Effect of Coarse or Fine Grinding on Utilization of Dry or Ensiled Corn by Lactating Dairy Cows[1]

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ABSTRACT

This study evaluated the effect of coarse or fine grinding of three forms of corn on the performance of lactating cows. Six diets, fed as total mixed rations, were identical except for the corn portion of the diet. Corn treatments were dry shelled corn, high moisture ensiled ear corn, and high moisture ensiled shelled corn, either coarsely or finely ground. The experimental design was a 6 × 6 Latin square with 36 cows. Eighteen cows were assigned to the six different treatments and were fed once daily. Within this group of 18 cows, six had a ruminal cannula and were used to evaluate nutrient digestibilities and ruminal fermentation. The remaining 18 cows, six of which were ruminally cannulated, were similarly assigned, except they were fed twice daily. In the group fed once daily, milk production and composition were not affected by treatment. Starch digestibility was greater with the high moisture and with the finely ground corn treatments. In addition, the high moisture ensiled corn treatments had reduced ruminal ammonia concentrations. In the group that was fed twice daily, milk production and protein yield were greatest for the finely ground high moisture ensiled shelled corn treatment. Starch utilization was improved by fine grinding. Lower ruminal ammonia concentrations were obtained with the high moisture ensiled corn treatments, and there was a tendency for reduced ammonia concentration with fine grinding. Results indicate that high moisture ensiled corn as well as fine grinding improved nitrogen and starch utilization.
(**Key words:** corn, milk, particle size, starch)

Abbreviation key: CG = coarsely ground, **DSC** = dry shelled corn, **FG** = finely ground, **HMEC** = high moisture ensiled ear corn, **HMSC** = high moisture ensiled shelled corn, **MUN** = milk urea nitrogen.

INTRODUCTION

The pericarp of the corn kernel and the protein matrix surrounding the starch granule inhibit microbial access to the starch granules. If the pericarp is not physically disrupted, several days are required for microorganisms to penetrate the pericarp and gain access to the starch granules (Orskov, 1986).

The majority of starch consumed by ruminants is degraded in the rumen (Owens et al. 1986). Fermentation of corn starch in the rumen can vary from 65 to 83%, depending on the type of corn as well as the processing method. Corn processing can be important for improving starch fermentation in the rumen as well as starch digestion in the total gastrointestinal tract. Due to the positive relationship between ruminal starch fermentation and overall starch digestion (Theurer, 1986), any processing method that improves ruminal starch fermentation will likely increase overall starch digestibility. In addition, greater starch fermentation in the rumen will increase microbial protein synthesis, providing more microbial nitrogen to the small intestine (Spicer et al. 1986; Herrera-Saldaña, 1990b).

As particle size decreases, the available surface area for microbial attachment increases exponentially (Ensor et al., 1970). Moe and Tyrrell (1977) demonstrated that grinding dry shelled corn increased nutrient fermentation by lactating cows, and Ekinci and Broderick (1997) made a similar observation with high moisture ensiled ear corn.

Moisture content, and perhaps the ensiling process, can affect starch fermentation. Clark and Harshbarger (1972) improved starch digestibility when high moisture ensiled ground shelled corn was fed instead of ground dry shelled corn. Additionally, Aldrich et al. (1993) demonstrated greater starch digestibility with high moisture ensiled shelled corn than with dry ear corn.

The objective of this experiment was to evaluate the effect of moisture level and particle size of corn grain on

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Table 1. Ingredients and nutrient composition of experimental diets.[1]

Ingredient, % of DM	DSC-CG	DSC-FG	HMEC-CG	HMEC-FG	HMSC-CG	HMSC-FG
Corn silage	14.5	14.5	14.5	14.5	14.5	14.5
Alfalfa silage	30.8	30.8	30.8	30.8	30.8	30.8
Roasted soybeans	12.7	12.7	12.7	12.7	12.7	12.7
Soybean meal	6.40	6.40	6.40	6.40	6.40	6.40
Corn treatment	33.2	33.2	33.2	33.2	33.2	33.2
Mineral and vitamin mix[2]	2.4	2.4	2.4	2.4	2.4	2.4
Nutrients, % of DM						
DM	53.5	53.5	50.8	50.8	50.4	50.4
CP	17.8	17.8	17.7	17.7	17.7	17.7
NDF	26.5	26.5	26.4	26.4	24.3	24.3
ADF	17.1	17.1	17.6	17.6	16.5	16.5
Starch + free glucose	35.2	35.2	35.2	35.2	35.5	35.5

[1]DSC = Dry shelled corn, CG = coarsely ground, FG = finely ground, HMEC = high moisture ensiled ear corn, HMSC = high moisture ensiled shelled corn.

[2]The mineral mixture contained (percentage units) 0.2, mangesium oxide; 0.4, salt; 0.6, dicalcium phosphate; 0.6, sodium bicarbonate; 0.5, limestone; and 0.1, trace mineral and vitamin mix. The trace mineral and vitamin mix contained: 19.4% calcium, >320 mg/kg of selenium, >7,098,000 IU of vitamin A/kg, >2,204,623 IU of vitamin D-3/k and >1764 IU of vitamin E/kg.

milk production and milk composition, starch digestion, and ruminal fermentation variables.

MATERIALS AND METHODS

Thirty-six Holstein cows were assigned to six squares according to their lactation number and the presence of a ruminal cannula. Two squares were formed with first lactation heifers and the other four with mature cows. Two of the squares contained mature cows fitted with a ruminal cannula. The six squares of cows were equally divided between once and twice daily feeding. Cows were randomly assigned to treatments within a square. First lactation heifers were 83 ± 18 DIM), and mature cows were 81 ± 19 DIM. Periods were 21 d, with the first 14 d considered as an adaptation period. The last 7 d constituted the sampling period. The six dietary treatments were dry shelled corn coarsely ground (**DSC-CG**), dry shelled corn finely ground (**DSC-FG**), high moisture ensiled ear corn coarsely ground (**HMEC-CG**), high moisture ensiled ear corn finely ground (**HMEC-FG**), high moisture ensiled shelled corn coarsely ground (**HMSC-CG**) and high moisture ensiled shelled corn finely ground (**HMSC-FG**). The only difference between diets was the type of corn utilized. Ingredients and nutrient composition of the experimental diets are presented in Table 1, and the chemical composition of the major ingredients is in Table 2.

Dry shelled corn was purchased as cracked corn to become DSC- CG, or it was ground through a hammer mill to become DSC-FG. The two high moisture ensiled corn treatments (HMEC-CG and HMSC-CG) were stored in Harvestore silos. When HMEC-CG and HMSC-CG were discharged from the silos they were ground through a hammer mill (Clay Hammer Mill, Cedar Falls, IA) to obtain HMEC-FG and HMSC-FG, respectively. The combine used to harvest HMEC had a cob saver, and based on previous measurements in this laboratory, the HMEC contained 8 to 9% (DM basis) of cob. Samples of each type of corn were collected and sieved every week. Samples were shaken according to Ensor et al. (1970) in a sieve shaker (Sieve Shaker Analyssette-3, Firtsch GMBH, Laborgerätebau, Germany). Sieves with 4.75-, 3.35-, 2.00-, and 1.18-mm openings were used. The distribution of corn particles (% as fed) on the sieves for each corn treatment is shown in Table 3. Particle size was estimated according to the equation used by Ensor et al. (1970). Geometric mean diameters for the six corn treatments were 3.28, DSC-CG; 1.11, DSC-FG; 4.43, HMEC-CG; 1.32, HMEC-FG; 3.78, HMSC-CG and 1.02, HMSC-FG. All of the FG corn pieces were smaller than 1.50 mm in diameter. A few cob pieces tended to inflate the mean particle size of the HMEC-CG treatment relative to the other two coarsely ground samples.

Table 2. Nutrient composition of the individual ingredients.

Ingredient	DM	OM	CP	NDF	ADF	Starch + free glucose
Corn silage	32.1	93.8	7.1	37.5	24.2	30.7
Alfalfa silage	37.6	93.2	21.6	36.8	32.3	9.3
Roasted soybeans	97.6	96.3	37.1	34.8	12.9	17.1
Soybean meal	91.5	95.9	43.5	18.7	13.4	16.5
DSC[1]	88.9	98.6	7.9	12.4	3.5	74.2
HMEC[2]	70.0	98.4	7.5	12.1	4.5	74.3
HMSC[3]	68.1	98.4	7.5	5.8	1.6	75.3

[1]DSC = Dry shelled corn.

[2]HMEC = high moisture ensiled ear corn.

[3]HMSC = high moisture ensiled shelled corn.

Table 3. Percentage of corn particles retained on sieves (% as fed).[1]

Sieve opening (mm)	DSC-CG	DSC-FG	HMEC-CG	HMEC-FG	HMSC-CG	HMSC-FG
4.75	14.5	0.65	53.8	2.38	49.4	0.70
3.36	39.7	1.99	23.9	12.8	21.8	3.83
2.00	35.8	11.9	6.37	18.1	8.28	16.9
1.18	1.74	29.2	5.80	15.9	4.97	16.4
0.60	3.13	26.4	3.65	16.6	3.48	15.6
Pan	5.16	29.9	6.48	34.2	12.1	46.6

[1]DSC = Dry shelled corn, CG = coarsely ground, FG = finely ground, HMEC = high mositure ensiled ear corn, HMSC = high moisture ensiled shelled corn.

Dry matter content of diet ingredients was determined once weekly. Dry matter was determined in a constant temperature oven at 60°C for 72 h. If forage DM varied more than 3%, diets were readjusted using the new forage DM measurements. During the sampling period, major diet ingredients and orts for each of the diets were collected daily and used to form a composite sample for the period. These samples were stored at –20°C for subsequent processing and analysis. At the end of each period, samples were thawed, dried, and ground in a Wiley mill through a 2-mm screen (Arthur H. Thomas, Philadelphia, PA.). Samples were analyzed for CP, NDF, and ADF. Concentrate ingredients were composited with samples from each period to analyze for starch + free glucose for the entire experiment. Forage composite samples were analyzed for starch + free glucose once per period. Crude protein was determined by measuring nitrogen by the thermoconductance method in a LECO FP-2000 (Leco, St. Joseph, MI). Neutral detergent fiber and ADF were determined sequentially in an Ankom-200 digestor (ANKOM Technologies, Fairport, NY). Starch + free glucose was determined according to Herrera-Saldaña (1990a).

Cows were housed in a tie-stall barn, and were fed a TMR either once or twice daily. Cows fed once daily were offered feed at 1000 h. Those fed twice daily received half of their daily allowance at 1000 h. The second half of their daily allowance was mixed at 1400 h and stored in plastic containers until offered to the cows at 2100 h. Feed offered and orts were recorded daily for individual cows. Cows were milked twice daily at 0600 h and 1630 h. Milk weights and milk composition during the 7-d sampling period were used for data analysis. The 3 a.m. and 3 p.m. samples for each individual cow were collected for analysis during the sampling period. Milk was analyzed for fat, protein, SNF, and milk urea nitrogen (**MUN**; Ag Source Milk Analysis Laboratory, Menomonie, WI).

Ruminal fluid was sampled from the ruminal cannulated cows during the first 24 h of the sampling period. Samples were obtained via the ruminal cannula with a 100-ml plastic cup from the ventral sac of the rumen. Ruminal fluid was collected immediately before feeding at 1000 h. This time point was considered 0 h. Additional samples were taken 1, 2, 3, 6, 9, 12, 14, 15, 18, 21, and 24 h after the first sample. Ruminal fluid was strained through two layers of cheesecloth for immediate pH determination. A 5-ml aliquot of ruminal fluid was used to determine VFA concentrations. Ruminal fluid was acidified in a 1:1 ratio (vol/vol) with undiluted formic acid. A second 10-ml aliquot was used for ammonia determination. This aliquot was acidified with 0.2 ml of 50% H_2SO_4. After acidification, samples were stored at –20°C. At the end of each period, samples were thawed and centrifuged for 20 min at 30,000 × *g* at 4°C. The supernatant of the samples acidified with formic acid was transferred to a 2-ml screw cap vial for VFA determination. Volatile fatty acids were determined according to Brotz and Schaefer (1987). The supernatant of the samples acidified with H_2SO_4 was transferred to a 2-ml disposable cup for ammonia determination. Ammonia concentration was determined according to Broderick and Kang (1980). At the end of each experimental period, ruminal contents were evacuated, weighed, and sampled for DM analysis.

Ytterbium was used as an external marker to estimate apparent digestibility in the gastrointestinal tract. One milliliter of solution containing 140 mg of ytterbium as $YbCl_3$ was added to a gelatin capsule with soybean meal. Gelatin capsules were administered via the ruminal cannula for the last 6 d of the adaptation period and throughout the sampling period at 0600 and 1800 h. The ruminal cannula was opened and the capsule was placed in the middle of the fiber mat, after which the cannula was closed. A composite sample of feces was made for each cow, utilizing fecal samples collected for rate of passage determinations. Samples were dried in a forced air oven at 60°C for 96 h. At the end of each period, samples were ground in a Wiley mill through a 2-mm screen (Arthur H. Thomas, Philadelphia, PA.). The composite samples of feces were analyzed for DM, OM, NDF, ADF, and starch + free glucose to calculate overall tract digestibilities.

Passage measurements were estimated for liquid, grain, and fiber fractions of ruminal digesta. Cobalt-EDTA, lanthanum chloride, and Cr-mordanted fiber were used as markers for the liquid, grain, and fiber fractions, respectively. Cobalt -EDTA was prepared according to Binnerts et al. (1968). Ten grams of Cobalt-EDTA was dissolved with overnight stirring in 100 ml of aqueous solution, providing a dose of 1 g of cobalt per cow. Two 50-ml syringes were filled with the solution for future application. Lanthanum marker was prepared as described by Hartnell and Satter (1979) and applied to each type of corn. Lanthanum was applied to give 1 g of lanthanum for every 500 g of marked grain (DM basis). Five hundred-gram (DM basis) doses of each of the six experimental corns marked with lanthanum were prepared for eventual insertion in the rumen. Chromium-mordanted fiber (wheat straw) was prepared according to Udén et al. (1980). Twenty-gram doses of Cr-mordanted fiber, containing approximately 1 g of chromium, were prepared for insertion into the rumen.

The three markers were pulse dosed into the rumen on the first day of the sampling period for each of the six periods. The ruminal cannula was opened, and a hole was made in the fiber mat. The three markers were placed in the hole and mixed with ruminal contents. Pulse dosed markers were administrated at 0500 h, 5 h before the first feeding. Fecal samples were collected at 0, 3, 6, 9, 12, 18, 24, 36, 48, 60, 72, 84 and 96 h after feeding. Fecal samples were dried in a forced air oven at 60°C for 96 h at the end of each period and ground in a Wiley mill through a 2- mm screen (Arthur H. Thomas).

Fecal composite samples were used for ytterbium analysis. Individual fecal samples were used to analyze for cobalt, lanthanum, and chromium. Samples were analyzed by direct current plasma spectroscopy according to Combs and Satter (1992). Passage rate was estimated by plotting the concentration of the marker versus time during the declining phase of marker concentration. The time of peak concentration for each of the elements was calculated based on the data for each element. All data points that preceded the peak concentration time were deleted and not used in fitting the model. In similar fashion, the asymptotic portion of the marker excretion data was deleted. A nonlinear method of calculating the slope was used, and the slope (-k) was equated to the turnover rate of the digesta fraction (%/h) (Littell et al., 1996; SAS, 1985).

Purine derivatives excreted in urine were used as an indirect method of estimating rumen microbial protein synthesis (Broderick and Merchen, 1992). A urine spot sample was obtained from each of the cows during the six periods. A 5-ml aliquot was diluted in 45 ml of a solution containing 0.036N H_2SO_4. Samples were stored at –20°C. At the end of each period, samples were thawed and analyzed for allantoin according to Fujihara et al. (1987) and creatinine according to Oser (1965).

Cows that were fed once daily were analyzed separately from those fed twice daily. The following model was used to evaluate effects on variables that did not have repeated measurements.

$$Yijkl = \mu + Si + Pj + Vk(i) + Tl + STil + PTjl + Eijkl$$

Yijkl = dependent variable;
μ = overall mean;
Si = effect of square i;
Pj = effect of period j;
Vk(i) = effect of cow k (within square i);
Tl = effect of treatment l;
STil = interaction between square i and treatment l;
PTil = interaction between period j and treatment l; and
Eijkl = error.

All terms were considered fixed except for Vk(i) and Eijkl which were considered random.

The following model was used to evaluate effects on variables that did have repeated measurements.

$$Yijkl = \mu + Pi + Tj + Vk + Vk(ij) + Zl + E_1jk + TZjl + E_2ijkl$$

Yijkl = dependent variable;
μ = overall mean;
Pi = effect of period i;
Tj = effect of treatment j;
Vk = effect of cow k;
Vk(ij) = effect of cow k (within the interaction of period i and treatment j);
E_1jk = plot error;
Zl = effect of time l;
TZjl = interaction between treatment j and time l; and
E_2ijkl = subplot error.

All terms were considered fixed except for Vk, Vk(ij), E_1jk and E_2ijkl which were considered random.

A mixed model procedure of SAS for a Latin square design was utilized (Littell et al., 1996; SAS, 1985).

RESULTS AND DISCUSSION

Results from the once and twice daily feeding portions of the study will be discussed separately.

Table 4. Effect of treatments on milk production, milk composition, and feed efficiency.[1]

	DSC-CG	DSC-FG	HMEC-CG	HMEC-FG	HMSC-CG	HMSC-FG	SEM	Trt *P*
Once daily feeding								
Milk, kg/d	37.7	37.2	34.9	36.3	37.9	36.2	1.57	0.26
4% FCM, kg/d	35.3	34.8	32.2	32.5	34.9	32.2	1.62	0.11
Fat, %	3.60	3.58	3.49	3.29	3.49	3.25	0.14	0.09
Fat, kg/d	1.35	1.33	1.21	1.20	1.31	1.18	0.07	0.09
Protein, %	3.02	3.05	3.08	2.96	3.03	3.13	0.05	0.12
Protein, kg/d	1.14	1.13	1.07	1.07	1.15	1.13	0.05	0.22
MUN,[2] m*M*	5.68^{a}	5.18^{bc}	5.59^{ab}	5.49^{abc}	5.08^{cd}	4.60^{d}	0.19	0.01
Twice daily feeding								
Milk, kg/d	37.2^{c}	38.9^{abc}	38.0^{bc}	37.8^{c}	39.3^{ab}	40.3^{a}	1.19	0.01
4% FCM, kg/d	36.5	37.1	36.7	36.0	36.8	36.1	1.28	0.82
Fat, %	3.82^{a}	3.67^{ab}	3.78^{ab}	3.72^{ab}	3.59^{b}	3.31^{c}	0.12	0.01
Fat, kg/d	1.44	1.43	1.43	1.39	1.40	1.33	0.06	0.25
Protein, %	3.10	3.08	3.03	3.09	3.11	3.09	0.04	0.46
Protein, kg/d	1.15^{bc}	1.20^{ab}	1.14^{c}	1.16^{bc}	1.21^{a}	1.23^{a}	0.03	0.01
MUN, m*M*	5.71^{a}	5.22^{b}	5.33^{ab}	5.25^{b}	5.13^{b}	4.64^{c}	0.14	0.01

[a,b,c]Means within row with different superscripts differ.

[1]DSC = Dry shelled corn, CG = coarsely ground, FG = finely ground, HMEC = high moisture ensiled ear corn, HMSC = high moisture ensiled shelled corn.

[2]Milk urea nitrogen.

Once Daily Feeding

Treatment means for milk production and milk composition are presented in Table 4. Milk production was not affected by treatment. Other experiments have evaluated moisture level of corn (Knowlton et al., 1998) or corn particle size (Ekinci and Broderick, 1997; Yu et al., 1995) separately. None of these experiments showed significant differences in milk yield due to moisture level of corn or corn particle size. However, Ekinci and Broderick (1997) reported a trend for higher milk production with finely ground HMEC compared with coarsely ground HMEC. A similar trend was reported by Yu et al. (1995) due to a reduction in corn particle size. Production of 4% FCM was not affected by treatment. Aldrich et al. (1993) reported higher production of 4% FCM for cows fed ground dry ear corn compared with cows that were fed HMSC.

Milk fat percentage and milk fat yield showed a trend for treatment effect ($P = 0.09$). Aldrich et al. (1993) reported a higher milk fat yield when feeding dry ear corn instead of HMSC. It is possible that more saliva is secreted with the dry feed to enable swallowing, thus contributing to a higher rumen pH, and a rumen fermentation less conducive to milk fat depression. Milk protein content was not affected by treatment. Milk urea nitrogen was lowest for the HMSC treatments ($P < 0.01$). Feed efficiency was not affected by treatment.

Treatment means for feed intake, nutrient digestibilities, digesta kinetics, and urine constituents are presented in Table 5. Intake of DM, NDF, ADF, and starch + free glucose were not affected by treatment. In two different experiments (Chandler et al., 1975; Clark et al., 1973), no difference in feed intake was observed when DSC and HMSC were compared. Dhiman and Satter (1993) did not find a difference in DMI when HMEC-CG was compared with HMEC-FG. Aldrich et al. (1993) did not find a difference in OM, ADF, or NSC intake when cows were fed with HMSC or dry ear corn. However, they reported a higher NDF intake when cows were fed with dry ear corn compared to HMSC. Ying and Allen (1998) did not observe any difference in DMI or starch intake when HMSC-CG, HMSC-FG, DSC-CG, or DSC-FG were compared.

Dry matter digestibility was not affected by treatment. Dhiman and Satter (1995) reported an increase in DM digestibility when HMEC-FG was fed instead of HMEC-CG. Ekinci and Broderick (1997) reported higher OM digestibilities due to fine grinding when cows were fed with HMEC. Overall digestibilities for NDF and ADF were not affected by treatment.

The digestibility of starch + free glucose was affected by treatment, with fine grinding substantially increasing digestibility. The high moisture treatments had a higher average digestibility of starch + free glucose than the dry treatments. Ying and Allen (1998) observed an improvement in ruminal starch digestibility due to an increase in moisture level and a reduction in corn particle size when HMSC-CG, HMSC-FG, DSC-CG, and DSC-FG were evaluated. Some other experiments have evaluated overall starch digestibility for each of these factors separately, and an increase in digestibility has been attributed to both an increase in moisture level and a reduction in corn particle size. Aldrich et al. (1993) observed greater starch digestibility when

Table 5. Effect of treatments on feed intake, nutrient digestibility, rumen kinetics, and urinary constituents of cows fed once daily.[1]

	DSC-CG	DSC-FG	HMEC-CG	HMEC-FG	HMSC-CG	HMSC-FG	SEM	Trt *P*
Intake, kg/d								
DM	25.8	24.7	23.3	22.8	24.6	24.9	1.58	0.25
Starch + free glucose	9.13	8.73	8.26	8.09	8.73	8.86	0.56	0.25
Digestibility, %								
DM	62.6	69.3	64.9	67.9	67.4	68.5	2.39	0.31
NDF	52.8	56.5	44.7	47.5	48.3	45.8	3.25	0.14
ADF	44.0	51.8	44.6	46.1	42.4	42.3	2.86	0.23
Starch + free glucose	80.4[e]	88.1[bc]	85.5[cd]	90.2[ab]	84.1[d]	91.8[a]	1.37	0.01
Fecal starch + free glucose %	18.8[a]	13.7[b]	14.8[b]	10.7[c]	15.7[b]	9.32[c]	0.79	0.01
Rate of passage, % h^{-1}								
Liquid	8.95	9.71	8.99	8.70	9.89	8.01	1.17	0.65
Fiber	2.76	2.71	2.29	2.84	2.43	2.57	0.31	0.50
Corn grain	5.32[a]	5.42[a]	3.85[b]	4.81[a]	5.47[a]	4.75[ab]	0.51	0.01
Urine constituents, m*M*								
Allantoin	18.8	22.6	19.2	21.0	24.9	23.6	1.62	0.08
Creatinine	7.13[c]	9.07[a]	8.42[abc]	7.18[c]	8.81[ab]	7.61[bc]	0.56	0.03
A:C ratio	2.67[bc]	2.54[bc]	2.34[c]	2.96[ab]	2.79[ab]	3.10[a]	0.20	0.01

[a,b,c,d]Means within row with different superscripts differ.

[1]DSC = Dry shelled corn, CG = coarsely ground, FG = finely ground, HMEC = high moisture ensiled ear corn, HMSC = high moisture ensiled shelled corn.

HMSC was fed compared with dry ear corn. Ying et al. (1998b) observed a trend for increased overall starch digestibility when HMSC was compared with DSC. Ekinci and Broderick (1997) and Ying et al. (1998a) also reported an increase in starch digestibility due to fine grinding. It is important to mention that we did not have the same variety of corn grown under the same field conditions for all treatments. Corn variety can have some effect on starch characteristics and starch digestibility.

The presence of cob in the HMEC treatment may have been responsible for the reduced passage rate in the corn grain fraction in the high moisture ensiled ear corn treatments ($P < 0.05$) (Table 5). Some of the La marker could have been applied to pieces of cob, and it may be that large cob pieces were accounting for the difference in passage rate. The allantoin:creatinine ratio was increased with feeding HMSC-FG, indicating that rumen microbial growth was increased with this treatment.

Treatment means for ruminal fermentation measurements are presented in Table 6. A comprehensive figure summarizing treatment effects over time on ruminal fermentation measurements is presented in Figure 1.

Table 6. Effect of treatments on rumen characteristics and ruminal fermentation measurements.[1]

	DSC-CG	DSC-FG	HMEC-CG	HMEC-FG	HMSC-CG	HMSC-FG	SEM	Trt *P*
Once daily feeding								
pH	6.12	6.09	6.10	5.99	5.96	5.94	0.09	0.09
NH_3, m*M*	10.2[a]	9.32[a]	8.74[ab]	6.79[c]	7.43[bc]	6.98[c]	0.61	0.01
C_2, m*M*	76.7	78.0	76.2	78.1	78.0	77.7	1.73	0.91
C_3, m*M*	24.8	27.2	27.0	29.6	29.2	32.9	2.60	0.09
C_4, m*M*	14.9	14.5	13.8	14.0	14.6	14.0	0.59	0.75
Tot VFA, m*M*	121.7	125.0	122.6	127.5	128.2	130.9	3.84	0.30
C_2:C_3 ratio	3.19[a]	3.05[a]	3.15[a]	2.95[a]	2.84[ab]	2.47[b]	0.24	0.04
Twice daily feeding								
pH	5.99[a]	5.97[a]	5.94[ab]	5.81[bc]	5.80[c]	5.80[c]	0.07	0.02
NH_3, m*M*	10.9[a]	10.1[ab]	8.88[bc]	7.53[c]	8.61[bc]	7.04[c]	0.67	0.01
C_2, m*M*	80.8	82.8	81.3	81.0	80.8	80.5	1.28	0.81
C_3, m*M*	26.1[c]	27.5[c]	30.9[bc]	34.2[ab]	36.5[ab]	39.1[a]	2.80	0.03
C_4, m*M*	15.2	16.0	14.5	14.9	14.8	13.8	0.59	0.08
Tot VFA, m*M*	127.8[c]	132.2[bc]	131.9[bc]	135.9[ab]	137.2[ab]	140.2[a]	3.10	0.02
C_2:C_3 ratio	3.18[a]	3.05[a]	2.87[ba]	2.50[bc]	2.46[bc]	2.13[c]	0.24	0.01

[a,b,c]Means within row with different superscripts differ.

[1]DSC = Dry shelled corn, CG = coarsely ground, FG = finely ground, HMEC = high moisture ensiled ear corn, HMSC = high moisture ensiled shelled corn.

Mean ruminal pH was not affected by treatment. This result was similar to the findings of Ekinci and Broderick (1997). Ruminal pH values for all treatments moved together throughout the day and remained below 6.00 for about 3 to 15 h after feeding.

Ruminal ammonia concentrations were affected by treatment. Feeding ground corn reduced ruminal ammonia concentration, indicating improved nitrogen utilization. Aldrich et al. (1993) observed a trend for increased ruminal ammonia concentrations with feeding dry ear corn instead of HMSC, probably as a consequence of reduced availability of starch with dry ear corn. Ekinci and Broderick (1997) also observed a reduced ruminal ammonia concentration due to fine grinding of corn. Ruminal ammonia concentrations peaked between 1 and 2 h postfeeding.

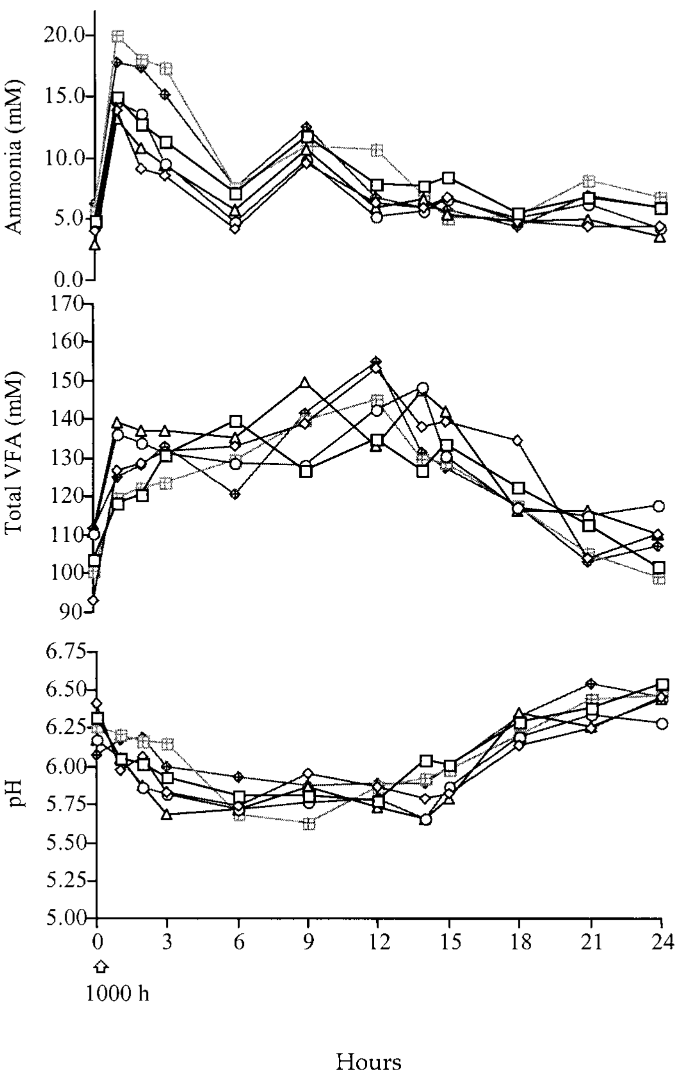

Figure 1. Effect of treatments on rumen environment of cows fed once daily. (box, high moisture ensiled shelled corn-coarsely ground; diamond, high moisture ensiled shelled corn-finely ground; circle, high moisture ensiled shelled corn-coarsely ground; triangle, high moisture ensiled shelled corn-finely ground; window pane, dry shelled corn-coarsely ground; diagonal window pane, dry shelled corn-finely ground).

Ruminal acetate and butyrate concentrations were not affected by treatment. Other studies have reported little or no effect on individual VFA concentrations by feeding DSC instead of HMSC (Clark and Harsbarger, 1972), or HMSC instead of dry ear corn (Aldrich et al., 1993). There was a trend ($P = 0.09$) for increased propionate concentration with HMSC-FG. This suggests a greater fermentation of starch by ruminal microbes as moisture level of the corn grain increased and particle size was reduced. Total ruminal VFA concentrations were not affected by treatment. This is similar to the findings of Clark and Harshbarger (1972) who compared DSC with HMSC and to Aldrich et al. (1993) who compared HMSC and dry ear corn in diets for lactating dairy cows. Ekinci and Broderick (1997) did not find any difference in total VFA concentration due to corn particle size. Ruminal acetate:propionate ratios were significantly affected ($P < 0.04$) by treatment with cows fed HMSC-FG having the lowest ratio.

In summary, starch digestion was improved by feeding finely ground corn, and feeding corn as HMEC. The increase in starch digestion was associated with a reduction in ruminal pH and ammonia concentration as the moisture level of the corn grain increased and particle size was reduced. Ruminal propionate concentration tended to increase with feeding HMSC-FG. This can be related to higher microbial growth, as measured by the allantoin:creatinine ratio.

Twice Daily Feeding

Treatment means for milk production and milk composition are presented in Table 4. Milk yield was significantly affected by treatment ($P < 0.01$), with the HMSC treatments appearing to support higher milk yields. Other experiments have shown the same response when HMSC was compared with DSC (Chandler et al. 1975; Clark et al. 1973). Knowlton et al. (1996) observed an increase in milk production ($P < 0.10$) when DSC was finely ground. Ekinci and Broderick (1997) found a small but not significant advantage when HMEC was finely ground compared to coarsely ground. Glenn et al. (1997) observed a trend for increased milk production due to fine grinding. Johnson and Koons (1997) significantly increased milk production when HMSC was finely ground instead of coarsely ground. In addition, earlier work of Moe and Tyrrell (1977) demonstrated that higher levels of milk production were obtained when DSC was finely ground compared with coarsely ground. Feeding HMSC, whether coarsely or

Table 7. Effect of treatments on feed intake, nutrient digestibility, rumen kinetics and urine constituents of cows fed twice daily.[1]

	DSC-CG	DSC-FG	HMEC-CG	HMEC-FG	HMSC-CG	HMSC-FG	SEM	Trt *P*
Intake, kg/d								
DM	26.3	26.8	25.2	25.2	25.8	25.4	1.87	0.69
Starch + free glucose	9.31	9.47	8.94	9.53	9.16	9.03	0.76	0.81
Digestibility, %								
DM	65.6	65.9	62.7	66.6	67.1	69.2	2.45	0.55
OM	68.5	67.5	65.1	66.4	67.2	71.0	2.40	0.59
NDF	56.8	50.6	45.8	45.9	45.1	45.7	3.30	0.08
ADF	51.8	45.3	44.4	46.4	44.1	39.9	3.00	0.16
Starch + free glucose	84.4[c]	86.5[bc]	83.2[c]	89.7[ab]	86.7[bc]	91.2[a]	1.48	0.01
Fecal starch + free glucose, %	18.7[a]	13.8[b]	15.9[b]	10.8[c]	14.3[b]	10.1[c]	1.08	0.01
Rate of passage, % h^{-1}								
Liquid	10.7	9.01	8.59	8.82	8.64	10.2	1.12	0.41
Fiber	2.29	2.49	2.95	2.42	2.85	2.80	0.32	0.50
Corn grain	6.23	5.31	4.57	5.81	5.83	5.66	0.49	0.08
Urine constituents, m*M*								
Allantoin	15.9	17.8	20.1	19.9	17.1	19.8	1.90	0.29
Creatinine	6.23	6.85	6.66	5.97	5.43	6.77	0.71	0.31
A:C ratio	2.58	2.69	2.93	3.36	2.78	3.04	0.22	0.17

[a,b,c]Means within row with different superscripts differ.

[1]DSC = Dry shelled corn, CG = coarsely ground, FG = finely ground, HMEC = high moisture ensiled ear corn, HMSC = high moisture ensiled shelled corn.

finely ground, resulted in reduced milk fat percentage. Milk fat percentage was significantly reduced as fermentability of starch in the diet increased, resulting in reduced fat yield. A reduction in milk fat percentage has been commonly observed as starch fermentability increases (Aldrich et al. 1993; Palmquist and Conrad, 1970).

Although protein percentage was not affected by treatment, protein yield was significantly affected by treatment ($P < 0.01$). Protein yield tended to be greater with the HMSC treatments, reflecting the higher milk production level of cows fed HMSC. An increase in protein yield has been associated with a reduction in corn particle size (Ekinci and Broderick, 1997; Knowlton et al., 1996). A square effect for protein yield was found.

Milk urea nitrogen was significantly affected by treatment ($P < 0.01$), being lowest for the HMSC-FG treatment. High moisture content and fine grinding of corn resulted in improved nitrogen utilization as indicated by the MUN values. Production of 4% FCM per kilogram of DMI was not affected by treatment.

Treatment means for feed intake, nutrient digestibilities, rumen kinetics, and urine constituents for cows that were fed twice daily are presented in Table 7. Intake of DM and starch + free glucose were not affected by treatment.

Digestibility of DM, NDF, and ADF were not affected by treatment. Digestibility of starch + free glucose was significantly affected by treatment ($P < 0.05$), with digestibility being the highest for HMSC-FG and HMEC-FG. As corn particle size decreases, the available surface area for microbial attachment increases exponentially (Ensor et al. 1970). Knowlton et al. (1996), Ekinci and Broderick (1997), and Glenn et al. (1997) observed an improvement in starch digestibility as corn particle size was reduced. Rates of passage measurements and allantoin:creatinine ratio were not affected by treatment, although the allantoin:creatinine ratio tended to be higher with the finely ground corn.

Treatment means for ruminal fermentation measurements are presented in Table 6. A comprehensive figure summarizing treatment effects over time on ruminal fermentation measurements is presented in Figure 2. A lower ruminal pH was observed when cows were fed with HMSC, either CG or FG.

Ruminal ammonia concentration was significantly affected by treatment ($P < 0.01$). An increase in moisture and a reduction in particle size decreased ruminal ammonia concentration. Ekinci and Broderick (1997) have shown a significant reduction in ruminal ammonia concentration as particle size of HMEC was reduced. When individual VFA were analyzed by treatment, only propionate was affected ($P < 0.05$). This is reflective of higher starch utilization, which is also associated with the reduction in ruminal ammonia concentration and a higher total VFA concentration. The acetate:propionate ratio was affected by treatment with the HMSC-FG having the lowest ratio.

In summary, when cows were fed twice daily, milk production was improved with feeding HMSC, especially with the HMSC-FG treatment. Higher availability of carbohydrates in the rumen improved milk production but reduced milk fat percent. Protein yield was increased with feeding HMSC either CG or FG, but this increase was due to the higher milk production level, not to higher protein content. In addition, the percentage of SNF in milk and SNF yield tended to be higher when HMSC was fed. Reduced MUN was observed with HMEC and with fine grinding, presumably reflecting improved nitrogen utilization within the rumen. Cows did not differ in feed efficiency when milk production was corrected for fat content. The moisture content of corn seems to be the most important factor in determining fermentability; however, particle size reduction also increased ruminal fermentation.

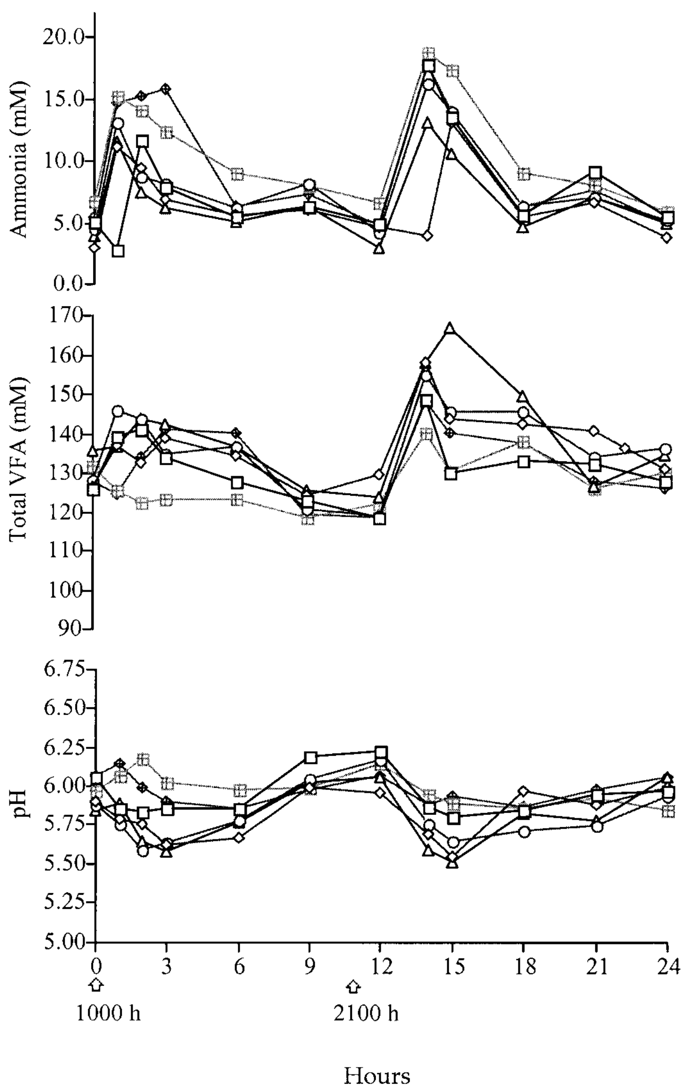

Figure 2. Effect of treatment on rumen environment of cows fed twice daily. (box, high moisture ensiled shelled corn-coarsely ground; diamond, high moisture ensiled shelled corn-finely ground; circle, high moisture ensiled shelled corn-coarsely ground; triangle, high moisture ensiled shelled corn-finely ground; window pane, dry shelled corn-coarsely ground; diagonal window pane, dry shelled corn-finely ground).

CONCLUSIONS

Feeding HMSC compared with HMEC results in higher milk production, reflecting the higher energy content of HMSC. The low energy value of the cob dilutes out the digestible energy of HMEC. The presence of cob in HMEC also requires more silo space for an equivalent amount of corn grain.

The digestibility of starch + free glucose was improved by both increasing the moisture level of corn and reducing corn particle size. The improved digestibility of starch may be reflected in higher levels of production, increased microbial protein production in the rumen, and hence improved nitrogen utilization by the cow. Ruminal fermentation is favored by higher availability of starch, thus improving ruminal ammonia utilization and providing more energy to the cow.

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