Effect of corn silage particle size and supplemental hay on rumen pH and feed preference by dairy cows fed high-starch diets¹

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ABSTRACT

The objectives of this experiment were to determine the effects of corn silage particle size and supplemental hay on rumen pH and feed preference in lactating dairy cows experiencing a bout of subacute ruminal acidosis (SARA). In this study, 12 lactating (8 ruminally cannulated), multiparous Holstein cows averaging 91 ± 40 d in milk and weighing 695 ± 95 kg (mean $\pm$ SD) were randomly assigned to a replicated 4×4 Latin square. During each of the four 21-d periods, animals were offered 1 of 4 diets that were chemically similar but varied in corn silage particle size and supplemental second cutting orchardgrass hay: short corn silage total mixed ration (TMR; ST); short corn silage TMR with 5.6% supplemental hay (SH); long corn silage TMR (L); and long corn silage TMR with 5.6% supplemental hay (LH). Cows were allowed to adapt to this feeding scheme for 14 d, and cannulated cows were then subjected to a rumen challenge to induce a bout of SARA by restricting feed before the challenge and providing 4 kg of ground wheat via the rumen cannula. Although baseline pH was low, the SARA challenge lowered ruminal pH further for all cows regardless of diet. Daily average rumen pH decreased from 5.44 and 5.45 to 5.33 and 5.38 for ST and SH, respectively, and from 5.64 and 5.54 to 5.47 and 5.39 for L and LH, respectively, from baseline to challenge phase. Following the rumen challenge, rumen concentrations of acetate, propionate, butyrate, and valerate increased. Decreasing corn silage particle size significantly increased TMR and total DMI during all phases of the model. Feeding short corn silage TMR increased milk, protein, and lactose yields. Cows fed supplemental hay had increased fat yield and protein concentration in the milk and responded minimally to the effects of particle size selection when challenged with SARA. Cows consuming short corn silage TMR changed feed preference for longer forage par-

ticles during the course of the SARA challenge. During the recovery phase, however, cows refused an average of 13.5% of the offered TMR and 78.7% of the supplemental hay. These results indicate that cows did not prefer the supplemental hay regardless of corn silage particle size during a bout of SARA, which may have been due to the possible adaptation of a low ruminal pH throughout the study.

Key words: acidosis, diet selection, particle size, ruminal pH

INTRODUCTION

High-producing dairy cattle require large amounts of dietary energy to meet the demands of increased milk production. In the United States, to accommodate this energy requirement, it has often been economical for producers to feed large amounts of cereal grains to provide energy to rumen microbes and their host. Cereal grains contain large quantities of highly fermentable carbohydrates that can result in a build-up of organic acids in the rumen and reduce rumen buffering (Kleen et al., 2003; Stone, 2004), causing a depression in rumen pH. Subacute ruminal acidosis occurs when rumen pH is below 5.5 for more than 3 h/d (Kleen et al., 2003; Stone, 2004; Gozho et al., 2005).

Subacute ruminal acidosis is a prevalent problem in the United States and an economic concern for producers. In a case study conducted on a 500-cow New York farm, Stone (1999) calculated a cost of \$400 to \$475 lost income per cow per year due to SARA. Based on reduced milk yield and efficiency of production, premature culling, and death loss (Krause and Oetzel, 2005), it has been estimated that SARA costs the US dairy industry \$500 million to \$1 billion/yr, with a cost per affected cow of \$1.12/d (Enemark, 2008). Based on the substantial economic and health effects of SARA, it has grown to be an important nutritional disorder of dairy cattle and requires critical attention and management.

Simulating SARA conditions by withholding feed for 12 to 24 h or reducing intake has been studied to move toward solutions to this costly disorder (Keunen et al., 2002; Dohme et al., 2008; Krause et al., 2009). Ruminants will select a diet to help maintain a healthy

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ruminal environment when given the opportunity to do so (Cooper et al., 1996). Growing evidence indicates that dairy cows will select feeds with high ruminal buffering capacity in an attempt to attenuate effects of very low ruminal pH. Keunen et al. (2002) demonstrated that lactating dairy cows induced with SARA increased their preference for long alfalfa hay over pelleted alfalfa. DeVries et al. (2008) determined that early lactation cows fed barley silage and chopped grass-legume hay-based diets generally increased their sorting for medium particles and against short and fine particles and exhibited no change in sorting long particles when challenged. Maulfair et al. (2013) simultaneously fed cows either a diet with long corn silage and dry cracked corn or a diet with short corn silage and dry fine ground corn, and cows were then challenged with a bout of SARA. Intake of the long corn silage diet increased from a baseline day of 18.1% of total daily DMI to 38.3% for that day in response to the rumen challenge. These studies suggest that early lactation cows can alter their sorting behavior and diet preference for higher physically effective fiber during a rumen challenge, which may help attenuate the effects of SARA.

Despite evidence of the ability of dairy cattle to alter their eating behavior or diet choice based on their rumen environment, no research has been published observing the influence of SARA on the diet preference and DMI of lactating dairy cows fed diets differing in corn silage particle size and hay availability. Therefore, the objectives of this experiment were to induce a bout of SARA in lactating dairy cows that had ad libitum access to 4 distinct high starch diets that varied in corn silage particle size and supplemental hay and to determine how SARA affects TMR feed preference in lactating dairy cows under this situation.

MATERIALS AND METHODS

Cows, Experimental Design, and Diets

The experimental protocol was reviewed and approved by The Pennsylvania State University Institutional Animal Care and Use Committee (PSU IACUC #39245). Twelve lactating (8 ruminally cannulated), multiparous Holstein cows averaging 91 ± 40 DIM, weighing 695 ± 95 kg (mean $\pm$ SD) were used. Animals were housed in individual stalls, milked twice per day at 0500 and 1700 h, and fed once per day at approximately 0800 h for a 10% refusal rate except for the restriction phase of the SARA model. The experimental design consisted of 3 replicated 4×4 Latin squares with a 2×2 factorial arrangement of treatments. Two squares were composed of ruminally cannulated cows and were

used for all rumen measurements, whereas all squares were used for production and intake data.

Cows were randomly assigned to 1 of 4 treatments. Treatments were designed to study the effects of 2 lengths of corn silage and 2 levels of hay supplementation: short corn silage TMR with 0% supplemental hay (**ST**), short corn silage TMR with 5.6% (DM basis) supplemental hay (**SH**), long corn silage TMR with 0% supplemental hay (**L**), and long corn silage TMR with 5.6% supplemental hay (**LH**). Diets were offered to cows in tie-stall feed mangers divided into halves via a plywood panel that eliminated cross-contamination of TMR and supplemental hay. Except for altering corn silage particle size and offering supplemental hay, the 4 treatment diets contained identical ingredients (Table 1). Diet composition was calculated based on the formulated proportions and actual nutrient composition of each ingredient. The supplemental hay was high-quality, unprocessed second cutting orchardgrass (*Dactylis glomerata* L.; Table 2) and was fed at 5.6% of the TMR on a DM basis at 0800 h. Dietary starch concentrations for long corn silage TMR was 26.0% (dry basis) and 29.4% for short corn silage TMR. Rations were balanced to meet or exceed NRC (2001) requirements for cows producing 52.2 kg of milk/d containing 3.4% fat and 3.0% true protein assuming a DMI of 29.1 kg/d. Water was available for ad libitum consumption. Feed was pushed up 4 times per day at 1230, 1600, 2400, and 0200 h.

The corn silage variety used in this study was Dekalb DKC 52–59 (Monsanto Company, St. Louis, MO) and was planted on May 12, 2011, and harvested on September 19, 2011. Corn silage was harvested with a John Deere 6750 self-propelled forage harvester (John Deere, Moline, IL). The cutterhead of the harvester used 12 and 48 knives (maximum capacity is 48 knives) with the length-of-cut transmission at its highest setting to produce a theoretical length of cut of 62.7 and 5.33 mm for the long and short corn silage, respectively. After harvesting, corn silage was ensiled in an Ag-Bag (Ag-Bag, St. Nazianz, WI) and allowed to ferment 7 mo before being fed.

The study consisted of four 21-d periods with 14 d of adaptation followed by a 7-d collection period. Dry matter intake of the 3 consecutive days immediately following the adaptation phase (d 15 to 17) was averaged to determine baseline DMI and designated as the baseline phase. Baseline feed preference and rumen conditions were determined on d 17. On d 18, feed intake for all cows was restricted to 75% of the previous day's TMR intake. Following feed restriction, on d 19 at 0745 h, 4 kg (as fed) of finely ground wheat was thoroughly mixed into the rumen digesta of 8 cows via the rumen cannulas, initiating SARA and providing a

Table 1. Ingredient and nutrient composition of experimental diets

Item	Treatment ¹			
	ST	SH	L	LH
Diet ingredient, %				
Corn silage	38.5	36.3	38.5	36.3
Alfalfa haylage	18.3	17.3	18.3	17.3
Orchardgrass hay	0.0	5.6	0.0	5.6
Ground corn	18.4	17.3	18.4	17.3
Roasted soybeans	7.1	6.8	7.1	6.8
Canola meal	9.0	8.4	9.0	8.4
Minerals and vitamin mix ²	2.8	2.7	2.8	2.7
Cottonseed hulls	5.3	4.9	5.3	4.9
Urea (Optigen) ³	0.5	0.5	0.5	0.5
Composition, ⁴ % of DM				
DM	53.6	54.8	52.7	53.9
CP	16.5	16.1	16.6	16.1
ADF	20.0	19.3	20.7	20.0
NDF	29.1	29.8	30.1	30.8
peNDF _{8.0} ⁵	11.5	11.7	15.0	15.3
peNDF _{4.0} ⁶	20.3	20.8	21.9	22.4
peNDF _{1.18} ⁷	26.4	27.1	27.4	28.1
Ash	6.6	6.1	6.7	6.2
Starch	29.4	29.4	26.0	26.0

¹Treatments: ST = short corn silage; SH = short corn silage and supplemental grass hay; L = long corn silage; LH = long corn silage and supplemental grass hay.

²Contained 45.8% dried corn distillers grains with solubles, 35.8% limestone (38% Ca), 8.3% magnesium oxide (54% Mg), 6.4% salt, 1.73% vitamin ADE premix, 1.09% selenium premix (0.06% selenium), and 0.88% trace mineral mix. Composition (DM basis): 11% CP, 18% NDF, 5.2% fat, 14.9% Ca, 0.35% P, 4.58% Mg, 0.41% K, 0.31% S, 357 mg/kg of Cu, 1,085 mg/kg of Zn, 181 mg/kg of Fe, 6.67 mg/kg of Se, 125,875 IU/kg of vitamin A (retinyl acetate), 31,418 IU/kg of vitamin D (activated 7-dehydrocholesterol), and 946 IU/kg of vitamin E (DL- α tocopheryl acetate).

³Alltech (Nicholasville, KY).

⁴Composition values for diets were calculated based on the formulated proportions and actual composition of each individual ingredient.

⁵Physically effective NDF_{8.0} = % of particles >8.0 mm $\times$ NDF of whole sample.

⁶Physically effective NDF_{4.0} = % of particles >4.0 mm $\times$ NDF of whole sample.

⁷Physically effective NDF_{1.18} = % of particles >1.18 mm $\times$ NDF of whole sample.

rumen challenge. Each cow was then allowed ad libitum access to her diet at 0800 h. The amount of TMR offered allowed for up to approximately 115% of total daily baseline intake to be consumed. Ad libitum TMR feeding continued on d 20 and 21 to monitor recovery from the rumen challenge.

Feed, Refusal, and Particle Size Analysis

Feed bunk contents for each animal were mixed and weighed before sampling. Approximately 1.13 kg of TMR was collected on d 17 to 20 of each period at 0, 8, 16, and 24 h after feeding to determine particle size distribution and DM content of the remaining feed. All samples of forage and TMR were sieved in the Penn State Particle Separator (PSPS), using 5 particle fractions (>19.0, >8.0, >4.0, >1.18, and <1.18 mm). Total mixed ration samples were then placed in a forced-air oven at 65°C for 48 h to determine DM content. Samples of all feed ingredients were taken on d 16 and 19 and

analyzed by Cumberland Valley Analytical Services Inc. (Hagerstown, MD) for CP (AOAC International, 2000), ADF (AOAC International, 2000), NDF (Van Soest et al., 1991), ash (AOAC International, 2000), NFC (Van Soest et al., 1991), and NE_L (NRC, 2001). Dried corn silage was ground through a 0.5-mm screen (Wiley Mill, Arthur H. Thomas Co. Inc., Swedesboro, NJ) for starch determination utilizing the procedure reported by Zanton and Heinrichs (2009). Corn silage fermentability was determined via in situ bags incubated in quadruplicate in the rumen of 2 lactating cows consuming a 62% forage to 38% concentrate diet (each cow incubated 2 bags of each sample for each time point) for 0.5, 1, 2, 4, 6, 8, 12, 16, 24, and 48 h. Approximately 7 g of samples were sealed in nylon bags (10 $\times$ 20 cm, 50 μ m pore size; Ankom, Macedon, NY) attached to a string that was secured to the rumen cannulas and weighted to anchor the bags in the center of the rumen. After removal from the rumen, bags were rinsed in cold water by hand until the water was clear.

Table 2. Particle size distribution and chemical composition of corn silage and hay and ruminal disappearance over time determined via in situ incubation for corn silage

Item	Hay	Corn silage			
		Short	Long	SEM	<i>P</i> -value ¹
Particle size, as-fed % retained					
19.0 mm	—	2.2	31.7	1.23	<0.01
8.0 mm	—	38.5	37.7	1.28	0.65
4.0 mm	—	42.3	21.1	1.27	<0.01
1.18 mm	—	15.5	9.1	1.11	<0.01
Pan	—	1.5	0.5	0.51	0.23
Composition, % of DM					
DM	88.5	42.2	40.2	2.29	0.55
CP	17.5	6.9	7.1	0.33	0.69
ADF	30.2	17.0	18.7	0.27	0.01
NDF	52.6	29.6	32.1	0.45	0.01
peNDF _{8.0} ²	—	8.6	10.2	0.35	<0.01
peNDF _{4.0} ³	—	24.5	29.0	0.53	<0.01
peNDF _{1.18} ⁴	—	29.1	31.9	0.82	<0.01
Ash	8.0	3.3	3.5	0.31	0.76
NFC	19.8	57.4	54.6	0.88	0.11
Starch	—	54.8	49.4	2.61	<0.01
NE _L , Mcal/kg	0.71	0.83	0.81	0.01	0.03
Ruminal disappearance over time, ⁵ %					
0.5 h	—	52.9	57.9	4.12	0.27
1.0 h	—	50.8	56.1	4.12	0.25
2.0 h	—	55.8	55.7	4.12	0.29
4.0 h	—	62.2	62.0	4.12	0.97
6.0 h	—	63.6	61.7	4.12	0.67
8.0 h	—	68.7	68.4	4.12	0.95
12.0 h	—	70.8	69.4	4.12	0.74
16.0 h	—	72.7	69.8	4.12	0.51
24.0 h	—	74.7	73.2	4.12	0.74
48.0 h	—	82.1	82.3	4.12	0.97

¹*P*-value reflects difference between short and long corn silage.

²Physically effective NDF_{8.0} = % of particles >8.0 mm × NDF of whole sample.

³Physically effective NDF_{4.0} = % of particles >4.0 mm × NDF of whole sample.

⁴Physically effective NDF_{1.18} = % of particles >1.18 mm × NDF of whole sample.

⁵Nylon bags were incubated in quadruplicate in the rumen of 2 lactating cows (each cow incubated 2 bags of each sample for each time point).

Bags were then dried in a forced-air oven at 65°C for 48 h and weighed to determine remaining DM.

Rumen Sampling

Ruminal contents were collected from dorsal, ventral, cranial, caudal, and medial areas of the rumen at 0.0, 1.5, 3.5, 5.5, 8.5, 11.5, 14.5, 18.0, 21.5, and 24.5 h after feeding (0.0 h) (Kononoff et al., 2003) on d 17 to determine baseline rumen conditions, and on d 18 (feed restriction phase), d 19 (rumen challenge phase), and d 20 (recovery phase). Collected digesta was mixed thoroughly and separated into 2 equal subsamples. One digesta subsample was filtered through a 0.28-mm fiberglass mesh screen (New York Wire, Mt. Wolf, PA). Rumen liquid pH was immediately determined using a handheld pH electrode (Oakton Instruments, Vernon Hills, IL). Approximately 5 mL of strained ruminal fluid was placed into bottles containing 1 mL of 25%

metaphosphoric acid and 1 mL of 0.6% 2-ethylbutyric acid (internal standard) and stored at approximately −20°C. Samples were later thawed and centrifuged 3 times at 4,000 × *g* for 30 min at 4°C to obtain a clear supernatant and were analyzed for VFA concentration using gas chromatography (Yang and Varga, 1989). The second ruminal digesta subsample was used for particle size distribution and DM analysis using the procedure of Maulfair et al. (2011). Samples were processed in duplicate and particle fractions determined were soluble, >0.15, >0.6, >1.18, >3.35, >6.7, and >9.5 mm. The soluble fraction of samples was calculated as the DM lost during sieving and drying. Data were analyzed using each particle fraction as a percentage of DM retained on ≥0.15 mm screen (retained) and also as the percentage of DM of the entire sample sieved (total).

Finally, rumens of the cannulated cows were completely emptied on d 21 of each period at 5 h after feeding. The rumen of each cow was emptied into large

plastic containers and mixed thoroughly. Total digesta amounts were weighed and recorded, and volume was calculated. A sample of approximately 2 kg of total digesta was collected for DM analysis. Digesta was then immediately returned to the rumen of each cow.

Milk Production

Milk production was recorded daily and milk samples were taken on d 15 and 16 (4 consecutive milkings). Samples were collected and preserved using 2-bromo-2-nitropropane-1,3-diol. Milk samples were analyzed for fat, true protein, and lactose by the Dairy One milk testing laboratory (State College, PA) using infrared spectrophotometry (Foss 605B MilkoScan, Foss Electric, Hillerød, Denmark).

Statistical Analyses

Statistical analysis was conducted using PROC MIXED of SAS (version 9.3, SAS Institute Inc., Cary, NC). Performance data were analyzed as a replicated 4 × 4 Latin square with model effects for square, period within square, and treatment as fixed effects as well as cow within square as a random effect. Sum of squares for all treatments were then partitioned into single degree of freedom contrasts for corn silage particle length (CS), hay inclusion (H), and CS by H interaction planned a priori. Square by treatment interaction was tested but was not significant and thus was dropped from the model. All denominator degrees of freedom for *F*-tests were calculated according to Kenward and Roger (1997), and repeated measurements for rumen pH, VFA, lactate, and ammonia concentrations and long and short corn silage disappearance analyzed using the first-order autoregressive covariance structure (Littell et al., 1998) as well as terms for phase and interaction of treatment by phase. Due to unequally spaced rumen sampling, the weighted mean daily ruminal pH, VFA, and NH₃ concentrations and ruminal digesta were determined by calculating the area under the response curve according to the trapezoidal rule (Shipley and Clark, 1972). Area under the curve for the SARA thresholds of 5.8 and 5.5 were also calculated using the trapezoidal rule (Shipley and Clark, 1972). A sorting index was calculated based on refusals for each of the 5 particle size fractions. This index was calculated as the ratio of actual intake to predicted intake for particles retained on each sieve of the separator (Leonardi and Armentano, 2003). Values equal to 100% indicate that cows were not sorting, values >100% indicate that cows were sorting for the particle fraction (selective consumption) and values <100% indicate that cows were sorting against the particle fraction (se-

lective refusals). The 95% confidence limits were used to determine if a selection index was significantly different from 100%. All data are presented as least squares means, and treatment effects are considered significant when $P \leq 0.05$ and a trend when $0.05 < P \leq 0.10$. Means separation tests were conducted using the protected least significant differences (PDIFF) procedure with significance at $P \leq 0.05$ and tendency at $P \leq 0.10$.

RESULTS AND DISCUSSION

Chemical Composition and Particle Size Distribution of Diets

Particle size distribution and chemical composition of corn silages used in this study are shown in Table 2. Chemical composition of the corn silages was similar for DM, CP, NFC, and ash; however, ADF and NDF were higher and starch and NE_L were lower for long corn silage compared with short corn silage. The reason for these differences in silage grown and harvested under identical conditions is unknown. Differences were unexpected and likely represented sampling variations. Chopping corn silage too long, however, can make compaction difficult during the ensiling process, trapping air in the forage mass and impairing fermentation and nutrient composition. Moreover, it is possible that the combination of long particles and rather dry silage may have led to a segregation of corn kernels through the forage mass. Rumen digestibility disappearance over time of long and short corn silage were not different at any time point (Table 2).

A large difference was observed in particle size distribution between long and short corn silage. When separated with the PSPS, long corn silage had more particles retained on the 19.0-mm screen, similar amounts on the 8.0-mm screen and pan, and fewer particles on the 4.0- and 1.18-mm screen than short corn silage. The long corn silage had 50% less particles retained on the 4.0-mm screen than the short corn silage and overall increased physically effective NDF (**peNDF**) as defined as particles >4.0 mm (Heinrichs, 2013) by 15.5%. Particle size distributions of treatment TMR are shown in Table 3. The L TMR had a larger proportion of particles on the 19.0-mm screen, whereas the ST TMR had a larger proportion of particles on the 8.0-, 4.0-, and 1.18-mm screens. These results were expected by the design of the treatments.

Ruminal Characteristics

In this study, SARA was achieved using the 1-d challenge model similar to Krause and Oetzel (2005) except that cows were fed 75% of the previous day's TMR

Table 3. Particle size distributions determined with the Penn State Particle Separator for short (ST) and long (L) TMR

Item	TMR ¹		SEM	P-value
	ST	L		
Particle size, DM % retained				
19.0 mm	2.9	21.9	1.80	<0.01
8.0 mm	36.4	27.8	1.48	<0.01
4.0 mm	30.5	23.0	0.85	<0.01
1.18 mm	21.0	18.3	1.34	<0.01
Pan	9.2	8.9	2.21	0.31

¹n = 768.

intake, compared with using a 50% feed restriction model. In a recent study, restricting feed to only 75% of the previous day's TMR intake successfully induced SARA (Maulfair et al., 2013). In addition, due to implementation of the preplanned high-starch diet, it was not considered to be necessary to restrict intake to 50% of the previous day's TMR intake to elicit a response. Daily weighted mean ruminal pH was different between short and long corn silage treatments for baseline, restriction, challenge, and recovery phase (Figure 1). Baseline weighted average rumen pH for all treatments was low compared with other studies investigating the SARA model (Keunen et al., 2002; Krause and Oetzel, 2005; Krause et al., 2009), and we believe this is due to

the high-starch diet. In a survey of field nutritionists, dietary starch concentration in rations for lactating dairy cattle that supported both positive production and health were between 15 to 25% of ration DM (Hall and Eastridge, 2014). Comparatively, the dietary starch concentrations in this study were high (26.0% for L and LH and 29.4% for S and SH). Despite the overall low ruminal pH during baseline, 5.44, 5.45, 5.64, and 5.54 for ST, SH, L, and LH, respectively, the rumen challenge lowered the weighted average rumen pH further for all treatments (Table 4). The drop in rumen pH for each diet was 0.11, 0.07, 0.17, and 0.18 units for ST, SH, L and LH, respectively. These values were comparable with other studies attempting

Figure 1. Effect of feeding TMR containing short or long corn silage and supplemental grass hay on rumen pH during baseline, feed restriction, rumen challenge, and recovery phase. L = long corn silage; LH = long corn silage and supplemental grass hay; ST = short corn silage; SH = short corn silage and supplemental grass hay.

Table 4. Effect of feeding TMR containing short or long corn silage and supplemental grass hay on rumen pH and digesta

Rumen pH	Treatment ¹				SEM	P-value ²		
	ST	SH	L	LH		CS	H	CS × H
Weighted average ³								
Baseline	5.44 ^b	5.45 ^b	5.64 ^a	5.54 ^{ab}	0.05	0.05	0.27	0.16
Restriction	5.60 ^b	5.57 ^b	5.79 ^a	5.66 ^b	0.04	0.01	0.08	0.20
Challenge	5.33 ^b	5.38 ^{ab}	5.47 ^a	5.36 ^b	0.04	0.16	0.44	0.03
Recovery	5.62 ^b	5.64 ^b	5.82 ^a	5.69 ^{ab}	0.06	0.01	0.23	0.12
Minimum								
Baseline	5.03	5.05	5.15	5.03	0.05	0.19	0.19	0.06
Restriction	5.11	5.08	5.16	5.13	0.05	0.25	0.47	0.92
Challenge	4.86	4.96	4.95	4.91	0.07	0.75	0.60	0.26
Recovery	5.11	5.14	5.15	5.01	0.08	0.86	0.72	0.48
Maximum								
Baseline	6.54 ^b	6.50 ^b	6.93 ^a	6.84 ^{ab}	0.12	0.05	0.61	0.84
Restriction	6.61 ^b	6.51 ^b	7.00 ^a	6.63 ^b	0.10	0.02	0.03	0.18
Challenge	6.76 ^{ab}	6.43 ^b	6.96 ^a	6.68 ^{ab}	0.14	0.12	0.04	0.86
Recovery	6.74 ^{ab}	6.58 ^b	7.03 ^a	6.89 ^{ab}	0.13	0.03	0.24	0.90
AUC ⁴ <5.8, pH units × min/d								
Baseline	531.2 ^a	510.2 ^a	355.5 ^b	444.4 ^{ab}	44.7	<0.01	0.40	0.18
Challenge	656.8	590.6	526.9	622.1	51.3	0.24	0.77	0.06
AUC <5.5, pH units × min/d								
Baseline	235.7 ^a	225.0 ^a	124.7 ^b	186.6 ^{ab}	34.1	0.04	0.46	0.30
Challenge	340.1	284.8	261.7	316.5	45.8	0.48	0.99	0.11
Rumen digesta ⁵								
Wet weight, kg	95.1	104.2	94.1	96.8	4.1	0.23	0.10	0.36
DM, %	19.5 ^{ab}	19.7 ^{ab}	18.2 ^b	20.9 ^a	0.59	0.95	0.02	0.05
DM weight, kg	18.3 ^{ab}	20.6 ^a	17.2 ^b	20.2 ^a	0.99	0.44	0.01	0.70
Volume, L	113.6	110.4	110.9	104.9	10.0	0.55	0.50	0.83
Density ⁶ , kg/L	0.89	0.97	0.88	0.93	0.06	0.57	0.16	0.71

^{a,b}Means within a row with different superscripts are different at $P \leq 0.05$.

¹Treatments: ST = short corn silage; SH = short corn silage and supplemental grass hay; L = long corn silage; LH = long corn silage and supplemental grass hay.

²CS = main effect of corn silage particle size; H = main effect of hay inclusion; and CS × H = the interaction between the corn silage particle size and hay inclusion.

³Weighted averages determined by calculating the area under the response curve according to the trapezoidal rule (Shipley and Clark, 1972).

⁴AUC = area under curve (area below pH threshold (5.5 or 5.8) and above pH profiles of cows).

⁵Manual empty.

⁶Density = wet weight (kg)/volume (L).

to induce SARA in dairy cattle, such as Keunen et al. (2002) who reported a 0.14-unit decrease. Increasing corn silage particle size increased weighted average rumen pH during the baseline, restriction, and recovery phase. Rumen pH was highest for diet L in all 4 phases. An interaction effect ($P = 0.03$) was observed between corn silage particle size and the supplementation of hay during the challenge phase. Offering orchardgrass hay to cows fed short corn silage TMR increased ruminal pH during the challenge phase. Recovery phase weighted average rumen pH values across all treatments were much lower compared with other studies (Keunen et al., 2002; Krause and Oetzel, 2005). It is possible that the cows adapted to the consistent low ruminal pH conditions, reflected in the baseline values, throughout the study. Minimum ruminal pH was unaffected by dietary treatment throughout the 4 phases of the model. Maximum ruminal pH, however, was higher for treatments containing long corn silage during the

baseline, restriction, and recovery phases and lower for those containing hay in the restriction and challenge phases. Cows consuming long corn silage maintained higher maximum rumen pH values (6.93 and 6.84 for L and LH, respectively) during the baseline phase than cows consuming short CS (6.54 and 6.50 for S and SH, respectively).

The area under the curve for ruminal pH 5.8 and 5.5 was smaller during the baseline phase for treatments containing long corn silage compared with short corn silage. There was no significant effect of treatment during the challenge phase for the area under the curve at ruminal pH 5.8 or 5.5. Both area under ruminal pH 5.8 and 5.5 increased from the baseline to challenge phase for all treatments. Ruminal digesta volume (as-fed basis) was not affected by corn silage particle size or hay inclusion. Cows consuming hay, however, had a greater ($P = 0.01$) ruminal digesta weight and no differences in density. The hay diets, however, may have

had a greater rumen buffering effect partially due to higher water holding capacity of the digesta. Water holding capacity has been shown to be positively correlated with increased fiber content of feeds, mainly the cellulose and hemicellulose fractions (Ramanzin et al., 1991). Further, diets containing hay or long corn silage may have elicited more chewing activity and saliva production, increasing rumen buffering capacity.

Effects of corn silage particle size and supplemental hay inclusion on the concentration of individual VFA are presented in Table 5. Acetate was unaffected by treatment during both the baseline and challenge phase. However, diets supplemented with hay had a tendency to have higher acetate concentrations during the challenge phase. Acetate production is commonly associated with feeding high-forage, low-starch diets. A treatment $\times$ phase interaction effect ($P < 0.01$) was found (data not shown). Acetate concentrations increased in all treatments from baseline to challenge phase. During the baseline phase, propionate was higher ($P = 0.01$) in short corn silage diets: 46.47 and 42.36 $\mu\text{mol/mL}$ for ST and SH, respectively, and 38.03 and 39.54 $\mu\text{mol/mL}$ for L and LH, respectively. Reducing corn silage particle size may have induced higher concentrations of propionate due to an increase in starch digestibility from the chopping process (Johnson et al., 2003). Treatments did not affect butyrate concentrations within phases, but butyrate concentrations had a tendency ($P = 0.10$) to be higher for diets containing long corn silage during the challenge phase. In addition, during the challenge phase, valerate concentrations were affected by corn silage particle size length. Cows consuming long corn silage diets had higher concentrations of valerate compared with short corn silage diets ($P = 0.05$). No treatment differences were found for isovalerate concentrations during baseline phase; however, cows consuming short corn silage had a tendency ($P = 0.10$) to have increased concentrations. An interaction effect ($P = 0.03$) was observed for isobutyrate concentrations. Feeding L diets yielded higher concentrations of isobutyrate than ST diets. Of the 3 major VFA, acetate increased to the greatest extent during the SARA challenge phase. The acetate to propionate ratio was affected by corn silage particle size during both the baseline and challenge phase. Decreasing the corn silage particle size length decreased the acetate to propionate ratio. During the challenge phase diets containing short corn silage had an acetate to propionate ratio of <2 . A ratio of <2 has been associated with SARA and decreased milk fat production (Sauvant and Mertens, 1998).

The weighted mean, minimum, and maximum NH_3 concentrations were similar among treatments, and the mean averaged 11.3 mg/dL during the baseline phase. During the challenge d, however, cows fed long corn

silage and consuming supplemental hay had lower NH_3 concentrations than cows not offered supplemental hay. No difference due to supplemental hay was detected in NH_3 concentrations of cows fed short corn silage. Lactate concentrations on baseline phase were not found to be different among treatments averaging 0.42 $\mu\text{mol/mL}$.

Sorting, DMI, and Refusals

Ration sorting was measured using a sorting index calculated by comparing TMR particle size distributions at the time of feeding (0 h) to 24 h after feeding (Table 6). Index values $>100\%$ indicate sorting for a particle fraction and values $<100\%$ indicate sorting against. During the baseline phase, cows consuming SH, L, and LH sorted against longer particles retained on the 19.0-mm sieve and sorted for finer particles retained on the bottom pan. Only cows consuming ST sorted against particles retained on the 8.0-mm sieve. Cows sorted for particles retained on the 1.18-mm sieve, in particular, when consuming long corn silage diets. During the challenge phase, cows consuming long corn silage-based diets sorted against long particles (those retained on the 19.0-mm sieve). Cows consuming only short corn silage with no supplemental hay, however, were capable of sorting for longer particle fractions (retained on the 19.0-mm sieve) and sorted against smaller particle fractions (retained on the 4.0 mm). During the recovery phase, minimal sorting activity occurred between treatments. No sorting occurred for particles retained on the 19.0-mm sieve for cows consuming ST, L, or LH. However, cows sorted against (86.2%) the longer particles when fed supplemental hay and short corn silage TMR. Cows consuming ST sorted against particles retained on the 8.0-mm sieve and sorted for smaller particles retained on the 1.18-mm sieve. These results indicate that cows consuming short corn silage TMR did change preference for longer forage particles during the challenge. Cows consuming long corn silage-based diets, however, selected against longer particles despite the challenge. Maulfair et al. (2013) found similar results where cows fed diets consisting of long corn silage and cracked corn sorted against particles retained on the top 3 sieves and for particles on the 3 smallest sieves when challenged with a bout of SARA. Cows fed short corn silage diet with dry fine ground corn in that study, however, did not sort against longer particles retained on the 18.0- and 8.98-mm sieves. In addition, DeVries et al. (2008) determined that lactating dairy cows experiencing a bout of ruminal acidosis altered their sorting behavior to select for longer particles.

The DMI and refusals for each diet for the baseline, feed restriction, rumen challenge, and recovery phase

Table 5. Effect of feeding TMR containing short or long corn silage and supplemental grass hay on rumen VFA and fermentation

Item	Treatment ¹				SEM	P-value ²		
	ST	SH	L	LH		CS	H	CS × H
VFA weighted average, ³ µmol/mL								
Acetate								
Baseline	92.98	89.15	88.88	89.42	3.56	0.43	0.50	0.37
Challenge	108.49	110.32	104.94	116.31	4.00	0.75	0.10	0.23
Propionate								
Baseline	46.47 ^a	42.36 ^{ab}	38.03 ^b	39.54 ^b	2.96	0.01	0.52	0.17
Challenge	59.03	57.64	46.36	58.52	5.03	0.21	0.25	0.15
Butyrate								
Baseline	18.10	18.04	18.24	17.72	0.98	0.92	0.75	0.80
Challenge	22.00	22.48	23.89	24.59	1.72	0.10	0.62	0.93
Valerate								
Baseline	3.62	3.15	3.31	3.16	0.31	0.52	0.19	0.49
Challenge	5.35 ^{ab}	5.11 ^b	5.97 ^{ab}	6.78 ^a	0.79	0.05	0.59	0.34
Isovalerate								
Baseline	2.29	2.43	2.23	2.12	0.20	0.30	0.92	0.48
Challenge	2.22	2.28	1.92	2.03	0.17	0.10	0.61	0.86
Isobutyrate								
Baseline	0.72 ^b	0.83 ^{ab}	0.89 ^a	0.80 ^{ab}	0.05	0.12	0.83	0.03
Challenge	0.75	0.76	0.95	1.01	0.22	0.32	0.86	0.91
Acetate:propionate								
Baseline	2.03 ^b	2.14 ^{ab}	2.52 ^a	2.41 ^{ab}	0.16	0.01	0.98	0.42
Challenge	1.99 ^b	1.98 ^b	2.52 ^a	2.09 ^b	0.15	0.02	0.08	0.10
NH ₃ , mg/dL								
Weighted mean								
Baseline	11.5	12.2	11.4	10.1	0.77	0.28	0.73	0.31
Challenge	14.2 ^{ab}	15.4 ^a	16.3 ^a	13.0 ^b	1.19	0.84	0.15	0.01
Lactate, µmol/mL								
Weighted mean								
Baseline	0.39	0.40	0.46	0.44	0.03	0.09	0.82	0.64
Challenge	0.50	0.41	0.46	0.44	0.05	0.89	0.29	0.48

^{a,b}Means within a row with different superscripts are different at $P \leq 0.05$.

¹Treatments: ST = short corn silage; SH = short corn silage and supplemental grass hay; L = long corn silage; LH = long corn silage and supplemental grass hay.

²CS = main effect of corn silage particle size; H = main effect of hay inclusion; and CS × H = the interaction between the corn silage particle size and hay inclusion.

³Weighted averages determined by calculating the area under the response curve according to the trapezoidal rule (Shipley and Clark, 1972).

are shown in Table 7. The daily TMR DMI was significantly lower ($P < 0.01$) for cows fed long corn silage compared with short corn silage during the baseline phase. This difference may be due to increased gut fill associated with bulk rumen fill, as has been noted previously (Kononoff and Heinrichs, 2003; Leonardi et al., 2005). These results are in agreement with studies that found that increasing particle size of corn silage decreases DMI (Stockdale and Beavis, 1994; Kononoff et al., 2003). Rumen challenge and recovery phase TMR DMI remained similar to baseline averages ($P = 0.36$). However, there tended to be an interaction ($P = 0.06$) effect between corn silage and hay treatments during challenge phase for TMR DMI. Hay DMI was unaffected by corn silage particle size throughout the 4 phases. Total mixed ration refusals increased dramatically from baseline to challenge phase for all diets and averaged 16 and 13.5% for the challenge and recovery phase, respectively. Cows on all diets refused more

TMR and hay on the challenge phase compared with the baseline phase. Total DMI increased in all treatments during the challenge phase due to the additional 4 kg (as fed) ground wheat challenge; however, recovery phase intake was similar to baseline intake, indicating that the cows did not respond to the ground wheat challenge as expected.

Rumen Particle Size

Corn silage particle size had a greater influence on ruminal digesta particle size distribution than hay supplementation (Table 8). Cows consuming short corn silage treatments had more ruminal digesta particles retained on the 6.7- and 3.35-mm sieves and less retained on the 9.5-mm sieve compared with cows consuming long corn silage treatments. Particle fractions as a percentage of total DM on the 9.5-mm screen were greater for cows consuming long corn silage, whereas cows consuming

Table 6. Effect of feeding TMR containing short or long corn silage and supplemental grass hay on mean sorting indices¹ during baseline, challenge, and recovery phases

Sieve ²	Treatment, ³ %				SEM	<i>P</i> -value ⁴		
	ST	SH	L	LH		CS	Hay	CS × H
Baseline								
19.0 mm	95.7	91.3*	92.4*	94.0*	2.61	0.90	0.53	0.19
8.0 mm	97.9*	98.9	99.4	99.4	0.81	0.20	0.51	0.58
4.0 mm	100.2 ^b	100.3 ^b	101.9*	100.9 ^{ab}	0.53	0.04	0.40	0.32
1.18 mm	100.8 ^b	100.6 ^b	103.3**	102.0 ^{ab*}	0.68	0.01	0.25	0.41
Pan	104.0*	101.9	104.9*	103.8*	1.34	0.29	0.23	0.71
Challenge								
19.0 mm	103.3 ^{a*}	95.4 ^b	93.3 ^{b*}	92.6 ^{b*}	3.00	0.01	0.05	0.10
8.0 mm	100.1	101.2	98.8	101.1	1.15	0.51	0.09	0.57
4.0 mm	97.7 ^{b*}	98.8 ^{ab}	101.3 ^a	100.4 ^a	1.06	0.01	0.87	0.25
1.18 mm	101.3 ^b	101.3 ^b	105.1 ^{a*}	104.9 ^{a*}	1.26	0.01	0.93	0.90
Pan	97.1 ^b	92.5 ^{b*}	105.9 ^{a*}	100.0 ^{ab}	2.85	0.01	0.04	0.78
Recovery								
19.0 mm	100.7	86.2*	94.0	96.6	4.65	0.68	0.19	0.07
8.0 mm	97.2*	100.0	99.6	101.2	1.16	0.14	0.07	0.62
4.0 mm	100.0	100.2	100.9	99.4	0.95	0.97	0.47	0.36
1.18 mm	102.7*	102.0	105.1*	102.4	1.20	0.21	0.12	0.36
Pan	100.9	97.2	103.6	101.4	2.50	0.18	0.25	0.76

^{a,b}Means within a row with different superscripts are different at $P \leq 0.05$.

¹Values = 100% indicate no sorting, values <100% indicated sorting against, and values >100% indicate sorting for.

²Pore size of sieves.

³Treatments: ST = short corn silage; SH = short corn silage and supplemental grass hay; L = long corn silage; LH = long corn silage and supplemental grass hay.

⁴CS = main effect of corn silage particle size; H = main effect of hay inclusion; and CS × H = the interaction between the corn silage particle size and hay inclusion.

*Sorting index is significantly different from 100% based on a 95% confidence limit.

short corn silage had greater percentage of total DM on the 3.35-mm screen. Physically effective fiber relates to the physical characteristics of a feed and is an indication of the potential of a feed to stimulate chewing (Mertens, 1997). Typically, physically effective fiber is determined using feed particles on or above the 1.18-mm sieve, because the 1.18-mm sieve is thought to be the threshold particle size for increased resistance to particles leaving the rumen of cattle and sheep (Evans et al., 1973; Poppi et al., 1980). Recently, however, several researchers have suggested that the critical particle size for rumen escape in dairy cattle may be larger than 1.18 mm. In the present study, diet particle sizes were 90.8 and 91.0% for the ST TMR and L TMR; and 98.5 and 99.6% for short and long corn silage particles retained on a 1.18-mm sieve, making them virtually identical. However, particle size percentages were 83.0 and 90.5% of the short and long corn silage particle size and 69.8 and 72.7% of the ST TMR and L TMR when using the 4.0-mm sieve to estimate effective fiber, allowing one to discern a meaningful difference in these very different diets. Using dry sieving, Yang et al. (2001) showed that ruminal outflow rate of particles <1.18 mm was faster and averaged 5.57%/h compared with particles retained on a 3.35-mm sieve, which had an average outflow rate of only 1.75%/h. The fecal

mean particle length for cattle averaged 1.86 mm when fed diets composed of alfalfa silage, barley silage, alfalfa hay, and steam-rolled barley. Interestingly, 24.8% of fecal particles were retained above the 1.18-mm sieve, whereas only 3.1% of particles were above the 3.35-mm sieve. In addition, Cardoza and Mertens (1986) observed that feed particles retained on sieves >4.0 mm would be retained in the rumen of dairy cows and contribute to chewing activity. Although the peNDF system has relied on the 1.18-mm sieve using a Ro-Tap 3-dimensional separator (W.S. Tyler, Mentor, OH) to determine physically effective fiber, it appears that the critical size for cattle is actually closer to a fraction of particles that would be retained on a 4.0-mm sieve (Maulfair et al., 2011) using a 2-dimensional separator device. The data from the present study suggest that the 4.0-mm sieve may be a better indicator of physical effectiveness and allow for more differentiation between diets that are indeed different.

Milk Production and Composition

Milk production was significantly different across diets (Table 9). Cows consuming long corn silage had lower ($P = 0.02$) milk production overall compared with cows consuming short corn silage, which follows

Table 7. Effect of feeding TMR containing short or long corn silage and supplemental grass hay on TMR and hay DMI, TMR and hay refusal, and total DMI during baseline, restriction, challenge, and recovery phase

Item	Treatment ¹				SEM	P-value ²		
	ST	SH	L	LH		CS	H	CS × H
TMR DMI, kg								
Baseline	28.8 ^{ab}	29.9 ^a	25.9 ^c	26.3 ^{bc}	1.7	<0.01	0.35	0.64
Restriction	25.4 ^b	26.3 ^a	22.8 ^c	23.1 ^{bc}	1.5	<0.01	0.40	0.71
Challenge	28.1 ^a	30.7 ^a	26.5 ^b	26.0 ^b	1.9	<0.01	0.22	0.06
Recovery	28.0 ^{ab}	29.6 ^a	26.4 ^b	26.3 ^b	1.9	0.02	0.47	0.43
Hay DMI, kg								
Baseline	0	1.0	0	1.2	0.16	0.20	—	—
Restriction	0	1.1	0	1.5	0.16	0.06	—	—
Challenge	0	0.7	0	0.6	0.16	0.50	—	—
Recovery	0	0.6	0	0.4	0.13	0.37	—	—
TMR refusal, %								
Baseline	6.3	5.7	8.6	5.2	1.5	0.53	0.19	0.35
Restriction	5.9	6.9	5.6	4.8	1.7	0.42	0.97	0.57
Challenge	17.1	14.1	15.9	16.9	2.7	0.70	0.65	0.33
Recovery	14.7	12.3	13.6	13.3	2.6	0.99	0.53	0.63
Hay refusal, %								
Baseline	—	46.4	—	45.2	7.5	0.89	—	—
Restriction	—	49.9	—	34.1	7.1	0.07	—	—
Challenge	—	71.7	—	76.9	6.8	0.45	—	—
Recovery	—	75.7	—	81.7	5.3	0.36	—	—
Total DMI, ³ kg								
Baseline	28.8 ^{ab}	30.9 ^a	25.9 ^c	27.5 ^{bc}	1.7	<0.01	0.03	0.77
Restriction	25.4 ^b	27.4 ^a	22.8 ^c	24.6 ^{bc}	1.5	<0.01	0.01	0.90
Challenge	29.8 ^b	33.0 ^a	28.3 ^b	28.3 ^b	1.9	<0.01	0.05	0.05
Recovery	28.0 ^{ab}	30.1 ^a	26.3 ^b	26.7 ^b	1.9	0.02	0.22	0.39

^{a-c}Means within a row with different superscripts are different at $P \leq 0.05$.

¹Treatments: ST = short corn silage; SH = short corn silage and supplemental grass hay; L = long corn silage; LH = long corn silage and supplemental grass hay.

²CS = main effect of corn silage particle size; H = main effect of hay inclusion; and CS × H = the interaction between the corn silage particle size and hay inclusion.

³Total DMI = TMR + hay DMI (baseline, restriction, and recovery phase); TMR + hay + wheat DMI (challenge phase).

Table 8. Effect of feeding TMR containing short or long corn silage and supplemental grass hay on daily mean ruminal digesta particle size distribution and DM content

Item, % of DM	Treatment ¹				SEM	P-value ²		
	ST	SH	L	LH		CS	H	CS × H
DM	23.4	24.9	24.6	24.6	0.01	0.39	0.16	0.18
Retained DM ³								
9.5 mm	7.8 ^b	9.0 ^b	19.2 ^a	19.6 ^a	0.81	<0.01	0.26	0.58
6.7 mm	7.4 ^a	7.2 ^{ab}	6.5 ^b	6.5 ^b	0.31	0.01	0.87	0.70
3.35 mm	25.5 ^a	25.7 ^a	19.6 ^b	19.4 ^b	0.77	<0.01	0.99	0.76
1.18 mm	22.6	21.3	21.2	20.9	0.51	0.09	0.15	0.33
0.60 mm	11.3	11.2	11.1	11.1	0.32	0.65	0.89	0.90
0.15 mm	19.3	19.4	19.4	20.9	0.86	0.11	0.09	0.15
Total DM ⁴								
9.5 mm	5.7 ^b	6.7 ^b	14.3 ^a	14.5 ^a	0.72	<0.01	0.32	0.51
6.7 mm	5.4 ^{ab}	5.5 ^a	4.8 ^b	4.8 ^b	0.27	0.02	0.99	0.89
3.35 mm	19.2 ^a	19.3 ^a	14.6 ^b	14.1 ^b	0.68	<0.01	0.76	0.65
1.18 mm	16.5	15.9	15.9	15.2	0.58	0.29	0.25	0.89
0.60 mm	8.3	8.4	8.3	8.1	0.31	0.74	0.84	0.64
0.15 mm	14.2	14.4	14.2	15.2	0.69	0.48	0.22	0.45
Soluble	21.7	22.2	22.1	23.3	1.44	0.58	0.52	0.80

^{a,b}Means within a row with different superscripts are different at $P \leq 0.05$.

¹Treatments: ST = short corn silage; SH = short corn silage and supplemental grass hay; L = long corn silage; LH = long corn silage and supplemental grass hay.

²CS = main effect of corn silage particle size; H = main effect of hay inclusion; and CS × H = the interaction between the corn silage particle size and hay inclusion.

³Retained DM = measurements determined from sample retained on sieve.

⁴Total DM = measurements determined from total sample including soluble fraction.

Table 9. Effect of feeding TMR containing short or long corn silage and supplemental grass hay on milk production and components

Item	Treatment ¹				SEM	P-value ²		
	ST	SH	L	LH		CS	H	CS × H
Milk yield, kg/d	44.1 ^{ab}	45.8 ^a	42.8 ^b	42.4 ^b	2.5	0.02	0.49	0.25
3.5% FCM, ³ kg/d	41.3 ^b	43.6 ^a	40.3 ^b	40.8 ^b	3.0	0.02	0.10	0.26
Fat, %	3.15	3.23	3.17	3.30	0.16	0.45	0.07	0.78
Fat, kg/d	1.40 ^b	1.49 ^a	1.37 ^b	1.41 ^{ab}	0.13	0.07	0.04	0.36
Protein, %	3.07 ^a	3.05 ^{ab}	3.05 ^{ab}	3.02 ^b	0.05	0.05	0.03	0.69
Protein, kg/d	1.36 ^{ab}	1.40 ^a	1.31 ^b	1.28 ^b	0.08	0.05	0.85	0.18
Lactose, %	4.87	4.73	4.78	4.76	0.07	0.60	0.16	0.28
Lactose, kg/d	2.15 ^{ab}	2.17 ^a	2.05 ^{ab}	2.03 ^b	0.12	0.01	0.99	0.60

^{a,b}Means within a row with different superscripts are different at $P \leq 0.05$.

¹Treatments: ST = short corn silage; SH = short corn silage and supplemental grass hay; L = long corn silage; LH = long corn silage and supplemental grass hay.

²CS = main effect of corn silage particle size; H = main effect of hay inclusion; and CS × H = the interaction between the corn silage particle size and hay inclusion.

³3.5% FCM = 0.432 (milk, kg) + 13.23 (fat, kg); (Gaines, 1928).

the DMI of the baseline phase. Cows consuming hay tended to have greater ($P = 0.07$) milk fat concentration, which is likely reflected in the increased ($P = 0.04$) milk fat yield by cows consuming diets with hay. Acetate production is associated with feeding diets high in forage and is the major precursor of milk fat, thus an increase in acetate may increase the concentration of milk fat. Further, acetate can be affected by salivation, which increases when feeding forages high in peNDF that stimulate mastication. No treatment difference was found for milk fat percentage; however, FCM was greatest (43.6 kg/d) for the SH treatment, higher ($P = 0.02$) for short corn silage diets than long corn silage diets, and tended ($P = 0.10$) to be greater for treatments supplemented with hay. Milk protein yield increased ($P = 0.05$) with shorter corn silage particle size, which has been observed in other studies, and is thought to be a result of increased digestibility (Clark and Armentano, 1999) due to the positive correlation between milk protein and dietary energy (Grieve et al., 1986). Lactose yield was also highest (2.17 kg/d) for SH treatments compared with the other treatments and greater ($P = 0.01$) for diets with short compared with long corn silage. These results are in agreement with studies that found changes in forage particle size influence milk production or components (Kononoff et al., 2003; Leonardi et al., 2005).

CONCLUSIONS

Feeding supplemental hay with diets containing either long or short particle size corn silage to cows challenged with SARA had minimal effects on DMI and rumen pH. It was determined that lactating cows preferred eating shorter particle size diets and the short diet with supplemental hay during the course of the

SARA challenge. Cows on these diets also produced more milk and milk fat. Cows consuming only short corn silage TMR were capable of changing feed preference for longer forage particles during the course of the SARA challenge. However, due to the preplanned high starch diet, cows may have adapted to the low rumen pH conditions, rendering the acidosis challenge less effective than previously reported. Results of this study indicate that lactating dairy cows with low ruminal pH due to high-starch diets can change forage particle size preference but respond in a minimal manner to being offered additional grass hay or longer forage particles. In addition, the data from this study show that using a TMR particle separator with a 4.0-mm sieve may be a better indicator of physical effectiveness.

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