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Replacing corn silage with different forage millet silage cultivars: Effects on milk yield, nutrient digestion, and ruminal fermentation of lactating dairy cows

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ABSTRACT

This study investigated the effects of dietary replacement of corn silage (CS) with 2 cultivars of forage millet silages [i.e., regular millet (RM) and sweet millet (SM)] on milk production, apparent total-tract digestibility, and ruminal fermentation characteristics of dairy cows. Fifteen lactating Holstein cows were used in a replicated 3 × 3 Latin square experiment and fed (ad libitum) a high-forage total mixed ration (68:32 forage:concentrate ratio). Dietary treatments included CS (control), RM, and SM diets. Experimental silages constituted 37% of each diet DM. Three ruminally fistulated cows were used to determine the effect of dietary treatments on ruminal fermentation and total-tract nutrient utilization. Relative to CS, RM and SM silages contained 36% more crude protein, 66% more neutral detergent fiber (NDF), and 88% more acid detergent fiber. Cows fed CS consumed more dry matter (DM; 24.4 vs. 22.7 kg/d) and starch (5.7 vs. 3.7 kg/d), but less NDF (7.9 vs. 8.7 kg/d) than cows fed RM or SM. However, DM, starch and NDF intakes were not different between forage millet silage types. Feeding RM relative to CS reduced milk yield (32.7 vs. 35.2 kg/d), energy-corrected milk (35.8 vs. 38.0 kg/d) and SCM (32.7 vs. 35.3 kg/d). However, cows fed SM had similar milk, energy-corrected milk, and solids-corrected milk yields than cows fed CS or RM. Milk efficiency was not affected by dietary treatments. Milk protein concentration was greatest for cows fed CS, intermediate for cows fed SM, and lowest for cows fed RM. Milk concentration of solids-not-fat was lesser, whereas milk urea nitrogen was greater for cows fed RM than for those fed CS. However, millet silage type had no effect on milk solids-not-fat and milk urea nitrogen levels. Concentrations of milk fat, lactose and total solids were not affected by silage type. Ruminal pH and ruminal NH_3-N were greater for cows fed RM and SM than for cows fed CS. Total-tract digestibility of DM (average = 67.9%), NDF (average = 53.9%), crude protein (average = 63.3%), and gross energy (average = 67.9%) were not influenced by dietary treatments. It was concluded that cows fed CS performed better than those fed RM or SM likely due to the higher starch and lower NDF intakes. However, no major differences were noted between the 2 forage millet silage cultivars.
Key words: corn silage, forage millet silage, dairy cow, milk yield

INTRODUCTION

Corn silage (**CS**) is a preferential and abundantly used forage in dairy cow nutrition, principally due to its high DM yield, single-cut harvest at optimum DM contents, high NE_L concentration, capacity to sustain high milk yields, and good ensiling characteristics. However, in many temperate regions of Canada, the production of CS is risky and low-yielding, despite the use of short-season cultivars. Indeed, the growing season with warm temperatures (above 15°C) is only between 70 and 90 d. Moreover, the high N fertilizer application rate that CS necessitates makes it uneconomical for cold regions. Alfalfa and perennial grasses are the most commonly used forages on such dairy farms. But, dairy producers are often challenged with on-farm forage shortages, especially during conditions of alfalfa winter kill. Therefore, we hypothesize that forage pearl millet may be used as an emergency forage or routinely as a new forage option by dairy producers located in temperate regions.

Pearl millet [*Pennisetum glaucum* (L.) R.] is an annual semi-arid tropical grass with high biomass yield and low N fertilizer requirement, and is drought resistant and adaptable to low soil pH (Maiti and Wesche-Ebeling, 1997). Because of its adaptability to harsh conditions, millet can be grown in areas unfavorable to other cereals, such as corn (Hanna, 1995). Data regarding the feeding value of pearl millet silage to lactating cows are limited. Moreover, from the few published studies that have investigated the nutritive values of pearl millet,

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findings are highly inconsistent. For example, pearl millet (harvested after 66 d of growth; 23% DM) silage fed to lactating cows in place of alfalfa silage plus CS had no effect on milk yield or milk fat concentration, but reduced DMI and milk protein levels (Messman et al., 1992). Kochapakdee et al. (2002) have shown reduced milk production and milk protein levels when cows were fed diets containing pearl millet silage (30% DM) compared with temperate CS. In contrast, feeding pearl millet (harvested at 80 d of growth; 27% DM) silage relative to CS had similar effects on feed intake, milk yield, and milk efficiency (Amer and Mustafa, 2010).

Pearl millet is mostly grown to grain in many African and Asian countries. However, unlike grain millet cultivars, forage pearl millet offer flexible harvest dates. Indeed, forage pearl millet may be harvested from vegetative (i.e., 24% DM) to more mature (32% DM) stages, thus making it extremely suitable for the cold regions. In this study, we were also interested in testing forage pearl millet cultivars containing high levels of water-soluble carbohydrates (**WSC**). High WSC is reported to improve ensilability of forages by accelerating lactic acid production (Adesogan et al., 2004). Therefore, the objectives of this study were to determine the effects of replacing CS with 2 different forage millet silage cultivars [i.e., regular millet (**RM**) and sweet millet (**SM**)] on milk yield, milk composition, apparent total-tract nutrient digestibility, and ruminal fermentation characteristics of lactating dairy cows.

MATERIALS AND METHODS

This study was conducted at the MacDonald Campus Farm of McGill University (Sainte-Anne-de-Bellevue, QC, Canada; 45°N, 73°W). All animal procedures were conducted under approval of the Animal Care Committee of the Faculty of Agriculture and Environmental Sciences of McGill University.

Silage Preparation

Two forage pearl millet hybrids, namely RM and SM, were seeded on June 1, 2012, and harvested on July 24, 2012, at the vegetative stage and approximately 1.65 m high. Millet seeds were provided by Bélisle Solution Nutrition Inc. (Saint-Mathias-sur-Richelieu, QC, Canada). Prior to millet seeding, 100 kg of urea N/ha (46% N) was evenly applied to each field. Millet (70% moisture) was chopped into at least 12-mm particle size using a New Holland forage harvester (model 900; New Holland, New Holland, PA) and ensiled under high pressure into 45-m-long horizontal Ag-Bag silos (2.1-m diameter and approximately 50 t each; Ag-Bag, Miller-St. Nazianz Inc., St. Nazianz, WI) for approximately 2 mo. The initial WSC content of fresh RM and SM were 74 ± 7.46 and 80 ± 0.77, g/kg, respectively. The compositions of experimental silages are given in Table 1.

Animals, Experimental Design, and Diets

Fifteen multiparous Holstein cows in early to mid lactation [milk yield: 39.9 ± 5.60 kg; DIM: 75.2 ± 54.51 d; BW: 660.2 ± 77.41 kg (average ± SD)] were used in a replicated 3 × 3 Latin square experiment with 21-d periods (14 d of diet adaptation and 7 d of data collection). Cows were housed in individual tie-stalls and had free access to water. Five cows were allotted to each treatment and blocked into 5 groups of 3 by parity, milk yield, and DIM.

Three high forage isonitrogenous diets (68:32 forage:concentrate ratio) were formulated to meet nutrient requirements of lactating dairy cows in early lactation (NRC, 2001; Table 2). Experimental treatments were the replacement of CS with RM or SM silages. In all diets, the silage portion consisted of 70% CS, RM, or SM, and the remaining 30% consisted of alfalfa silage. For the objectives of this study, the proportions of experimental silages were kept constant in all dietary treatments (Table 2). Diets were offered as a TMR once daily in the morning (0800 h) for ad libitum intake. Orts were measured daily to determine daily feed intake per cow. Total mixed rations and silages were sampled daily during the data-collection periods (d 15–21 of each period) and composited by period.

In Situ Ruminal Nutrient Degradabilities of Experimental Silages

One representative sample each of CS, RM, and SM silages was obtained by mixing 200 g of the dried (65°C for 48 h) silages from each of the 3 periods. A 5-g subsample of each mixture was then placed into nylon bags (20 × 10 cm, 50-μL pore size; Ankom Technology Corp., Macedon, NY) and incubated in the rumens of 3 lactating cows (1 bag per treatment per time period per cow) fed a single type of ration and fitted with rumen cannulas for 0, 3, 6, 12, 24, 48, 72, and 96 h. At the end of each incubation time, bags were removed from the rumens and manually washed under cold tap water until the water was clear. The 0-h incubation was determined by washing the bags containing the samples. The washed bags were then dried in a forced-air oven at 65°C for 48 h. In situ residues were analyzed for DM and NDF (Van Soest et al., 1991). Data of ruminal DM and NDF disappearances were used to determine nutrient kinetic parameters by using the equation of Dhanoa (1988):

Table 1. Fermentation characteristics and chemical composition (mean ± SD) of millet and corn silages (DM basis)

	Experimental silage[1]		
Item	CS	RM	SM
Chemical composition, % of DM unless otherwise stated			
DM, %	34.7 ± 1.37	26.1 ± 1.71	25.3 ± 0.75
Ash	3.6 ± 0.25	12.1 ± 0.65	11.7 ± 0.26
NDF	35.6 ± 2.29	58.4 ± 1.62	60.1 ± 1.74
ADF	20.0 ± 1.57	37.6 ± 0.39	37.8 ± 0.90
ADL	1.8 ± 0.25	2.5 ± 0.15	2.6 ± 0.17
CP	9.6 ± 0.30	12.8 ± 0.34	13.4 ± 0.87
Soluble protein, % of CP	44.1 ± 4.66	61.5 ± 2.08	58.4 ± 2.72
NPN, % of CP	41.5 ± 4.30	58.6 ± 2.03	56.8 ± 3.15
Neutral detergent-insoluble CP, % of CP	16.8 ± 0.39	23.1 ± 1.76	22.8 ± 1.76
Acid detergent-insoluble CP, % of CP	10.9 ± 0.10	9.0 ± 0.56	8.5 ± 0.72
Starch	29.7 ± 1.09	0.5 ± 0.52	0.2 ± 0.07
Ether extract	2.2 ± 0.25	2.0 ± 0.05	2.0 ± 0.10
NE_L,[2] Mcal/kg	2.06 ± 0.025	1.65 ± 0.006	1.64 ± 0.021
Fermentation characteristics			
pH	3.95 ± 0.06	4.47 ± 0.08	4.56 ± 0.11
Water-soluble carbohydrates, %	2.9 ± 0.33	1.3 ± 0.36	2.4 ± 0.34
Lactic acid, %	6.9 ± 0.17	5.8 ± 0.17	4.6 ± 0.20
Acetic acid, %	1.3 ± 0.16	0.8 ± 0.20	1.7 ± 0.03
Aerobic stability, h	151 ± 15.2	32 ± 8.1	125 ± 30.4

[1]CS = corn silage; RM = regular millet silage; SM = high water-soluble carbohydrates (sweet) millet silage.
[2]Estimated according to Weiss et al. (1992).

Table 2. Ingredients and chemical composition (mean ± SD) of experimental diets

	Dietary treatment[1]		
Item	CS	RM	SM
Ingredient, %			
Pearl millet silage		36.98	
Pearl millet silage			36.58
Corn silage	38.58		
Alfalfa silage	30.39	30.11	30.01
High-moisture corn	19.67	23.01	23.53
Soybean meal	9.8	6.35	6.33
Mineral premix[2]	1.56	1.54	1.54
Megalac[3]		2.01	2.01
Chemical composition, % of DM			
DM, %	47.2 ± 0.83	40.3 ± 1.18	41.8 ± 2.35
Ash	5.9 ± 0.45	9.2 ± 0.26	8.4 ± 0.55
Ether extract	2.5 ± 0.30	3.0 ± 0.16	3.1 ± 0.38
NDF	32.4 ± 1.70	38.5 ± 2.99	37.9 ± 0.41
ADF	19.4 ± 1.97	24.1 ± 1.73	22.8 ± 0.59
ADL	2.9 ± 0.53	2.7 ± 0.55	3.0 ± 0.35
CP	15.2 ± 0.41	15.5 ± 0.36	15.9 ± 0.33
Neutral detergent-insoluble CP, % of CP	14.9 ± 1.66	13.6 ± 1.83	16.1 ± 0.86
Acid detergent-insoluble CP, % of CP	8.1 ± 0.08	7.9 ± 0.72	8.1 ± 0.45
Starch	23.5 ± 2.27	16.4 ± 2.41	16.1 ± 0.95
NDF:starch	1.4 ± 0.20	2.4 ± 0.52	2.3 ± 0.11
NE_L,[4] Mcal/kg	1.87 ± 0.055	1.75 ± 0.049	1.78 ± 0.023
RUP	22.8 ± 2.37	24.8 ± 2.19	27.7 ± 0.78

[1]Experimental diet (68:32 forage:concentrate ratio; DM basis) contained corn silage (CS), regular millet silage (RM), or high water-soluble carbohydrates (sweet) millet silage (SM).
[2]Contained 38.84% sodium bicarbonate, 25.07% dicalcium phosphate, 15.10% NaCl, 5.35% Mg, 4.57% K, 1.56% Ca, 2.04% Na, 0.63% Zn, 0.54% Mn, 0.22% Cu, 0.02% Co, 0.01% I, 0.01% sodium selenite, 1.38% mineral oil, 3.63% canola meal, 2,200 kIU of vitamin E/kg, 2,900 kIU of vitamin A/kg, and 1,450 kIU of vitamin D/kg.
[3]Manufactured by Church & Dwight Co. Inc. (Princeton, NJ). Analysis: 84% fat, 12.5% ash, and 9% Ca.
[4]Estimated according to Weiss et al. (1992).

$$p = a + b\ (1 - e^{-c(t - Lt)}),$$

where p represents the nutrient disappearance at time t, a is the soluble fraction (%), b is the potentially degradable fraction (%), c is the rate of degradation of the b fraction (%/h), and Lt is the lag phase (h). The parameters were estimated by PROC NLIN of SAS (SAS Institute, 2008) using iterative least squares regression (Gauss-Newton method). Effective degradabilities (**ED**) of DM and NDF were calculated according to the equation of Ørskov and McDonald (1979):

$$ED = a + bc/(c + k),$$

where k represents the ruminal outflow rate (6.25%/h), and a, b, and c are as described previously.

Milk Production and Analysis

Cows were milked twice daily at 0500 and 1700 h. Milk yields were recorded at each milking by cow. Milk samples were collected twice daily on 2 consecutive days of each data-collection period, composited by cow according to volume, and analyzed for fat, protein, lactose, and MUN using an infrared analyzer (Valacta, Sainte-Anne-de-Bellevue, QC, Canada) according to the Association of Official Analytical Chemists (AOAC, 1990). Milk TS content was determined according to AOAC (1990).

Ruminal Fermentation and Apparent Total-Tract Nutrient Digestibility

Three multiparous lactating Holstein cows [milk yield: 37.8 ± 7.5 kg; DIM: 52.0 ± 25.51 d; BW: 671.5 ± 37.75 kg (average ± SD)] fitted with rumen cannulas were used in a 3 × 3 Latin square experiment to determine the effects of dietary treatments on ruminal fermentation and total-tract nutrient digestibility. Cows were kept in tie-stalls with free access to water. The cows were fed the same experimental diets and followed the same experimental protocol as in the production study.

Rumen fluid samples were collected from different areas in the rumen with a syringe screwed to a stainless steel tube ending by a fine metal mesh (RT Rumen Fluid Collection Tube; Bar Diamond Inc., Parma, ID). The collection began before the morning feeding (0 h) and 2, 4, 6, 8, 10, and 12 h postfeeding on d 16 and 17 of each period. Ruminal pH was determined immediately using an Accumet pH meter (Fisher Scientific, Montreal, QC, Canada). Thereafter, two 50-mL samples were immediately preserved by adding 5 mL of 25% metaphosphoric acid and 5 mL of 0.1 *N* HCl for measurements of VFA and NH_3-N, respectively. Samples were kept at −20°C for later analysis.

Chromic oxide was used as an inert external marker to determine total fecal output. Gelatin capsules containing 10 g of Cr_2O_3 were inserted into the rumen of each cow twice daily in equal intervals starting on d 10 of the adaptation period. Grabbed fecal samples were collected 4 times daily on d 15, 17, and d 21 of each period. Samples were then dried at 60°C in a forced-air oven for 72 h and pooled by cow within each period.

Chemical Analysis

Thawed samples of fresh and ensiled forages were homogenized with 500 mL of distilled water and the pH of the extract was immediately determined using an Accumet pH meter (Fisher Scientific). Extracts were centrifuged at 12,000 × *g* for 15 min at 4°C and analyzed for organic acids (lactic, acetic, propionic, and butyric acid) by using HPLC (Andersson and Hedlund, 1983). The conditions for the HPLC analysis were 0.013 *M* H_2SO_4 as mobile phase and a flow rate of 0.6 mL/min. Silage concentrations of WSC were determined colorimetrically within aliquots of filtered extracts using the phenolic-sulfuric acid reaction (DuBois et al., 1956).

Subsamples of silages and TMR were dried in a forced-air oven at 65°C for 72 h, subsequently ground through a 1-mm screen using a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA), and then analyzed for DM, ash, and ether extract following standard procedures (AOAC, 1990). Crude protein (N × 6.25) was analyzed using a Leco Nitrogen Analyzer (TruSpec Nitrogen Determinator System; Leco Corp., St. Joseph, MI). Nonprotein N and soluble CP were determined for silages samples according to Licitra et al. (1996). Neutral detergent fiber (Van Soest et al., 1991) and ADF (AOAC, 1990) were determined using an Ankom Fiber Analyzer (Ankom Technology Corp., Macedon, NY). Analysis of NDF was performed using heat-stable α-amylase and without the use of sodium sulfite. Acid detergent lignin of TMR and silage samples was determined according to AOAC (1990). Neutral and acid detergent-insoluble protein concentrations were estimated by analyzing NDF and ADF residues, respectively, for total N (Licitra et al., 1996). Starch was analyzed colorimetrically according to McCleary et al. (1997). Gross energy (**GE**) of feed samples was determined using an oxygen bomb calorimeter (model 6200; Parr Instrument Co., Moline, IL).

Samples of experimental silages for the 3 periods were agitated to ensure air exposure and individually packaged loosely into 500-mL plastic containers. Thermal insulator was wrapped around the sides of each

container to prevent heat dissipation and 4 holes were made on the top and bottom of each container to permit air exchange. Thermocouple probes were inserted in the core of each plastic container to detect temperature difference from the environment. Aerobic stability was defined as the time required to increase the temperature by 2°C (Kung et al., 2000). The temperature, measured using a HotMux data logger (DDC Corp., Pennsauken, NJ), was recorded every 5 min.

Dried fecal samples were analyzed for DM, NDF, and GE as previously described. Chromic oxide content was determined according to the procedure of Fenton and Fenton (1979).

Ruminal fluid samples were centrifuged at 12,000 × *g* for 15 min at 4°C and analyzed for acetic, propionic, and butyric acids using HPLC, as described previously. Ruminal NH_3-N was determined colorimetrically with a multichannel Lachat Autoanalyzer (Lachat Instruments, Milwaukee, WI).

Statistical Analysis

Data of the performance study and total-tract nutrient utilization were analyzed as a replicated 3 × 3 Latin square design using PROC MIXED of SAS (SAS Institute, 2008) and the following model:

$$Y_{ijkh} = \mu + trt_i + block_j + animal_{jk} + per_h + e_{ijkh},$$

where Y_{ijkh} represents the observation, μ is the population mean, trt_i is the fixed effect of the ith treatment (i = 1, 2, or 3), $block_j$ is the fixed effect of the jth block (j = 1, 2, 3, 4, or 5), $animal_{jk}$ is the random effect of the kth animal (k = 1, 2, or 3) in the jth block, per_h is the fixed effect of the hth period (h = 1, 2, or 3), and e_{ijkh} is the random error. In situ ruminal degradability data for experimental silages were analyzed using an ANOVA and a completely randomized design with treatment as main effect and cows as replicates.

Ruminal fermentation parameters data were analyzed as repeated measures in time using PROC MIXED (SAS Institute, 2008) and the following model:

$$Y_{ijkh} = \mu + trt_i + animal_{ij} + per_k + time_h + trt_i \times time_h + e_{ijkh},$$

where Y_{ijkh} represents the observation, μ is the population mean, trt_i is the fixed effect of the ith treatment (i = 1, 2, or 3), $animal_{ij}$ is the random effect of the jth cow (j = 1, 2, or 3) on the ith treatment, per_k is the fixed effect of the kth period (k = 1, 2, or 3), $time_h$ is the fixed effect of the hth time (h = 1, 2, 3, 4, 5, 6, or 7); $trt_i \times time_h$ is the interaction effect between treatment and time, and e_{ijkh} is the residual error $\left[e_{ijkhl} \sim N\left(0, \sigma^2_{cow}\right)\right]$. Significant differences were declared at $P < 0.05$.

RESULTS

Chemical Composition of Millet Silages and Experimental Diets

Relative to CS, forage millet cultivars contained 66% more NDF, 88% more ADF, and 36% more CP (Table 1). Starch was higher (approximately 85 times) in CS than RM and SM silages likely due to the grain content (30%) of CS. Corn silage also contained higher (+0.42 Mcal/kg) NE_L than millet silages. However, ether extract was similar among all silage types. None of the abovementioned analyzed parameters were different between the 2 forage millet silages. However, SM contained 1.8 times higher WSC and was aerobically more stable than RM. In addition, both WSC concentrations and aerobic stability were comparable between CS and SM. Lactic and acetic acids were the main fermentation acids in all silage types, whereas butyric acid was generally undetectable (data not shown). However, a tendency existed for acetic acid concentration to be the highest in SM, whereas CS tended to contain high lactic acid levels. Both millet silages stabilized at a higher pH than CS (Table 1). However, no heat damage or putrid odors were noticed from millet silages.

In Situ Ruminal Nutrient Degradability of Experimental Silages

In contrast to forage millet silages, CS had greater ($P < 0.05$) in situ effective DM degradability but lower ($P < 0.05$) effective NDF degradability (Table 3). The in situ soluble DM fraction was greater ($P < 0.05$), whereas the in situ slowly degradable DM fraction was lower ($P < 0.05$) for CS than for forage millet silages. However, CS, RM and SM had similar ruminal degradable rates for DM, soluble NDF fraction, and slowly degradable NDF fraction. Moreover, effective degradability as well as degradability of both soluble and slowly degradable fractions for DM and NDF were not influenced by forage millet cultivars.

Animal Performance

Dry matter, NDF, starch, and NE_L intakes were not affected by the 2 millet diets (Table 4). However, cows fed RM or SM consumed more ($P < 0.05$) NDF, but less ($P < 0.05$) DM, starch, and NE_L than CS-fed cows. However, CP intakes were similar across dietary treatments.

Table 3. In situ ruminal degradability of millet and corn silages

	Experimental silage[1]				
Item	CS	RM	SM	SEM[2]	*P*-value[3]
DM					
Soluble fraction, %	57.0[a]	33.3[b]	34.7[b]	0.85	<0.0001
Slowly degradable fraction, %	23.4[b]	49.4[a]	45.6[a]	2.09	0.0002
Degradation rate, %/h	3.5	4.4	4.5	0.38	0.21
Lag time, h	1.1	0.8	1.9	0.38	0.19
Effective degradability, %	65.3[a]	53.7[b]	53.8[b]	1.22	0.0008
NDF					
Soluble fraction, %	2.6	3.1	5.8	1.17	0.20
Slowly degradable fraction, %	69.5	70.7	66.4	4.22	0.74
Degradation rate, %/h	1.9[b]	4.5[a]	4.0[a]	0.38	0.014
Lag time, h	1.2	0.4	1.6	0.50	0.26
Effective degradability, %	18.9[b]	32.5[a]	31.7[a]	2.16	0.015

[a,b]Values with different superscripts within the same row are different ($P < 0.05$).
[1]CS = corn silage; RM = regular millet silage; SM = high water-soluble carbohydrates (sweet) millet silage.
[2]Pooled SEM.
[3]*P*-value for treatment effects.

Milk, lactose, TS, SNF, ECM, and SCM yields were similar between cows fed CS and SM, but lower ($P < 0.05$) among cows fed RM than CS (Table 4). Milk protein yields were highest ($P < 0.05$) for cows fed CS, intermediate ($P < 0.05$) for cows fed SM, and lowest ($P < 0.05$) with RM. However, milk efficiency, and yields

Table 4. Performance of lactating dairy cows fed millet or corn silage diets

	Dietary treatment[1]				
Item	CS	RM	SM	SEM[2]	*P*-value[3]
Intake					
DM, kg/d	24.4[a]	22.7[b]	22.8[b]	0.63	0.0047
DM, % of BW	3.75[a]	3.49[b]	3.50[b]	0.130	0.0052
NDF, kg/d	7.9[b]	8.8[a]	8.6[a]	0.24	0.0012
NDF, % of BW	1.21[b]	1.35[a]	1.33[a]	0.050	0.0016
CP, kg/d	3.7	3.5	3.6	0.09	0.061
CP, % of BW	0.57	0.54	0.56	0.020	0.089
Starch, kg/d	5.7[a]	3.7[b]	3.7[b]	0.22	<0.0001
NE_L, Mcal/d	45.5[a]	39.7[b]	40.6[b]	1.35	<0.0001
Yield, kg/d					
Milk	35.2[a]	32.7[b]	34.0[ab]	1.57	0.016
Fat	1.44	1.37	1.43	0.071	0.34
Protein	1.15[a]	0.99[c]	1.06[b]	0.038	<0.0001
Lactose	1.59[a]	1.48[b]	1.54[ab]	0.075	0.037
TS	4.53[a]	4.15[b]	4.38[ab]	0.170	0.0046
SNF	3.10[a]	2.78[b]	2.94[ab]	0.116	0.0017
ECM	38.0[a]	35.2[b]	37.0[ab]	1.52	0.018
SCM	35.3[a]	32.7[b]	34.4[ab]	1.38	0.014
4% FCM	35.6	33.7	35.1	1.54	0.10
Milk efficiency[4]	1.46	1.46	1.51	0.070	0.34
Composition, %					
Fat	4.09	4.25	4.27	0.185	0.37
Protein	3.30[a]	3.04[c]	3.14[b]	0.092	<0.0001
Lactose	4.50	4.53	4.52	0.043	0.66
TS	12.93	12.76	12.95	0.273	0.50
SNF	8.84[a]	8.51[b]	8.69[ab]	0.142	0.035
MUN, mg/dL	8.6[b]	10.1[a]	10.8[a]	0.88	0.0001

[a–c]Values with different superscripts within the same row are different ($P < 0.05$). [1]Experimental diet (68:32 forage:concentrate ratio; DM basis) contained corn silage (CS), regular millet silage (RM), or high water-soluble carbohydrates (sweet) millet silage (SM).
[2]Pooled SEM.
[3]*P*-value for treatment effects.
[4]Milk yield/DMI.

Table 5. Total-tract nutrient digestibility and ruminal fermentation of lactating dairy cows fed millet or corn silages in the diet

	Dietary treatment[1]				
Item	CS	RM	SM	SEM[2]	*P*-value[3]
Total-tract digestibility, %					
DM	70.43	66.02	67.34	1.822	0.50
OM	71.72	68.78	69.86	1.748	0.65
CP	65.68	61.48	62.75	2.128	0.58
NDF	52.69	53.06	55.85	3.687	0.82
GE[4]	68.40	66.68	68.67	2.456	0.83
Starch	91.27	90.39	89.44	1.924	0.83
Ruminal fermentation					
pH	5.77[b]	6.04[a]	6.12[a]	0.063	<0.0001
NH_3-N, mg/dL	9.9[b]	15.0[a]	14.6[a]	1.09	0.0007
VFA, m*M*	134.9[a]	133.1[ab]	128.7[b]	4.88	0.011
Molar proportion, %					
Acetate	56.4[b]	65.6[a]	63.9[a]	1.49	0.0002
Propionate	30.1[a]	22.9[b]	24.9[ab]	1.21	0.031
Butyrate	13.5	11.5	11.2	1.09	0.21
Acetate:propionate	1.98[b]	3.01[a]	2.74[a]	0.160	0.0002

[a,b]Values with different superscripts within the same row are different ($P < 0.05$). [1]Experimental diet (68:32 forage:concentrate ratio; DM basis) contained corn silage (CS), regular millet silage (RM), or high water-soluble carbohydrates (sweet) millet silage (SM).

[2]Pooled SEM.

[3]*P*-value for treatment effects.

[4]Gross energy.

of fat and 4% FCM were not affected by dietary treatments. With the exception of milk protein yields, none of the milk yields were different between RM and SM.

Protein concentration was highest in the milk of cows fed CS, intermediate for cows fed SM, and lowest for cows fed RM ($P < 0.05$; Table 4). However, milk fat, lactose and TS levels were similar across experimental diets. Cows fed CS produced milk with greater ($P < 0.05$) SNF than RM; however, similar milk SNF levels were recorded between CS- and SM-fed cows. Cows fed CS produced milk with lower ($P < 0.05$) MUN levels than for those fed RM and SM.

Ruminal Fermentation and Total Apparent Nutrient Digestibility

No treatments × time interactions were significant for any of the ruminal fermentations (Table 5). Therefore, only main treatment effects were reported. Ruminal pH and NH_3-N concentrations were greater ($P < 0.05$) for cows fed RM or SM relative to cows fed CS. Total VFA levels were lower ($P < 0.05$) for SM-fed cows than for CS-fed cows. However, total VFA was not different between cows fed CS and RM or SM and RM. Feeding forage millet diets relative to CS increased ($P < 0.05$) molar proportions of acetate, whereas the molar proportion of propionate was greater ($P < 0.05$) for cows fed CS than for cows fed RM. Consequently, the acetate:propionate ratio was increased ($P < 0.05$) as a result of feeding forage millet diets relative to CS. Ruminal butyrate levels were not affected by dietary treatments. Apparent total-tract digestibility of DM, CP, NDF, GE, and starch were not influenced by silage type and averaged 67.93, 63.30, 53.87, 67.92, and 90.37%, respectively (Table 5).

DISCUSSION

This study investigated the effects of replacing CS with a regular or high-WSC forage millet silage in the diets of lactating dairy cows on milk production, rumen fermentation characteristics, and total-tract nutrient digestibility. Corn silage contained approximately 30% grains (Chase, 2012). In contrast, unlike grain millet cultivars, the 2 forage millet cultivars were harvested at the vegetative stage and before seed setting. If experimental diets were to be balanced for starch, the RM and SM rations would have necessitated additional grains (i.e., high-moisture corn). However, to better reflect dairy production in the more temperate regions whereby CS and corn grains are extremely limited, we deliberately formulated diets with replacement of equal proportions of CS with RM or SM. The CS diet contained 85 times more starch than the RM or SM diet (Table 2). Calcium salts of palm oil (Megalac; Church & Dwight Co. Inc., Princeton, NJ) were added to the RM and SM diets to balance for NE_L across dietary treatments.

In this study, forage millet silages contained 66% more NDF, 88% more ADF, and 36% more CP compared with CS (Table 2). However, the nutritive values of both forage millet cultivars were equivalent. The greater residual WSC concentration of SM relative to RM is likely due to the lower utilization of WSC by lactic acid bacteria. The greater concentration of acetic acid may explain the higher aerobic stability of CS and SM relative to RM. Increases in acetic acid concentration in silages treated with *Lactobacillus buchneri* improved aerobic stability in barley silages (Kung et al., 2000). Values of NDF and CP of millet silages were in agreement with Messman et al. (1992) and Ward et al. (2001). In contrast to our previous study with high WSC millet (Amer and Mustafa, 2010), SM had comparable CP and ADF levels but lower (11%) NDF level. The lower NDF contents of SM may be attributed to differences in maturity stages (vegetative vs. heading) at which millet was harvested and ensiled. Advancement in maturity of grass forages is usually associated with reduced CP, and increased NDF and ADF contents (Rinne et al., 1997; Cone et al., 1999; Holtshausen et al., 2012). However, this was not evidenced when comparing the findings of our study with those of Amer and Mustafa (2010).

Forage millet had a higher effective in situ degradability of NDF than CS (Table 3). Our findings were somewhat expected, given the fact that advanced maturity of forages is negatively correlated with fiber (NDF and ADF) digestibility (Rinne et al., 2002; Holtshausen et al., 2012). Whereas CS is normally harvested at mature stages, forage millet was harvested earlier at the vegetative stage. The higher CP contents and greater quantities of more effectively degradable fiber of forage millet make it an interesting silage in dairy cow diets. In contrast, the higher DM degradability of CS than RM and SM as observed in the current study were mainly due to its higher WSC contents and, in particular, starch. Starch of corn grains is a rapidly fermentable carbohydrate in the cow rumen. In agreement with our findings, Amer and Mustafa (2010) reported higher in vitro DM but lower in vitro NDF disappearance for CS than forage millet silage. However, RM and SM had similar nutritive values and in situ degradability of DM and NDF, given that these were harvested at same maturity (vegetative) stage.

Total-tract digestibility of DM, CP, and NDF were not affected by dietary treatments (Table 5). However, in the production study (Table 4), dairy cows fed forage millet diets consumed greater NDF than those fed CS, likely because RM and SM were ruminally more degradable than CS or due to the higher NDF contents of millet diets. Similar findings have previously been reported. For instance, Amer and Mustafa (2010) reported that dairy cows fed millet silage consumed more NDF (1.35 vs. 1.18% of BW) than when fed a CS diet. Ward et al. (2001) observed that heifers fed pearl millet silage consumed more NDF than those fed sorghum or tropical CS. On the other hand, cows fed CS consumed higher DM as a result of its higher starch intake (Table 4). However, DMI was not influenced by forage millet silages. Previous studies indicated that cows fed pearl millet consumed greater (Ward et al., 2001), similar (Amer and Mustafa, 2010), or less (Messman et al., 1992; Kochapakdee et al., 2002) DM than cows fed CS. Inconsistent findings between studies may be related to factors such as the forage:concentrate ratio, maturity stage at which millet was harvested, and diet composition.

Our findings indicated that milk yield was greater among cows fed CS than RM, but not compromised when cows were fed the SM diet (Table 4). The lower milk production recorded among RM-fed cows relative to CS-fed cows is most likely due to their lower DM (starch) and NE_L intakes. Kochapakdee et al. (2002) also reported a 12% reduction in milk yield as a result of feeding cows pearl millet silage compared with CS. However, despite the lower DM and NE_L intakes among cows fed SM compared with CS, their similarity in milk yield is difficult to explain at this time. In agreement with our findings, unaffected milk yields between cows fed high-WSC pearl millet silage and CS have previously been reported (Amer and Mustafa, 2010).

Higher milk yield and milk protein levels, but lower milk fat concentrations are typically observed among dairy cows fed high-starch diets (Table 4). The lower carbohydrate intake (i.e., lower supply of gluconeogenic precursors, such as propionate) and lower intakes of MP (soybean meal) may explain the reduction in milk protein concentration due to feeding forage millet silages (Broderick, 2003; Jenkins and McGuire, 2006). Our explanation about lower MP intake or amino acid supply is consistent with the increases in ruminal NH_3-N concentrations (Table 5). Reductions in milk protein levels among cows fed pearl millet silage compared with CS were also observed by Messman et al. (1992) and Kochapakdee et al. (2002).

In the present study, we observed a reduction in ruminal NH_3-N for cows fed CS relative to those fed millet silages. Our findings are in agreement with Brito and Broderick (2006) and Hassanat et al. (2013), who also reported a decrease in ruminal NH_3-N concentration with increasing proportions of CS in the diets, and associated this effect with reduced urinary N losses. In fact, when NH_3-N level in the rumen exceeds microbial uptake, excess NH_3-N is absorbed through the rumen, transferred to the liver, metabolized into urea, and excreted in urine (Van Soest, 1994). However, NH_3-N

utilization in the rumen is mainly affected by carbohydrate availability (Russell et al., 1992). According to Hristov et al. (2005), higher intakes of fermentable carbohydrates may reduce NH_3-N synthesis in the rumen (by reducing the deamination of AA or enhancing microbial capture of released AA) or increase NH_3-N utilization by the rumen microbes.

Feeding cows forage millet silages compared with CS caused substantial changes in the ruminal environment (Table 5). The higher starch contents (23.5 vs. 16.3% of DM) of the CS diet led to an acidic ruminal environment (average pH of 5.77 vs. 6.08) and shifted the VFA pattern toward proportionally more propionate at the expense of acetate (Bradford et al., 2006). In the current study, cows fed the CS diet consumed 45% more starch than RM- or SM-fed cows. Ruminal fermentation of starch produces more propionate than fermentation of other carbohydrates such as glucose, fructose, and sucrose (Heldt et al., 1999). In agreement with our findings, Messman et al. (1992) reported greater molar proportions of acetate and acetate:propionate ratio, but lower propionate proportions when cows were fed a combination of pearl millet and alfalfa silages than for cows fed a combination of corn and alfalfa silages. Reports indicate that low ruminal pH favors lower acetate:propionate ratio (Lana et al., 1998). In general, a higher acetate:propionate ratio is an indicator of lipogenic versus glycogenic VFA production (Messman et al., 1992). The significantly lower acetate proportion in the rumen of cows fed the CS diet may be associated with lower in situ ruminal NDF degradation. Fibrolytic activity in the rumen may be impaired when feeding cows diets rich in fermentable carbohydrates. At low rumen pH (6.0 to 5.8), growth or activity of cellulolytic bacteria is compromised and, hence, so is fiber digestibility (Russell et al., 1992).

CONCLUSIONS

Under the condition of a high forage:concentrate diet, feeding cows forage millet silages in replacement of CS reduced DMI, milk yield (RM only), and milk protein concentration, likely because of higher NDF and lower starch contents. Nevertheless, cows fed pearl millet diets consumed more NDF because pearl millet silages were ruminally more degradable than CS. Forage millet diets necessitated less (<55%) soybean meal, given that forage millet silages contained 36% higher CP than CS. The effects of forage millet cultivars had minimal influence on the performance of dairy cows due to similarity in chemical compositions, in situ degradability, nutrient digestibility, and rumen fermentation. Finally, based on findings of this study, forage millet silages may be an alternative to CS, especially in the more temperate regions.

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