J. Dairy Sci. 97:7012–7020
http://dx.doi.org/10.3168/jds.2013-7856

Exchanging physically effective neutral detergent fiber does not affect chewing activity and performance of late-lactation dairy cows fed corn and sugarcane silages

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ABSTRACT

The objective of this study was to determine whether replacing the physically effective neutral detergent fiber (peNDF) of corn silage with sugarcane silage peNDF would affect performance in dairy cows. Twenty-four late-lactation Holstein cows were assigned to eight 3 × 3 Latin squares with 21-d periods. The dietary treatments were (1) 25% peNDF of corn silage, (2) 25% peNDF of sugarcane silage, and (3) 12.5% peNDF of corn silage + 12.5% peNDF of sugarcane silage. The physical effectiveness factors (pef) were assumed to be 1 for corn silage and 1.2 for sugarcane silage, as measured previously by bioassay. Thus, peNDF was calculated as neutral detergent fiber (NDF) × pef. The concentrate ingredients were finely ground corn, soybean meal, pelleted citrus pulp, and mineral-vitamin premix. Dry matter intake (22.5 ± 0.63 kg/d), 3.5% fat-corrected milk yield (28.8 ± 1.13 kg/d), milk composition (fat, protein, lactose, urea, casein, free fatty acids, and somatic cell count), and blood metabolites (glucose, insulin, and nonesterified fatty acids) were unaffected by the treatments. The time spent eating, ruminating, or chewing was also similar among the diets, as was particle-sorting behavior. By contrast, chewing per kilogram of forage NDF intake was higher for the sugarcane silage (137 min/kg) than the corn silage diet (116 min/kg), indicating the greater physical effectiveness of sugarcane fiber. Based on chewing behavior (min/d), the estimated pef of sugarcane silage NDF were 1.28 in the corn silage plus sugarcane silage diet and 1.29 in the sugarcane silage diet. Formulating dairy rations of equal peNDF content allows similar performance if corn and sugarcane silages are exchanged.

Key words: chewing behavior, corn silage, physical effectiveness factor, sugarcane silage

INTRODUCTION

Corn silage is one of the most important sources of forage fed to dairy cows worldwide (Neylon and Kung, 2003; Wilkinson and Toivonen, 2003). In many countries, corn silage produces more energy per hectare than any other crop. However, in tropical areas, fresh or ensiled sugarcane (*Saccharum officinarum* L.) is also characterized by a high DM yield (>30 t DM/ha) within one harvest and a suitable nutritive value at maturity (48-h DM digestibility >60%; Daniel et al., 2013a), enabling high animal stocking rates.

In dairy rations, exchanging NDF among usual forage sources (e.g., corn, sorghum, alfalfa, wheat) typically yields similar levels of performance (Mertens, 1995, 1996). However, the replacement of corn silage with sugarcane decreases DMI and milk yield (Costa et al., 2005), even when diets are formulated to contain identical concentrations of forage NDF (**FNDF**; Corrêa et al., 2003).

Although dietary forage adequacy is important to reduce the risk of ruminal acidosis, excessive amounts of FNDF may limit DMI and animal performance (Allen, 1997). Because not all sources of NDF are equal, the effective fiber concept was developed in an attempt to formulate rations based on a diet's ability to maintain optimal rumen function (Mertens, 1997). Physically effective NDF (**peNDF**) has been related to the physical and chemical characteristics of fiber (e.g., particle size, density, fragility, moisture, and digestibility) that influence chewing activity, rumen mat consistency, and rumen motility (Armentano and Pereira, 1997; Mertens, 1997). Mathematically, peNDF is the product of the physical effectiveness factor (**pef**) and the NDF content of a feed (i.e., peNDF = pef × NDF; Armentano and Pereira, 1997). Whereas NDF is determined by laboratory analysis (Van Soest et al., 1991), pef can be measured by both animal physiological responses (Armentano and Pereira, 1997; Mertens, 1997) and laboratory methods, such as the proportion of feed retained on a sieve with an aperture of 1.18 (Mertens, 1997; Kononoff et al., 2003) or 8 mm (Lammers et al., 1996).

Received December 19, 2013.
Accepted August 12, 2014.
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In dairy diets containing usual forage sources (e.g., corn, alfalfa, temperate grasses, barley, or oat crops), peNDF estimated using sieves (peNDF$_{>1.18}$) is negatively correlated with DMI and positively correlated with rumen pH and chewing activity (Zebeli et al., 2006; 2012). However, peNDF$_{>1.18}$ is not entirely consistent with animal responses when different sources of NDF are considered, primarily because this method assumes, among others, that particle fragility and digestibility do not differ among sources of NDF (Mertens, 1997).

Based on animal physiological responses (i.e., chewing behavior and rumen parameters), we recently demonstrated that the physical effectiveness of sugarcane forage NDF was 20% higher than that of corn silage (Goulart et al., 2009). A higher pef of sugarcane NDF is most likely because the low NDF digestibility (<35%), as measured in vivo (Corrêa et al., 2003) or 48-h in vitro (Daniel et al., 2013a), which results in a higher potential to regulate feed intake due to rumen filling (Goulart et al., 2009; Oliveira et al., 2011). Accordingly, the main objective of the present study was to determine if the source of peNDF affects the performance of lactating dairy cows. We hypothesized that balancing peNDF would equalize the feed intake, chewing activity, and milk yield of dairy cows fed diets based on corn silage, sugarcane silage, or both.

MATERIALS AND METHODS

All experimental procedures were approved by the Committee on Animal Use and Care at the College of Agriculture "Luiz de Queiroz," University of São Paulo.

Forage Sources

Corn and sugarcane crops were cultivated at the Department of Animal Science ("Luiz de Queiroz" Campus) during the 2009 and 2010 crop year. Whole-plant corn (30F90Bt DuPont Pioneer; Santa Cruz do Sul, Brazil) was harvested and chopped to a theoretical cut of 10 mm (Pecus 9004 Nogueira, São João da Boa Vista, Brazil) at 34% DM, packed in a bunker silo without any additive, and ensiled for 290 d. Sugarcane (RB85–5453 variety; Ridesa Brasil) was mechanically harvested at 14 mo of growth with a pull-type forage harvester (Colhiflex Mentamit, Cajurú, Brazil) to a theoretical cut of 10 mm. A hand refractometer (DZ Tokyo; Tokyo, Japan) was used to measure the concentration of soluble solids in the stalk juice, which averaged 21.6 ± 0.8°Brix. In sugarcane, more than 90% of the Brix content comprises soluble sugars; therefore, the sugarcane was mature at harvest (Preston, 1977).

During harvesting, a solution of sodium benzoate (375 g/L) was sprayed onto the chopped sugarcane (4 mL/kg) to obtain a final dosage of 1.5 g of sodium benzoate per kilogram as fed. The treated sugarcane was ensiled in a bunker silo for 65 d. Although most Brazilian farmers do not use additives when ensiling whole-plant corn (Bernardes and Rêgo, 2014), fermentative losses in sugarcane silages can only be prevented if additives are adopted (Schmidt et al., 2007). In addition, the length of storage of corn silage was longer than that for sugarcane silage because the corn crop was harvested in the summer (February), whereas the sugarcane crop matured and was harvested in the spring (October). After packing, silage densities were 659 ± 53 and 645 ± 39 kg/m^3 (as-fed basis), whereas feedout rates were 26 ± 6 and 29 ± 4 cm/d for corn and sugarcane silages, respectively.

Experimental Design and Data Collection

Twenty-four lactating Holstein cows (9 primiparous and 15 multiparous) were housed and individually fed in a tiestall barn with sand beds and a cooling system. Fresh water was provided ad libitum. At the beginning of the trial BW of cows was 640 ± 55 kg, milk yield was 30.7 ± 3.4 kg/d, and DIM was 292 ± 38 d (mean ± SD).

Cows were grouped based on parity and milk yield into eight 3 × 3 Latin squares with 21-d periods (14 d for adaptation and 7 d for sample collection) and randomly assigned to 3 dietary treatments: (1) 25% peNDF of corn silage (**CS**); (2) 25% peNDF of sugarcane silage (**SS**); and (3) 12.5% peNDF of corn silage + 12.5% peNDF of sugarcane silage (**CSSS**). The CSSS treatment was included to investigate possible interactions between peNDF sources. The pef values were assumed to be 1 for corn silage and 1.2 for sugarcane silage, as determined previously by bioassay (Goulart et al., 2009). To measure pef, chewing activity (min/kg of DM) was chose as animal response to alter according to fiber input in 3 diets: negative control (containing 10% NDF from corn silage), positive control (containing 20% NDF from corn silage), and test (containing 10% NDF from corn silage + 10% NDF from sugarcane). Fiber from concentrates (finely ground corn, protein supplement, and minerals) was considered ineffective (pef = 0). By concept, the pef of a given feed is relative to a standard feed, for instance, corn silage (pef = 1). The slope ratio in which chewing (min/kg of DM) was plotted against dietary input of NDF from corn silage and sugarcane was therefore used to define the sugarcane pef as 1.2 (Goulart et al., 2009). Additional details on the measurement of pef based on animal responses are provided in Armentano and Pereira (1997).

Ration ingredients were mixed for 15 min in a self-propelled mixer (Data Ranger American Calan, Northwood, NH) and offered twice daily (0800 and 1800 h). The amount of feed offered was adjusted daily to allow more than 10% orts. Feed intake was determined by calculating the difference between the amounts of feed offered and refused during the 7-d collection phase in each period. Six trained observers recorded cow behavior (eating and ruminating) by visual observation every 10 min for 48 h on d 15, 16, and 17 of each period, including the time during which the cows were in the milking parlor (Maekawa et al., 2002). Chewing (eating + ruminating) per kilogram of DM and NDF were calculated along with nutrient intake during the chewing measurement. On the same days, the particle size distributions of the diets and orts were determined using the Penn State Particle Size Separator (Lammers et al., 1996). The proportion of particles retained above an 8-mm sieve was defined as $\mathbf{pef}_{>8}$. The dietary content of peNDF based on sieves ($\mathbf{peNDF}_{>8}$) was calculated as NDF × $\text{pef}_{>8}$. Sorting behavior was determined based on the observed intake of each particle size fraction expressed as a percentage of the predicted intake (as-fed basis). Values <100% indicated selective refusal, values >100% indicated preferential intake, and values equal to 100% indicated no sorting (Leonardi and Armentano, 2003).

Cows were injected with recombinant bST (500 mg/head; Boostin, Intervet Schering-Plough, Cruzeiro, Brazil) on d 1 and 11 of each period and milked twice daily in a milking parlor (0600 and 1700 h). Milk production was recorded daily during the collection periods, and composite samples were collected in flasks containing bronopol on d 16 and d 19 of each period. Milk was analyzed for fat, protein, lactose, CN, FFA, and MUN by Fourier transform infrared spectroscopy (Lefier et al., 1996) and for SCC by flow cytometry (Clínica do leite, Piracicaba, Brazil). Production of FCM was calculated as (Tyrrell and Reid, 1965) 3.5% FCM (kg/d) = 0.4324 × milk yield (kg/d) + 16.216 × milk fat yield (kg/d). Milk energy content was calculated as (NRC, 2001) milk NE_L (Mcal/kg) = 0.0929 × fat % + 0.0547 × protein % + 0.0395 × lactose %. Daily secretion of milk energy (Mcal/d) was computed as milk NE_L × milk yield.

Blood samples were obtained from coccygeal vessels 1 h before and 6 h after morning feeding on d 21. Samples were collected in 7-mL vacuum tubes (Vacuette, Cen-Med Enterprises; New Brunswick, NJ) containing either no preservatives or K_3EDTA-sodium fluoride for serum and plasma separation, respectively. After centrifugation (2,000 × g for 20 min at 5°C), insulin (chemiluminescence immunoassay; Vlasenko et al., 1989) was analyzed in the serum, whereas glucose (glucose oxidase; LABTEST Diagnóstica S.A., Lagoa Santa, Brazil; Trinder, 1969) and NEFA (colorimetric method; Randox Laboratories Ltd., Crumlin, United Kingdom; Johnson and Peters, 1993) were determined in the plasma.

Samples of feeds and orts (~300 g) were collected daily during the sampling days in each period. Orts were composited by cow within each period, whereas the silages and concentrates were composited to form 2 representative samples per period. Samples were oven-dried (72 h at 60°C) and ground through a 1-mm screen (Wiley mill, Arthur H. Thomas, Philadelphia, PA). Subsamples were analyzed for DM in a forced-air oven at 105°C (AOAC, 1980), CP by the Dumas method (Wiles et al., 1998), ether extract (AOAC, 1990), ash (AOAC, 1980), NDF (assayed with sodium sulfite and amylase, expressed exclusive of residual ash; Van Soest et al., 1991), and neutral-detergent insoluble CP (Goering and Van Soest, 1970). Thus, NFC was calculated as: 100 − [CP + (NDF − neutral-detergent insoluble CP) + ether extract + ash]. Feed ingredients were further analyzed for indigestible NDF (**iNDF**) by 288-h ruminal in situ incubation (Huhtanen et al., 1994), starch (Hall, 2009), and 80% ethanol-soluble carbohydrates (**ESC**; Hall et al., 1999). Potentially digestible NDF was computed as NDF − iNDF. Aliquots of fresh silages were used to determine the particle size distribution and to prepare aqueous extracts (Kung et al., 1984) for measuring pH, lactic acid (Pryce, 1969), acetic acid (Palmquist and Conrad, 1971), and ethanol (Sigma procedure No 332 − UV; Kung et al., 2000). Afterward, DM of corn silage (Weissbach, 2009) and sugarcane silage (Daniel et al., 2013b) were corrected for volatile compounds.

Calculation of pef

The pef of sugarcane silage NDF was verified using data from individual cows, based on both the SS [1] and CSSS [2] diets compared with the CS diet (Armentano and Pereira, 1997; Mooney and Allen, 1997), as follows:

$$\text{pef}_{\text{sugarcane silage}} = \beta_{\text{ss}}/\beta_{\text{cs}}, \quad [1]$$

$$\text{pef}_{\text{sugarcane silage}} = \beta_{\text{csss}}/\beta_{\text{cs}}, \quad [2]$$

where

$$\beta_{\text{ss}} = (C_{\text{ss}} - \beta_0)/(\text{FNDF in SS diet}),$$

$$\beta_{\text{cs}} = (C_{\text{cs}} - \beta_0)/(\text{FNDF in CS diet}),$$

$$\beta_{\text{csss}} = [C_{\text{csss}} - \beta_0 - (\beta_{\text{cs}} \times \text{FNDF in CS diet})]/(\text{FNDF in SS diet});$$

C_{ss}, C_{cs}, and C_{csss} are the chewing time per day in the SS, CS, and CSSS treatments, respectively; and β_0 is the basal chewing time (minutes per day) at 0% FNDF (355 min/d; Mooney and Allen, 1997).

Statistical Analysis

Before performing ANOVA, data were evaluated for normality of residuals (Shapiro-Wilk test) and homogeneity of variances (Bartlett test). The SCC data were not normally distributed and were $\log_{10}$-transformed before analysis. After verifying that the assumptions of the analysis were met for all dependent variables, ANOVA was performed using the MIXED procedure of SAS Institute (2001) with the following model:

$$y_{ijkl} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + \delta_l + \alpha\delta_{il} + \varepsilon_{ijkl},$$

where μ = overall mean; α_i = fixed effect of Latin square (i = 1 to 8); $\beta_{j(i)}$ = random effect of cow within square (j = 1 to 24); γ_k = fixed effect of period (k = 1 to 3); δ_l = fixed effect of diet (l = CS, CSSS, or SS); $\alpha\delta_{il}$ = fixed effect of interaction between Latin square and diet; and ε_{ijkl} = residual error. The interaction between Latin square and diet was not significant ($P \geq 0.14$) for any variable and was subsequently removed from the model. Means were compared using the Tukey-Kramer test. Differences were considered significant at $P \leq 0.05$, whereas tendencies were considered at $0.05 < P \leq 0.10$. The 95% CI of the mean of the sugarcane silage pef was calculated using the MEANS procedure of SAS Institute (2001).

RESULTS AND DISCUSSION

The chemical and physical traits of the silages and experimental diets are shown in Tables 1 and 2, respectively. Silages had typical compositions, as reported for these crops grown in Brazilian tropical zones (Schmidt et al., 2007; Paziani et al., 2009). The application of sodium benzoate upon sugarcane ensiling was effective for nutrient preservation (Pedroso et al., 2008), as indicated by the high content of ESC (>27% of DM). Starch represented the major component of NFC in corn silage, whereas ESC was the main NFC in sugarcane silage. The fermentation profiles suggest that the forages were properly conserved (Pahlow et al., 2003).

Table 1. Chemical and physical traits of experimental forages[1] (% DM, unless otherwise stated)

Item[2]	Corn silage (SD)	Sugarcane silage (SD)
Nutrient		
DM, % as fed	32.52 (1.98)	27.01 (1.86)
OM	95.70 (0.56)	96.99 (0.24)
CP	7.30 (0.79)	3.98 (0.19)
Ether extract	3.20 (0.22)	1.49 (0.12)
Starch	23.38 (0.91)	—
ESC	3.43 (0.22)	27.56 (1.17)
NFC	31.18	30.29
NDF	54.02 (1.83)	61.23 (1.60)
iNDF	18.91 (1.92)	30.00 (1.67)
iNDF/NDF, %	35.01	48.99
pdNDF	35.12	31.23
pef	1.00	1.20
peNDF	54.02	73.48
$\text{peNDF}_{>8}$	41.96	45.68
Fermentation profile		
pH	3.84 (0.06)	3.63 (0.08)
Lactic acid	3.41 (1.14)	3.35 (1.13)
Acetic acid	1.22 (0.13)	2.23 (0.20)
Ethanol	0.98 (0.20)	2.01 (0.61)
Particle size distribution, % as fed		
>19 mm	16.96 (2.38)	7.64 (2.31)
8 to 19 mm	60.72 (1.93)	66.96 (2.42)
<8 mm	22.32 (3.88)	25.40 (3.91)
$\text{pef}_{>8}$	0.78	0.75
Mean particle size, mm	13.92 (1.67)	12.23 (1.46)

[1] n = 6.

[2] DM = DM corrected for volatile compounds; ESC = ethanol-soluble carbohydrates; iNDF = indigestible NDF; pdNDF = potentially digestible NDF; pef = physical effective factor based on animal responses (Goulart et al., 2009); peNDF = physically effective NDF (i.e., NDF × pef); $\text{peNDF}_{>8} = \text{NDF} \times \text{pef}_{>8}$, where $\text{pef}_{>8}$ is the proportion of particles retained above an 8-mm sieve.

Table 2. Composition of experimental diets (% DM, unless otherwise stated)

Item	Treatment[1] CS	CSSS	SS
Ingredient			
Corn silage	48.87	24.50	—
Sugarcane silage	—	18.72	37.53
Ground corn	14.10	18.38	22.68
Citrus pulp	13.29	13.33	13.36
Soybean meal	21.41	22.75	24.09
Mineral-vitamin mix[2]	2.32	2.33	2.34
Nutrient[3]			
DM, % as fed	48.17	48.00	47.83
OM	93.02	93.35	93.67
CP	16.59	16.60	16.61
Ether extract	3.06	2.76	2.46
NFC	40.25	42.00	43.76
Starch	22.79	20.19	17.56
ESC	7.20	11.75	16.31
Starch + ESC	29.99	31.93	33.87
NDF	33.13	31.99	30.85
iNDF	10.45	11.62	12.79
pdNDF	22.68	20.37	18.06
FNDF	26.40	24.70	22.98
peNDF	26.40	26.99	27.58
$\text{peNDF}_{>8}$	11.93	11.29	8.87
Particle distribution, % as fed			
>19 mm	6.13	5.53	2.74
8 to 19 mm	29.87	29.76	26.00
<8 mm	64.00	64.71	71.26
$\text{pef}_{>8}$	0.36	0.35	0.29

[1] CS = 26% peNDF of corn silage; CSSS = 13% peNDF of corn silage + 13% peNDF sugarcane silage; SS = 26% peNDF of sugarcane silage (DM basis).

[2] Mineral-vitamin mix contained (DM basis): Ca, 10.0%; P, 4.2%; Mg, 4.5%; K, 2.0%; S, 1.8%; Na, 12.3%; Zn, 2,800 mg/kg; Mn, 1,400 mg/kg; Fe, 1,050 mg/kg; Cu, 500 mg/kg; I, 28 mg/kg; Cr, 20 mg/kg; Se, 18 mg/kg; Co, 14 mg/kg; vitamin A, 200,000 IU/kg; vitamin D_3, 40,000 IU/kg; vitamin E, 1,200 IU/kg; biotin, 80 mg/kg.

[3] ESC = ethanol-soluble carbohydrates; iNDF = indigestible NDF; pdNDF = potentially digestible NDF; FNDF = forage NDF; peNDF = physically effective NDF based on animal responses (Goulart et al., 2009; corn silage physically effective factor = 1, sugarcane silage physically effective factor = 1.2, and concentrates physically effective factor = 0); $\text{peNDF}_{>8} = \text{NDF} \times \text{pef}_{>8}$, where $\text{pef}_{>8}$ is the proportion of particles retained above an 8-mm sieve.

Table 3. Feed intake and ingestive behavior of cows fed corn and sugarcane silage-based diets

Item	Treatment[1] CS	CSSS	SS	SEM	*P*-value
DMI, kg/d	22.22	22.68	22.60	0.63	0.74
Eating, min/d	215	223	221	13.00	0.69
Ruminating, min/d	449	464	491	18.60	0.15
Chewing, min/d	668	687	709	28.50	0.23
Chewing/DMI,[2] min/kg	30.7	31.0	31.4	1.12	0.88
Chewing/NDF intake, min/kg	92.5	96.9	101.9	3.49	0.19
Chewing/FNDF[3] intake, min/kg	116^{b}	126^{ab}	137^{a}	4.57	0.01
Chewing/peNDF[4] intake, min/kg	116	115	114	4.16	0.93
Chewing/$\text{peNDF}_{>8}$[5] intake, min/kg	257^{b}	275^{b}	354^{a}	10.92	<0.01

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

[1] CS = 26% peNDF of corn silage; CSSS = 13% peNDF of corn silage + 13% peNDF sugarcane silage; SS = 26% peNDF of sugarcane silage (DM basis).

[2] DMI determined on days of ingestive behavior evaluation.

[3] Forage NDF.

[4] Physically effective NDF based on animal responses.

[5] Physically effective $\text{NDF}_{>8}$ based on sieves.

Table 4. Selection behavior of cows fed corn and sugarcane silage-based diets

Particle sorting index, % as fed	Treatment[1]				
	CS	CSSS	SS	SEM	*P*-value
>19 mm	71.93	68.61	61.74	7.99	0.64
8 to 19 mm	99.68	99.65	98.88	1.15	0.51
<8 mm	102.55	102.13	102.92	0.78	0.38

[1] CS = 26% physically effective NDF (peNDF) of corn silage; CSSS = 13% peNDF of corn silage + 13% peNDF sugarcane silage; SS = 26% peNDF of sugarcane silage (DM basis).

Although different forage harvesters were used to harvest the corn and sugarcane crops, the particle distributions and, consequently, the mean particle sizes were similar across the silages (13.9 and 12.2 mm for corn and sugarcane silages, respectively). Therefore, the observed physical effectiveness is largely attributable to differences in the nature of NDF in the forages, with little or no influence of particle size (Mertens, 1997). Peculiarities of chemical composition, cross-linkage of cell wall polymers, and organization of plant tissues (Wilson, 1993; Jung and Allen, 1995) may be responsible for the observed differences in NDF effectiveness. Consistent with a previous report (Daniel et al., 2013a), iNDF represented nearly 50% of NDF in sugarcane, which is substantially higher than that proportion in corn silage (approximately 35% of NDF). Finally, due to the higher pef and concentration of NDF in sugarcane silage, the SS diet had a lower forage-to-concentrate ratio than either the CSSS or CS diet. The peNDF content of the diets was 26.4 to 27.6% of DM, values slightly greater than the planned 25% of DM. These deviations may be considered small relative to the lack of precision inherent in measuring NDF effectiveness (Pereira et al., 1999). Mainly due to the lower inclusion of forage, SS had lower $\text{pef}_{>8}$, lower NDF, and, consequently, lower $\text{peNDF}_{>8}$. In contrast to the decrease in $\text{peNDF}_{>8}$, peNDF increased when corn silage was replaced with sugarcane silage in the diets.

As hypothesized, exchanging peNDF sources did not affect the DMI or ingestive behavior of dairy cows (Table 3). In contrast to variables based on sieve measurements, eating, ruminating, and chewing activities (min/d) did not vary among treatments, indicating that a difference in the physical value of the diets existed. However, chewing per kilogram of FNDF intake was higher ($P = 0.01$) for SS than for CS, with intermediate values resulting from the CSSS treatment. This finding supports the higher pef of sugarcane silage NDF

Table 5. Milk yield, milk composition, and energy efficiency of cows fed corn and sugarcane silage-based diets

Item	Treatment[1]				
	CS	CSSS	SS	SEM	*P*-value
Milk yield, kg/d	27.58	26.69	26.48	0.98	0.38
3.5% FCM, kg/d	29.54	28.59	28.18	1.12	0.56
Fat, %	3.92	3.94	3.91	0.14	0.96
Fat, kg	1.09	1.05	1.03	0.05	0.67
Protein, %	3.74	3.67	3.72	0.10	0.69
Protein, kg	1.02	0.98	0.98	0.03	0.50
CN, %	2.90	2.84	2.89	0.07	0.67
CN, kg	0.79	0.76	0.76	0.03	0.46
Lactose, %	4.49	4.47	4.56	0.04	0.09
Lactose, kg	1.24	1.19	1.20	0.05	0.44
SNF, %	9.14	9.06	9.17	0.09	0.49
SNF, kg	2.51	2.42	2.43	0.08	0.45
TS, %	13.07	13.01	13.07	0.20	0.95
TS, kg	3.60	3.47	3.46	0.12	0.51
FFA, μmol/L	111	112	112	31.9	0.99
MUN, mg/dL	14.34	13.80	14.68	1.08	0.54
SCC, × 1,000/mL	179	123	146	—	—
Log_{10} SCC	4.84	4.50	4.65	0.18	0.32
Milk NE_L, Mcal/kg	0.75	0.75	0.75	0.02	0.99
Milk NE_L excretion, Mcal/d	20.62	19.82	19.73	0.71	0.56
Milk NE_L excretion/DMI, Mcal/kg	0.91	0.88	0.87	0.03	0.25

[1] CS = 26% physically effective NDF (peNDF) of corn silage; CSSS = 13% peNDF of corn silage + 13% peNDF sugarcane silage; SS = 26% peNDF of sugarcane silage (DM basis).

Table 6. Blood metabolites of cows fed corn and sugarcane silage-based diets

Item	Treatment[1] CS	CSSS	SS	SEM	*P*-value
1 h before morning feeding					
Glucose, mg/dL	58.27	57.55	59.72	4.36	0.38
NEFA, mmol/L	0.18	0.19	0.19	0.02	0.99
6 h after morning feeding					
Glucose, mg/dL	56.54	57.94	58.94	4.61	0.39
NEFA, mmol/L	0.16	0.15	0.13	0.02	0.46
Insulin, mU/L	0.20	0.21	0.19	0.02	0.64

[1] CS = 26% physically effective NDF (peNDF) of corn silage; CSSS = 13% peNDF of corn silage + 13% peNDF sugarcane silage; SS = 26% peNDF of sugarcane silage (DM basis).

relative to corn silage NDF (Goulart et al., 2009). The total chewing time (>650 min/d) and chewing per kilogram of DMI (>30 min/kg) were characteristic of high-forage-based diets (Mertens, 1997; Pereira et al., 1999), suggesting that DMI was regulated by distension of the reticulo-rumen (Huhtanen, 2013). Although plenty of evidence exists to support the notion that FNDF is a primary factor responsible for gut filling and intake control (Mertens, 1992), the results of the present experiment suggest that a lower dietary concentration of sugarcane silage NDF was required to achieve the same level of DMI observed for the corn silage-based diet. Indeed, sugarcane NDF has a higher potential than corn silage NDF to limit feed intake by physical distension of the gastrointestinal tract (Goulart et al., 2009; Oliveira et al., 2011).

Chewing per peNDF intake (min/kg) was quite similar among diets, as observed in other studies (Armentano and Pereira, 1997; Mertens, 1997). By contrast, chewing activity per peNDF$_{>8}$ intake (min/kg) was remarkable higher for the SS diet, suggesting that at the same content of NDF and particle size, sugarcane silage has a greater capacity than corn silage to stimulate chewing. A high proportion of iNDF (Daniel et al., 2013a), which leads to low NDF digestibility, is a reasonable explanation for the high physical effectiveness of sugarcane NDF (Corrêa et al., 2003; Goulart et al., 2009).

Based on chewing behavior (min/d), the estimated pef values of sugarcane silage NDF were 1.28 in the CSSS diet (95% CI = 1.11 to 1.41) and 1.29 in the SS diet (95% CI = 1.15 to 1.39). The pef was initially defined as varying from 0 (when NDF does not stimulate chewing) to 1 (when NDF is fully effective in promoting chewing; Mertens, 1997). Because pef is a relative factor, sugarcane may be considered an odd source of peNDF with a pef higher than 1.

The preferential consumption of particles did not differ among treatments (Table 4), most likely because the particle distributions were similar across the silages and TMR. However, the animals consistently sorted against longer particles in favor of finer particles. This trend is commonly observed in dairy cows (Leonardi and Armentano, 2003). Avoiding very long particles in TMR might reduce particle selection and alleviate nutrient imbalance resulting from sorting.

In addition to chewing behavior, milk fat concentration has been used as an animal response for measuring NDF effectiveness (Armentano and Pereira, 1997; Mertens, 1997). Milk yield and most of the milk components were unaffected by the treatments (Table 5). Therefore, this supports the view that the diets had the same content of peNDF. Although milk protein content was high in all treatments, the efficiency of the transfer of dietary N to milk N was similar ($P = 0.48$) across all diets (CS = 26.4%, CSSS = 25.4%, SS = 25.8%; SEM = 1.01), and the values were typical of corn silage-based diets (Huhtanen and Hristov, 2009). The lactose concentration tended ($P = 0.09$) to be higher for cows fed the SS diet than for those fed the other diets, primarily due to the higher proportion of concentrates in this diet (Sutton, 1989). Regardless, all treatments led to similar daily excretion of milk components.

Because the energy excretion in milk and DMI were unaffected by the treatments, milk NE$_L$ excretion per DMI (Mcal/kg) suggests that the diets had the same energetic efficiency for production (Table 5). Therefore, a higher inclusion of concentrates is required for sugarcane silage-based diets to match the nutritive value of corn silage-based diets. As sugarcane silage is typically cheaper than corn silage in Brazil, diets containing sugarcane silage could nonetheless be attractive, depending on the price of concentrate feeds. The higher stocking rates allowed by sugarcane silage should be taken into account as well.

Like energetic efficiency, blood metabolites related to energetic status (NEFA, glucose, and insulin) were unaffected by the diets (Table 6). All values remained within a normal range (Tennant and Center, 2008), suggesting that the supply of energetic nutrients and the turnover of body reserves were similar among treatments (van Knegsel et al., 2007). However, additional research is needed to assess the long-term effects of a low-forage sugarcane-based diet on animal health.

CONCLUSIONS

Formulating dairy rations with an equal peNDF allows similar performance if corn and sugarcane silages are exchanged.

ACKNOWLEDGMENTS

The authors are grateful for the financial support of the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP, São Paulo, Brazil), the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Brasília, Brazil), and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Brasília, Brazil).

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