), and low feed intake (n = 2). Cows on the low-sugar (**LS**) treatment were removed because of displaced abomasa (n = 4), metritis (n = 2), and low feed intake (n = 1). Seven of these cows were primiparous (HS, n = 4; LS, n = 3) and the remaining 5 were multiparous (HS, n = 2; LS, n = 3). Ten of the 24 multiparous cows were fitted with a ruminal cannula during a previous lactation. Throughout the study, cows were housed in individual tie stalls and were released into an exercise lot for 2 h/d. Cows were fed once daily at 0900 h and the amount of TMR offered was given to yield feed refusals between 5 and 10% of the total feed offered on an as-fed basis. Cows were milked twice daily at 0400 and 1500 h.

Based on expected calving date and prepartum diet, cows were randomly assigned to 1 of 2 treatments differing in dietary sugar concentration. Prepartum diets consisted of either timothy hay-based diets with a forage-to-concentrate ratio of 63:37 (Penner et al., 2008) or the standard prepartum diet for the University of Alberta Dairy Research and Technology Centre, which contained a forage-to-concentrate ratio of 73:27 (DM basis). Cows were fed their respective experimental diets on the day of calving if they calved before 1100 h or on the following day if they calved after 1100 h. Dietary treatments in this study were designated as LS (n = 27) or HS (n = 25), and contained 4.5 or 8.8% sugar on a DM basis (Table 1). To increase the dietary sugar concentration without changing the dietary CP and ether extract (**EE**) content, cracked corn was replaced by sucrose (Wetaskawin Co-op, Wetaskawin, Alberta, Canada), urea, and canola oil for the HS diet relative to the LS diet. Diets were formulated using the Cornell-Penn-Miner System (CPM Dairy, version 3.0.8; Cornell University, Ithaca, NY; University of Pennsylvania, Kennett Square, PA; and William H. Miner Agricultural Research Institute, Chazy, NY) to supply adequate NE_L and MP for a 650-kg cow producing 35 kg of milk with a fat concentration of 3.5%, and both diets were formulated to contain similar CP and forage NDF concentrations.

Data and Sample Collection

Samples were collected on 3 consecutive days during wk 1, 2, 3, and 4 of lactation. The actual initial days of sampling were (average ± SE) d 5.2 ± 0.3, 12.2 ± 0.3, 19.2 ± 0.3, and 26.1 ± 0.3 relative to parturition for wk 1, 2, 3, and 4, respectively.

During the collection periods, the weight of feed offered and refused was recorded daily. A representative sample of the total daily refusal (12.5%) was collected and composited over the 3-d collection period. Feed ingredient samples were collected once weekly, except

Table 1. Ingredient composition, nutrient composition, and particle size distribution of low-sugar (LS) and high-sugar (HS) diets fed to transition cows during the first 4 wk of lactation

	Treatment	
Item	LS	HS
Ingredient composition, % of DM		
Barley silage	39.6	39.4
Alfalfa hay	10.1	10.1
Basal concentrate mix[1]	17.5	17.4
Rolled barley grain	7.9	7.9
Rolled corn grain	7.0	6.9
Cracked corn grain	4.8	—
Sucrose	—	4.7
Soy Plus[2]	4.2	4.3
Canola meal	2.9	3.0
Corn gluten meal	2.1	2.2
Rolled peas	1.4	1.4
Sodium bicarbonate	1.3	1.3
Canola oil	0.7	0.9
Calcium carbonate	0.3	0.3
Urea	0.1	0.3
Nutrient composition, % of DM		
DM	51.2	51.4
OM	90.8	90.9
CP	20.5	20.2
NDF	34.2	33.4
Ether extract	2.7	2.7
Starch	20.6	18.5
Total ethanol-soluble carbohydrates[3]	4.5	8.7
NFC[4]	33.4	34.5
Particle size distribution, %		
>18 mm	31.7	28.9
9 to 18 mm	41.3	37.2
1.18 to 9 mm	18.4	20.1
Pan	8.7	13.8

[1]Contained 39.0% canola meal, 14.0% high-fat product (ADM Alliance Nutrition, Lethbridge, Alberta, Canada), 11.0% AminoPlus (Ag Processing Inc., Omaha, NE), 8.25% ground wheat, 5.75% soybean meal, 4.15% Enertia (ADM Alliance Nutrition), 4.00% ground barley, 3.25% mill run, 2.13% micromineral and vitamin mix, 2.00% linseed meal, 1.62% limestone, 1.50% sodium bicarbonate, 1.50% canola oil, 1.05% calcium phosphate, and 0.80% salt.

[2]Soy Plus (West Central, Ralston, IA).

[3]Determined according to Hall et al. (1999), using sucrose as a standard.

[4]NFC = 100 − (%NDF + %CP + %ether extract + %ash).

for forage samples (barley silage and alfalfa hay), which were collected twice weekly. Individual feed ingredient samples and weekly refusal composites were analyzed for particle size distribution using the modified Penn State Particle Size Separator (Kononoff et al., 2003). All samples were dried in a forced-air oven at 55°C for 48 h to determine the DM content. Diets were adjusted for DM content weekly, if required, to maintain the desired forage-to-concentrate ratio on a DM basis.

Body weight and BCS (5-point scale; Wildman et al., 1982) were measured at the beginning of each collection period. Milk yield was recorded, and milk samples were collected for 6 consecutive milkings during the collection period. Furthermore, blood and fecal samples were collected every 9 h over a 72-h duration. Blood was sampled from the coccygeal vessel into a Vacutainer tube containing sodium heparin (Fisher Scientific Company, Nepean, Ontario, Canada) and immediately placed on ice until centrifugation at 2,500 × *g* for 20 min at 4°C. Harvested plasma was then thawed and composited by cow and week, and stored at −20°C. Fecal samples were also composited by cow and week and stored at −20°C, and the composite was dried at 55°C.

For the 10 ruminally cannulated cows, ruminal pH was measured every 30 s over a 48-h duration in each collection period using the Lethbridge Research Center Ruminal pH Measurement System (Dascor, Escondido, CA) as described by Penner et al. (2006a). Daily nadir, mean, and maximum pH, as well as the duration and that ruminal pH was below 5.8, were determined as described by Penner et al. (2007). Additionally, ruminal digesta were collected from the cranial, ventral, and caudal dorsal regions, and strained through a perforated material (Peetex, pore size = 355 μm; Sefar Canada Inc., Scarborough, Ontario, Canada) immediately after collection. Samples were collected at the same time blood and feces were collected. Ruminal fluid samples were immediately placed on ice until being stored at −20°C. Samples were then thawed and composited to yield 1 sample per cow per period for analysis.

Sample Analysis

Dried feed ingredient and fecal samples were ground to pass through a 1-mm screen using a Wiley mill (Thomas-Wiley, Philadelphia, PA). Fecal samples, weekly forage composites, and monthly concentrate composites were analyzed for concentrations of DM, OM, starch, NDF, and indigestible NDF. All feed ingredient samples were then composited by month, and additionally analyzed for concentrations of CP, EE, and total ethanol-soluble carbohydrates.

Dry matter concentration was determined after drying samples at 135°C for 2 h (AOAC, 2002; method 930.15). Organic matter concentration was calculated as the difference between the DM content and ash content. Ash content was determined after placing samples in a muffle furnace for 5 h at 550°C (AOAC 2002; method 942.05). Starch was measured by an enzymatic method (Karkalas, 1985) after samples were gelatinized with sodium hydroxide, and glucose concentration was measured using a glucose oxidase-peroxidase enzyme (No. P7119; Sigma, St. Louis, MO) and dianisidine dihydrochloride (No. F5803; Sigma). Absorbance was determined with a plate reader (SpectraMax 190; Molecular Devices Corp., Sunnyvale, CA). Neutral detergent fiber concentration was determined using amylase and sodium sulfite (Van Soest et al., 1991). Indigestible NDF was determined after incubating samples in the

rumen of a lactating cow for 120 h, and this was used as an internal marker to determine the apparent total tract nutrient digestibility (Cochran et al., 1986). Crude protein concentration was quantified by flash combustion with gas chromatography and thermal conductivity detection (Carlo Erba Instruments, Milan, Italy; Rhee, 2005). Ether extract was determined using a Goldfisch extraction apparatus (Labconco, Kansas City, MO; Rhee, 2005). Total ethanol-soluble carbohydrates were determined according to Hall et al. (1999) and Dubois et al. (1956).

Individual milk samples were analyzed for concentrations of fat, CP, lactose, and MUN by infrared spectroscopy (MilkoScan 605; Foss Electric, Hillerød, Denmark; AOAC, 2002) at the Alberta Central Milk Testing Laboratory (Edmonton, Alberta, Canada). Milk samples were composited by cow and period based on the yield of milk fat from each milking, and analyzed to determine the milk fatty acid profile. Milk fatty acids were extracted and esterified using methanolic acid, and fatty acid profiles were determined using gas chromatography (Khorasani et al., 1991).

Plasma samples were analyzed for glucose, insulin, BHBA, NEFA, and plasma urea N concentrations. Plasma glucose concentration was measured using a glucose oxidase-peroxidase enzyme (No. P7119; Sigma) and dianisidine dihydrochloride (No. F5803; Sigma). Absorbance was determined with a plate reader (SpectraMax 190; Molecular Devices Corp., Sunnyvale, CA). A commercial kit was used to determine the plasma concentration of insulin (Coat-A-Count; Diagnostic Products Corporation, Los Angeles, CA). Plasma BHBA concentration was determined using the enzymatic oxidation of BHBA to acetoacetate with 3-hydroxybutrate dehydrogenase (No. H6501; Roche, Mississauga, Ontario, Canada), and the concomitant reduction of NAD to NADH was determined using a plate reader at the wavelength of 340 nm. A commercial kit was used to determine the concentration of NEFA in plasma (NEFA HR 2; Wako Diagnostics, Richmond, VA). The concentration of plasma urea N was determined according to Fawcett and Scott (1960) with modifications for use of a plate reader.

Ruminal fluid samples were centrifuged at 26,000 × *g* for 15 min at 4°C, and supernatants were collected. The centrifuged supernatant was analyzed for VFA concentration by gas chromatography according to the method described by Khorasani et al. (1996). Rumen NH_3-N concentration was determined colorimetrically as described by Fawcett and Scott (1960).

Calculations and Statistical Analysis

Sorting behavior was evaluated by calculating the sorting index for particles retained on each sieve of the Penn State Particle Size Separator (Nasco, Modesto, CA). The sorting index was calculated by expressing the actual intake of each fraction as a percentage of the theoretical intake of the corresponding fraction (Leonardi and Armentano, 2003). Values <100% and >100% indicate selective refusal and selective consumption, respectively.

The NE_L intake was calculated from apparent total tract DM digestibility according to NRC (2001), with the following modifications. The total digestible nutrients (**TDN**) from EE was calculated, assuming that fatty acid content was EE − 1 (Allen, 2000) and that fatty acids were completely digestible (NRC, 2001). Thus, the equation used to estimate dietary TDN was

$$\text{TDN} = \text{digested DM} + (\text{digested fatty acids} \times 1.25).$$

The TDN was then used to calculate dietary NE_L as described in NRC (2001). The energy required for maintenance was calculated as $NE_M = 0.080$ Mcal/kg of $BW^{0.75}$, and NE_L (Mcal/d) was calculated according to NRC (2001) with the observed milk yield and concentrations of milk fat, milk CP, and milk lactose.

Data were analyzed using the MIXED procedure (version 9.1; SAS Institute Inc., Cary, NC), accounting for repeated measures. The model included the fixed effects of treatment, parity (primiparous vs. multiparous), week of lactation, prepartum management, and the 2- and 3-way interactions between treatment, parity, and week of lactation. Because this study was conducted over a 9-mo period and cows were under different prepartum management, the effect of prepartum management (n = 3) was included in the model as a blocking factor to remove variations arising from differences in prepartum management. The BCS measured in wk 1 was used as a covariate and week of lactation was included as a repeated measure. The treatment × parity × week interaction was not significant for dependent variables of primary interest and was therefore removed from the final statistical model. Treatment means and interaction terms were separated using the Bonferroni test. The SEM presented is a weighted average of the SEM because treatments contained a different number of cows (LS, n = 27; HS, n = 25). Significance was declared when $P < 0.05$, and tendencies are discussed when $P < 0.10$. For ruminally cannulated cows, the same statistical model was used; however, the model did not include parity because only multiparous cows were used.

Data were also analyzed using the MIXED procedure (version 9.1.3; SAS Institute Inc.) with week of lactation as a regression variable to further characterize the response over time. Linear and quadratic effects of week were tested.

Table 2. Dry matter intake and sorting behavior for cows fed low-sugar (LS; n = 27) or high-sugar (HS; n = 25) diets during the first 4 wk of lactation

	Treatment				Week					*P*-value	
Variable	LS	HS	SEM[1]	*P*-value	1	2	3	4	SEM	Linear	Quadratic
DMI, kg/d	17.2	18.3	0.5	0.035	14.9	17.4	19.0	19.8	0.6	<0.001	0.055
Sorting index[2]											
19-mm sieve	95.7	98.1	2.2	0.335	95.6	101.5	97.8	92.6	2.6	0.187	0.010
8-mm sieve[3]	102.4	99.6	1.1	0.031	101.7	99.9	99.5	103.1	1.3	0.350	0.009
1.18-mm sieve[4]	94.9	97.5	1.7	0.215	92.8	94.4	99.2	98.4	1.9	0.019	0.414
Pan	99.6	108.4	2.9	0.006	110.7	99.9	102.3	103.3	3.4	0.143	0.022

[1]SEM is presented as weighted SEM.

[2]The sorting index was calculated by expressing the actual intake of each fraction as a percentage of the theoretical intake of the corresponding fraction (Leonardi and Armentano, 2003). Values <100% and >100% equate to selective refusal and selective consumption, respectively. Feed refusals and individual feed ingredients were separated using the modified Penn State Particle Size Separator as described by Kononoff et al. (2003).

[3]Treatment × week interaction ($P = 0.035$).

[4]Treatment × parity interaction ($P = 0.033$).

RESULTS

DMI and Sorting Behavior

Feeding HS increased DMI ($P = 0.035$) during the first 4 wk of lactation by 1.1 kg/d when compared with cows fed LS (Table 2). Further, feeding HS altered the sorting behavior of cows, including decreased ($P = 0.031$) sorting for particles retained on the 8-mm sieve and increased ($P = 0.006$) sorting for particles retained on the pan, compared with cows fed LS. Interactions between treatment and week of lactation were detected for the sorting of particles retained on the 8-mm sieves ($P = 0.035$; data not shown). Cows fed LS sorted for long particles in wk 1, 2, and 4 compared with cows fed HS. Additionally, a treatment × parity interaction was observed for particles retained on the 1.18-mm sieve ($P = 0.033$), in which primiparous cows fed LS sorted against particles retained on the 1.18-mm sieve but no differences were observed for multiparous cows.

Dry matter intake increased linearly over the first 4 wk of lactation ($P < 0.001$), with average intakes of 14.9, 17.4, 19.0, and 19.8 kg/d for wk 1, 2, 3, and 4 of lactation, respectively. Sorting behavior was also affected by week of lactation. For particles retained on the 19-mm sieve, a quadratic response over time was observed ($P = 0.010$) because cows tended to increase the selective consumption of long particles from wk 1 to 2 but selectively refused long particles thereafter. A quadratic ($P = 0.009$) effect of week of lactation was detected for particles retained on the 8-mm sieve, in which cows increased their selective consumption of this fraction in wk 4 relative to wk 2 and 3. Although cows sorted against particles retained on the 1.18-mm sieve, the selective refusal decreased linearly ($P = 0.019$) from wk 1 to 4 of lactation. Further, a quadratic response ($P = 0.022$) was observed for sorting for particles retained on the pan; cows decreased the selective consumption of fine particles from wk 1 to 2, but the selective consumption did not change after wk 2.

Ruminal Fermentation

For the ruminally cannulated cows used in this study, BW and DMI did not differ between treatments, averaging 631 kg and 17.3 kg/d, respectively (Table 3). Feeding HS tended ($P \leq 0.092$) to increase nadir, mean, and maximum ruminal pH by 0.20, 0.15, and 0.18 pH units, respectively. The number of episodes that ruminal pH was below 5.8 was not different between treatments. Furthermore, the duration (min/d and min/kg of DMI) and area (pH × min/d) that ruminal pH was below 5.8 were not affected by dietary treatment. Dietary treatment did not affect ruminal VFA concentration, molar proportions of individual VFA, or concentration of NH_3-N. However, treatment × week interactions ($P \leq 0.019$) were detected for molar proportions of isobutyrate and isovalerate, in which concentrations increased from wk 1 to 4 for cows fed LS, but not for cows fed HS.

Although week of lactation did not affect BW for the ruminally cannulated cows, DMI increased linearly from wk 1 to 4. Nadir and mean ruminal pH did not change during the first 4 wk of lactation, but the tendency ($P = 0.056$) for a quadratic effect of week was observed for maximum pH, in which it increased by 0.24 pH units from wk 1 to 2, but did not change after wk 2. The number of episodes, and the duration and area that ruminal pH was below 5.8 were not affected by week of lactation. When the duration for which ruminal pH was below 5.8 was corrected for DMI (Penner et al., 2009b), a tendency for a quadratic ($P = 0.066$) effect of week of lactation was detected, in which the duration per kilogram of DMI was decreased from wk 1 to 2, but did not change thereafter.

Table 3. Body weight, DMI, and ruminal fermentation for ruminally cannulated cows fed low-sugar (LS) or high-sugar (HS) diets during the first 4 wk of lactation (n = 5 for each treatment)

	Treatment				Week					*P*-value	
Item	LS	HS	SEM[1]	*P*-value	1	2	3	4	SEM	Linear	Quadratic
BW, kg	600	662	24	0.100	634	628	617	647	20	0.657	0.207
DMI, kg/d	16.7	17.9	1.1	0.421	14.0	17.4	18.3	19.5	1.0	<0.001	0.128
Ruminal pH											
Nadir	5.42	5.62	0.07	0.092	5.44	5.55	5.54	5.56	0.08	0.227	0.505
Mean	6.06	6.21	0.05	0.076	6.02	6.17	6.18	6.15	0.07	0.113	0.168
Maximum	6.65	6.83	0.06	0.074	6.58	6.82	6.79	6.79	0.06	0.070	0.056
Ruminal pH <5.8											
Bouts, episodes/d	10.1	6.0	1.9	0.174	9.3	8.2	8.1	6.4	2.2	0.240	0.850
Duration, min/d	322	174	62	0.133	352	209	164	268	100	0.396	0.257
Duration, min/kg of DMI	25.7	13.1	5.6	0.153	41.0	12.2	10.2	14.2	8.3	0.051	0.066
Area, pH × min/d	79.4	38.3	19.9	0.184	102.6	46.7	26.0	60.1	31.8	0.285	0.187
Ruminal VFA and NH_3											
Total VFA, m*M*	120	117	5	0.735	117	101	125	131	5	0.006	0.035
Molar proportion, %											
Acetate	58.9	58.6	1.4	0.868	57.8	57.7	60.6	58.8	1.1	0.080	0.248
Propionate	24.2	24.1	1.1	0.948	25.6	23.7	23.1	24.1	1.0	0.173	0.082
Butryate	12.2	12.8	0.4	0.256	12.2	13.5	11.9	12.2	0.5	0.522	0.337
Isobutryate[2]	0.98	0.93	0.06	0.507	0.86	0.99	0.92	1.05	0.05	0.004	0.993
Valerate	1.78	1.69	0.09	0.494	1.74	1.87	1.57	1.76	0.09	0.499	0.690
Isovalerate[3]	1.53	1.43	0.19	0.736	1.33	1.64	1.45	1.49	0.14	0.303	0.035
Caproate	0.44	0.53	0.05	0.288	0.45	0.52	0.45	0.53	0.05	0.328	0.921
Acetate:propionate	2.46	2.50	0.16	0.874	2.34	2.47	2.66	2.47	0.14	0.144	0.086
NH_3-N, mg/dL	18.8	19.1	2.2	0.927	17.7	16.5	20.4	21.3	1.8	0.005	0.347

[1]SEM is presented as weighted SEM.
[2]Treatment × week interaction ($P = 0.014$).
[3]Treatment × week interaction ($P = 0.019$).

The concentration of ruminal VFA increased quadratically ($P = 0.035$) during the first 4 wk of lactation, with a numerical reduction in the concentration in wk 2 compared with wk 1, but with an increased concentration in wk 3 and 4 relative to wk 2 (Table 3). Molar proportions of the majority of individual VFA were not affected by week of lactation, with the exception of the branched-chain VFA isobutyrate and isovalerate. The molar proportion of isobutyrate increased linearly ($P = 0.004$) from wk 1 to 4, and the molar proportion of isovalerate changed quadratically ($P = 0.035$), with an increase in wk 2 compared with wk 1, but no differences were observed between wk 2, 3, and 4. Ruminal NH_3-N concentration increased linearly ($P = 0.005$) during the first 4 wk of lactation.

Apparent Total Tract Digestibility

Dietary treatment did not affect the apparent total tract digestibility of DM, OM, NDF, and starch, averaging 63.3, 65.2, 43.2, and 93.5%, respectively (Table 4). Treatment × parity interactions ($P \leq 0.022$) were detected for the digestibility of NDF and starch. The interaction for NDF digestibility was a result of a greater difference in the observed digestibility between primiparous and multiparous cows fed LS (48.5 vs. 37.5%) than that between primiparous and multiparous cows fed HS (45.9 vs. 40.8%). Starch digestibility was not different between primiparous and multiparous cows fed HS (93.8%), but multiparous cows fed HS had lower starch digestibility than primiparous cows fed LS (91.5 vs. 95.1%). Further, multiparous cows fed LS had lower starch digestibility than primiparous and multiparous cows fed HS. Week of lactation did not affect the digestibility of DM, OM, or NDF, but starch digestibility decreased linearly ($P = 0.007$) during the first 4 wk of lactation.

Plasma Metabolites and Hormones

Plasma glucose concentration was lower ($P = 0.006$) for cows fed HS compared with cows fed LS (51.3 vs. 54.0 mg/dL; Table 5); however, plasma insulin concentration was not affected by treatment, averaging 4.7 μIU/mL across treatments. Feeding HS increased the concentrations of plasma BHBA (17.5 vs. 10.5 mg/dL; $P = 0.001$) and NEFA (344 vs. 280 μEq/L; $P = 0.013$). Treatment × parity interactions were detected for concentrations of BHBA and NEFA ($P \leq 0.003$) in plasma, whereby multiparous cows fed HS had higher plasma concentrations of BHBA and NEFA than all other cows. Plasma urea N concentration tended to be

Table 4. Apparent total tract digestibility for cows fed low-sugar (LS; n = 27) or high-sugar (HS; n = 25) diets during the first 4 wk of lactation

	Treatment				Week					*P*-value	
Digestibility, %	LS	HS	SEM[1]	*P*-value	1	2	3	4	SEM	Linear	Quadratic
DM	62.7	64.0	0.8	0.123	64.0	62.4	63.7	63.2	0.9	0.804	0.436
OM	64.7	65.8	0.7	0.169	65.9	64.3	65.5	65.1	0.9	0.747	0.434
NDF[2]	43.0	43.4	1.2	0.761	44.1	41.4	43.6	43.6	1.5	0.842	0.252
Starch[3]	93.3	93.8	0.4	0.331	94.6	93.6	92.9	93.0	0.5	0.007	0.218

[1]SEM is presented as weighted SEM.
[2]Treatment × parity interaction ($P = 0.022$).
[3]Treatment × parity interaction ($P = 0.014$).

higher ($P = 0.098$) for cows fed HS than for those fed LS.

Between wk 1 and 4 of lactation, plasma glucose tended ($P = 0.082$) to increase linearly, but plasma insulin concentration was not affected. The concentration of BHBA was not affected by week of lactation, but NEFA concentration decreased linearly ($P < 0.001$) from wk 1 to 4. Plasma urea N concentration tended to increase ($P = 0.079$) during the first 4 wk of lactation.

Lactation Performance

Dietary treatment did not affect BW or milk yield (Table 6). However, the yield of milk fat tended ($P = 0.096$) to be increased by feeding HS compared with LS. Additionally, a treatment × parity interaction was detected for milk fat yield, whereby multiparous cows fed HS had greater milk fat yield than all other cows, and primiparous cows fed HS had the lowest milk fat yield. No differences in milk fat yield were detected between primiparous and multiparous cows fed LS. Milk composition was not affected by treatment, but interactions between treatment × parity were detected for milk fat concentration ($P = 0.024$). The interaction for milk fat concentration was a result of multiparous cows fed LS having greater milk fat concentration than primiparous and multiparous cows fed HS, but primiparous cows fed LS had lower milk fat concentration than primiparous and multiparous cows fed HS. Concentration of MUN was not affected by dietary treatment.

Body weight decreased linearly from wk 1 to 4, resulting in a net loss of 31 kg. Over the same time, milk yield and milk lactose yield increased linearly ($P < 0.001$). The increase in milk yield between wk 1 and 4 was 8.5 kg/d, and lactose yield increased by nearly 0.5 kg/d. No changes in the milk fat or CP yield were detected over the first 4 wk of lactation, but the concentrations of milk fat ($P = 0.047$) and CP ($P < 0.001$) decreased quadratically from wk 1 to 4 of lactation, with greater reductions at the earlier stage of lactation. Milk lactose concentration increased quadratically ($P = 0.013$) with greater increases at the earlier stage of lactation. Milk urea N concentration increased linearly ($P = 0.017$).

Milk Fatty Acid Composition

Feeding HS had a minor effect on milk fatty acid composition because the majority of fatty acids measured were not affected by treatment. However, cows fed HS had lower concentrations of C4:0 ($P = 0.013$) and C18:1 *trans* ($P = 0.042$) fatty acids in milk fat (Table 7). A treatment × week interaction ($P = 0.010$)

Table 5. Plasma metabolites and hormones for cows fed low-sugar (LS; n = 27) or high-sugar (HS; n = 25) diets during the first 4 wk of lactation

	Treatment				Week					*P*-value	
Variable	LS	HS	SEM[1]	*P*-value	1	2	3	4	SEM	Linear	Quadratic
Glucose, mg/dL	54.0	51.3	0.9	0.006	52.2	51.7	52.6	54.2	1.1	0.082	0.200
Insulin, μIU/mL	4.22	4.11	0.37	0.799	4.12	3.55	4.48	4.53	0.46	0.181	0.477
BHBA,[2] mg/dL	10.5	17.5	1.8	0.001	12.3	14.8	14.5	14.5	2.3	0.470	0.515
NEFA,[3] μEq/L	280	344	23	0.013	398	349	276	225	28	<0.001	0.970
PUN,[4] mg/dL	8.01	8.95	0.52	0.098	8.16	7.81	8.84	9.12	0.63	0.079	0.500

[1]SEM is presented as weighted SEM.
[2]Treatment × parity interaction ($P < 0.001$).
[3]Treatment × parity interaction ($P = 0.003$).
[4]Plasma urea N.

Table 6. Body weight and lactation performance for cows fed low-sugar (LS; n = 27) or high-sugar (HS; n = 25) diets during the first 4 wk of lactation

	Treatment				Week					*P*-value	
Variable	LS	HS	SEM[1]	*P*-value	1	2	3	4	SEM	Linear	Quadratic
BW, kg	573	581	7	0.338	598	577	565	567	9	0.001	0.130
Yield, kg/d											
Milk	33.0	34.4	1.0	0.185	28.8	33.2	35.5	37.3	1.2	<0.001	0.196
Fat[2]	1.35	1.44	0.05	0.096	1.38	1.39	1.39	1.41	0.06	0.685	0.886
CP	1.05	1.09	0.03	0.226	1.04	1.05	1.07	1.10	0.04	0.147	0.744
Lactose	1.47	1.53	0.05	0.225	1.21	1.47	1.61	1.70	0.06	<0.001	0.059
Milk composition, %											
Fat[3]	4.21	4.27	0.12	0.668	4.87	4.23	4.01	3.86	0.15	<0.001	0.047
CP	3.26	3.23	0.05	0.682	3.68	3.21	3.08	3.00	0.06	<0.001	<0.001
Lactose	4.43	4.43	0.04	0.994	4.21	4.43	4.54	4.54	0.05	<0.001	0.013
MUN, mg/dL	14.2	14.2	0.4	0.908	13.6	14.0	14.6	14.7	0.4	0.017	0.557

[1]SEM is presented as weighted SEM.
[2]Treatment × parity interaction ($P = 0.024$).
[3]Treatment × parity interaction ($P < 0.001$).

was detected for the concentration of C16:0, whereby cows fed LS had a numerically higher concentration than cows fed HS in wk 1.

Week of lactation had strong effects on concentrations of fatty acids, with differences being detected in nearly all measured individual fatty acids ($P \leq 0.010$). In general, the concentrations of short- and mid-chain fatty acids increased from wk 1 to 4, with the exception of butyric acid. The long-chain fatty acids C16:0, C17:1, C18:2, and C20:0 were not affected by week of lactation, but concentrations of C16:1, C17:0, C18:0, C18:1 *trans*, C18:1 *cis*, and C20:1 were affected by the week of lactation ($P \leq 0.018$). Generally, concentrations of long-chain fatty acids decreased linearly during the first 4 wk of lactation, but concentrations of C18:1 *trans* and C20:1 increased linearly.

Energy Balance

Energy intake was increased ($P = 0.018$) by feeding HS compared with LS (Table 8). The energy expended for lactation tended ($P = 0.094$) to be higher for cows fed HS than for those fed LS, but no differences were observed for the net energy required for maintenance.

Table 7. Milk fatty acid composition (% of total fat) for ruminally cannulated multiparous cows fed low-sugar (LS) or high-sugar (HS) diets during the first 4 wk of lactation (n = 5 for each treatment)

	Treatment				Week					*P*-value	
Milk fatty acid composition, %	LS	HS	SEM[1]	*P*-value	1	2	3	4	SEM	Linear	Quadratic
C4:0	1.78	1.51	0.06	0.013	1.68	1.70	1.54	1.65	0.10	0.581	0.939
C6:0	1.33	1.15	0.09	0.179	1.12	1.23	1.28	1.33	0.08	0.009	0.564
C8:0	0.91	0.80	0.07	0.273	0.69	0.80	0.91	1.02	0.06	<0.001	0.991
C10:0	2.36	2.03	0.24	0.370	1.75	1.96	2.37	2.69	0.20	<0.001	0.699
C12:0	2.73	2.38	0.29	0.427	2.12	2.25	2.75	3.11	0.25	<0.001	0.469
C14:0	9.63	8.84	0.78	0.498	8.23	8.47	9.71	10.52	0.66	<0.001	0.467
C14:1	0.62	0.73	0.05	0.158	0.58	0.60	0.72	0.79	0.05	<0.001	0.489
C15:0	0.95	0.86	0.08	0.442	0.79	0.83	0.96	1.04	0.07	<0.001	0.551
C16:0[2]	27.3	26.6	1.1	0.650	27.7	26.6	26.8	26.7	0.9	0.138	0.164
C16:1	2.19	2.32	0.14	0.532	2.45	2.44	2.14	2.00	0.13	0.001	0.548
C17:0	0.65	0.66	0.03	0.882	0.73	0.68	0.61	0.59	0.03	<0.001	0.654
C17:1	0.44	0.36	0.14	0.698	0.52	0.27	0.54	0.26	0.17	0.460	0.873
C18:0	11.4	11.4	0.4	0.959	11.8	12.1	11.1	10.7	0.4	0.011	0.316
C18:1 *trans*	3.14	2.72	0.12	0.042	2.71	2.84	3.11	3.07	0.13	0.010	0.458
C18:1 *cis*	28.9	31.4	1.6	0.309	31.4	31.4	29.3	28.5	1.4	0.018	0.655
C18:2	2.66	2.68	0.18	0.922	2.71	2.66	2.71	2.60	0.15	0.440	0.731
C20:0	0.51	0.67	0.07	0.141	0.61	0.58	0.59	0.58	0.05	0.366	0.548
C20:1	0.39	0.39	0.04	0.978	0.34	0.36	0.43	0.43	0.03	<0.001	0.547
C_4 to C_{14}	19.4	17.5	1.4	0.378	16.2	17.1	19.4	21.1	1.2	<0.001	0.630
C_{18} to C_{20}	49.4	52.0	2.1	0.424	52.2	52.3	49.9	48.3	1.8	0.010	0.437

[1]SEM is presented as weighted SEM.
[2]Treatment × week interaction ($P = 0.010$).

Table 8. Calculated energy intake, expenditure, and energy balance for cows fed low-sugar (LS; n = 27) or high-sugar (HS; n = 25) diets during the first 4 wk of lactation

	Treatment				Week					*P*-value	
Variable	LS	HS	SEM[1]	*P*-value	1	2	3	4	SEM	Linear	Quadratic
NE_L intake, Mcal/d	25.2	27.2	0.7	0.018	22.3	25.3	28.1	29.2	0.9	<0.001	0.227
NE_L output,[2] Mcal/d	24.1	25.4	0.7	0.094	23.4	24.5	25.2	25.9	0.8	0.008	0.739
NE_M, output, Mcal/d	9.35	9.44	0.09	0.369	9.66	9.40	9.25	9.27	0.11	0.001	0.134
Total net energy output, Mcal/d	33.5	34.9	0.7	0.084	33.0	34.0	34.5	35.2	0.9	0.041	0.852
Net energy balance, Mcal/d	−8.31	−7.52	0.86	0.393	−10.81	−8.62	−6.33	−5.91	1.04	<0.001	0.317

[1]SEM is presented as weighted SEM.

[2]Treatment × parity interaction ($P = 0.041$).

The calculated total energy output for cows fed HS tended ($P = 0.084$) to be greater than that for cows fed LS; consequently, the calculated energy balance was not different between treatments, averaging −7.92 Mcal/d over the first 4 wk of lactation.

A linear ($P < 0.001$) increase in energy intake was observed between wk 1 and 4 of lactation. However, this increase in energy intake corresponded to a linear increase ($P = 0.008$) in the energy expended in milk and a linear decrease ($P = 0.001$) in the energy required for maintenance. Overall energy output increased linearly ($P = 0.041$) from wk 1 to 4. These changes resulted in a linear increase ($P < 0.001$) in the energy balance from wk 1 to 4, but cows were still in a negative energy balance in wk 4 of lactation.

DISCUSSION

Effects of Dietary Sucrose Concentration

During the postpartum phase of the transition period, cows undergo marked changes, including rapid increases in both DMI and milk yield (NRC, 2001). These changes are accompanied by an increase in hepatic gluconeogenesis and adipose tissue mobilization to support the energy demand for lactation (Ingvartsen and Andersen, 2000; Drackley et al., 2001). Despite the well-documented changes during the transition period (Reynolds et al., 2003, 2004) and the number of review papers dedicated to this unique stage of production (Drackley, 1999; Ingvartsen and Andersen, 2000; Overton and Waldron, 2004), few studies have focused on dietary strategies to optimize performance during the postpartum phase of the transition period.

Past studies have reported increases in DMI (Nombekela et al., 1994; Broderick and Radloff, 2004) or total OM intake (Heldt et al., 1999) when diets contained sucrose. For example, Broderick and Radloff (2004) fed dried or liquid molasses as a source of sugar in replacement for high-moisture corn grain, and found increased DMI with additional sugar. In a more recent study, Broderick et al. (2008) reported a linear increase in DMI as the proportion of sugar increased from 0 to 7.5% in increments of 2.5%. Dietary modifications that increase DMI during the postpartum phase of the transition period should also increase energy intake and may improve lactation performance.

The results of the current study confirm previous findings (Broderick and Radloff, 2004; Broderick et al., 2008) that replacement of corn with sucrose increases DMI, and demonstrate a potential nutritional strategy for increasing DMI during early lactation. Although we hypothesized that feeding HS would increase DMI and lactation performance, feeding HS did not increase milk yield even though it increased energy intake. However, milk fat yield and milk energy output tended to be higher for cows fed HS compared with cows fed LS. Because energy intake was increased and energy output tended to be higher for cows fed HS, the overall energy balance was not different between treatments. The data from the current study demonstrate that increasing the energy supply to cows in early lactation may not result in improvements in energy balance.

On the basis of the data collected in the current study, it is difficult to define mechanisms responsible for the greater DMI observed for cows fed HS compared with LS. In a past study, Nombekela et al. (1994) evaluated the palatability of diets with a sweet, sour, salty, or bitter taste by comparing the voluntary DMI and preferential eating order of each respective diet. They found that diets containing sucrose were preferentially eaten 59% of the time, and that sucrose inclusion (1.5% DM basis) increased DMI by 12% compared with the control diet. In a subsequent study, Nombekela and Murphy (1995) fed diets with (1.5% of dietary DM) or without sucrose to cows during the first 12 wk of lactation. In that study, they found that inclusion of sucrose did not affect DMI, and as such, small improvements in palatability likely had a marginal impact on DMI during early lactation. Past studies have reported increased NDF passage to the omasum (Broderick et al., 2008) with increased dietary sucrose concentration,

whereas others have reported increases in the solid or liquid passage rates with sucrose (Rooke et al., 1987; Sutoh et al., 1996). As such, it may be possible that in the current study, sucrose increased the digesta passage rate, leading to the observed increase in DMI. Further studies are warranted to determine the mechanisms responsible for increased DMI when sucrose replaces corn grain.

In the literature, the effect of sucrose on milk yield is variable, with some studies reporting increases in milk yield (Broderick and Radloff, 2004) and others reporting no effect of sugar supplementation on milk yield (Nombekela and Murphy, 1995; Cherney et al., 2003; Broderick et al., 2008). In the current study, sucrose did not affect milk yield. The response may partially be due to the amount of sugar included; Broderick and Radloff (2004) found quadratic effects of dietary sugar inclusion on milk yield in which low dietary sugar concentration (up to 7%) increased milk yield but diets exceeding 7% sugar decreased milk yield. They further concluded that the optimal dietary sugar concentration was approximately 5% (DM basis). In our study, dietary sugar concentrations, as determined using total ethanol-soluble carbohydrates, were 4.5 and 8.7% for LS and HS, respectively. As such, our LS treatment was close to the optimal level defined by Broderick and Radloff (2004) and the HS treatment was above the range defined as optimal, which may explain the lack of treatment effect on milk yield.

In the current study, we found that milk fat yield tended to be higher for cows fed HS compared with LS. Our results are supported by past research demonstrating a linear increase in milk fat yield with increasing dietary sucrose concentration (Broderick et al., 2008). In contrast, Nombekela and Murphy (1995), using cows during the first 12 wk of lactation, found no effect of sucrose on milk fat yield and further reported a decrease in milk CP yield for cows fed 1.5% sucrose. Differences between our study and the study of Nombekela and Murphy (1995) may be due to the higher sucrose inclusion rate used in our study. In addition, Nombekela and Murphy (1995) investigated the first 12 wk of lactation, whereas we investigated the first 4 wk of lactation only. The increase in milk fat yield in our study may be attributed to increased mobilization of adipose tissue for cows fed HS compared with those fed LS because milk fat yield was positively related to concentrations of plasma NEFA ($r = 0.384$, $P < 0.001$; data not shown). In addition, in our study, milk fat yield was positively related to plasma BHBA concentration ($r = 0.308$, $P < 0.001$; data not shown). Kessel et al. (2008) also reported that cows with elevated levels of BHBA in plasma had greater milk fat yield. Further, the increase in milk fat yield observed in our study is consistent with the improved ruminal pH status for cows fed HS compared with those fed LS.

During the postpartum phase of the transition period, cows are at risk for ruminal acidosis (Penner et al., 2007), and increases in the ruminally degradable carbohydrate may exacerbate this condition. Contrary to our pretrial hypothesis, we observed tendencies for increased nadir, mean, and maximum ruminal pH for cows fed HS compared with those fed LS. Past research has shown that the in vitro rate of sucrose hydrolysis ranges between 1,200 and 1,400%/h, with fermentation of the comprising monosaccharides ranging between 400 and 620%/h (Weisbjerg et al., 1998). As such, the observed tendencies for an increase in nadir ruminal pH and mean pH, and an increase in maximum pH for cows fed HS, compared with those fed LS, is surprising. In fact, during wk 1 and 4 of lactation, cows fed HS had higher rumen pH than cows fed LS. Previous in vitro (Vallimont et al., 2004) and vivo studies (Heldt et al., 1999; Broderick and Radloff, 2004; Broderick et al., 2008) have reported no effect of sucrose on rumen pH, and more recently, Penner et al. (2009a) reported that sucrose tended to improve ruminal pH, which is consistent with our results.

There are several possible explanations for why the replacement of starch for sucrose improved ruminal pH status in the current study. One possibility is that a portion of the dietary sucrose was respired before consumption by the cows; however, the proportion of sucrose lost to respiration is expected to be insignificant because diets were made fresh daily (Owens et al., 2008). Second, disappearance of carbohydrates from the rumen may not necessarily result in fermentation acid production if OM is converted to microbial N (Allen, 1997) or stored as glycogen (Hall and Weimer, 2007). Although in vitro, sucrose has previously been shown to increase the efficiency of microbial N production per kilogram of OM (Ribeiro et al., 2005), ruminal NH_3-N was not affected by treatment, raising the question of whether possible increases in microbial N production in the current study could have resulted in the improved pH status observed. Further, we did not measure bacterial glycogen content and are unable to speculate on its contribution to improved pH status in the current study. The results of the current study demonstrate that the replacement of corn starch with sucrose does not increase the risk of ruminal acidosis, and therefore may be a viable nutritional strategy during early lactation.

Data in the current study were covariate adjusted using BCS in the first week of lactation. Therefore, it was not expected that differences in the concentrations of plasma BHBA and NEFA between treatments were due to differences in BCS at the time of parturition.

We observed that cows fed HS had 23 and 67% increases in plasma concentrations of NEFA and BHBA, respectively, compared with cows fed LS. The increases in BHBA and NEFA concentrations may be of some concern for ketosis and fatty liver disease. Duffield et al. (2009) recently suggested that plasma BHBA concentrations exceeding 14.4 mg/dL during the first 2 wk of lactation place cows at greater risk of experiencing hyperketonemia. This indicates that cows fed HS may be at greater risk for hyperketonemia than cows fed LS; however, cows fed HS had greater DMI than cows fed LS, suggesting that the elevated concentrations of BHBA did not negatively affect animal performance.

Hepatic NEFA uptake is related to blood flow and plasma concentration of NEFA (Grummer, 2008). Although we did not measure liver triglyceride content, it is possible that cows fed HS had increased liver triglycerides, which may have decreased hepatic gluconeogenesis. This is supported by the observation of lower plasma glucose concentration for cows fed HS compared with those fed LS. However, the calculated energy balance was not different between treatments. As such, the elevated concentrations of BHBA and NEFA for cows fed HS may indicate impaired hepatic function, but further research is required to confirm this speculation.

Effects of Week of Lactation

Dry matter increased linearly over the first 4 wk of lactation, which is consistent with past studies (Reynolds et al., 2003, 2004). To our knowledge, this is the first study that investigated the sorting behavior of cows during early lactation. During the first 4 wk of lactation, we observed marked changes in the sorting behavior, regardless of the dietary treatment. In general, cows decreased sorting for fine particles from wk 1 to 2, but increased sorting for fine particles from wk 2 to 4. It is unclear why cows altered their sorting behavior, but past studies using cows in midlactation have suggested that changes in sorting behavior may occur in response to ruminal pH status (Yang and Beauchemin, 2007; DeVries et al., 2008).

Few studies have examined changes in ruminal pH during early lactation comprehensively; however, the results of Fairfield et al. (2007), Penner et al. (2007), and the current study all suggest that cows in early lactation experience severe ruminal acidosis. For example, we observed that cows spent on average 352, 210, 164, and 268 min/d with ruminal pH below 5.8 during wk 1, 2, 3, and 4 of lactation,. Similarly, Penner et al. (2007) reported that the severity of ruminal acidosis, as indicated by the duration that ruminal pH was below 5.8, did not differ between the first 5 d of lactation and on d 17 and 37 of lactation, but they did report a reduction in the severity of ruminal acidosis by d 58 of lactation.

Although DMI was lowest during the first week of lactation, the time that ruminal pH was below 5.8/kg of DMI was greatest. The intake of fermentable OM is one of the factors influencing ruminal pH (Allen, 1997; Nocek, 1997), yet clearly during early lactation, other factors may regulate ruminal pH. A classical study by Dirksen et al. (1985) suggested that the absorptive surface area of the ruminal papillae limits VFA absorption; the authors further recommended feeding additional fermentable carbohydrate prepartum to increase the ruminal papillae surface area and speculated that it would prevent ruminal pH depression postpartum. However, subsequent studies using diets that are typically fed in North America (Andersen et al., 1999; Penner et al., 2006b) have not supported the speculation made by Dirksen et al. (1985). Alternatively, the activity of the ruminal epithelia may be decreased by short-term feed restriction (Gäbel and Aschenbach, 2002) because cows approaching parturition reduce DMI by approximately 30% (Hayirli et al., 2002). Thus, the combined effect of reduced epithelia function and increased diet fermentability after parturition may partially explain the increased severity of ruminal acidosis. However, other factors, such as unadapted microflora (Nagaraja and Titgemeyer, 2007) during diet transition, may lead to increased lactate production (Owens et al., 1998), although lactate accumulation in dairy cows is rare (Nocek, 1997). A recent study did not detect ruminal lactate concentrations greater than 5 m*M* when ruminally cannulated transition cows were fed prepartum diets differing in the forage-to-concentrate ratio (Penner et al., 2007).

Visceral tissue mass increases in early lactation in response to increased DMI (Reynolds et al., 2004); therefore, we hypothesized that nutrient digestibility would also increase as lactation progressed because of hypertrophy of the digestive tract. However, results of the current study do not support our hypothesis. Apparent total tract digestibility of DM, OM, and NDF did not change over the first 4 wk of lactation, but the digestibility of starch decreased over time. Past studies either have not investigated the change in digestibility over time (measured at 23 to 26 DIM; Dann et al., 1999) or have evaluated changes later in lactation (wk 6 and 14; Aikman et al., 2008). It is unclear why starch digestibility decreased over time because the ruminal microflora would be expected to adapt to the diet during the first 4 wk of lactation, increasing starch digestion (Tajima et al., 2000), and increasing the supply of ruminal fermentable carbohydrate has been shown to increase ruminal starch digestion (Oba and Allen, 2003). It may be possible that the increase in DMI

observed during the first 4 wk of lactation is associated with an increase in passage rate, thereby decreasing starch digestion. However, an increased passage rate would also have affected the digestibility of other nutrients such as NDF, which did not occur in the current study. Further, secretion of pancreatic α-amylase would be expected to increase (Richards et al., 2003) during the first 4 wk of lactation because the increase in DMI should lead to more starch and MP entering the duodenum. As such, we are unable to speculate why starch digestibility decreased over time, and further studies are warranted to verify this finding.

CONCLUSIONS

The results of the present study demonstrate that the replacement of cracked corn grain with sucrose may increase DMI and increase milk fat yield for postpartum transition cows, although it may decrease plasma glucose concentration and increase adipose tissue mobilization. Further, the replacement of corn with sucrose may reduce the severity of ruminal acidosis, but the mechanisms behind this response require further investigation. Collectively, results of the current study indicate that replacement of cracked corn grain with sucrose may be a viable strategy for improving the productivity of postpartum transition cows.

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