Effects of replacing grass silage with forage pearl millet silage 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 grass silage (GS) with forage millet silages that were harvested at 2 stages of maturity [i.e., vegetative stage and dough to ripe seed (mature) stage] 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 total mixed ration (60:40 forage:concentrate ratio). Dietary treatments included control (GS), vegetative millet silage (EM), and mature millet silage (MM) diets. Experimental silages comprised 24% of dietary dry matter (DM). Soybean meal and slow-release urea were added in millet diets to balance for crude protein (CP). Three additional ruminally fistulated cows were used to determine the effect of treatments on ruminal fermentation and total-tract nutrient utilization. Cows fed the GS diet consumed more DM (22.9 vs. 21.7 ± 1.02 kg/d) and CP (3.3 vs. 3.1 ± 0.19 kg/d), and similar starch (4.9 ± 0.39 kg/d) and neutral detergent fiber (NDF; 8.0 ± 0.27 kg/d) compared with cows fed the MM diet. Replacing the EM diet with the MM diet did not affect DM, NDF, or CP intakes. Cows fed the MM diet produced less milk (26.1 vs. 29.1 ± 0.79 kg/d), energy-corrected milk (28.0 vs. 30.5 ± 0.92 kg/d), and 4% fat-corrected milk (26.5 vs. 28.3 ± 0.92 kg/d) yields than cows fed the GS diet. However, cows fed diets with EM and GS produced similar yields of milk, energy-corrected milk, and 4% fat-corrected milk. Feed efficiency (milk yield:DM intake) was greater only for cows fed the GS diet than those fed the MM diet. Milk protein yield and concentration were greater among cows fed the GS diet compared with those fed the EM or MM diets. Milk fat and lactose concentrations were not influenced by diet. However, milk urea N was lower for cows fed the GS diet than for those fed the MM diet. Ruminal NH₃-N

was greater for cows fed the EM diet than for those fed the GS diet. Total-tract-digestibility of DM (average = 66.1 ± 3.3%), NDF (average = 55.1 ± 2.4%), CP (average = 63.6 ± 4.2%), and gross energy (average = 64.5 ± 2.6%) were not influenced by experimental diets. We concluded that cows fed GS and EM diets had comparable performance, whereas milk yield was significantly reduced with the MM diet, likely because reduced intakes of DM and net energy for lactation.

Key words: dairy cow, forage millet silage, grass silage, milk yield

INTRODUCTION

High-quality forages are essential to maximize milk production on dairy farms. However, in Canada's temperate regions, forage production is somewhat limited because of the extremely cold winters. Indeed, in these cold regions, the growing season with warm temperatures (above 15°C) is between 70 and 90 d only. Perennial forages such as alfalfa and grasses [i.e., tall fescue (*Festuca arundinacea* Schreb.), orchard grass (*Dactylis glomerata* L.), and brome grass (*Bromus inermis* L.)] are cultivated as mix stands to optimize yield and nutritive values of harvested forages. However, the recurrence of alfalfa winterkill frequently causes low yields and on-farm forage shortages, and the quality of grasses is often reduced due to delayed harvesting at advanced maturity stages during intermittent periods of drought or rain. In our previous study, we showed that, relative to corn silage, cows fed a high water-soluble carbohydrate (WSC) forage pearl millet silage had higher NDF intake, similar milk and milk fat yields, and similar feed efficiency (milk yield:DMI) but lower DMI and milk protein yield (Brunette et al., 2014). However, comparisons of forage millet silages with perennial grass silages are lacking.

Pearl millet [*Pennisetum glaucum* (L.) R.] is a tropical annual grass possessing the C4 photosynthetic pathway with high biomass yield, low N fertilizer requirement, drought resistance, and adaptable to low soil pH. Moreover, it has the capacity to grow rapidly in ideal climatic conditions (Maiti and Wesche-Ebeling, 1997).

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Pearl millet offers flexible harvest dates, an important factor influencing yield and nutritive values of most forages. In general, the nutritive values and digestibility of forages decline rapidly with advancement in maturity (Elizalde et al., 1999). However, millet harvested at d 96 had lower or similar NDF content compared with millet harvested at d 56 (Hassanat et al., 2006; LeBlanc et al., 2012), whereas in vitro digestibility of NDF was reduced by only 8% (Hassanat et al., 2006).

The majority of published studies have compared millet silages with corn silages. Data regarding the performance of lactating dairy cows fed pearl millet silage is limited. Messman et al. (1992) reported no effect on milk yield or milk fat concentration but lower DMI and milk protein levels when lactating cows were fed pearl millet silage (harvested after 66 d of growth; 23% DM) in replacement of alfalfa silage plus corn silage. Moreover, feed intake, milk yield, and feed efficiency were similar when lactating cows were fed pearl millet (harvested at 80 d of growth; 27% DM) silage in replacement of corn silage (Amer and Mustafa, 2010). However, milk production and milk protein levels were lower when cows were fed diets containing pearl millet silage (30% DM) compared with temperate corn silage (Kochapakdee et al., 2002).

Unlike other Gramineae forages, the WSC content of sweet millet increases with advancing maturity (LeBlanc et al., 2012). High WSC is highly desirable because it improves the ensilability of forages by accelerating lactic acid production (Adesogan et al., 2004), and it increases the efficiency of ruminal microbial protein (Merry et al., 2006) and N utilization (Miller et al., 2001). Therefore, the objectives of this study were to evaluate the effects of replacing grass silage as a forage constituent in a TMR with high WSC forage millet silages that were harvested at 2 different stages of maturity—early boot stage (vegetative or early millet; **EM**) and dough to ripe seed stage (mature millet; **MM**)—on milk yield, milk composition, apparent total-tract nutrient digestibility, and ruminal fermentation characteristics of lactating dairy cows.

MATERIALS AND METHODS

Forage Material and Ensiling

Forage pearl millet was seeded on May 31, 2013, in a sandy loam soil at the MacDonald Campus Farm of McGill University (Ste Anne de Bellevue, Quebec, Canada; 45°N, 73°W). Millet seeds were provided by Bélisle Solution Nutrition Inc. (Saint-Mathias-sur-Richelieu, QC, Canada). A presowing supply of 100 kg of urea N/ha (46% N) was applied evenly to the fields. Millet fields were harvested at 2 intervals in 2013: on August

5 (65 d), at early boot stage (EM) approximately 1.83 m high, and on September 17 (108 d), at dough to ripe seed stage (MM) approximately 3.66 m high. Early and mature millets were chopped to a theoretical length of 12 mm using, respectively, a New Holland forage harvester (model 900; New Holland, PA) and a John Deere self-propelled forage harvester with camper head (harvester model series 7380, corn header model series SPFH 770, John Deere, Moline, IL). Harvested millets were ensiled under high pressure into horizontal Ag-Bag silos (2.1 m in diameter; AgBag, Miller-St. Nazianz Inc., St. Nazianz, WI) for approximately 8 mo for EM and 6 mo for MM.

In this study, the first cut (at early boot stage) of a 4-yr-old alfalfa-grass field containing >90% of a mixture of grasses [tall fescue (*Festuca arundinacea* Schreb.), orchard grass (*Dactylis glomerata* L.), and brome grass (*Bromus inermis* L.)] was used as control silage (grass silage, **GS**). Grass silage was stored for 8 mo. The initial WSC content of the parental crops (fresh forages) of GS, EM, and MM ($n = 3$ samples) were 60 ± 6.67 , 149.7 ± 8.02 , and 138.5 ± 13.23 g/kg, respectively. The DM contents for fresh GS, EM, and MM were $27.7\% \pm 0.43$, $21.6\% \pm 1.64$, and $31.5\% \pm 0.65$, respectively. Chemical composition and fermentation characteristics of experimental silages are shown in Table 1.

Experimental Design and Cows

All animal procedures were approved by the Animal Care Committee of the Faculty of Agriculture and Environmental Sciences of McGill University. Fifteen primiparous lactating Holstein cows (BW: 620 ± 79.9 kg) in early to mid lactation (DIM: 134 ± 64.1 d) producing 30.7 ± 6.0 kg/d (average $\pm$ SD) of milk before the trial 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). Fifteen cows were blocked into 5 groups of 3 by parity, milk yield, and DIM, and treatments were distributed within each block. Cows were housed in tiestalls and provided with free access to water.

Milk Production and Milk Compositions

Cows were milked twice daily at 0500 and 1700 h, and milk yields were recorded by cow. Milk samples were collected on d 16 and 17 of each data collection period at both milkings and combined by cow according to volume. Milk samples were analyzed for fat, protein, lactose, and MUN using an infrared analyzer (Valacta, Sainte-Anne-de-Bellevue, Canada) according to AOAC (1990; method no. 972.16). Milk TS were determined according to AOAC (1990; method no. 925.23).

Dietary Treatments and Sample Collection

Three high-forage isonitrogenous diets (60:40 forage:concentrate ratio) were formulated to meet nutrient requirements of lactating dairy cows in early lactation (NRC, 2001; Table 2). Dietary treatments were the replacement of GS with EM or MM silage. For all diets, the total forage portion consisted of 41% experimental silage (GS, EM, or MM), 34% corn silage, and 21% dry hay. Diets were offered as a TMR once daily in the morning (1000 h) for periods 1 and 2, and twice daily for period 3 (0900 h and 0200 h) to prevent spoilage of the diets. Experimental diets were provided for ad libitum intake (5% orts, on an as-fed basis).

During data collection (d 15–21 of each period), feed offered and orts were measured daily to determine daily feed intake per cow, and TMR and silages were sampled daily and pooled by period.

In Vitro and In Situ DM and NDF Disappearances of Experimental Silages

One representative sample (pooled daily collections) of experimental silages from each period ($n = 3$) was dried separately in a forced-air oven at 65°C for 48 h

and subsequently ground through a 1-mm screen using a Wiley mill (A. H. Thomas, Philadelphia, PA). Then, 0.25 g of each sample was placed into acetone prerinsed F57 filter bags (Ankom Technology Corp., Macedon, NY) and incubated with rumen fluid from a lactating cow for 48 h at 39°C in a DaisyII fermenter (Ankom Technology, Fairport, NY) to determine in vitro DM disappearances. In vitro NDF disappearances were determined by analyzing for NDF residue in samples before and after the 48-h incubation with rumen fluid.

Equal portions (200 g) of dried and ground (2-mm particle size using a Wiley mill) replicates of GS, EM, and MM silages from each period were composited to obtain one sample for each experimental silage. A 5-g subsample of each silage sample was then placed into nylon bags (0.025 g/cm², 50- μ m pore size, Ankom Technology Corp.) and incubated in the rumen of 3 multiparous lactating cows (one bag per treatment per time period per cow) fed a single type of ration and fitted with rumen fistulas for 0, 3, 6, 12, 24, 48, 72, and 96 h. Following each incubation time, bags were removed from the rumen and manually washed under cold tap water until the rinsing water was clear. Bags used for time-zero disappearance and containing the samples were washed together with the other bags. The washed

Table 1. Fermentation characteristics and chemical composition of grass and millet silages ($n = 3$, DM basis)

Item	Experimental silage ¹					
	GS		EM		MM	
	Mean	SD	Mean	SD	Mean	SD
Chemical composition, % of DM unless otherwise stated						
DM	30.1	1.08	22.0	0.87	27.0	0.19
Ash	8.2	0.15	8.9	0.42	5.2	0.23
NDF	47.2	1.04	63.3	2.79	63.4	1.05
ADF	29.7	0.21	39.1	1.26	39.6	0.56
ADL	2.3	0.24	2.9	0.05	4.3	0.18
CP	17.7	0.24	10.4	0.58	6.2	0.59
Soluble protein, % of CP	66.0	2.26	70.8	2.59	76.4	3.26
Neutral detergent insoluble CP, % of CP	11.3	0.88	11.7	1.04	10.6	0.37
Acid detergent insoluble CP, % of CP	3.5	0.56	4.0	0.60	4.8	0.38
Starch	0.2	0.09	0.5	0.04	2.7	0.21
Ether extract	4.7	0.19	2.7	0.06	1.7	0.19
NE _L , ² Mcal/kg	1.62	0.01	1.39	0.03	1.38	0.01
In vitro DM disappearance (48 h), % of DM	84.7	0.84	76.7	1.95	70.0	1.01
In vitro true DM disappearance (48 h), % of DM	87.1	0.73	79.3	1.81	72.4	1.11
In vitro NDF disappearance (48 h), % of DM	72.7	1.56	67.3	2.33	56.6	1.68
Fermentation characteristics						
pH	4.01	0.04	4.43	0.15	3.72	0.18
Water-soluble carbohydrates, %	3.0	0.06	1.6	0.29	3.9	0.74
Lactic acid, %	8.0	0.05	4.3	3.24	8.5	0.07
Acetic acid, %	1.7	0.05	5.4	3.14	1.4	0.05
Butyric acid, %	0.3	0.00	0.3	0.11	0.1	0.04

¹GS = mixed grass silage; EM = high water-soluble carbohydrate (WSC) millet silage harvested at 65 d (early millet); MM = high WSC millet silage harvested at 108 d (mature millet).

²Estimated according to NRC (2001).

Table 2. Ingredients and chemical composition (% of DM unless otherwise stated) of experimental diets (n = 3)

Item	Dietary treatment ¹					
	GS		EM		MM	
	Mean	SD	Mean	SD	Mean	SD
Ingredients						
Pearl millet silage			24.3		24.4	
Grass silage	24.5					
Corn silage	20.6		20.6		20.6	
Dry hay	14.5		14.5		14.5	
High-moisture corn	24.4		24.6		24.4	
Soybean meal	8.56		10.41		12.64	
Soybean hulls	4.89		2.26			
Mineral premix ²	1.70		1.70		1.70	
Megalac ³	0.81		1.42		1.21	
Slow release urea ⁴			0.53		0.61	
Chemical composition						
DM	45.7	1.69	40.1	1.46	42.5	1.72
Ash	6.7	0.71	6.9	0.61	5.9	0.65
Ether extract	3.4	0.12	3.2	0.16	2.7	0.22
NDF	35.2	2.07	39.6	3.29	37.7	3.84
ADF	22.1	1.42	24.3	0.59	23.5	3.49
ADL	2.2	0.26	2.4	0.16	2.7	0.10
CP	14.5	0.75	14.4	0.65	14.1	0.64
Soluble CP, % of CP	38.0	1.34	39.2	2.31	38.8	0.93
Neutral detergent insoluble CP, % of CP	12.2	0.64	12.2	0.71	11.4	0.79
Acid detergent insoluble CP, % of CP	3.8	0.39	3.7	0.55	3.6	0.39
Starch	21.4	0.82	20.6	2.59	22.8	3.05
NDF:Starch	1.6	0.11	2.0	0.40	1.7	0.40
Digestible energy, ⁵ Mcal/kg	3.0	0.16	2.7	0.30	2.7	0.07
NE _L , ⁶ Mcal/kg	1.69	0.03	1.64	0.031	1.65	0.03
In vitro DM disappearance (48 h)	86.2	2.31	82.0	1.49	81.7	2.49
In vitro true DM disappearance (48 h)	89.2	1.65	85.5	0.74	85.4	1.85
In vitro NDF disappearance (48 h), % of NDF	69.5	3.94	63.1	3.30	60.8	6.85

¹GS = grass silage-based diet, EM = early (65 d) millet silage-based diet, MM = mature (108 d) millet silage-based diet.

²Contained 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.

³Manufactured by Church & Dwight Co. Inc. (Princeton, NJ).

⁴Maxiflex; manufactured by Bélisle Solution Nutrition Inc. (Saint-Mathias-sur-Richelieu, Québec, Canada).

⁵Calculated as gross energy (GE) × GE digestibility.

⁶Estimated according to NRC (2001).

bags were then dried in a forced-air oven at 65°C for 48h. Data of ruminal DM and NDF disappearances were used to determine nutrient kinetic parameters by using the equation of Dhanoa (1988):

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

where p represents the nutrient disappearance at time t; a = particle loss (soluble fraction) (%); b = potentially degradable fraction (%); c = rate of degradation of the b fraction (%/h); and Lt = lag phase (h). The parameters were estimated by PROC NLIN of SAS (SAS Institute, 2010) using iterative least squares regression (Gauss-Newton method). Lag time was not included for NDF disappearance. 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.

Ruminal Measurements and Apparent Total-Tract Nutrient Digestibility

Three multiparous lactating Holstein cows [milk yield of 38.2 ± 9.19 kg/d; DIM of 64.0 ± 96.44 d; BW of 701.8 ± 51.31 kg (average ± SD)] fitted with rumen fistulas 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 tiestalls and had 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 parts (anterior dorsal, anterior ventral, medium ventral, posterior dorsal, and posterior ventral locations) of the rumen on d 17 and 18 of each period using a syringe screwed to a stainless steel tube ending with a fine metal mesh (RT Rumen Fluid Collection Tube, Bar Diamond Inc., Parma, ID). Rumen fluid collections started before the morning feeding (0 h) and were further sampled at 2, 4, 6, 8, 10, and 12 h postfeeding. Ruminal pH was determined using an Accumet pH meter (Fisher Scientific, Montreal, QC, Canada). After pH determination, two 50-mL samples were immediately preserved by adding 5 mL of 25% metaphosphoric acid for VFA analysis, and 5 mL of 0.1 N HCl for $\text{NH}_3\text{-N}$ analysis. Samples were stored 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 placed into the rumen of each cow twice daily in equal intervals starting on d 12 of the adaptation period. Fecal grab samples were collected 4 times daily on d 17, 18, and d 19 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.

Samples Preparation and Chemical Analysis

Fifty-gram thawed representative samples of ensiled forages (pooled daily collections) from each period ($n = 3$) were homogenized with 1,000 mL of distilled water and thoroughly ground in a blender (Oster blender, model 6811-33, Oster/Sunbeam, Boca Raton, FL) for 1 min, thereafter the pH of the extract was immediately determined using an Accumet pH meter (Fisher Scientific). Extracts were centrifuged at $12,000 \times g$ for 15 min at 4°C and analyzed for organic acids (lactic, acetic, propionic, and butyric acids) by using HPLC (Andersson and Hedlund, 1983). The conditions for HPLC analysis were mobile phase: 0.013 M H_2SO_4 and flow rate: 0.6 mL/min. Silage extracts were analyzed for $\text{NH}_3\text{-N}$ colorimetrically with a multichannel Lachat Autoanalyzer (Lachat Instruments, Milwaukee, WI). Extracts of feed samples were obtained and centrifuged as described above. The WSC concentrations of fresh forages and silages were determined colorimetrically within aliquots of filtered extracts using the phenolic-sulfuric acid reaction (DuBois et al., 1956).

Composited TMR and silage samples ($n = 3$) were dried (not corrected for loss of volatile materials) in a forced-air oven at 65°C for 72h, then ground through a 1-mm screen using a Wiley mill (A. H. Thomas), and analyzed for DM and ash according to AOAC (1990)

procedures. Crude protein ($\text{N} \times 6.25$) was analyzed using a Leco Nitrogen Analyzer (Truspec Nitrogen Determinator System, Leco Corp., St. Joseph, MI). Soluble CP was determined according to Licitra et al. (1996). Neutral (Van Soest et al., 1991) and acid (AOAC, 1990) detergent fiber were determined using an Ankom Fiber Analyzer (Ankom Technology Corp.). In vitro and NDF residues were also analyzed for NDF. The NDF analysis was performed using heat-stable α -amylase and without the inclusion of sodium sulfite. Acid detergent lignin and ether extract of TMR and silage samples were analyzed following standard procedures (AOAC, 1990). Neutral and acid detergent insoluble protein were estimated by analyzing NDF and ADF residues, respectively, for total N (Licitra et al., 1996). Starch was analyzed colorimetrically as described by McCleary et al. (1997). Gross energy (GE) of feed samples was determined using an oxygen bomb calorimeter (model 6200; Parr Instrument Co., Moline, IL).

Dried fecal samples were analyzed for DM, ash, CP, NDF, and GE as previously described. Chromic oxide content was analyzed following the Fenton and Fenton (1979) procedure. Frozen rumen fluid samples were thawed, centrifuged at $12,000 \times g$ for 15 min at 4°C and then analyzed for acetic, propionic, and butyric acids using HPLC, as described previously. Ruminal $\text{NH}_3\text{-N}$ was determined as detailed previously.

Statistical Analysis

Data of the performance study were analyzed as a replicated 3×3 Latin square design using PROC MIXED of SAS (SAS Institute, 2010) and the following model:

$$Y_{ijkh} = \mu + \text{trt}_i + \text{block}_j + \text{cow}_{jk} + \text{per}_h + e_{ijkh},$$

where Y_{ijkh} represents the observation, μ is the population mean, trt_i is the fixed effect of the i th treatment ($i = 1, 2, \text{ or } 3$), block_j is fixed effect of the j th block ($j = 1, 2, 3, 4, \text{ or } 5$), cow_{jk} is the random effect of the k th cow ($k = 1, 2, \text{ or } 3$) within the j th block, per_h is the fixed effect of the h th period ($h = 1, 2, \text{ or } 3$), and e_{ijkh} is the random error. Data for total-tract nutrient utilization were analyzed using the same statistical model as in the performance study but without the fixed effect of block. 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 characteristics data were analyzed as repeated measures in time using PROC MIXED of SAS (SAS Institute, 2010) and the following model:

$$Y_{ijkh} = \mu + \text{trt}_i + \text{cow}_{ij} + \text{per}_k + \text{time}_h \\ + \text{trt}_i \times \text{time}_h + e_{ijkh},$$

where Y_{ijkh} represents the observation, μ is the population mean, trt_i is the fixed effect of the i th treatment ($i = 1, 2$, or 3), cow_{ij} is the random effect of the j th cow ($j = 1, 2$, or 3) on the i th treatment, per_k is the fixed effect of the k th period ($k = 1, 2$, or 3), time_h is the fixed effect of the h th time ($h = 1, 2, 3, 4, 5, 6$, or 7), $\text{trt}_i \times \text{time}_h$ is the interaction effect between treatment and time, and e_{ijkh} is the residual error [$e_{ijkh} \sim N(0, \sigma^2_{\text{cow}})$].

RESULTS

Composition of Silages and Experimental Diets

To obtain high-quality grass silages, a mixture of grasses (>90% field populations of tall fescue, orchard grass and brome grass) was harvested and ensiled at the early boot or immature stage. In contrast, forage sweet millet offered flexible harvest dates. Therefore, we targeted harvesting EM and MM at the vegetative and heading stages, respectively. However, due to unfavorable rainy weather conditions, millet silages were harvested at early boot stage (EM; 65 d, 22% DM) and dough to ripe seed stage (MM; 108 d, 27% DM) for EM and MM, respectively.

On a DM basis, MM contained higher starch and ADL but lower ash than GS and EM silages (Table 1). However, CP contents of both EM and MM were lower than GS. Ether extracts were also higher in GS than in EM and MM. Relative to GS, forage millet silages contained 34% more NDF and 32% more ADF but lower NE_L . Despite differences in maturity, NDF and ADF contents did not differ between EM and MM. In vitro DM and NDF disappearances were highest for GS, intermediate for EM, and lowest for MM. The WSC concentrations of MM were 2.4 times higher than those of EM but comparable to those of GS. Lactic and acetic acids were the main fermentation acids in all silage types. However, EM contained higher concentrations of acetic acid, whereas GS and MM had higher lactic acid levels. Both GS and EM stabilized at a higher pH than did MM.

Experimental diets were formulated to contain a high forage-to-concentrate ratio (60:40) and equal proportions of CP, NDF, and NE_L (Table 2). Forages were added in equal proportions in all experimental diets. Relative to GS, EM and MM silages contained 41% and 65% less CP (Table 1). Therefore, to balance for CP and soluble CP across treatments, soybean meal and slow-release urea (Maxiflex; Bélisle Solution Nutrition Inc., Saint-Mathias-sur-Richelieu, QC, Canada) were

added in greater quantities to the EM and MM diets (Table 2). Calcium salts of palm oil (Megalac; Church & Dwight Co. Inc., Princeton, NJ) were added in all diets to balance for NE_L whereas soybean hulls were added into GS and EM rations to balance for fiber. Nevertheless, in contrast to EM and MM, the GS diet contained higher NE_L and digestible energy, and lower NDF and ADL.

In Situ DM and NDF Degradability of Experimental Silages

In situ degradability of the soluble DM fraction was greater ($P < 0.01$) for GS than for forage millet silages (Table 3). However, the slowly degradable DM fraction ($P = 0.64$) and rate of DM degradation ($P = 0.28$) were similar across silage types. Relative to forage millet silages, GS had greater ($P < 0.01$) in situ effective DM degradability. However, effective DM degradability was similar between EM and MM. On the other hand, GS, EM, and MM had similar ruminal degradability for soluble NDF fraction ($P = 0.15$), slowly degradable NDF fraction ($P = 0.05$), and rate of NDF degradation ($P = 0.12$). However, in situ effective NDF degradability was greater ($P = 0.01$) for GS and EM than for MM (Table 3).

Feed Intake, Milk Production, and Composition

Dry matter intake was similar for cows fed GS and EM diets (Table 4). However, cows fed the GS diet consumed more ($P = 0.01$) DM than cows fed the MM diet. However, NDF intake was not influenced ($P = 0.10$) by treatment. Intakes of CP ($P = 0.01$) and NE_L ($P < 0.01$) were greater for cows fed GS than for cows fed millet silages. However, stage of maturity for millet silages had no effect on DM, CP, and NE_L intakes.

Milk, lactose, TS, SNF, ECM, SCM, and 4% FCM yields were greater ($P < 0.01$) for cows fed GS than for those fed MM but were similar for cows fed EM (Table 4). Cows fed EM produced lower ($P < 0.01$) milk, protein, lactose, ECM, and 4% FCM yields than cows fed the MM diet. Milk protein yield was highest ($P < 0.01$) for cows fed GS, intermediate ($P < 0.01$) for cows fed EM, and lowest ($P < 0.01$) for cows fed MM. However, milk fat yield was not influenced ($P = 0.18$) by dietary treatment. Feed efficiency was similar between GS and EM but lower ($P = 0.01$) with MM.

Milk fat percentages tended ($P = 0.08$) to be higher for cows fed millet silages than for cows fed GS. However, milk protein concentration was higher ($P < 0.01$) for cows fed GS than for those fed EM or MM. Milk lactose ($P = 0.97$), TS ($P = 0.54$), and SNF ($P = 0.48$) concentrations were not influenced by treatment. Milk

Table 3. In situ ruminal degradability of grass and millet silages in lactating dairy cows fed a single diet

Item	Experimental silage ¹			SEM ²	P-value ³
	GS	EM	MM		
DM					
Soluble fraction, %	45.3 ^a	40.6 ^b	39.6 ^b	0.64	<0.01
Slowly degradable fraction, %	36.9	35.9	32.1	3.63	0.64
Degradable rate, %/h	2.2	1.6	1.3	0.37	0.28
Lag time, h	4.5	3.8	2.8	0.60	0.21
Effective degradability, %	54.7 ^a	47.7 ^b	44.2 ^b	0.95	<0.01
NDF					
Soluble fraction, %	7.8	7.3	4.1	1.24	0.15
Slowly degradable fraction, %	74.2	70.8	59.0	3.55	0.05
Degradable rate, %/h	2.8	2.5	1.7	0.34	0.12
Effective degradability, %	30.7 ^a	27.2 ^a	16.7 ^b	2.30	0.01

^{a,b}Values with different superscripts within a row are different ($P < 0.05$).

¹GS = mixed grass silage; EM = high water-soluble carbohydrate (WSC) millet silage harvested at 65 d (early millet); MM = high WSC millet silage harvested at 108 d (mature millet).

²Pooled SEM.

³P-value for treatment effects.

urea nitrogen was greater ($P = 0.01$) for cows fed MM than those fed GS. However, MUN levels were not different between cows fed GS and EM or between cows fed EM and MM.

Nutrient Digestibility and Ruminal Fermentation

Apparent total-tract digestibility of DM ($P = 0.22$), OM ($P = 0.16$), CP ($P = 0.41$), NDF ($P = 0.08$), and

Table 4. Performance of lactating dairy cows fed grass and millet silage treatments

Item	Dietary treatment ¹			SEM ²	P-value ³
	GS	EM	MM		
Intake					
DM, kg/d	22.9 ^a	22.1 ^{ab}	21.7 ^b	1.02	0.01
NDF, kg/d	8.06	8.43	8.02	0.27	0.10
CP, kg/d	3.27 ^a	3.10 ^b	3.10 ^b	0.19	0.01
Starch, kg/d	4.85 ^a	4.55 ^b	4.86 ^a	0.39	<0.01
NE _L , Mcal/d	38.5 ^a	35.9 ^b	35.3 ^b	1.92	<0.01
Yield, kg/d					
Milk	29.1 ^a	28.4 ^a	26.1 ^b	0.79	<0.01
Fat	1.1	1.1	1.1	0.04	0.18
Protein	1.0 ^a	0.9 ^b	0.8 ^c	0.03	<0.01
Lactose	1.3 ^a	1.3 ^a	1.2 ^b	0.04	<0.01
TS	3.9 ^a	3.7 ^{ab}	3.5 ^b	0.11	<0.01
SNF	2.8 ^a	2.6 ^{ab}	2.4 ^b	0.10	0.01
ECM	30.5 ^a	30.0 ^a	28.0 ^b	0.92	<0.01
SCM	29.6 ^a	28.9 ^{ab}	27.1 ^b	0.83	0.01
4% FCM	28.3 ^a	28.3 ^a	26.5 ^b	0.92	<0.01
Feed efficiency ⁴	1.30 ^a	1.33 ^{ab}	1.23 ^b	0.06	0.01
Composition, %					
Fat	3.85	4.02	4.13	0.11	0.08
Protein	3.32 ^a	3.17 ^b	3.20 ^b	0.07	<0.01
Lactose	4.63	4.65	4.65	0.06	0.97
TS	13.35	13.21	13.50	0.26	0.54
SNF	9.50	9.19	9.38	0.28	0.48
MUN, mg/dL	10.43 ^b	11.43 ^{ab}	12.33 ^a	1.08	0.01

^{a-c}Values with different superscripts within the same row are different ($P < 0.05$).

¹Experimental diets (60:40 forage:concentrate ratio; DM basis) contained a mixture of grass silage (GS), vegetative stage of high water-soluble carbohydrate (WSC) millet silage (EM; 65 d), or mature stage of high WSC millet silage (MM; 108 d).

²Pooled SEM.

³P-value for treatment effects.

⁴Milk yield:DMI.

Table 5. Total-tract nutrient digestibility and ruminal fermentation of lactating dairy cows fed grass or millet silage diet

Item	Dietary treatment ¹			SEM ²	<i>P</i> -value ³
	GS	EM	MM		
Digestibility, %					
DM	69.1	66.1	63.1	3.34	0.22
OM	71.6	70.3	66.2	2.25	0.16
CP	65.3	65.2	60.4	4.15	0.41
NDF	58.1	59.4	47.6	2.40	0.08
Gross energy	68.1	62.3	63.1	2.64	0.41
Fermentation					
pH	6.14	6.12	6.29	0.12	0.27
NH ₃ -N, mg/dL	10.3 ^b	13.7 ^a	11.8 ^{ab}	0.59	<0.01
VFA, mM	114.1	122.1	113.2	4.69	0.34
Molar proportion, %					
Acetate	63.6	66.6	64.7	2.07	0.42
Propionate	24.2	23.7	22.1	1.71	0.42
Butyrate	12.3 ^a	9.73 ^b	13.2 ^a	0.61	<0.01
Acetate:propionate	2.77	2.83	2.93	0.26	0.80

^{a,b}Values with different superscripts within the same row are different ($P < 0.05$).

¹Experimental diets (60:40 forage:concentrate ratio; DM basis) contained a mixture of grass silage (GS), vegetative stage of high water-soluble carbohydrate (WSC) millet silage (EM; 65 d), or mature stage of high WSC millet silage (MM; 108 d).

²Pooled SEM.

³*P*-value for treatment effects.

GE ($P = 0.41$) were not affected by silage type or maturity stage (Table 5). No time $\times$ treatment interactions were observed for ruminal fermentation; therefore, only main effects are reported (Table 5). Ruminal pH ($P = 0.27$) and total VFA levels ($P = 0.34$) were not affected by treatments. Ruminal NH₃-N concentration was greater ($P < 0.01$) for cows fed EM than for cows fed GS but were not different between cows fed GS and MM or between cows fed GS and EM. Feeding GS or MM compared with EM increased ($P < 0.01$) molar proportions of butyrate. However, molar proportions of acetate ($P = 0.42$) and propionate ($P = 0.42$) were not affected by treatment.

DISCUSSION

Relative to GS, both millet silages had a lower DM content. Ward et al. (2001) reported low DM (i.e., <28%) for millet and sorghum silages; the authors suggested that silages with <28% DM are susceptible to clostridial fermentation and high butyrate concentration. Silages with concentrations of butyric acid >0.5% (DM basis) may be considered as clostridial silages (Kung and Shaver, 2001). Therefore, in agreement with Ward et al. (2001), the lower butyrate concentrations in grass and millet silages in the current study suggest that clostridial fermentation of experimental silages did not occur. Furthermore, the low pH and high lactic acid concentration suggest that the forage millet silages were well preserved. Our results for organic acids and pH for

EM and MM silages were similar to those reported by Messman et al. (1992), Ward et al. (2001), and Amer and Mustafa (2010) for well-preserved millet silages.

In general, advancing maturity of grasses is usually associated with reduced CP and higher concentrations of NDF and ADF (Rinne et al., 1997; Cone et al., 1999; Holtshausen et al., 2012). However, despite advancements in maturity, the NDF and ADF contents were not different between EM and MM. However, maturity significantly increased ADL and reduced CP contents of millet silages. In agreement with our findings, Hassanat et al. (2006) reported similar NDF and ADF concentrations, higher ADL, but lower CP when millet silages were harvested at the vegetative and heading stage. Our CP, NDF, and ADF data for EM and MM were in good agreement with millet silages harvested at the flowering (65 d) and dough stage (102 d), respectively (Morales et al., 2011). In contrast to our previous study with high WSC millet (vegetative stage, 53 d; Brunette et al., 2014), EM (early boot stage, 65 d) and MM (dough to ripe seed stage, 108 d) had lower CP levels but higher NDF, ADF, and ADL levels. These differences may be explained by differences in the maturity stages at which millet was harvested and ensiled. However, MM silage contained more WSC (3.9 vs. 1.6%) and starch (2.7 vs. 0.5%) than EM. Our results were expected given that WSC deposition in millet stems increases with maturity (LeBlanc et al., 2012), whereas the higher starch was due to presence of millet seeds in MM. However, the process of grain setting and maturation occurred at the

expense of WSC in fresh corn plants (Filya, 2004). This may explain the higher WSC content of pre-ensiled EM (149.7 ± 8.02 g/kg on fresh basis) relative to MM (138.5 ± 13.23 g/kg on fresh basis). Nevertheless, the forage millet cultivar used in this study is expected to contain fewer seeds (less starch) than typical grain millet cultivars. The greater residual WSC concentration of MM and GS relative to EM is likely due to the lower utilization of WSC by lactic acid bacteria. On the other hand, the higher concentration of acetic acid in EM relative to other silages suggested that prolonged heterolactic fermentation of WSC (i.e., further conversion of lactic acid into acetic acid) may have occurred during ensiling. The higher *in vitro* disappearances and *in situ* degradability of DM for GS than millet silages may be explained by its higher CP (a constituent of DM) contents. Likewise, corn silage that contained lower NDF and ADF but higher starch content also had higher *in situ* DM degradability than regular and high WSC millet silages (Amer and Mustafa, 2010; Brunette et al., 2014). However, *in situ* effective degradability of NDF was similar between GS and EM. The similarity in NDF degradability occurred despite the fact that EM contained higher NDF (63.3 vs. 47.2%), ADF (39.1 vs. 29.7%), and ADL (2.9 vs. 2.3%) contents than GS. The lower NDF degradability of MM than EM is attributable to its higher ADL concentration (4.3 vs. 2.9%) as a result of advanced maturity. We previously showed higher *in situ* NDF degradability of millet silages than corn silage (Brunette et al., 2014).

Cows fed GS consumed more DM than did cows fed MM, which was mostly in the form of CP and NE_L . Higher DM intake of the GS diet can be attributed to the higher effective rumen DM degradability of GS silage. Despite the higher NDF digestibility of GS and EM than MM silage, NDF intake was not different across treatments, probably because of the addition of soybean hulls to the GS and EM diets to balance for fiber. However, NDF degradability of experimental silages may also explain DMI differences. Forages with greater NDF digestibility may allow for greater DMI because of faster disappearance from the rumen. Indeed, rumen degradability of NDF was higher in GS than in MM. In agreement with our results, Oba and Allen (1999) reported that diets with improved *in vitro* or *in situ* NDF digestibility showed greater DMI and performance of lactating dairy cows. However, although rumen NDF degradability was higher for millet silages than for corn silages, cows fed corn silage did consume higher DMI as a result of higher starch intake (Brunette et al., 2014).

Under the conditions of this study, milk yield was greater for cows fed GS than for those fed MM, likely due to higher intakes of DM and NE_L . A reduction in

milk yield among cows fed regular millet silage compared with corn silage has previously been associated with lower DM (starch) and NE_L intakes (Brunette et al., 2014). Cows fed EM also consumed less NE_L . However, milk yields were similar between GS- and EM-fed cows. In our previous study, cows fed high WSC millet silage had lower DM and NE_L intakes but milk yields were not different when compared with corn silage (Brunette et al., 2014). On the other hand, despite equivalent DM and NE_L intakes, the lower milk yield obtained in MM-fed cows compared with EM-fed cows is difficult to explain at this time. Data regarding the performance of cows fed millet silages are inconsistent. Whereas Kochapakdee et al. (2002) reported a 12% reduction in milk yield as a result of feeding pearl millet silage compared with corn silage, Amer and Mustafa (2010) observed no difference in milk yield between cows fed high-WSC pearl millet silage and those fed corn silage.

The reductions in milk protein yields and milk protein concentrations among cows fed the millet diets relative to those fed GS may be explained by lower NE_L and CP (i.e., MP from soybean meal) intakes (Broderick, 2003; Jenkins and McGuire, 2006; Brunette et al., 2014). Lower milk protein levels when feeding cows with pearl millet silage compared with corn silage have been reported previously (Messman et al., 1992; Kochapakdee et al., 2002). In contrast, milk protein yield and milk protein concentration were not different between cows fed high WSC millet and corn silage (Amer and Mustafa, 2010). Our findings indicate significantly lower ruminal NH_3 -N concentration among cows fed GS compared with those fed EM but only numerically lower compared with cows fed the MM diet. The higher ruminal NH_3 -N concentration of millet-fed cows might be explained by differences in diet formulations, and more specifically due to addition of slow-release urea (source of NPN) to the diets. Moreover, NH_3 -N utilization in the rumen is mainly affected by carbohydrate availability (Russell et al., 1992). In agreement with Hristov et al. (2005), we believe that higher intakes of fermentable carbohydrates (starch) by cows fed the GS and MM diets might have reduced NH_3 -N synthesis in the rumen (by reducing the deamination of AA or enhancing microbial capture of released AA) or increased NH_3 -N utilization by rumen microbes. Moreover, a reduction in ruminal NH_3 -N concentration due to higher starch intake or increased proportions of corn silage in the diets has previously been associated with reduced urinary N losses (Brito and Broderick, 2006; Hassanat et al., 2013). We previously observed a reduction in ruminal NH_3 -N for cows fed corn silage (higher starch) relative to those fed millet silages (Brunette et al., 2014).

In the current study, feeding cows GS or millet silages had no significant effect on ruminal pH, VFA concentrations, molar proportions of acetate and propionate, or acetate:propionate ratio. Our findings occurred despite higher starch intakes by cows fed the GS and MM diets. Higher starch intakes are usually associated with a more acidic ruminal environment and a VFA pattern shifted toward proportionally more propionate at the expense of acetate (Bradford et al., 2006; Brunette et al., 2014). According to Heldt et al. (1999), ruminal fermentation of starch produces more propionate than fermentation of other carbohydrates such as glucose, fructose, and sucrose. Data investigating the effects of millet silages with grass silages on ruminal fermentation are lacking. When millet silages were compared with corn silage (higher starch intake), molar proportions of acetate and acetate:propionate ratio were significantly increased at the expense of propionate proportions (Messman et al., 1992; Brunette et al., 2014).

Taken together, EM and GS were comparable given that cows had similar DM and NDF intakes, and produced equivalent milk yields. All of these effects occurred despite the lower CP and NE_L intakes of EM-fed cows. Findings of lower milk yield with MM compared with GS and EM indicate clearly that MM was harvested at a too-extreme maturity stage. Indeed, MM suffered from lodging in the field, millet kernels were filled with seeds, and lignin content was considerably increased (+48%), which consequently reduced NDF digestibility. The high WSC contents of sweet millet make it suitable as forage for cows. Unfortunately, unfavorable weather conditions delayed the harvesting of millet. Nevertheless, we believe that forage millet may be used as an emergency forage or routinely as a new forage option by dairy producers. On the majority of dairy farms, grasses are seeded together with legume forages (i.e., alfalfa). However, if grasses were to be seeded as pure stands, yields would have been too low in the first year of cultivation to sustain on-farm forage needs. Unlike grasses (pure stands), forage pearl millet (annual Gramineae) is high yielding and offers flexible harvest dates from the vegetative (i.e., 24% DM) to more mature (i.e., 32% DM) stages, thus making it suitable for the cold regions.

CONCLUSIONS

We found no differences in performance between EM and GS diets but detected lower milk yields among MM-fed cows. However, both millet diets required supplementation with CP sources (i.e., soybean meal and slow-release urea) to meet daily CP requirements for lactating cows. In contrast to GS, cows fed MM consumed less dietary DM and NE_L , probably due to

higher lignin contents of the MM silage. Advanced maturity of millet (MM vs. EM) did not affect NDF and ADF levels but increased lignin and reduced CP contents of millet silages. Milk CP yield and milk CP concentrations were higher for cows fed GS than for those fed the millet silages because of higher dietary CP intakes. Forage millet silages may be an alternative to GS, especially in more temperate regions. However, millet diets should adequately be balanced to meet the cow's CP requirements, and forage millet should be harvested before seed setting to improve dairy cow performance.

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