

Effect of Alfalfa Silage Storage Structure and Roasting Corn on Production and Ruminal Metabolism of Lactating Dairy Cows¹

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ABSTRACT

The objective of this study was to determine if feeding roasted corn would improve production and nutrient utilization when supplemented to lactating cows fed 1 of 3 different alfalfa silages (AS). Forty-two lactating Holstein cows (6 fitted with ruminal cannulas) averaging 77 d in milk and 43 kg of milk/d pretrial were assigned to 2 cyclic changeover designs. Treatments were AS ensiled in bag, bunker, or O₂-limiting tower silos and supplemented with ground shelled corn (GSC) or roasted GSC (RGSC). Silages were prepared from second-cutting alfalfa, field-wilted an average of 24 h, and ensiled over 2 d. Production and N utilization were evaluated in 36 cows during four 28-d periods, and ruminal fermentation was evaluated with 6 cows during five 21-d periods. Experimental diets contained 40% AS, 15% corn silage, and 35% of either GSC or RGSC on a dry matter basis. No significant interactions between AS and corn sources were detected for any production trait. Although the chemical composition of the 3 AS was similar, feeding AS from the O₂-limited tower silo elicited positive production responses. Yields of 3.5% fat-corrected milk and fat were increased 1.7 kg/d and 150 g/d, and milk fat content was increased 0.3% when cows were fed diets based on AS from the O₂-limiting silo compared with the other 2 silages. The responses in milk fat were paralleled by an average increase in acid detergent fiber digestibility of 270 g/d for cows fed AS from the O₂-limiting tower silo. However, ruminal concentrations of lipogenic volatile fatty acids were unchanged with AS source. Cows fed RGSC consumed 0.6 kg/d more dry matter and yielded 30 g/d more protein and 50 g/d more lactose than cows fed

GSC diets. There was no evidence of increased total tract digestibility of organic matter or starch, or reduced ruminal NH₃ concentration, when feeding RGSC. Free amino acids increased, and isovalerate decreased in rumen fluid from cows fed RGSC diets. However, responses in production with roasted corn were mainly due to increased dry matter intake, which increased the supply of energy and nutrients available for synthesis of milk and milk components.

Key words: alfalfa silage storage structure, dairy cow, milk production, roasted corn

INTRODUCTION

Ensiling is a common practice on farms, and technologies offer many ways to help ensure consistent preservation. Different options for harvesting and various silo types can affect silage quality (Muck and O'Kiely, 2002). Alfalfa protein can be subject to extensive degradation during ensiling. Alfalfa silage (AS) is high in protein that is rapidly degraded in the rumen. Nonprotein N in AS may range from 43% (Nagel and Broderick, 1992) to 87% (Muck, 1987) of total CP. The NPN in AS is rapidly degraded to ammonia in the rumen and, if not captured as microbial protein, will be absorbed, converted to urea in the liver, and excreted in the urine. Additionally, dietary forage quality may have a more dominant effect on rumen fermentation pattern than source or amount of dietary concentrate (Keady and Mayne, 2001), or supplementation of a glucogenic precursor (Shingfield et al., 2002).

Improvements in milk and protein yield with diets based on AS have been achieved by replacing solvent-extracted soybean meal with protein sources higher in RUP (Broderick et al., 1990; Faldet and Satter, 1991; Broderick, 1992), and by adding energy to the diets as high moisture corn (HMC; Vagnoni and Broderick, 1997). Moreover, grinding of HMC has increased yield of milk and milk components and reduced ruminal ammonia concentrations (Ekinici and Broderick, 1997). These results indicated that milk production could be

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Table 1. Composition of alfalfa silages stored in 3 types of silos (bag, bunker, and O₂-limiting tower silos), corn silage, and ground corn¹

Component	Bag AS		Bunker AS		O ₂ -limiting AS		Corn silage		GSC		RGSC	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DM, %	48.9	4.3	47.4	2.9	49.0	2.3	48.4	2.2	89.5	0.8	92.7	0.6
CP, % of DM	22.3	1.0	22.4	0.6	21.7	0.8	6.1	0.2	9.27	0.20	9.49	0.32
Ash, % of DM	10.1	0.5	9.84	0.35	9.45	0.48	3.96	0.27	1.54	0.49	1.57	0.21
NDF, % of DM	35.4	3.3	39.1	1.1	37.9	2.4	43.1	2.2	9.46	0.58	9.52	0.82
ADF, % of DM	26.7	2.9	29.9	1.0	29.2	2.0	23.3	1.3	2.27	0.14	2.14	0.18
NDIN, ² % of total N	20.6	2.7	18.8	2.0	18.3	3.1	—	—	18.9	2.6	25.0	3.3
ADIN, % of total N	4.54	0.71	5.09	1.38	5.47	0.40	—	—	5.15	2.94	4.67	1.82
NDIN – ADIN, % of total N	16.1	2.5	13.7	2.0	12.8	2.8	—	—	13.8	3.6	20.3	3.9
Starch, % of DM	—	—	—	—	—	—	—	—	67.9	0.8	68.2	0.9
NPN, % of total N	45.8	7.3	49.9	7.5	49.5	9.25	69.1	16.0	—	—	—	—
NH ₃ , % of total N	2.30	0.64	2.48	0.42	1.94	0.32	4.39	1.55	—	—	—	—
Total AA-N, % of total N	19.1	2.9	23.4	3.7	22.0	3.3	18.4	5.4	—	—	—	—
pH	4.64	0.21	4.68	0.12	4.48	0.08	4.26	1.09	—	—	—	—
Succinate, % of DM	0.37	0.10	0.42	0.09	0.37	0.08	0.16	0.05	—	—	—	—
Lactate, % of DM	4.65	0.69	4.87	0.93	5.13	1.09	2.58	0.86	—	—	—	—
Formate, % of DM	0.06	0.03	0.09	0.04	0.07	0.02	0	0	—	—	—	—
Acetate, % of DM	0.90	0.47	1.41	0.31	0.93	0.21	0.66	0.25	—	—	—	—
Propionate, % of DM	0	0	0.02	0.05	0.01	0.03	0	0	—	—	—	—
Butyrate, % of DM	0	0	0.03	0.06	0	0	0	0	—	—	—	—
2,3-Butandiol, % of DM	0.33	0.05	0.38	0.07	0.33	0.04	0.24	0.03	—	—	—	—
Ethanol, % of DM	0.22	0.11	0.19	0.10	0.24	0.11	0.12	0.12	—	—	—	—

¹AS = alfalfa silage, GSC = ground shelled corn, and RGSC = roasted ground shelled corn.

²NDIN = neutral detergent insoluble N.

improved on AS diets by increasing the supply of fermentable energy in the rumen. Roasting dry corn has been proposed as a means of increasing energy availability to the rumen microbes by gelatinizing the starch. Cunningham and Perry (1972) reported more rapid BW gain and improved feed efficiency when growing dairy heifers were fed roasted corn compared with dry corn; however, little research has been performed on feeding of roasted corn to lactating dairy cows.

The objective of this experiment was to determine whether roasting improved utilization of dry shelled corn when fed with alfalfa ensiled in bag, bunker, or O₂-limited tower silos, for milk production, N utilization, and ruminal fermentation in high-yielding dairy cows.

MATERIALS AND METHODS

Experimental Procedure

The alfalfa from the same fields was ensiled in 3 different silos: bag (AgBag Systems, Inc., St. Nazianz, WI), bunker, or O₂-limited tower silo (Harvestore, Engineered Storage Products Company, DeKalb, IL). Dimensions for bag, bunker, and O₂-limited tower silos were 2.4 m diameter × approximately 52 m long, 4.9 m wide × 20.1 m long × 3.5 m high, and 4.3 m diameter × 15 m high, respectively. First-cutting alfalfa was harvested over a 2-d period in May 2004, to produce re-growth of similar maturity across all fields. The second-

cutting alfalfa was mown June 27–28, 2004, using a New Holland FX 58 forage harvester (CNH Global, New Holland, PA) and field-wilted for an average of 24 h. A portion of each field was allotted to each silo. The alfalfa was ensiled over June 28 to 29, 2004. All forages were chopped to a theoretical length of 2.9 cm and ensiled after application of a commercial inoculant (H/MF Inoculant, Pharm Tech, Des Moines, IA) to supply 1×10^5 cfu of total lactic acid bacteria/g of wet silage. The bag and bunker silos were filled on both dates, where the O₂-limiting silo was filled only on June 29. Drying conditions were good, and no rainfall was recorded during harvest. All AS was weighed and sampled as fed out in 2005 from each silo. Total DM losses in the silos were calculated as gaseous losses plus spoiled silage that was not fed. Gaseous losses were estimated from the ratio of the total amount removed (fed plus spoiled) to total amount filled into each silo. Composition of the 3 sources of AS is in Table 1. Silage densities in bag and bunker silos, calculated from the total amount filled and silo dimensions, were 165 and 296 kg of DM/m³, respectively.

The corn grain fed in this trial was either unroasted or roasted using a mobile system consisting of a propane-fired roaster with a throughput rate of 12 t/h (Roast-A-Matic, Schnupp's Grain Roasting Inc., Lebanon, PA). The corn kernels passed directly through the propane flame (approximate flame temperature of 650°C) and were heated to a temperature of 135°C when exiting the roaster. Before the feeding study, a prelimi-

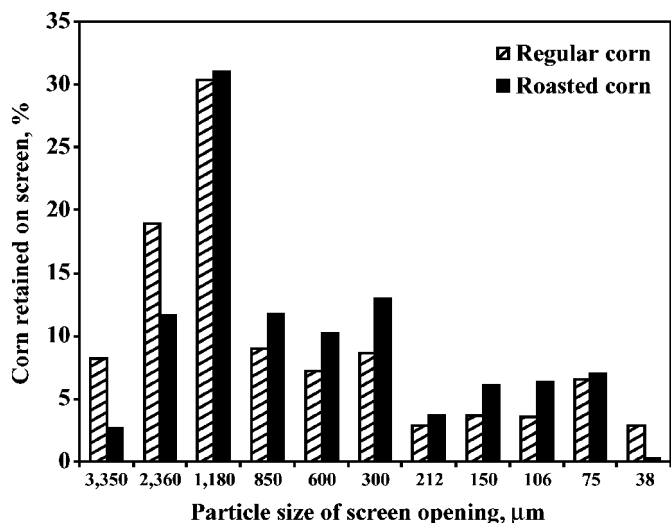


Figure 1. Corn particle size distribution (% of a 150-g corn sample) of regular (striped bars) and roasted dry corn (black bars) used in the ruminal metabolism and lactation trial with dairy cows.

nary in vitro incubation was done with dry corn roasted in this manner. Unroasted and roasted corn was ground through 4- and 8-mm screens using a Wiley mill (Arthur H. Thomas, Philadelphia, PA). Duplicate samples of 10 g of DM of both grind sizes from control and roasted corn were weighed into 250-mL spinner flasks (Belco, Vineland, NJ); 100 mL of McDougall's buffer (McDougall, 1948) was added to each flask. The flasks were held at 39°C for 1 h before adding inoculum. Two blank flasks containing only McDougall's buffer (no corn) were also used. Ruminal contents were collected 2 h after feeding from 2 cannulated lactating cows consuming 60% alfalfa silage, 30% ground corn, and 10% soybean meal (DM basis). Contents were strained through 4 layers of cheesecloth and equal volumes of the resulting ruminal fluid were blended and brought to 39°C. Then, 2 mM cysteine-HCl and 10 mM NH_3 were added and incubations begun by adding 200 mL of this inoculum to all flasks. Flasks were incubated at 39°C under a CO_2 atmosphere with continuous mixing using magnetic stir bars. Duplicate 2-mL aliquots were removed from each flask every hour from time 0 (immediately after inoculating) to 6 h, mixed with 0.5 mL of 25% TCA (wt/vol), and vortexed; samples were held on ice for 30 min and then centrifuged ($10,000 \times g$ for 15 min at 2°C). Supernatants were analyzed for NH_3 (Broderick et al., 2004) immediately after the incubation. Mean NH_3 concentrations from blank vessels and vessels containing corn were plotted as a function of time. The grain to be fed in the lactation trial was augered into trucks directly from the roaster and cooled to ambient temperature on the trucks before being transported and stored in bins

until ground. Both unroasted and roasted corn were ground with a hammer mill to produce the control ground shelled corn (GSC) and roasted ground shelled corn (RGSC). A portable, vertically oscillating sieve shaker Ro-Tap RX-29 model (W. S. Tyler Inc., Mentor, OH) was used to determine the particle size distributions of GSC and RGSC by placing approximately 150 g of sample on the top screen of the stack of sieves and shaking for 20 min. Eleven screens with sieve sizes between 38 and 3,350 μm were used in all determinations. Particle size distribution is shown in Figure 1. The arithmetic mean particle size and percentage of particles recovered on sieves were calculated for each sample as described by Grant et al. (1990). Composition of the 2 corn sources is given in Table 1.

Forty-two lactating Holstein cows, 30 multiparous (6 fitted with ruminal cannulas) and 12 primiparous, with mean BW of 591 (SD 62) kg, parity 2.3 (SD 1.2), 77 (SD 30) DIM, and producing 43 (SD 6) kg of milk/d at the start of the trial, were used in 2 separate trials. Production and N utilization were evaluated using 36 cows in a cyclic changeover design with 3 replications of 2 blocks of 6 cows, in an arrangement with four 28-d periods (Davis and Hall, 1969). Cows were blocked by parity and DIM and, within block, randomly allocated to the sequences of experimental treatments. Cows fitted with ruminal cannulas were used in a separate 1-block cyclic changeover design with five 21-d periods (Davis and Hall, 1969) and randomly assigned to treatment sequence. Dietary treatments were in a 3×2 factorial arrangement, consisting of the 3 sources of AS and the 2 sources of corn (GSC or RGSC). The experimental diets were fed as TMR and contained (DM basis) 40% AS, 15% corn silage, and 35% of either GSC or RGSC as principal concentrate source (Table 2). The proportions of AS, GSC, and RGSC in the diets as fed were adjusted weekly based on DM determined at 60°C for 48 h. Amounts of solvent soybean meal and roasted soybeans were adjusted to provide 17% CP across diets. The ratio of corn silage to AS (15:40) was formulated to maintain 28% NDF across diets. Cows were housed in tie stalls, had free access to water, and were offered feed once daily at 1200 h; orts were recorded once daily and feeding rate adjusted to yield orts of approximately 10% of intake. Body weights were measured on 3 consecutive days at the start of the trial and at the end of each period. All cows were injected with bST (500 mg of Posilac; Monsanto, St. Louis, MO) beginning on d 1 of the trial and at 14-d intervals throughout. The Research Animal Resource Center of the University of Wisconsin-Madison approved all procedures involving animal care and experimental procedures.

Weekly composites of corn silage, all 3 AS, TMR, and orts were taken from daily samples of about 0.5 kg, and

Table 2. Composition of experimental diets comprising alfalfa silages (AS) stored in 3 types of silos (bag, bunker, and O₂-limiting tower silos) and 2 sources of corn¹

	Bag AS		Bunker AS		O ₂ -limiting AS	
	GSC	RGSC	GSC	RGSC	GSC	RGSC
	— % of DM —					
Ingredient composition						
Bag alfalfa silage	40.0	40.1	—	—	—	—
Bunker alfalfa silage	—	—	41.1	41.2	—	—
O ₂ -limiting alfalfa silage	—	—	—	—	40.5	40.6
Corn silage	14.8	14.8	14.5	14.5	14.6	14.7
GSC	35.1	—	34.5	—	34.8	—
Roasted GSC	—	34.9	—	34.3	—	34.6
Solvent soybean meal	5.11	5.12	5.02	5.03	5.07	5.08
Roasted soybeans	4.01	4.02	3.94	3.95	3.97	3.98
Sodium bicarbonate	0.50	0.50	0.49	0.49	0.50	0.50
Salt	0.20	0.20	0.20	0.20	0.20	0.20
Dicalcium phosphate	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin-mineral mix ²	0.10	0.10	0.10	0.10	0.10	0.10
Chemical composition						
DM, %	66.8	67.8	66.0	66.9	66.4	67.4
CP	17.7	17.8	17.7	17.8	17.4	17.5
Ash	6.8	6.8	6.6	6.6	6.5	6.5
NDF	25.5	25.6	26.9	27.0	26.5	26.6
ADF	15.4	15.4	16.7	16.7	16.5	16.5
Fat ³	3.1	3.6	3.3	3.5	3.0	3.4
Starch ³	24.2	26.8	24.2	24.6	24.6	25.3
NE _{Lp} ⁴ , Mcal/kg of DM	1.69	1.71	1.69	1.70	1.68	1.70

¹GSC = ground shelled corn, and RGSC = roasted ground shelled corn.

²Provided (per kilogram of DM): 56 mg of Zn, 46 mg of Mn, 22 mg of Fe, 12 mg of Cu, 0.9 mg of I, 0.4 mg of Co, 0.3 mg of Se, 6,440 IU of vitamin A, 2,000 IU of vitamin D, and 16 IU of vitamin E.

³Averages content calculated from analyzed TMR samples from each period.

⁴Computed according to NRC (2001) using composition above and tabulated values of lignin to calculate content in diets. The NE_{Lp} for each diet was computed from the total digestible nutrient (TDN) value at 1× maintenance using the relationship between feeding level as multiple of maintenance and the unit decline in diet TDN given by NRC (2001).

stored at -20°C. Weekly samples were also taken from solvent soybean meal, roasted soybeans, GSC, and RGSC. The proportion of dietary DM from each ingredient was calculated from the weekly DM determinations of feed samples at 60°C for 48 h. After drying, feed ingredients and TMR were ground through a 1-mm screen (Wiley mill; Arthur H. Thomas, Philadelphia, PA). Composites were prepared of the TMR, GSC, and RGSC from the last 2 wk of every period in the production trial. Weekly samples of TMR and feed ingredients were analyzed for total N using a combustion assay (Leco FP-2000 N analyzer; Leco Instruments, Inc., St. Joseph, MI), and DM content at 105°C (AOAC, 1980). These results were used for weekly adjustment of the diet composition. Intake of DM was computed based on the 60°C DM determinations for TMR and orts. Feed ingredients and TMR samples from both experiments were analyzed for DM at 105°C, ash content by combustion at 550°C for 16 h, total N by combustion assay, and sequentially for NDF and ADF (Van Soest et al., 1991) using heat-stable α-amylase and sodium sulfite (Mertens et al., 2002) in an Ankom Fiber Analyzer (Ankom Technology Corp., Fairport, NY). The N content of

NDF and ADF residues was determined by the same combustion assay as for total N. Composition of diets was calculated from the chemical composition of the dietary ingredients and proportion of dietary DM from each ingredient. The TMR samples were analyzed for total fat according to AOAC (1997; method 920.39, Dairyland Laboratories, Arcadia, WI) and starch. Samples of GSC and RGSC were also analyzed for starch using a modification of the enzymatic method described by Bach Knudsen (1997). Samples (0.2 g) were weighed into 60-mL tubes with Teflon-lined screw caps. After hydrolysis of the starch to glucose using heat-stable α-amylase (1,740 liquefon units added per tube; Spezyme, Genencor Int., Rochester, NY) and amyloglucosidase (100 units added per tube; Megazyme E-AMGDF, Megazyme, Bray, Co. Wicklow, Ireland), the tubes were further incubated at 100°C for 30 min. Thereafter, 30 mL of distilled water was added to each tube and all tubes were mixed by inversion. Total volume of the sample solution was determined as final weight minus initial weight of tube, divided by the density of the sample solution (0.998 g/mL). A 2.0-mL aliquot was collected from each tube and centrifuged at 12,000 × g

for 10 min to clarify the sample solution. Centrifuged samples were diluted with distilled water to achieve concentrations of glucose that fell within the standard curve range of 0 to 100 $\mu\text{g}/\text{mL}$. Samples were analyzed for glucose using a glucose oxidase-peroxidase assay (Karkalas, 1985). Standard cornstarch and blank samples were included in every run. Glucose concentrations were converted to equivalent starch concentrations by multiplying the glucose value by 0.9.

Extracts from fresh weekly samples of AS were prepared as described by Muck (1987) and pH was measured. Organic acids (formate, acetate, propionate, butyrate, lactate, and succinate), ethanol, and 2,3-butanediol were analyzed by HPLC using a BioRad Aminex HPX-87H column (BioRad Laboratories, Hercules, CA) at 42°C (mobile phase, 0.0075 N H_2SO_4 at 0.6 mL/min) with a refractive index detector (RID-6A, Shimadzu Corp., Kyoto, Japan). A second set of silage extracts were deproteinized and analyzed for NPN according to Muck (1987), and for NH_3 and total AA-N by flow injection analysis as described by Broderick et al. (2004). All TMR samples were analyzed for indigestible ADF (**IADF**; ADF remaining after a 12-d in situ incubations; Huhtanen et al., 1994).

Cows were milked twice daily and yield was recorded at each milking. Milk samples were collected (a.m. and p.m.) on d 19 of each period from all the cows and on d 26 from the 36 cows in the production group. At collection, all milk samples were preserved with 2-bromo-2-nitropropane-1,3-diol. Individual a.m. and p.m. milk samples were analyzed for fat, protein, lactose, SNF, and MUN by infrared analysis (Ag-Source, Verona, WI). On d 27 and 28 in each period of the production trial, spot urine and fecal grab samples were collected from all 36 cows 6 h before and after feeding. Fecal samples were dried in a forced draft oven (60°C; 72 h) and ground through a 1-mm screen (Wiley mill). Equal amounts of DM from each fecal subsample were mixed to obtain one composite sample for each cow in each period. Fecal samples were analyzed for total N, DM, ash, NDF, ADF, starch, and IADF as described earlier. Indigestible ADF was used as an internal marker to estimate apparent total tract digestibility of nutrients (Cochran et al., 1986). Urine samples (15 mL) were acidified at collection with 60 mL of 0.072 N H_2SO_4 , and stored at -20°C. Thawed urine samples were filtered through Whatman no. 1 filter paper. Urine filtrates were analyzed for creatinine (Oser, 1965) and urea (Broderick and Clayton, 1997) by flow injection (Lachat QuikChem 8000, Lachat Instruments, Milwaukee, WI), for total N (VarioMAX, Elementar Americas, Inc., Mt. Laurel, NJ), for allantoin using the method of Vogels and van der Drift (1970) adapted to a 96-well plate reader, and for uric acid using a commercial kit

(no. 1830, Thermo, DMA, Waltham, MA). Daily urine volume and excretion of urea N, total N, allantoin, uric acid, and total purine derivatives (allantoin plus uric acid) were estimated using creatinine as a marker assuming an excretion of 29 mg/kg of BW (Valadares et al., 1999). Blood was collected into heparinized test tubes from the coccygeal artery of each of the 36 cows in the production group on d 28 of each period at 4 h after feeding. Blood samples were held on ice until stored in the freezer at -20°C. Blood was deproteinized by mixing 1.25 mL of 25% (wt/vol) TCA with 5 mL of whole blood, and centrifuged (15,000 \times g, 4°C, 15 min); supernatants were stored at -20°C until analyzed for urea (Broderick and Clayton, 1997).

Samples of ruminal fluid were collected on d 16 in each of the 5 periods of the ruminal trial from 3 locations in the midventral sac of the rumen of each of the 6 ruminally cannulated cows at 0 (just before feeding), 1, 2, 4, 8, 16, and 24 h after feeding. Samples were withdrawn using a 60-mL plastic syringe connected to a metal filter probe as described by Olmos Colmenero and Broderick (2006). The pH of the samples was measured immediately after collection; thereafter, 15 mL of rumen fluid of each sample was preserved with 0.3 mL of 50% (vol/vol) sulfuric acid, and stored at -20°C. Ruminal fluid samples were later thawed and analyzed for VFA (Brotz and Schaefer, 1987), total free AA, and NH_3 (Broderick et al., 2004).

Statistical Analyses

All data were analyzed using the MIXED procedures of SAS (SAS Institute, 1999–2000). Concentrations of NH_3 over time in in vitro incubations with roasted and control corn were analyzed according to the model

$$Y_{ijkl} = \mu + R_i + T_j + G_k + H_l + TG_{jk} + TH_{jl} + GH_{kl} + TGH_{jkl} + RTGH_{ijkl} + E_{ijkl}$$

where Y_{ijkl} = dependent variable; μ = overall mean; R_i = effect of replicate i ; T_j = effect of roasting treatment j ; G_k = effect of grind size k ; H_l = effect of incubation hour l ; TG_{jk} = interaction between roasting treatment j and grind size k ; TH_{jl} = interaction between roasting treatment j and incubation hour l ; GH_{kl} = interaction between grind size k and incubation hour l ; TGH_{jkl} = 3-way interaction between roasting treatment j , grind size k , and incubation hour l ; $RTGH_{ijkl}$ = 4-way interaction between replicate i , roasting treatment j , grind size k , and incubation hour l ; and E_{ijkl} = residual error. All terms were considered fixed, except for R_i , $RTGH_{ijkl}$ and E_{ijkl} , which were considered random.

Average intake and milk production data from each cow over the last 14 d of each period of the production

cyclic changeover trial were analyzed according to the model

$$Y_{ijklm} = \mu + B_i + C_{j(i)} + P_k + S_l + T_m + ST_{lm} \\ + BP_{ik} + BST_{ilm} + PST_{klm} + E_{ijklm},$$

where Y_{ijklm} = the dependent variable in block i on animal j in period k with silage type l and roasting treatment m ; μ = the overall mean; B_i = effect of block i ; $C_{j(i)}$ = effect of cow j within block i ; P_k = effect of period k ; S_l = effect of silage type l ; T_m = effect of roasting treatment m ; ST_{lm} = interaction between silage type l and roasting treatment m ; BP_{ik} = interaction between block i and period k ; BST_{ilm} = 3-way interaction between block i , silage type l , and roasting treatment m ; PST_{klm} = 3-way interaction between period k , silage type l , and roasting treatment m ; and E_{ijklm} = random residual. Least squares means are reported and mean separation was done by least significant difference. All terms were considered fixed, except for $C_{j(i)}$ and E_{ijklm} , which were considered random.

A repeated measures model with the SP(POW) structure of SAS was used to analyze *in vivo* ruminal pH, concentrations of VFA (acetate, propionate, butyrate, isobutyrate, valerate, and isovalerate), NH_3 , and total free AA. The model used to analyze main effects was identical to that model presented above except that block was replaced by an effect of hour. Interactions between treatments and hour were considered fixed. Least squares means are reported and mean separation was done by least significant difference.

RESULTS AND DISCUSSION

Feed Quality and Diet Composition

The compositions of the AS, corn silage, GSC and RGSC are in Table 1. There were only small differences in the analyzed composition parameters among the AS. Low contents of NDF (<40% of DM) and ADF (<30% of DM), and average CP content above 22% of DM indicated that all 3 AS were of high quality. The silages were generally well fermented with comparable pH and similar levels of fermentation products. However, concentration of NH_3 and total AA-N (% of total N) were highest for the bunker AS and, although the amount was small, butyrate was found only in this silage. Presence of butyrate may have indicated a secondary clostridial fermentation that reduced silage quality (McDonald et al., 1991). In addition, the lactate to acetate ratio was lowest for the bunker AS (3.45), intermediate for the bag AS (5.17), and highest for the AS ensiled in the O_2 -limited tower silo (5.52), indicating differences in the type of fermentation among the silages. A more

heterofermentative lactic acid fermentation will typically be seen in conditions with some oxygen tension (McDonald et al., 1991). The NPN content in all 3 AS was below the average of 54% from 19 experiments reported by Broderick (1995). Muck (1987) reported that the rate of proteolysis decreased linearly with increases in DM concentrations between 17 and 73% at ensiling. Likewise, increased silage DM content reduced the rate and extent of fermentation (Muck, 1990). Relatively high and similar DM contents across the 3 AS may explain why larger differences were not observed in NPN content and fermentation characteristics among AS storage structures. Total DM losses, divided between spoiled silage and gaseous losses, were 2.7 and 9.5% (bag AS), 6.5 and 9.1% (bunker AS), and 0.1 and 7.0% (O_2 -limited AS). Observed differences in DM losses among the silos indicated that total losses were greater for bag and bunker silos and lower for the O_2 -limiting tower silo. Lower concentrations in the DM of CP, ash, and NDF, lower proportion of total N as NH_3 , and higher lactate to acetate ratio were all consistent with lower DM losses in the O_2 -limiting structure.

Roasting increased DM content in the corn fed in the lactation trial by 3% and increased neutral detergent insoluble N (NDIN) by 6% (Table 1). Higher NDIN content in RGSC, in addition to slightly lower ADIN, increased the proportion of total N in NDIN minus ADIN compared with the GSC. This fraction has been characterized as degraded slowly in the rumen, but still digestible and absorbable as AA in the small intestine (Sniffen et al., 1992). Otherwise, there was no indication from chemical composition that roasting altered nutrient content. Mean particle sizes of GSC and RGSC were 567 and 477 μm , respectively. Particle size distribution of the regular and roasted dry corn is illustrated in Figure 1. The solvent soybean meal and roasted soybeans contained (DM basis, \pm SD): 54.6 (\pm 0.2) and 42.7 (\pm 4.3)% CP, and 8.1 (\pm 2.3) and 26.3 (\pm 0.5)% NDF, respectively. Ingredient and chemical composition of the 6 diets is in Table 2. Due to variation in ingredient composition, average NDF across diets was 26.4% rather than 28%, the content for which diets were originally formulated.

Milk Production and Composition

No significant interactions ($P \geq 0.15$) between AS and corn sources were detected for any production trait (Table 3). Yield of 3.5% FCM and milk fat content and yield were affected ($P < 0.01$), and there was a trend for an effect on feed efficiency ($P = 0.10$), due to source of AS (Table 3). Mean yield of 3.5% FCM was 1.7 kg/d greater ($P < 0.01$) in cows fed AS from the O_2 -limited silo than AS from the bag and bunker silos. Effect of

Table 3. Effects of alfalfa silages (AS) stored in 3 types of silos (bag, bunker, and O₂-limiting tower silos) and 2 sources of corn¹ on DMI, BW gain, production efficiency, and milk production and composition

Item	Bag AS		Bunker AS		O ₂ -limiting AS		SE	<i>P</i> > F ²		
	GSC	RGSC	GSC	RGSC	GSC	RGSC		Corn	Silage	C × S
DMI, kg/d	23.7 ^{ab}	24.6 ^a	24.1 ^{ab}	23.9 ^{ab}	23.5 ^{bc}	24.5 ^a	0.4	0.02	0.92	0.15
Milk yield, kg/d	38.5	39.9	39.4	39.2	39.3	40.1	0.8	0.09	0.60	0.34
Milk/DMI	1.64	1.62	1.65	1.64	1.69	1.66	0.03	0.19	0.10	0.88
3.5% FCM, kg/d	38.0 ^c	39.9 ^{abc}	39.3 ^{bc}	39.0 ^c	41.3 ^{ab}	42.2 ^a	1.02	0.18	<0.01	0.39
BW gain, kg/d	0.06	0.30	0.35	0.31	0.36	0.48	0.12	0.28	0.13	0.52
Milk composition and yield										
Fat, %	3.46 ^c	3.55 ^{bc}	3.49 ^c	3.44 ^c	3.79 ^a	3.76 ^{ab}	0.09	0.98	<0.01	0.66
Fat yield, kg/d	1.31 ^c	1.40 ^{bc}	1.37 ^c	1.36 ^c	1.50 ^{ab}	1.53 ^a	0.05	0.27	<0.01	0.49
Protein, %	2.96	2.96	2.92	2.95	2.96	2.94	0.03	0.99	0.42	0.31
Protein yield, kg/d	1.14	1.18	1.14	1.17	1.16	1.18	0.03	0.02	0.63	0.67
Lactose, %	4.83	4.84	4.84	4.84	4.84	4.83	0.03	0.92	1.00	0.69
Lactose yield, kg/d	1.87	1.95	1.89	1.94	1.91	1.94	0.04	0.02	0.81	0.77
SNF, %	8.70	8.72	8.69	8.72	8.72	8.70	0.05	0.63	0.93	0.42
SNF yield, kg/d	3.36	3.50	3.40	3.47	3.43	3.49	0.08	0.02	0.79	0.69
MUN, mg/dL	14.8	14.6	15.3	14.5	14.8	14.8	0.3	0.13	0.69	0.24

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹GSC = ground shelled corn, and RGSC = roasted ground shelled corn.

²Probability of a significant effect of corn type, silage source, and interaction between corn type and silage source (C × S).

silage source on milk fat content and yield was similar to that observed for yield of 3.5% FCM (Table 3). Milk fat content and yield from diets based on AS stored in bag or bunker did not differ ($P > 0.67$). On average, cows fed AS from the bag and bunker silos yielded milk with 0.3 percentage units less milk fat content and secreted 0.15 kg/d less milk fat than cows fed AS from the O₂-limited silo ($P < 0.01$).

The observed differences in yield of 3.5% FCM were associated with increases in milk fat content observed on diets containing AS from the O₂-limited silo. Huhtanen et al. (2003) analyzed literature relationships among fermentation characteristics in grass silage and milk production parameters and suggested that decreases in milk fat content and yield were associated with increased extent of lactic acid fermentation mediated through both decreased silage DMI and lower proportion of lipogenic VFA produced in the rumen. Diets were fed as TMR, and AS source did not affect total DMI in this study (Table 3). Furthermore, all AS sources had relatively low concentrations of lactic acid (Table 1) and decreases in milk fat in cows fed AS from bag and bunker vs. AS from the O₂-limited silo were not likely due to lactic acid. Effects of silage fermentation on milk fat yield were comparable to those on milk fat content (Huhtanen et al., 2003).

Dry matter intake increased by 0.6 kg/d, and yields of milk protein, lactose, and SNF were increased, respectively, by 30, 50, and 90 g/d, for cows fed RGSC compared with GSC ($P = 0.02$; Table 3). There was a trend for RGSC to increase milk yield by 0.6 kg/d ($P = 0.09$; Table 3). The dry-heat processing of roasting has

been reported to gelatinize cornstarch (Reeve and Walker, 1969). Felsman et al. (1972) reported increased in vitro glucose release within a 5-h period and increased DM digestibility by beef cattle as the roasting temperature of the corn was increased from 116 to 137°C. A more rapid decline in NH₃ in ruminal in vitro incubations containing roasted corn suggested increased microbial growth (Figure 2); mean NH₃ concentration over all times for both grind sizes was 2.5 mM lower ($P < 0.01$) for roasted corn. This suggested that

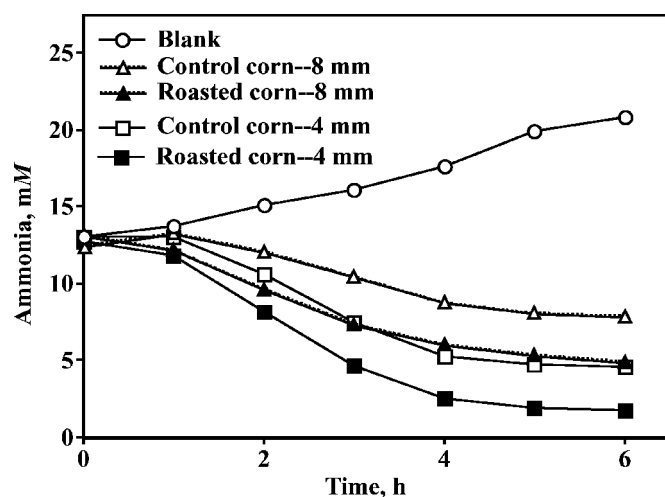


Figure 2. Concentrations of NH₃ in ruminal in vitro blank incubations (no added carbohydrate) and in vitro incubations with control or roasted dry shelled corn that had been ground through 4-mm or 8-mm screens. Mean NH₃ concentration was reduced ($P < 0.01$) by 2.50 mM at both grind sizes in incubations containing roasted corn.

Table 4. Effects of alfalfa silages (AS) stored in 3 types of silos (bag, bunker, and O₂-limiting tower silos) and 2 sources of corn¹ on intake and estimated apparent total tract digestibility

Item	Bag AS		Bunker AS		O ₂ -limiting AS			<i>P</i> > F ²		
	GSC	RGSC	GSC	RGSC	GSC	RGSC	SE	Corn	Silage	C × S
Intake, kg/d										
DM	23.7 ^{ab}	24.6 ^a	24.1 ^{ab}	23.9 ^{ab}	23.5 ^{bc}	24.5 ^a	0.4	0.02	0.92	0.15
OM	22.0 ^b	22.9 ^a	22.4 ^{ab}	22.3 ^{ab}	21.8 ^b	22.9 ^a	0.4	0.01	0.96	0.12
CP	4.22 ^{bc}	4.40 ^a	4.35 ^{ab}	4.32 ^{ab}	4.08 ^c	4.23 ^{bc}	0.08	0.03	<0.01	0.15
NDF	7.00 ^{bc}	6.82 ^c	7.45 ^a	7.04 ^{bc}	7.19 ^{ab}	7.43 ^a	0.13	0.12	<0.01	<0.01
ADF	4.50 ^{bc}	4.34 ^{bd}	4.30 ^d	4.48 ^b	4.68 ^a	4.77 ^a	0.08	0.42	<0.01	0.03
Starch	5.73 ^c	6.57 ^a	5.83 ^c	5.87 ^c	5.78 ^c	6.21 ^b	0.11	<0.01	<0.01	<0.01
Apparent digestibility, ³ %										
DM	60.5	61.4	59.4	59.4	60.2	60.3	0.9	0.67	0.18	0.84
OM	61.5	62.6	60.6	60.5	61.1	61.3	0.9	0.57	0.20	0.77
CP	53.5	53.6	50.2	50.6	52.9	51.4	1.4	0.74	0.06	0.74
NDF	42.7 ^c	41.9 ^c	45.7 ^{ab}	42.5 ^c	45.8 ^{ab}	44.1 ^{bc}	0.8	0.01	0.01	0.34
ADF	42.7 ^{bc}	41.6 ^{cd}	39.3 ^d	42.0 ^{bc}	46.4 ^a	44.0 ^b	0.8	0.64	<0.01	0.01
Starch	84.1	83.8	85.4	84.9	83.8	84.3	2.0	0.94	0.59	0.94

^{a-d}Means within a row with different superscripts differ ($P < 0.05$).

¹GSC = ground shelled corn, and RGSC = roasted ground shelled corn.

²Probability of a significant effect of corn type, silage source, and interaction between corn type and silage source (C × S).

³Estimated using the indigestible ADF content in TMR and feces as internal marker.

RGSC would provide greater ruminal fermentable energy than GSC when fed in the lactation trial. Diets based on AS with high levels of NPN have shown increased yield of milk and protein by increasing ruminal carbohydrate fermentation (Ekinici and Broderick, 1997) or by adjusting the ratio of fermentable energy to RDP (Vagnoni and Broderick, 1997; Broderick, 2003). The differences between GSC and RGSC diets in DMI and protein yield were relatively small in this study, and there was only a tendency for increased milk yield with roasted corn. Finely ground corn has more extensive ruminal digestion of starch compared with medium- or coarse-rolled corn (Rémond et al., 2004). It is likely that higher level of NPN in the AS or coarser processing of the corn may have increased the production response to roasting in the present study.

Intake and Apparent Digestibility

Intakes of DM, OM, CP, and starch were altered by corn source ($P \leq 0.03$). Intake of CP and starch was also influenced by AS source ($P < 0.01$), and there was an interaction between corn and AS source for starch intake ($P < 0.01$; Table 4). In addition, effect of AS source and the interaction term were both significant for NDF and ADF intake ($P \leq 0.03$; Table 4). Higher DM content in experimental diets containing RGSC (Table 2) may explain the observed 0.6 kg/d greater DMI. Differences in intake of OM, CP, and starch due to corn type paralleled the changes in DMI, but greater starch intake could have resulted partly from the higher concentrations of starch observed in the RGSC diets (Table 2).

In addition, diets with AS from the O₂-limiting silo contained 0.3 percentage units less CP, which was consistent with higher CP intake on diets from the bag and bunker silos. Moreover, differences in NDF content between AS sources (Table 1) and diets (Table 2) probably explained observed differences in NDF intake. Additionally, the proportion of dietary DM from AS was slightly higher for the diets made using AS from bunker and O₂-limiting silos. Average dietary starch content across AS source and proportion of dietary DM from corn silage and dry corn paralleled the differences in intake of starch due to AS source. The effect of AS source on ADF intake was not compatible with differences in diet ADF content. Likewise, the significant changes in intake due to an interaction between corn type and AS source on NDF, ADF, and starch are difficult to explain.

Apparent total tract digestibility of NDF and ADF were affected by AS source ($P \leq 0.01$), apparent digestibility of NDF was affected by corn type ($P = 0.01$), and there was an interaction between corn and AS source for apparent digestibility of ADF ($P = 0.01$; Table 4). In addition, apparent total tract digestibility of CP tended to be affected by AS source ($P = 0.06$; Table 4). It was surprising that the different AS sources in this study induced changes in CP, NDF, and ADF digestibility, because all fields were second-cutting regrowth of equal maturity when ensiled. Higher NDF concentration in the bunker AS (Table 1) was in accordance with the observed higher DM losses in that silo, and a lower fiber digestibility could be expected despite the fact that NDF intake on bunker AS diets was equal to that on diets containing AS from the O₂-limiting silo. However,

digestibility of NDF for these diets could not be separated ($P = 0.33$). Means of ADF digestibility for cows fed AS diets from bag, bunker, and the O₂-limiting tower silo were 42.2, 40.7, and 45.2%, respectively, and ADF digestibility from both bag and bunker silos was lower ($P < 0.01$) than for cows fed AS from the O₂-limiting tower silo. Increased apparent digestibility of ADF for cows fed AS from the O₂-limiting tower silo coincided with the observed increase in milk fat content and yield of milk fat and 3.5% FCM. Most major species of ruminal bacteria that digest structural carbohydrate ferment cellulose mainly to lipogenic VFA (Van Soest, 1994). The finding of higher ADF digestibility for cows fed AS from the O₂-limiting silo, combined with the greater ADF intake on these diets, resulted in 270 g/d greater total tract digestion compared with the diets from the 2 other AS sources. Intake of CP on AS diets from the bag and bunker were comparable in magnitude (4.31 and 4.34 kg/d, respectively) and higher ($P \leq 0.01$) than intake of CP on AS diets from the O₂-limited silo (4.16 kg/d). Increased apparent digestibility of CP is usually observed when there is increased intake of dietary CP due to dilution of metabolic fecal N, and true digestibility of protein may not necessarily be increased. The fact that apparent CP digestibility on bunker AS diets was lower than on bag AS diets ($P = 0.02$) in this study (53.5 vs. 50.4%) could indicate a reduction in true CP digestibility of that diet.

The observed decrease in apparent total tract digestibility of NDF with RGSC diets was in accordance with other findings of reduced fiber digestibility when increasing ruminal fermentation of starch (Overton et al., 1995; Broderick 2003). Roasting did not alter the apparent total tract digestibility of starch ($P = 0.94$; Table 4). This is not in agreement with our preliminary observation of increased ruminal NH₃ uptake (Figure 2) and other results showing increased starch digestibility with enhanced processing of corn or increased intake of fermentable carbohydrates (Ekinici and Broderick, 1997; Lykos et al., 1997; Krause et al., 2003). Rémond et al. (2004) observed decreased total tract digestibility of starch with increases in mean particle size from 0.6 to 3.7 mm. The effect of roasting on total tract digestibility of starch in this study probably did not result because of the small difference in particle size of the corn. The interaction between corn and AS source for apparent ADF digestibility differentiated between bunker and tower AS sources (Table 4). This can be explained, in part, by the difference in ADF intakes (Table 4). Moreover, the apparent total tract digestibility of DM, OM, CP, and starch in this study was lower than expected. Levels of apparent total tract digestibility of OM, CP, and starch above 70, 65, and 90% have been reported for diets with ground corn as the principal

concentrate source (Rémond et al., 2004). These results suggested that IADF concentrations might have been underestimated in the feces or overestimated in the feed, resulting in underestimation of digestibility.

In the study of Lykos et al. (1997), no effect of diet on DMI was observed, but increased ruminal degradation rates of starch elicited a positive response in milk production. Additionally, smaller particle sizes and higher passage rates with the diet highest in ground HMC increased starch digestibility in the small intestine, total tract digestibility of starch, and total tract digestibility of OM (Lykos et al., 1997). Treatment effects on production were related to increased nutrient and energy availability. There was no association between the effects of RGSC on production parameters and the digestibility data of this study. The tendency for increased milk yield and the response in yield of nonfat components with RGSC diets were probably related to increased DMI.

Ruminal Metabolism and Nitrogen Utilization and Excretion

Generally, there were few effects of diet on ruminal metabolites in this study (Table 5). There were no changes due to diet in total or individual VFA concentrations ($P \geq 0.32$) over the 24-h sampling period. An increase in total VFA with RGSC diets could be expected because roasting was expected to increase ruminal fermentability of the dietary starch (Figure 1). Ekinici and Broderick (1997), Vagnoni and Broderick (1997), and Krause et al. (2003) did not detect any changes in total ruminal VFA concentrations, but percentage of acetate was lower and percentage of propionate higher when more rapidly available starch sources were fed. A shift in ruminal fermentation pattern with decreased acetate to propionate ratio is consistent with what would be expected from increased carbohydrate fermentation. On the other hand, no effect of AS source on ruminal production of lipogenic VFA was observed, consistent with the observed increases in milk fat yield and content with AS diets from the O₂-limiting silo. Concentrations of VFA in the rumen are a balance between production and disappearance or interconversion, and important differences in production rates may not be apparent from concentrations or molar proportions (Firkins et al., 2006). Ruminal pH tended to be depressed ($P = 0.07$) for cows fed GSC compared with RGSC (Table 5). This was unexpected and in contrast with the results of Overton et al. (1995), Lykos et al. (1997), and Vagnoni and Broderick (1997), which showed a mean reduction in pH with an increased amount of more rapidly fermentable carbohydrates. Ruminal pH was affected by hour of sampling ($P < 0.01$)

Table 5. Effects of alfalfa silages (AS) stored in 3 types of silos (bag, bunker, and O₂-limiting tower silos) and 2 sources of corn¹ on ruminal metabolites

Metabolites	Bag AS		Bunker AS		O ₂ -limiting AS		SE	<i>P</i> > <i>F</i> ²		
	GSC	RGSC	GSC	RGSC	GSC	RGSC		Corn	Silage	C × S
pH	6.35	6.46	6.38	6.41	6.37	6.46	0.07	0.07	0.94	0.43
Ammonia, mM	6.6	7.2	5.2	6.6	6.3	6.1	0.6	0.19	0.18	0.31
Free AA, mM	2.56 ^c	4.81 ^a	2.09 ^b	4.70 ^{ab}	2.96 ^c	3.30 ^{bc}	0.54	<0.01	0.58	0.07
Total VFA, mM	100	104	102	98.1	110	99.7	5.2	0.33	0.50	0.22
Acetate (A), mM	62.8	65.7	63.8	62.9	69.5	63.3	3.0	0.48	0.43	0.11
Propionate (P), mM	21.2	21.8	22.1	20.0	22.6	20.7	1.6	0.31	0.91	0.68
A:P	3.09	3.21	3.09	3.26	3.19	3.19	0.15	0.27	0.93	0.65
Butyrate, mM	11.9	12.1	11.3	11.0	13.3	11.4	0.9	0.30	0.26	0.22
Isobutyrate, mM	1.08	1.05	1.03	1.03	1.09	1.02	0.05	0.17	0.39	0.20
Valerate, mM	1.71	1.68	1.69	1.64	1.81	1.69	0.12	0.46	0.71	0.77
Isovalerate, mM	1.68 ^{ab}	1.48 ^c	1.55 ^{abc}	1.56 ^{abc}	1.69 ^a	1.54 ^{bc}	0.09	<0.01	0.57	0.03
Branched-chain VFA, mM	2.75 ^{ab}	2.53 ^c	2.58 ^{abc}	2.59 ^{abc}	2.78 ^a	2.56 ^{bc}	0.13	0.02	0.53	0.06

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹GSC = ground shelled corn, and RGSC = roasted ground shelled corn.

²Probability of a significant effect of corn type, silage source, and interaction between corn type and silage source (C × S).

in this study. There was an immediate decline in pH for all diets after feeding, reaching a minimum value at 8 h (for cows fed bunker AS diets and tower AS plus RGSC) or 12 h (with bag AS diets and tower AS plus GSC). The minimum pH values (ranging from 5.90 to 6.12) at 8 and 12 h across diets were not significantly different ($P \geq 0.47$). A subsequent increase following minimum pH was observed for all diets. It is likely that the ruminal degradability of cornstarch was high irrespective of roasting in this study, and the small difference in mean pH of 6.36 and 6.44 for cows fed GSC and RGSC diets, respectively, was of minor importance. Fineness of the grind could also explain why ruminal total and individual VFA concentrations were not affected by corn type in this study. The concentrations of isovalerate and total branched-chain VFA (BCVFA) in ruminal fluid were lower ($P \leq 0.02$) for cows fed RGSC than for cows fed GSC (Table 5). The interaction term for corn and AS source was also significant ($P = 0.03$) for ruminal isovalerate concentration, indicating that the effect of corn was not observed in bunker AS diets (Table 5). Lykos et al. (1997) also observed decreased concentration of BCVFA with increased rate of ruminal degradation of cornstarch. The BCVFA are end products of protein degradation (Andries et al., 1987), and a decrease in concentration could indicate reduced protein breakdown in the rumen. The decrease in BCVFA, if accompanied by a decrease in ruminal NH₃ concentration, could indicate greater microbial protein synthesis (Firkins et al., 2006). Lykos et al. (1997) observed decreases in ruminal NH₃ concentration with increases in the level of ruminal available carbohydrates in the diets. There was no indication of improved in vivo utilization of NH₃ by ruminal microbes due to corn or AS source ($P \geq 0.18$) in this study (Table 5). However, total

free AA concentration increased in rumen fluid from cows fed RGSC diets compared with cows fed GSC diets ($P < 0.01$; Table 5). The concentration of total free AA in rumen fluid was relatively high and reflected the extensive ruminal degradation of CP in the diets fed in this experiment as well as the large amount of N present as peptides and free AA in AS.

Dietary effects on variables related to N utilization and excretion are in Table 6. In contrast to other reports showing decreased milk or blood urea with dietary increased ruminal degradability of carbohydrates (Ekinci and Broderick, 1997; Lykos et al., 1997; Broderick, 2003), there was no indication of more efficient use of N by cows fed RGSC vs. GSC ($P \geq 0.13$; Table 6). Urinary excretion of allantoin and uric acid was also not affected by corn source ($P \geq 0.83$), suggesting that microbial protein synthesis was not altered (Table 6). In the study of Olmos Colmenero and Broderick (2006), increased urine volume was associated with increased urinary N excretion and a higher proportion of urinary N as urea. Although urine volume was affected by AS source ($P = 0.05$; Table 6), mean volumes for bag, bunker, and O₂-limiting tower AS diets were 20.5, 21.7, and 21.1 L/d, respectively, and means could not be separated ($P \geq 0.12$). Neither was there evidence for altered urinary excretion of N due to AS source ($P \geq 0.67$). However, there were trends ($P = 0.06$) for increased fecal N excretion in amount and as proportion of N intake with bunker AS diets (Table 6). These trends were consistent with the observation of lower apparent digestibility of CP in the bunker AS vs. bag AS (Table 4). The tendencies for increased urinary N ($P = 0.07$) and urea excretion ($P = 0.09$) with RGSC diets paralleled the increased intake of CP due to corn type (Table 4). Furthermore, there were no changes in N utilization (Table 5) or N

Table 6. Effects of alfalfa silages (AS) stored in 3 types of silos (bag, bunker, and O₂-limiting tower silos) and 2 sources of corn¹ on N metabolism

Item	Bag AS		Bunker AS		O ₂ -limiting AS		SE	<i>P</i> > <i>F</i> ²		
	GSC	RGSC	GSC	RGSC	GSC	RGSC		Corn	Silage	C × S
BUN, mg/dL	14.1	14.0	15.2	14.6	14.0	15.0	0.5	0.78	0.14	0.14
MUN, mg/dL	14.8	14.6	15.3	14.5	14.8	14.8	0.3	0.13	0.69	0.24
Urinary excretion										
Urine volume, L/d	20.1	20.8	21.2	22.2	20.1	22.1	0.9	0.30	0.05	0.68
Total N, g/d	166	164	162	169	162	170	4	0.07	0.96	0.28
Total N, % of N intake	24.7	23.4	23.5	24.5	24.8	25.0	0.6	0.94	0.12	0.07
Urea N, g/d	148	147	145	150	145	154	4	0.09	0.78	0.29
Urea N, % of total urinary N	87.6	88.4	88.4	86.4	88.7	88.1	1.7	0.56	0.67	0.65
Allantoin, mmol/d	338	356	345	345	351	329	12	0.84	0.74	0.16
Uric acid, mmol/d	50.0	53.2	54.0	49.1	50.5	52.0	2.2	0.83	0.97	0.12
Purine derivatives, mmol/d	388	409	399	394	401	381	12	0.87	0.77	0.15
Fecal excretion										
DM, kg/d	9.34	9.54	9.73	9.78	9.40	9.72	0.32	0.39	0.54	0.89
N, g/d	314 ^b	329 ^{ab}	346 ^a	342 ^a	308 ^b	329 ^{ab}	13	0.24	0.06	0.53
N, % of N intake	46.1	46.5	49.8	49.4	47.2	48.6	1.4	0.75	0.06	0.73

^{a,b}Means within a row with different superscripts differ (*P* < 0.05).

¹GSC = ground shelled corn, and RGSC = roasted ground shelled corn.

²Probability of a significant effect of corn type, silage source, and interaction between corn type and silage source (C × S).

efficiency with corn type (Table 6). Overall, differences in N utilization were most likely not detected due to the small differences in chemical composition among the 3 AS sources and the similar digestibility of starch on the 2 corn sources.

CONCLUSIONS

The relatively small differences in chemical composition in AS from the different silo structures may have been due to effects of DM content at ensiling. However, DM losses and lactate to acetate ratio were lower in the O₂-limited silo. Despite no observed influence on rumen fermentation pattern, AS from the O₂-limiting tower silo elicited positive responses in yield of 3.5% FCM, which derived from increased milk fat content and yield. The production responses due to AS source corresponded with an observed increase in fiber digestibility for cows fed AS from the O₂-limiting tower silo. Dry matter intake increased, as did yields of milk protein, lactose, and SNF, for cows fed RGSC compared with GSC. There was also a trend for RGSC diets to increase milk yield. The responses in production with roasted corn were mainly due to increased DMI, which increased the supply of energy and nutrients available for synthesis of milk and milk components. Although roasting increased NH₃ uptake in vitro, there was no indication of improved in vivo utilization of NH₃ by ruminal microbes, or increased carbohydrate fermentation or digestibility, with different corn sources.

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