Silage Chop Length and Hay Supplementation on Milk Yield, Chewing Activity, and Ruminal Digestion by Dairy Cows

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ABSTRACT

The effects of whole-plant corn silage (CS) particle size and long unprocessed grass hay (LH) supplementation on milk yield, chewing activity, and ruminal digestion in dairy cows were evaluated in 2 experiments. In Experiment 1, corn silage harvested at fine (6 mm; FCS) or coarse (23 mm; CCS) theoretical cut length were fed to 22 lactating Holstein cows. Treatments were 2 total mixed rations containing 58% of dry matter (DM) as FCS or CCS. Diet DM intake tended to be higher in cows fed FCS than those fed CCS (23.4 vs. 22.1 kg/d). However, milk yield and composition, body condition score, and plasma metabolite concentrations were not affected by the dietary treatments. In the second experiment, 5 cannulated Holstein cows were used in a 5 × 5 Latin square design to evaluate the effects of the addition of LH to the diets evaluated in Experiment 1 on chewing activity and ruminal digestion. Treatments were 5 total mixed rations: FCS-based diet plus the addition of 0, 5, or 10% LH (DM basis) and CCS-based diet plus 0 or 5% LH. Long hay addition linearly decreased DM intake in cows fed FCS-based diets (25.0 to 21.7 kg/d), but increased DM intake in those fed CCS-based diets (22.7 to 27.1 kg/d). The intake of neutral detergent fiber (NDF) increased with LH addition in CCS-based diets (7.6 vs. 9.4 kg/d). Rumination time increased (16.8 to 21.0 min/kg of DM intake) when LH was added to FCS-based diets, but it decreased when included in CCS-based diets (18.8 vs. 12.9 min/kg of DM intake). Ruminal pH was higher (5.9 vs. 5.7) and lag-time for in situ NDF disappearance was shorter (3.5 vs. 8.7 h) for cows fed CCS compared with cows fed FCS. The rate of NDF disappearance tended to be higher for the CCS-based diet with 5% LH than for the diet with 0% LH (2.0 vs. 4.4 %/h), but solids passage rate was not affected by the treatments. These results suggest that addition of LH to FCS-based diets does not affect ruminal environment or digestion, but depressed DM

intake. In contrast, addition of LH to CCS-based diets may improve ruminal NDF digestion, increasing DM intake by reducing filling effect and time needed for rumination.

Key words: corn silage, particle size, long hay, chewing activity

INTRODUCTION

Whole-plant corn silage (CS) is used in many countries as a primary source of forage for lactating dairy cows because of its high biomass production per hectare and positive ensiling characteristics (McDonald, 1981). Although a CS-based diet may appear to be of adequate fiber content, its physical effectiveness to maintain adequate rumination activity and saliva flow may be less than the fiber in grass silage-based diets (Clark and Armentano, 1999). Furthermore, when CS is part of TMR fed to early lactation dairy cows, the high proportion of concentrates in these diets may increase the risk of digestive problems by lowering ruminal pH (Clark and Armentano, 1999). Therefore, it is important to determine the optimal CS particle size, or theoretical cut length (TCL), to improve silo packing density and fermentation without adversely affecting subsequent ruminal digestion and animal performance.

The inclusion of small proportions of long (unprocessed) hay (LH) into diets based on finely chopped CS may be a strategy to maintain adequate physical effectiveness of the diet (Beauchemin et al., 1994). However, there is little information on effects of LH supplementation on digestion of CS-based diets with adequate concentrations of NDF in dairy cattle. Furthermore, very few experiments have simultaneously addressed the effects of the TCL of CS and LH supplementation on chewing activity and ruminal digestion.

The objective of this study was to determine effects of TCL of CS (i.e., fine vs. coarse) on milk yield and composition in early lactation dairy cows. In addition, interactions between the TCL and LH supplementation on intake, chewing activities, and ruminal digestion were evaluated.

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MATERIALS AND METHODS

Experiments were conducted at the National Institute of Agriculture Technology (INTA) in Balcarce, Argentina (37°45'S, 58°18'W). Corn (hybrid Dekalb 705, Buenos Aires, Argentina) was planted at the INTA in a field (25 ha) at a theoretical planting density of 72,500 seeds/ha in 0.76-m rows. Corn was fertilized with 24 kg of P/ha as diammonium phosphate (18-46-0) and 60 kg of N/ha as urea (0-46-0); Broad Strike-Dual herbicide (Dow Elanco, Buenos Aires, Argentina) was also applied. Whole plant corn was harvested at half milk line using a precision-chop harvester equipped with an on-board kernel processor (model FX375, New Holland, New Holland, PA). The TCL of the forage harvester was set at 6 mm (fine chop length, **FCS**) or 23 mm (coarse chop length, **CCS**). The kernel processor was set at a 2-mm roll clearance. The 2 CS treatments (FCS and CCS) were ensiled for approximately 5 mo in stack silos (50-m long, 15-m wide, and 3.5-m high). The silos were packed by tractors, covered with black plastic (over 6-mm thick) held down with tires spread over the surface at a density of about 0.2 tires per m² of surface area. The face removal rate for both silages was about 20 cm/d.

Experiment 1

Cows and Treatments. Twenty-two multiparous Holstein cows (630 ± 52 kg of BW) were paired according to milk yield in the previous lactation and randomly assigned to treatments, which consisted of 2 TMR containing 58% of DM as FCS or CCS along with a concentrate mixture that included pelleted sunflower meal, cracked dry shelled corn, urea, and a mineral-vitamin premix (Table 1). The cows received the experimental diets in individual outdoor pens beginning 15 d before expected calving date. This period plus the first 7 d of lactation were the adaptation period to the diet. Cows were fed twice daily (0830 and 1430 h) in quantities to achieve approximately 10% refusal. Cows were milked twice daily at 0630 and 1630 h.

Data Collection and Sample Analysis. Daily DMI was determined by difference between total DM offered and refused. Samples from TMR offered and refused were collected on 3 consecutive days per wk and composited by week before analyses. All samples were dried at 60°C in a forced-air oven, ground through a 1-mm screen (Wiley Mill, Philadelphia, PA), and analyzed for DM after 24 hr at 105°C in a forced-air oven, OM (weight loss after 450°C for 8 h), and NDF and ADF (Van Soest et al., 1991). Also determined were CP (AOAC, 1990), in vitro DM digestibility using the 2-stage procedure (Tilley and Terry, 1963), and starch (AOAC, 1990).

Table 1. Diet ingredient and nutrient composition of the experimental diets (mean ± SD)

Treatments	Corn silage			Experiment 1		Experiment 2				
	FCS	CCS	Hay ¹	FCS	CCS	F0	F5	F10	C0	C5
Ingredients, % DM										
Fine (6-mm) corn silage	—	—	—	58	—	62	57	52	—	—
Coarse (23-mm) corn silage	—	—	—	—	58	—	—	—	62	57
Cracked shelled corn	—	—	—	18	18	16	16	16	16	16
Pelleted sunflower meal	—	—	—	24	24	20	21	21	20	21
Long hay ¹	—	—	—	—	—	0	5	10	0	5
Urea	—	—	—	0.5	0.5	1.0	0.9	0.9	1.0	0.9
Mineral-vitamin premix ²	—	—	—	0.4	0.4	0.2	0.2	0.2	0.2	0.2
Chemical composition										
DM, %	32.7 ± 2.3	31.4 ± 3.6	86.7 ± 1.7	42.9 ± 2.8	41.3 ± 2.1	47.2 ± 2.5	51.3 ± 1.9	55.9 ± 1.6	48.2 ± 2.1	52.6 ± 1.8
OM, % of DM	93.4 ± 0.5	92.9 ± 0.2	91.1 ± 0.6	92.4 ± 0.7	92.9 ± 0.5	92.9 ± 0.4	93.3 ± 0.9	92.2 ± 0.6	89.4 ± 0.8	92.5 ± 0.8
CP, % of DM	9.5 ± 1.2	9.4 ± 2.3	10.9 ± 1.9	18.9 ± 1.0	17.9 ± 1.3	15.9 ± 0.4	16.1 ± 0.3	15.9 ± 0.7	16.4 ± 0.7	16.4 ± 0.5
NDF, % of DM	41.8 ± 2.4	44.7 ± 3.1	62.2 ± 2.9	33.5 ± 2.1	32.2 ± 3.2	32.3 ± 3.4	36.2 ± 1.9	38.3 ± 2.4	33.4 ± 1.4	34.7 ± 2.2
ADF, % of DM	24.9 ± 0.9	27.7 ± 1.1	42.2 ± 2.1	19.9 ± 0.8	19.3 ± 1.0	17.3 ± 0.7	19.5 ± 1.2	21.3 ± 1.5	17.9 ± 0.9	19.4 ± 0.6
Starch, % of DM	14.6 ± 1.8	12.1 ± 1.6	—	20.4 ± 2.1	18.1 ± 2.2	23.5 ± 2.5	20.6 ± 3.2	19.7 ± 2.9	22.3 ± 2.2	20.2 ± 2.6
IVDMD, % ³	63.4 ± 1.2	60.5 ± 1.1	53.9 ± 3.4	69.2 ± 0.9	69.2 ± 1.3	72.3 ± 2.5	71.1 ± 3.1	69.9 ± 1.6	70.6 ± 1.8	68.8 ± 1.9

¹Grass (*Agropyrum elongatum* L.) unprocessed hay.

²Composition (%), minimum guarantee; as fed: 21% Ca(PO₄)₂, 4.6% P₂O₅, 6% MgO, 3% dehydrated molasses, 0.15% FeSO₄, 0.4% CuSO₄, 0.3% ZnSO₄, 0.004% MnSO₄, 0.02% Na₂SeO₃, 0.01% I, vitamin A (6,500,000 IU/kg), vitamin D₃ (1,600,000 IU/kg), vitamin E (12,500 IU/kg), and 64.5% excipient.

³IVDMD = In vitro DM digestibility.

Particle size of CS and TMR were measured using a Nasco (Fort Atkinson, WI) Penn State Forage Particle Separator (Kononoff et al., 2003). Two samples (750 g as fed) of CS and each TMR were separated into 3 fractions: particles greater than 19 mm, particles between 19 and 8 mm, and particles smaller than 8 mm. Fractions were weighed separately, and the weights were plotted on Weibull paper to obtain the particle size distribution and mean particle size (**MPS**; Lammers et al., 1996). The physical effectiveness factor (ranging from 0 to 1) was measured as sum of proportion of particles retained on both 19.0- and 8.0-mm sieves (Beauchemin and Yang, 2005). The physically effective fiber (**peNDF**) was determined by multiplying the NDF content by its physical effectiveness factor as described by Beauchemin and Yang (2005).

Milk yield was measured individually at each milking from 7 to 75 DIM. Milk samples were collected twice weekly from the a.m. and p.m. milking of the same day, composited by weight within day, and analyzed for fat, total protein, and lactose by infrared spectrophotometry (AOAC, 1990; Foss 605B Milko-Scan, Foss Electric, Hillerød, Denmark). Cows were weighed on 2 consecutive days after the a.m. milking at 15, 30, 45, 60, and 75 DIM, the same days on which BCS was determined by 3 independent scorers using a 5-point scale (Wildman et al., 1982). Subcutaneous fat depth was estimated between the 12th and 13th rib using a Pie Medical 480 scanner (McDonald et al., 1999). Blood samples were collected from the jugular vein on 15, 30, 45, and 60 DIM immediately after the a.m. milking and before feeding. Blood samples were collected in tubes containing sodium heparin (Abbott Laboratory, Rosario, Argentina), centrifuged ($5,000 \times g$ for 10 min), and plasma was stored at -20°C . Plasma was analyzed for glucose (Wiener Laboratory, Rosario, Argentina) and urea (Wiener Laboratory) as described by Schroeder et al. (2003).

Results of milk yield and composition were analyzed as a completely randomized design with repeated measures adjusted by covariance, using milk yield and composition recorded in the previous lactation, with the MIXED procedure of SAS (SAS Institute, 1998) according to the model

$$Y_{ijk} = \mu + T_i + C_j + W_k + (T \times W)_{ik} + \beta (x_{ij} - \bar{x}_{..}) + e_{ijk},$$

where Y_{ijk} is the dependent variable, μ is the population mean, T_i is the treatment effect ($i = 1$ to 2), C_j is effect of the cow on treatment i ($j = 1$ to 22), W_k is effect of the week k ($k = 1$ to 11), $(T \times W)_{ik}$ is the treatment $\times$ week interaction, β is the linear regression coefficient indicating the dependence between Y_{ij} and the corres-

ponding covariable x_{ij} , $\bar{x}_{..}$ is the mean of all the covariables, and e_{ijk} is the experimental error term.

Dry matter intake, BW, BCS, subcutaneous fat depth, and plasma metabolites were analyzed using the same model, but the covariable term was not included. The differences in particle size distribution between the TMR offered and refused were analyzed with a t -test for paired means. Significance was accepted if $P < 0.05$.

Experiment 2

Cows and Treatments. A total of 5 rumen-cannulated Holstein lactating cows (575 ± 24 kg BW, 113 ± 14 DIM) were used in a 5×5 Latin square design. Due to the use of antibiotic to prevent infections after the ruminal surgery performed 4 wk before the beginning of the experiment, these cows were milked separately and milk yield data were not recorded. However, the average milk yield estimated from 3 measurements during the experiment was 16.6 ± 3.1 kg/d. Period lengths were 16 d with 11 d for adaptation and 5 d for data collection. The 5 dietary treatments (Table 1) were 1) TMR based on FCS similar to that of Experiment 1 (**F0**); 2) F0 plus 5% (DM basis) LH (**F5**); 3) F0 plus 10% LH (**F10**); 4) TMR based on CCS similar to that of Experiment 1 (**C0**); and 5) C0 plus 5% LH (**C5**). The CS used in Experiments 1 and 2 were the same. Unprocessed grass (*Agropyrum elongatum* L.) hay was used as source of LH (Table 1). The LH was top-dressed in each individual bunk and hand-mixed with the TMR, avoiding further processing of LH by the TMR mixer. The TMR mixer (Mainero 2910, Cordoba, Argentina) was a 3-auger, open-top mixer, with a capacity of 8.5 m^3 . Forage-to-concentrate ratio was modified to achieve diets with similar CP (16%) content (Table 1). Cows were fed once daily (0900 h) in quantities to achieve at least 10% refusal, and housed in individual, shaded, outdoor pens with permanent access to feed and water.

Data Collection and Sample Analysis. Samples of TMR offered and refused were collected weekly, composited into 2 samples for each period and treatment, processed, and analyzed as described in Experiment 1. Particle size of the TMR was estimated as described in Experiment 1.

Total DMI was determined during the last 5 d of each period by difference between feed offered and refused. Chewing activities were visually determined by observation every 5 min during 24 h. Activities were classified as time spent eating (**ET**), time spent ruminating (**RT**), and idle time (resting, licking, and drinking). Total chewing time (**TCT**) was calculated as the sum of ET plus RT.

Rumen liquid was obtained from the dorsal, ventral, and caudal areas of the rumen starting at 0600 h at 0,

3, 6, 9, 12, 15, 18, and 21 h and squeezed through 4 layers of cheesecloth. The pH of the filtered ruminal fluid was measured immediately using a digital pH meter (Orion portable pH meter 250A, Orion Research Inc., Boston, MA). Four ruminal liquid samples were collected on the same day every 6 h (starting at 0600 h), centrifuged ($15,000 \times g$ at 4°C for 15 min), and analyzed for VFA using gas chromatography and ammonia (NH_3) as described by Schroeder et al. (2003). In situ DM and NDF disappearance of CS were estimated using 23×10 cm Dacron bags with a mean pore size of $50 \mu\text{m}$. Approximately 20 g of CS (as fed) were incubated in each bag according to the diet offered to the cow (e.g., FCS for F0, F5, and F10, and CCS for C0 and C5 treatments, respectively). The CS incubated in the bags were neither dried nor ground to maintain potential treatment effects as recommended by Johnson et al. (1999). Samples were placed in the ventral sac of the rumen and removed at 0 (0600 h), 3, 6, 9, 12, 15, 21, 48, and 72 h of ruminal incubation. Bags were immediately rinsed in cold running tap water and frozen until the end of sampling, then washed in running tap water until effluent was clear, dried in a forced-air oven (48 h at 60°C) and weighed. Residues from each incubation time were ground to pass a 1-mm screen (Wiley mill) and analyzed for DM (105°C for 48 h) and NDF (Van Soest et al., 1991). Kinetics of DM and NDF disappearance were estimated using a nonlinear model as described by Ørskov and McDonald (1979). To evaluate effects of dietary treatments on ruminal NDF digestion, additional Dacron bags containing a standard NDF ground through a 2-mm screen were incubated in the rumen for 0 and 48 h (Schroeder et al., 2003). The NDF was extracted and prepared by treating plant material (*Agropyrum elongatum* L.) with sodium lauryl sulfate to remove soluble material, washing with water and acetone, and drying at 65°C (Udén et al., 1980). The NDF degradation was corrected by the weight loss of the 0-h bags. The solid passage rate was estimated using NDF marked with chromium oxide [Cr_2O_3 , 160 g/kg (wt/wt)] as proposed by Udén et al. (1980). Cows received a single dose of 60 g of marked fiber to the rumen through the cannula, and fecal samples were collected at 0 (0600 h), 12, 15, 21, 48, and 72 h after dosing, frozen until the end of the period, dried in a forced-air oven at 60°C , ground to pass a 1-mm screen, and analyzed for Cr concentration by atomic spectrophotometry (Williams et al., 1962). Fecal Cr concentration was analyzed according to the model

$$Y = L0 \times [(e^{-L1 \times T - \tau} \times L1^2 \times T - \tau/L2 - L1 - L1^2)/(L2 - L1)^2 + e^{-L2 \times T - \tau} \times L1^2/(L2 - L1)^2]$$

where Y represents the marker concentration in feces at time T, L0 represents the initial Cr concentration in the ruminal contents, L1 represents the mixing rate constant of the marker in the ruminal content, L2 represents the solids rate of passage, and τ represents a time delay due to passage of dietary residues through the lower gastrointestinal tract. Fill value of total dietary NDF was an estimate of the fiber that remains in the rumen (i.e., digestible nondigested plus indigestible) according to the disappearance rate and passage rate. These rates were estimated using the NDF ruminal disappearance model including a discrete lag-time as described by Hoover (1986), as follows:

$$Y = FD \times e^{Kd \times \text{Lag} / (Kd + Kp)} + I/Kd,$$

where Y represents the fill NDF, Kd is the fractional rate of NDF disappearance, Kp is the fractional rate of passage, e is the base of natural logarithms, and Lag is the time before NDF disappearance begins. Corn silage NDF in situ disappearance parameters were used to estimate the fill value of total dietary NDF.

Data were subjected to ANOVA analysis using the GLM procedure of SAS (SAS Institute, 1998) according to the model:

$$Y_{ijkl} = \mu + P_i + C_j + L_k + H_l + (L \times H)_{kl} + \varepsilon_{ijkl},$$

where Y_{ijkl} is the dependent variable, μ is the population mean, P_i is the period effect ($i = 1$ to 5), C_j is the random effect of the cow ($j = 1$ to 5), L_k is the effect of the CS chop length ($k = 1$ to 2), H_l is effect of the LH level ($l = 1$ to 3 for FCS diets and 1 to 2 for CCS diets), $(L \times H)_{kl}$ is the interaction among the factors chop length and LH level, and ε_{ijkl} is the experimental error. Ruminal pH, NH_3 and VFA data were analyzed as a Latin square with repeated measures using the MIXED procedure of SAS (SAS Institute, 1998). Orthogonal contrasts were used to compare the following means among treatments: F0 vs. C0, linear and quadratic effect of LH level in FCS-based diets, and linear effect of LH level in CCS-based diets.

RESULTS AND DISCUSSION

Chemical and Physical Characteristics of CS and Diets

The nutritive composition of the CS used in our study (Table 1) was within the typical range observed for CS produced in Argentina (Schroeder et al., 2000). Increasing the TCL of CS and including long fibrous forages such as LH are 2 strategies used to increase peNDF and MPS of the diet (Beauchemin et al., 1994). However,

Table 2. Particle size distribution of the corn silages, experimental TMR, and orts

	Corn silage ¹		TMR						
			Experiment 1		Experiment 2 ²				
	FCS	CCS	FCS	CCS	F0	F5	F10	C0	C5
Sieve size, % DM retained on sieve or pan									
19.0 mm	2.3	24.9	3.0	16.0	3.9	17.9	25.9	17.0	24.4
8.0 mm	26.6	43.9	45.0	52.5	51.4	41.0	31.3	51.9	46.4
Pan	71.1	31.2	52.0	31.5	44.8	41.1	42.8	31.1	29.2
PEF ³	0.29	0.69	0.48	0.69	0.55	0.59	0.57	0.69	0.71
peNDF ⁴	12.1	30.8	16.1	22.2	17.8	21.4	21.8	23.0	24.6
MPS, ⁵ cm	0.5	1.2	0.5	1.0	0.8	0.9	0.9	1.3	1.5
Orts sieve size, % DM retained on sieve or pan									
19.0 mm	—	—	5.0	18.5	4.4	17.7	26.8	17.7	25.9
8.0 mm	—	—	40.0	49.7	38.1	49.4	24.4	48.9	48.0
Pan	—	—	55.0	31.8	57.4	32.9	48.8	33.4	26.1

¹FCS = Fine corn silage, 6-mm theoretical cut length; CCS = coarse corn silage; 23-mm theoretical cut length.

²F0 = TMR based on FCS similar to that of Experiment 1; F5 = F0 plus 5% (DM basis) long hay (LH); F10 = F0 plus 10% LH; C0 = TMR based on CCS similar to that of Experiment 1; and C5 = C0 plus 5% LH.

³PEF = Physical effectiveness factor determined as the proportion of particles (DM basis) retained by both sieves of the Penn State Particle Separator.

⁴peNDF = Physically effective NDF, estimated as NDF content (Table 1) multiplied by PEF.

⁵MPS = Mean particle size (Weibull distributed).

changes in TCL affected peNDF and MPS of the TMR in greater magnitude than supplementation with LH (Table 2). This was due to the increase in the proportion of the particles retained on the 8.0-mm sieve, which represent the greatest proportion of the diet, whereas LH inclusion only affected the proportion of the longest particles (>19.0 mm). The CCS presented more than 24% of particles >19.0 mm (Table 2), similar to the CS used in previous studies (Bal et al., 2000; Kononoff and Heinrichs, 2003). Moreover, the range of TCL used in our study (6.0 vs. 23.0 mm) was considered as the maximum possible under practical conditions (Kononoff and Heinrichs, 2003), indicating that a desirable spread of particle size was obtained in the experimental diets (Table 2). The proportion of long particles (>19.0 mm) in FCS-based diets without added LH was below the proposed requirement to achieve optimal physical effectiveness (Heinrichs and Lammers, 1997). However, the total NDF concentration (>32%, Table 1) was above the minimum (25 to 28%) recommended by the NRC (2001). In addition, all treatments, except FCS-based TMR in Experiment 1 and F0 in Experiment 2 (Table 2), presented a level of total dietary peNDF content above the value (19.7%) recommended by Mertens (1997).

The aggressive kernel processing during harvest was used to minimize effects of TCL of CS on grain digestion (Bal et al., 2000). Cooke and Bernard (2005) observed a similar apparent digestibility of starch for CS with different TCL (19.5 vs. 25.4 mm) when a 2-mm roll clearance processor was used. Thus, in our study it is assumed that TCL of CS did not affect significantly the starch digestion.

Intake, Milk Yield, and Composition

In Experiment 1, cows fed FCS-based TMR tended ($P < 0.10$) to have higher DMI and had higher ($P < 0.05$) NDF, starch, and CP intake (Table 3) than cows fed CCS-based TMR. There was a treatment $\times$ week interaction (Table 3) because of greater differences between treatments at wk 3, 8, and 9 of lactation; however, the intake was also higher in FCS-fed cows during the other weeks evaluated. Previous studies have observed variable effects of TCL of CS on DMI, observing both increases (Fischer et al., 1994; Stockdale and Beavis, 1994) and lack of effects (Bal et al., 2000; Kononoff and Heinrichs, 2003) when CS of smaller TCL were fed to dairy cows. In addition, previous studies have observed that cows sort against longer particles when fed a diet with larger MPS (Kononoff and Heinrichs, 2003; Leonardi and Armentano, 2003). However, in our study the orts had similar particle size distribution to the TMR offered (Table 2), indicating that cows did not sort significantly. Similar results were observed by Leonardi et al. (2005), who suggested that when silages represent more than 50% of dietary DM (58% in this study) the extent of sorting was reduced. Furthermore, in our study all the cows were multiparous, and it has been shown that primiparous cows sort more against larger particles than multiparous cows (Leonardi et al., 2005).

The increase in nutrient intake was not associated with changes in milk yield and composition, BW, BCS, or plasma metabolites measured during the first 75 DIM (Table 3). These results are in agreement with previous studies in which diets based on CS with re-

Table 3. Dry matter intake, milk yield and composition, changes in weight, body condition score, and plasma metabolite concentrations in lactating dairy cows fed diets based on corn silage with fine or coarse theoretical cut length (Experiment 1)

	Treatments ¹			Effects, <i>P</i> <		
	FCS	CCS	SEM	TCL	Wk	TCL × Wk
Intake						
DM, kg/d	23.4	22.1	0.65	0.10	0.01	0.01
DM, % of BW	4.1	3.8	0.18	0.10	0.01	0.01
NDF, kg/d	7.9	7.1	0.21	0.05	0.01	0.01
NDF, % of BW	1.4	1.2	0.20	0.05	0.01	0.01
Starch, kg/d	4.8	4.0	0.12	0.01	0.01	0.01
CP, kg/d	4.4	3.9	0.12	0.01	0.01	0.01
Milk yield						
Milk, kg/d	24.2	22.9	1.49	NS ²	0.01	NS
4% FCM, kg/d	24.9	23.9	1.59	NS	0.05	NS
Efficiency, kg of 4% FCM/kg of DMI	1.06	1.08	1.01	NS	—	—
Milk composition						
Milk fat, kg/d	1.0	0.9	0.07	NS	0.05	NS
Milk fat, %	4.3	4.3	0.20	NS	0.01	NS
Milk protein, kg/d	0.8	0.8	0.04	NS	NS	NS
Milk protein, %	3.5	3.5	0.09	NS	0.01	NS
Lactose, %	4.9	4.9	0.11	NS	0.10	NS
BW and BCS						
BW change, kg/d	0.29	0.44	0.17	NS	—	—
BCS change, ³ points	−0.5	−0.4	0.80	NS	—	—
SFD change, ⁴ mm	0.3	−0.1	0.22	NS	—	—
Plasma metabolites						
Glucose, mg/dL	62.2	59.5	2.18	NS	0.01	NS
Urea, mg/dL	17.7	17.4	1.25	NS	NS	NS

¹FCS = Fine corn silage, 6-mm theoretical cut length (TCL); CCS = coarse corn silage; 23-mm TCL.

²NS = Not significant, *P* > 0.05.

³Differences between values recorded at the beginning and at the end (75 DIM) of the experiment. Body condition score using a five-point scale (1 = thin to 5 = fat; Wildman et al., 1982).

⁴Differences between values recorded at the beginning and at the end (75 DIM) of the experiment. Subcutaneous fat depth (SFD) measured between the 12th and 13th rib (McDonald et al., 1999).

duced particle size did not affect milk yield in early lactating dairy cows (Clark and Armentano, 1999; Kononoff and Heinrichs, 2003). A possible increase in total tract digestibility in cows fed CCS-based TMR due to a longer retention time may partially compensate for the differences in nutrient intake and explain the lack of effects on milk yield. However, efficiency of fat-corrected milk yield (Table 3), as well as particles rate of passage measured in Experiment 2, were not affected by TCL of CS. The moderate genetic merit of the cows used in our study and the high variability among cows (Table 3) could limit the capacity of the cows to respond to small increases in nutrient intake or our ability to detect those differences statistically.

Intake, Chewing Activities, and Ruminal pH

In Experiment 2, the cows fed F0 tended (*P* < 0.10) to increase DMI (+2.3 kg of DM/d) compared with those fed C0 (Table 4), which was consistent with the results from Experiment 1 (Table 3). Kononoff et al. (2003) observed increases in DMI of similar magnitude (+2.3 kg of DM/d) when a TMR based on CS with reduced

particle size was fed to dairy cows. A significant (*P* < 0.05) interaction between TCL of CS and LH supplementation was observed for DMI (Table 4), with LH supplementation linearly decreasing DMI in FCS-based diets (25.0 to 21.7 kg/d) but increasing DM (22.7 vs. 27.1 kg/d) and NDF (7.6 vs. 9.4 kg/d) intakes when cows were fed with CCS-based diets. These increases in DM (3.9 vs. 4.6%) and NDF (1.3 vs. 1.6%) intake were also significantly higher when expressed as percentage of BW. Similarly, Fischer et al. (1994) observed increased DMI in response to the inclusion of LH in a basal diet with larger particle size. Leonardi et al. (2005) suggested that increases in dietary particle size might have a positive effect on DMI when ruminal pH is low, but a negative effect when ruminal pH is high (>5.8). Conversely, in our study the increase in MPS by adding LH (Table 2) increased DMI in those cows consuming CCS-based diets (Table 4), which presented a higher ruminal pH (Table 5), suggesting that factors other than ruminal pH were involved. However, more research is needed to understand the physiological mechanisms involved in that type of response before definitive conclusions can be made.

Table 4. Intake and chewing activity in dairy cows fed diets based on corn silage with fine or coarse theoretical cut length and supplemented with 0, 5, or 10% long hay¹ (Experiment 2)

Item	Long hay addition, ² %					SEM
	F0	F5	F10	C0	C5	
Intake						
DM, kg/d ^{ab}	25.0	23.0	21.7	22.7	27.1	0.83
DM, % of BW ^{ab}	4.3	3.9	3.7	3.9	4.6	0.23
NDF, kg/d ^b	8.1	8.4	8.3	7.6	9.4	0.46
NDF, % of BW ^b	1.4	1.4	1.4	1.3	1.6	0.08
Chewing activity, min/d						
Total	812	840	860	821	725	37.4
Eating	401	440	406	405	383	36.2
Ruminating	411	380	454	416	342	35.0
Chewing activity, min/kg of DM						
Total ^b	33.1	37.0	40.1	37.0	27.4 ^b	2.5
Eating	16.3	19.7	19.1	18.2	14.4	2.2
Ruminating ^{ab}	16.8	16.5	21.0 ^a	18.8	12.9	1.4
Chewing activity, min/kg of NDF						
Total ^b	102.4	102.3	104.6	110.7	78.8	7.8
Eating	50.5	54.4	49.8	54.4	41.6	6.2
Ruminating ^b	52.0	45.6	54.7	56.3	37.2	4.0

^{a,b}Orthogonal contrast ($P < 0.05$): a = linear effect of long hay supplementation in FCS diets, and b = effect of long hay supplementation for CCS diets.

¹Grass (*Agropyrum elongatum* L.) unprocessed hay.

²F = Fine corn silage, 6-mm theoretical cut length; C = coarse corn silage; 23-mm theoretical cut length; 0, 5, and 10 represent the percentage of long hay added.

Total chewing time (818 min/d), ET (403 min/d), and RT (412 min/d) were similar for cows fed F0 or C0 diets (Table 4). Long hay supplementation linearly increased RT (min/kg of DM) in cows fed FCS-based diets, but this effect was not observed when TCT was adjusted by NDF intake, suggesting that the greater chewing effort was related to the higher NDF content in F5 and F10 (Table 1) rather than the larger MPS of these diets (Table 2). Furthermore, LH supplementation in cows fed CCS-based diets decreased the TCT and RT (Table 4), suggesting that factors other than NDF concentration may influence the chewing activity necessary to

reduce each unit of DM and NDF to smaller particles in these diets. Similar results were observed by Fischer et al. (1994), who found that RT increased when LH was included in a fine-chopped alfalfa silage-based diet, but decreased when included in a coarse-chopped alfalfa silage-based diet. Furthermore, supplementation with LH increased RT in cows fed a diet containing 27% NDF, but decreased RT when the NDF content was 32% NDF (Beauchemin et al., 1994). These results seem to indicate that LH supplementation produces different effects on chewing activities depending on the MPS and the NDF level of the basal diet, being more useful to

Table 5. Ruminal pH, ammonia, and VFA in dairy cows fed diets based on corn silage with fine or coarse theoretical cut length and supplemented with 0, 5, or 10% long hay¹ (Experiment 2)

Item ³	Long hay addition, ² %					SEM
	F0	F5	F10	C0	C5	
pH ^a	5.69	5.72	5.80	5.85	5.91	0.06
NH ₃ , mg/dL	18.5	21.5	18.1	19.5	19.7	2.6
Total VFA, mM	118.4	115.0	117.2	116.5	112.7	6.4
Acetate (A), molar proportion	54.4	56.0	52.8	56.8	57.0	1.4
Propionate (P), molar proportion	20.7	19.9	22.9	20.1	20.6	1.3
A:P ratio	2.63	2.88	2.47	2.85	2.82	0.2
Butyrate, molar proportion ^a	13.3	12.6	12.8	11.2	10.6	0.7

^aOrthogonal contrast ($P < 0.05$): effect of theoretical cut length.

¹Grass (*Agropyrum elongatum* L.) unprocessed hay.

²F = Fine corn silage, 6-mm theoretical cut length; C = coarse corn silage; 23-mm theoretical cut length; 0, 5, and 10 represent the percentage of long hay added.

³The effect of the sampling time was significant ($P < 0.05$) and the effect of the interaction time × treatment was not significant ($P > 0.10$) for all the variables analyzed.

increase the physical effectiveness of diets with smaller MPS and lower levels of NDF.

The decrease in the ruminal pH (Table 5) associated with the reduction in TCL observed in our study was in agreement with a previous study in which dairy cows fed CS-based TMR presented a lower ruminal pH (6.0 vs. 6.2) when TCL was reduced from 24 to 6 mm (Gregorini et al., 2002). In the present study, cows fed FCS-based TMR presented a mean ruminal pH of 5.8 or lower, but greater than 5.0, which is often considered as the range at which incidence of subclinical ruminal acidosis increases (Beauchemin and Yang, 2005). Although cows fed C5 spent less time ruminating (Table 4), ruminal pH was not different from that of cows fed C0 (Table 5), indicating that ruminal pH and chewing activities were poorly related. Previous studies suggested that in dairy cows consuming ad libitum diets containing high levels of ruminal degradable OM, chewing activities may not affect the ruminal pH because salivary buffer production is not enough to counterbalance the acid production by ruminal fermentation (Kononoff et al., 2003; Beauchemin and Yang, 2005).

The lower ruminal pH observed in cows fed FCS-based diets was not associated with changes in total VFA concentration or acetate to propionate ratio (Table 5). Previous studies using alfalfa hay (Santini et al., 1983) or alfalfa silages (Grant et al., 1990) with different TCL demonstrated decreases in the acetate to propionate ratio as particle size was reduced. Kononoff et al. (2003) also observed a lower acetate to propionate ratio in cows consuming FCS-based diet, suggesting that this result was due to changes in NDF intake and increases in starch digestibility due to the greater processing of CS. In our study, the lack of effects of TCL on pH and the acetate to propionate ratio was in agreement with a similar NDF intake (Table 4) and the assumed similar grain (starch) digestion among treatments because of the use of a kernel processor (2-mm roll clearance) during harvesting (Cooke and Bernard, 2005).

Ruminal DM and NDF In Situ Disappearance

Theoretical cut length of the CS did not affect in situ DM disappearance (Table 6). This result was in agreement with previous studies that observed a similar DM digestion in CS with different TCL when grain digestion was not affected by grain processing in CCS, for example, by use of kernel processor at harvesting (Stockdale and Beavis, 1994; Bal et al., 2000). Long hay supplementation tended ($P < 0.10$) to increase the rate of DM in situ disappearance on FCS-based diets (2.9 to 7.8%/h), and a numerical increase was also evident on CCS-based diets (Table 6). However, effective DM

disappearance (kg/d) tended ($P < 0.10$) to linearly decrease due to LH supplementation, indicating that the increase in the rate of disappearance was not enough to compensate for the numerical increase in the solids passage rate associated with LH supplementation (Table 6).

It has been suggested that adhesion of cellulolytic bacteria to fiber may decrease when ruminal pH is lower than 6.0 (Mourino et al., 2001). Thus, the tendency ($P < 0.10$) for longer lag-time of NDF in situ disappearance for F0 compared with C0 (8.9 vs. 3.8 h; Table 6) may be related to the lower ruminal pH observed in this treatment (Table 5). However, effective ruminal disappearance of NDF was not significantly affected by TCL of CS (Table 6). Long hay addition in CCS-based diets tended ($P < 0.10$) to increase the rate of ruminal NDF disappearance (2.0 vs. 4.4%/h), resulting in a numerical increase in effective NDF disappearance in the rumen. The values of the standard NDF in situ disappearance observed in our study were similar to those observed by Schroeder et al. (2003) using the same standard NDF in dairy cows fed a CS-based TMR. Similar to the tendency observed for a faster rate of disappearance of the CS DM, LH supplementation in FCS-based diets tended ($P < 0.10$) to linearly increase the standard NDF disappearance (Table 6), suggesting that LH improved ruminal conditions for fiber digestion when cows were fed a FCS-based diet. However, the numerical increase in the rate of passage by LH addition seemed to relegate the positive effects of a more adequate ruminal condition for NDF digestion.

Despite the differences in DMI (Table 4), significant differences in solids passage rates were not observed (Table 6). This result was unexpected, but was in agreement with previous studies in which silages with different TCL (Bal et al., 2000; Beauchemin and Yang, 2005; Leonardi et al., 2005) or LH addition (West et al., 1997) did not affect particles passage rate.

The reduction in the filling effect of NDF in the cows fed C5 compared with those fed C0 (Table 6) may be related to the shorter RT and the decreased RT for each unit of NDF consumed (Table 4). Lower filling effect of NDF on C5 may also explain the higher NDF intake observed in this treatment (Table 4) because those differences in NDF intake were removed when expressed as calculated fill NDF intake (Table 6).

CONCLUSIONS

Under the conditions of this study, using diets with more than 32% NDF and cows of moderate genetic merit, the reduction in the TCL of CS from 23 to 6 mm increased intake of nutrients, but did not affect milk yield and milk composition.

Table 6. Ruminal disappearance and solids passage rate in dairy cows fed diets based on corn silage with fine or coarse theoretical cut length and supplemented with 0, 5, or 10% long hay¹ (Experiment 2)

Item	Long hay addition, ² %					SEM
	F0	F5	F10	C0	C5	
DM disappearance						
Soluble fraction, %	32.0	32.9	29.4	30.9	32.4	1.6
Slowly digestible fraction, %	44.3	44.0	40.8	49.0	50.5	6.3
Disappearance rate, %/h	2.9	5.0	7.8	3.0	5.0	2.1
Effective disappearance, % ³	48.4	50.0	44.8	47.2	51.6	4.5
Effective disappearance, kg/d ³	7.9	6.3	5.0	6.8	7.9	1.3
NDF disappearance						
Lag-time, h	8.9	7.8	9.5	3.8	3.2	2.2
Slowly digestible fraction, %	51.5	50.2	53.0	53.1	52.5	4.8
Disappearance rate, %/h	2.2	2.0	2.9	2.0	4.4	0.6
Effective disappearance, % ³	5.5	4.6	5.2	7.6	13.3	3.4
Standard NDF disappearance, % ⁴	22.3	25.7	29.6	27.6	31.0	2.9
Solids passage rate, %/h	5.4	5.9	6.3	6.1	7.3	0.9
Dietary calculated fill NDF, % ^{5,a}	31.0	32.3	30.2	30.2	21.4	2.8
Calculated fill NDF intake, kg/d	2.5	2.6	2.5	2.2	2.0	0.4

^aOrthogonal contrast ($P < 0.05$): effect of long hay supplementation for CCS diets.

¹Grass (*Agropyrum elongatum* L.) unprocessed hay.

²F = Fine corn silage, 6-mm theoretical cut length; C = coarse corn silage; 23-mm theoretical cut length; 0, 5, and 10 represent the percentage of long hay added.

³Calculated according Ørskov and McDonald (1979).

⁴NDF obtained from *Agropyrum elongatum* L. hay and incubated for 48 h into the rumen.

⁵Calculated according Hoover (1986).

Supplementation with LH seems to be a suitable strategy to increase RT in cows fed FCS-based diets. However, these effects may be related to the increase in NDF concentration rather than the increase in the MPS of the diets. Furthermore, the addition of LH to CCS-based diets did not affect ruminal NDF disappearance, but increased DMI by reducing filling effect of NDF and the time needed for rumination. These results suggest that the effects of LH supplementation on chewing activities may depend on the MPS and the NDF concentration of the diet. Further studies are needed to evaluate the long-term effects and interactions among MPS, NDF, and peNDF level, and LH supplementation on ruminal digestion, chewing activities, and milk yield.

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