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Influence of Corn Processing and Frequency of Feeding on Cow Performance[1,2]

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ABSTRACT

Twenty cows, including five fitted with rumen cannulae, were used to study the influence of corn processing and frequency of feeding on milk yield and ruminal fermentation characteristics. Cows were assigned to five treatments in a 5 × 5 Latin square experiment. Each period was 3 wk. Cows were fed 45% forage and 55% grain in a total mixed ration. Diets contained 35% corn either coarsely ground and fed once a day (1×), finely ground (FGC) fed 1×, steam-flaked (SFC) fed 1×, FGC fed four times a day (4×), or SFC fed 4×. Processing of corn and frequency of feeding had no influence on dry matter intake. Digestibility of starch was increased 6 and 3 percentage units by feeding SFC corn compared with coarsely and finely ground corn, respectively. Cows fed SFC or FGC produced 4% more milk with lower fat content compared with coarsely ground corn. Increasing the feeding frequency did not improve milk fat content. The fat-corrected milk yield was not different among treatments. Feeding SFC resulted in a low acetate-to-propionate ratio in the rumen fluid than FGC. Cows fed SFC produced 45 and 115 g more milk protein per cow/d than cows fed FGC or coarse, respectively. With the value of increased milk protein observed in this study, it would be more economical to feed SFC or finely ground corn to dairy cows compared with coarse ground. The breakeven price of flaking corn in this study was $32 and $12/metric tonne compared with coarse and FGC, respectively. Based on a survey conducted by the authors, the price of flaking corn in the United States ranged between $7 to $22/metric tonne during year 2000.

(**Key words:** corn, cow, milk, protein)

Abbreviation key: CGC = coarsely ground corn, **CG-1×** = coarsely ground corn fed once daily, **FGC** = finely ground corn, **FG-1×** = finely ground corn fed once daily, **FG-4x** = FGC fed four times daily, **SFC** = steam-flaked corn, **SF-4×** = SFC fed four times daily.

INTRODUCTION

Starch is a primary source of energy in ruminant diets and represents 70 to 80% of most cereal grains that are fed to high producing dairy cows. Efficient utilization of starch is fundamental to improving feed efficiency in dairy cows. Increasing starch digestion in the rumen increases propionic acid as a proportion of total VFA in the rumen (Chen et al., 1994; Poore et al., 1993). Propionic acid is a major gluconeogenic precursor in ruminants, and increasing the proportion of propionic acid might result in higher net energy absorption from the rumen, an increase in glucose synthesis by the liver, a reduction in the use of AA for milk protein synthesis (Theurer, 1986), and ultimately improved animal performance.

Processing of grain has been used as a tool to increase ruminal carbohydrate availability (Owens et al., 1997; Theurer, 1986). Different methods of processing corn and sorghum for feeding to dairy cows have been investigated recently (Plascencia and Zinn, 1996; Ekinci and Broderick, 1997; Joy et al., 1997; Knowlton et al., 1998; Santos et al., 1998; Yu et al., 1998). Steam flaking of corn or sorghum is used extensively in finishing beef cattle diets and has consistently improved feed efficiency of feedlot cattle through increased starch utilization (Theurer, 1986). A review of recent studies with dairy cows showed a positive response to including steam-flaked corn (**SFC**) in dairy diets (Theurer et al., 1999a). The adoption of grain processing methods at the farm level will depend on the processing and storage costs associated with the method used. For example, the cost of grinding corn on the farm will be about one-half the cost of steam flaking. Little research compares the feeding value of finely ground corn (**FGC**) with SFC in lactating dairy cows.

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[2]Trade names and the names of commercial companies are used in this report to provide specific information. Mention of a trade name or manufacturer does not constitute a guarantee or warranty of the product by the Utah State University or an endorsement over products not mentioned.

Feeding frequency also influences the starch availability to the rumen microorganisms and to the host animal. Johnson (1976) reported that feeding cattle more frequently increases the efficiency of feed utilization in the rumen, stimulates feed intake, and results in increased milk production. A review of 35 studies on the effects of increased feeding frequency (Gibson, 1984) showed increased milk yield in four experiments, unchanged milk yield in 24, and decreased milk yield in 7. For all experiments, the average effect of increased feeding frequency was a 2.7% increase in milk yield and 7.3% increase in milk fat content. Milk protein and lactose contents were unaffected by feeding frequency. Little information exists in the literature on the combined effects of corn processing and feeding frequency on animal performance.

Many dairy producers feed cows twice daily. Some producers mix feed once a day and feed two or more times during the day. Our hypothesis is that increasing the frequency of feeding in addition to processing of corn will further enhance the utilization of starch and improve cow performance. Therefore, a study was conducted to evaluate the influence of processing of corn and frequency of feeding on DMI, milk yield, milk composition, characteristics of ruminal fermentation, and digestibility of feed in lactating dairy cows fed a high concentrate, corn-based TMR.

MATERIALS AND METHODS

Animals and Experimental Procedures

The study was conducted from March to June 1998 at the George B. Caine Dairy Teaching and Research Center at Utah State University. Twenty multiparous Holstein dairy cows (five cows fitted with rumen cannulae and 15 intact cows) were blocked into four groups. Cows without cannulae were blocked into three groups according to milk yield, and cows fitted with rumen cannulae formed the fourth group. Cows within each group were assigned randomly to five treatments. The experimental design was a replicated 5 × 5 Latin square. The experimental period was 3 wk; the first 2 wk served as an adaptation period, and measurements were made during the last week in each period. Cows in the five treatments were fed diets containing either coarsely ground corn (**CGC**) fed once daily (**CG-1**×), FGC fed once daily (**FG-1**×), SFC fed once daily (**SF-1**×), FGC fed four times daily (**FG-4**×), or SFC fed four times daily (**SF-4**×). Animal care and procedures were approved and conducted under established standards of the Utah State University Institutional Animal Care and Use Committee.

Corn Processing

The coarse, fine, and flaked corn was prepared from the same batch of shelled corn. The CGC and FGC were prepared by passing dry corn through a hammer mill (model 55, Gehl Company, West Bend, WI) using 1.27- and 0.953-cm screen sizes, respectively. Representative samples of CGC and FGC were screened through 4.75-, 2.0-, 1.18-, and 0.5-mm sieves, and percentage of corn particles retained on each screen were determined. The geometric mean particle size of CGC and FGC was then calculated using the dry-sieving technique (ASAE Standards, 1995). The particle size distributions of CGC and FGC were 3.9, 47.5, 14.1, 29.1, 5.4 and 0, 19.3, 21.6, 51.4, 7.7% retained on screen when passed through the 4.75-, 2.0-, 1.18-, 0.5-mm screen sizes and bottom pan, respectively. The average geometric mean particle sizes were 1650 and 1130 microns for CGC and FGC, respectively.

The SFC was prepared as follows: Corn was cooked and flaked with a Roskamp Flaker (model SP1800-36, Roskamp Mill, California Pellet Mill Co., Waterloo, IA). A chest situated directly above the rollers (46 × 61 cm, corrugated) was filled to capacity (441 kg) with corn and brought to a constant temperature (102°C) at atmospheric pressure using steam (boiler pressure 9.3 pressure per square cm). The corn was steamed for 20 min before rollers were started. The total time that the grain was exposed to the steam was 30 min. During the preliminary adjustment period the first chest of SFC was allowed to pass through the rollers, then a second chest full of corn was processed for the study. During this preliminary period, the rollers became warm, and the tension of the rollers was adjusted to provide flakes of desired densities between 360 g/L (28 lb/bu) to 386 g/L (30 lb/bu). Flake density was determined on freshly processed corn samples obtained directly from the cooler using a handheld weight-per-bushel tester (Seedburo Equipment, Chicago, IL). A total of two batches of SFC were prepared during the study. Flake density and thickness of samples from each batch were also determined in the laboratory in a 2-L glass cylinder. The average flake density and thickness were 350 g/L (27.2 lb/bu) and 0.251 cm, respectively. In most cited studies, the flake density of SFC was 360 g/L (Theurer et al., 1999a). Precautions were taken to keep SFC fresh during feeding by storing in a clean, dry, concrete commodity shed.

Feeding and Management of Cows

Cows were housed in a tie-stall barn and fed individually. Diets were fed as a TMR and contained 45% forage and 55% grain. The forage portion of the diet consisted of alfalfa hay and corn silage in a 4:1 ratio on a DM

Table 1. Ingredient and chemical composition of diets.

Composition	Diet[1]			SEM	*P*
	CGC	FGC	SFC		
	(% of DM)				
Ingredient					
Alfalfa hay[2]	36.0	36.0	36.0		
Corn silage[2]	9.0	9.0	9.0		
Corn	35.0	35.0	35.0		
Molasses	1.1	1.1	1.1		
Soybean meal, 49% CP	11.0	11.0	11.0		
Cottonseed, whole linted	3.5	3.5	3.5		
EnerG II[3]	1.3	1.3	1.3		
Dehydrated beet pulp	1.2	1.2	1.2		
Dicalcium phosphate[4]	0.6	0.6	0.6		
Sodium bicarbonate	0.3	0.3	0.3		
Trace-mineralized salt[5]	0.5	0.5	0.5		
Vitamin ADE mix[6]	0.5	0.5	0.5		
Chemical					
DM	60.8	58.9	60.1	1.0	0.45
NE_L Mcal/kg, DM[7]	1.66	1.73	1.73	ND[8]	ND
CP	16.5	16.4	16.5	0.1	0.80
RUP[7]	6.0	5.9	5.9	0.06	0.35
NDF	29.3[b]	29.3[b]	30.0[a]	0.12	0.01
ADF	18.2[b]	18.2[b]	18.9[a]	0.03	0.01
Starch	27.9	28.2	26.8	ND	ND

[a,b]Means in the same row with different superscripts differ significantly at *P* value mentioned in the last column.

[1]CGC = Coarsely ground corn, FGC = finely ground corn, SFC = steam-flaked corn.

[2]Alfalfa hay and corn silage contained 90.0, 18.2, 40.6, 30.3, and 28.2, 6.5, 53.2, 28.5% DM, CP, NDF, and ADF, respectively.

[3]A registered trademark for rumen-inert calcium-salts of long-chain fatty acids (Bioproducts, Inc., Fairlawn, OH); contained 82.3% fat and 8.8% calcium.

[4]Dicalcium phosphate contained: minimum 21% P, 18% Ca, and maximum 0.21% Fl.

[5]Composition: 95 to 97% NaCl, 0.55% Zn, 0.55% Mn, 0.35% Fe, 0.14% Cu, 0.008% I, 0.006% Se, and 0.002% Co.

[6]Contained 1,102,317 IU of vitamin A, 330,695 IU of vitamin D and 6614 IU of vitamin E/kg of DM.

[7]Calculated using NRC (1989) NE_L and RUP values for feed stuffs. The RUP (as a percentage of total CP) values used for alfalfa hay, corn silage, CGC, FGC, SFC, soybean meal, and beet pulp were 28, 31, 60, 58, 58, 35, and 45, respectively. The RUP content of cottonseed was 30.4% of total CP (NRC, 1996).

[8]ND = Not determined.

basis (Table 1). Diets were balanced for minerals and vitamins and were formulated to meet the nutrient requirements of cows producing 50 kg of 3.5% FCM/d according to NRC (1989) recommendations. All diets had similar ingredient composition, except that the corn used was processed differently. At the start of the experiment, cows averaged 100 DIM (range of 21 to 186 d) and were producing 42 kg of milk/d (range of 32 to 56 kg of milk/d). Diets were offered at 0700 h immediately after milking to cows fed once daily, and at 0700, 1200, 1600, and 2100 h to cows fed four times. Orts were restricted to 5 to 10% of an intake on an as-fed basis. Cows were weighed on 2 consecutive days at the beginning of the experiment after the morning milking. Average BW of the cows at the beginning of the experiment was 650 kg (range 567 to 730 kg).

The DM content of the diets ranged from 58.9 to 60.8% during the entire experiment (Table 1). The NE_L content of the diet was estimated using NRC (1989) values for individual dietary ingredients. The NE_L values used for alfalfa hay, corn silage, CGC, FGC, SFC, soybean meal, cottonseed, molasses, EnerG II, and beet pulp were 1.35, 1.50, 1.84. 2.04, 2.04, 1.94, 2.23, 1.72, 4.96, and 1.79 Mcal/kg of DM, respectively. The RUP content of each diet was calculated using NRC (1989) values for each ingredient. Weekly NE_L and RUP intakes were calculated by multiplying the NE_L and RUP contents of the diets with DMI for the respective week.

Sample Collection, Analysis, and Calculations

Daily feed offered and orts for individual cows were recorded. Samples of each TMR and orts from individual cows were collected during wk 3 in each period. The TMR samples for each diet were stored in the freezer (–20°C). The orts samples were mixed for cows within each treatment and stored in the freezer. Weekly composite samples of TMR and orts were analyzed for DM. Samples of forage and other feed ingredients were collected once weekly and analyzed for DM. The DM content of the feed ingredients was determined by oven-drying at 60°C for 48 h. Dietary formulations were adjusted weekly, if necessary, to account for small changes in ingredient DM content.

Samples of dried feed and orts from each period were ground through a Wiley mill using a 1-mm screen (Arthur H. Thomas, Philadelphia, PA) and analyzed for NDF and ADF using the Filter Bag Technology of ANKOM (ANKOM^{200} Fiber Analyzer, ANKOM Technology Corporation, Fairport, NY). The CP content of the dietary ingredients and orts samples were determined with a Protein Nitrogen Analyzer model 2100 (ThermoQuest Italia S.P.A., Strada Rivoltana, Milan, Italy). Composite samples of feed ingredients from five periods were analyzed for starch content by incubating with glucoamylase enzyme to hydrolyze starch and produce dextrose. Hydrolyzed samples were injected into the chamber of a YSI Analyzer model 2700 (YSI Incorporated, Yellow Springs, OH), where dextrose diffuses into a membrane containing glucose oxidase. The dextrose was immediately oxidized to hydrogen peroxide and D-glucono-4-lactone. The hydrogen peroxide was detected amperometrically at the platinum electrode surface. Starch was determined by multiplying dextrose by 0.9.

During analysis, the samples were further dried at 105°C for 8 h to determine absolute DM. Chemical analysis was expressed on the basis of this final DM. The chemical composition of the TMR was calculated from the chemical composition of individual ingredients of the diet. Daily DMI for individual cows was calculated by subtracting the weekly mean of orts from the weekly mean of feed offered. The CP and NDF intakes were calculated by subtracting CP and NDF amounts in orts from feed offered. The amount of CP and NDF in orts was calculated by multiplying weekly mean orts for individual cows with treatment average CP and NDF content in orts during that week.

Milk production was recorded daily. Two milk samples (with and without preservative) were collected from two consecutive a.m. and p.m. milkings during the last week in each period. Milk samples with preservative from individual cows were analyzed for fat, protein, lactose, SNF, and urea N by the Rocky Mountain Dairy Herd Improvement Laboratory (Logan, UT) with midinfrared wavebands (2 to 15 μm) procedures with a Bentley 2000 (Bentley Instruments, Chaska, MN). Final milk composition for each day was expressed on weighted milk yield of a.m. and p.m. samples.

Weighted composite milk samples without preservative from two consecutive a.m. and p.m. milkings were analyzed for fatty acid composition. To determine fatty acid composition, milk fat was extracted by boiling in a detergent solution (Hurley et al., 1987) and derivatized to methyl esters by mixing 30 mg of fat with 5 ml of 4% HCl-methanol (Chin et al., 1992). Heptadecanoic acid was used as an internal standard. The methyl esters were extracted with 5 ml of hexane and 1 ml of distilled water. The hexane extract was washed twice with distilled water and dried over anhydrous sodium sulfate. Fat samples were analyzed in a gas chromatograph (model 6890 Series II, Hewlett-Packard Co., Wilmington, DE) fitted with a flame-ionization detector and 3397A integrator. Samples containing methyl esters in hexane (1 μl) were directly injected through the split-less injection port onto a Supelcowax 10, fused silica capillary column (100 m × 0.32 mm, 0.25 μm film thickness; Supelco Inc., Bellefonte, PA). Gas chromatography conditions were the same as described by Dhiman et al. (1999). Fatty acids were identified by comparing the retention times with methylated fatty acid standards including conjugated linoleic acid. The conjugated linoleic acid reported is *cis*-9, *trans*-11 $C_{18:2}$. The percentage of each fatty acid was calculated by dividing the area under the fatty acid peak by the sum of the areas under the total reported fatty acid peaks.

Gross feed efficiency was calculated as kilograms of 3.5% FCM yield per kilogram of DMI on an individual cow basis. Average fat and protein yields were calculated by multiplying the milk yield by the fat and protein content for the respective week on an individual cow basis. Apparent digestibilities of dietary DM, NDF, and starch were determined with Yb as an external marker. A Yb solution was prepared by dissolving 1.15 g of 99% pure Yb_2O_3 (1 g of Yb) in 1.38 ml of concentrated HCl and diluting with water to 25 ml. The Yb solution was sprayed onto 454 g of beet pulp shreds, which was fed daily to each cow. The labeled beet pulp was fed in the morning before the regular feed was offered to ensure complete consumption of label beet pulp. The Yb marker was fed during the last 9 d in each period. Fecal grab samples (200 to 300 g fresh basis) were collected from individual cows at 0600, 1100, 1700, and 2300 h on d 8 and at 0400, 0900, 1400, 2000 h on d 9 of marker feeding.

Fecal samples were dried in an oven at 60°C for 72 h and ground through a 2-mm screen using a Wiley mill. A composite fecal sample (1 g) for each period from individual cows was dry ashed in duplicate for 16 h at 500°C in a muffle furnace. Concentrations of Yb (mg/kg) in fecal samples were determined by direct current plasma spectroscopy (Spectra Metrics, Inc., subsidiary of Beckman Instruments, Inc., Andover, MA) using the procedure described by Combs and Satter (1992). The total tract DM digestibility (percentage) for individual cows was calculated using the following formula: 1-(concentration of Yb in DM consumed/concentration of Yb in the fecal sample) × 100.

Composite fecal samples for each period from individual cows were reground through a 1-mm screen using Wiley mill and analyzed for NDF and starch content as described earlier. Apparent digestibility of NDF and starch, expressed as a percentage, were computed as the difference between intake and amount excreted in feces divided by intake. The fecal output was calculated by multiplying diet DMI by 1 minus fractional feed DM digestibility on an individual cow basis. The amount of starch and NDF excreted in feces was calculated by multiplying fecal output with NDF and starch content of feces on an individual cow basis.

During the last 2 d of each period, blood samples (15 ml) from individual cows were collected from the coccygeal vein or artery at 5 h postfeeding. The blood samples were collected in serum separation tubes (Vacutainer brand SST Gel and clot activator; Becton Dickinson and Co., Franklin Lakes, NJ). The blood samples were allowed to clot for a minimum of 30 min at room temperature and then centrifuged at 2200 × *g* for 15 min at 4°C to separate serum. The serum samples were stored at –20°C until further analysis. Serum samples were analyzed for glucose concentration colorimetrically using the Beckman glucose kit (#442640; The Beckman Synchron CX Systems, Brea, CA).

Ruminal fluid samples were collected during the last 2 d in each period from rumen cannulated cows at 0, 1, 2, 3, 5, 7, 9, 12, 18, and 24 h after the morning feeding. Ruminal liquor samples were strained through two layers of cheesecloth. The pH was determined in strained ruminal fluid samples immediately after collection using a pH meter (model #310, Orion Research Inc., MA). Samples of strained ruminal fluid (15-ml) were preserved in a plastic vial containing 0.3 ml of 50% sulfuric acid for NH_3 analysis and stored at –20°C for further analysis. Ruminal fluid samples (10-ml) were acidified with 98% formic acid (1:1; vol/vol) and stored at –20°C before preparation and analysis for VFA. The ruminal fluid samples for NH_3 analysis were thawed and centrifuged at 30,000 × *g* for 20 min at 4°C; supernatants were analyzed for NH_3 using an alkaline phenolhypochlorite colorimetric procedure (Chaney and Marbach, 1962). Acidified ruminal fluid samples for VFA analysis were centrifuged at 10,000 × *g* at 4°C for 20 min and analyzed for VFA using a gas chromatograph (Brotz and Schaefer, 1987; model 6890 Series II, Hewlett-Packard Co., Wilmington, DE).

Statistical Analyses

Data were analyzed as a 5 × 5 Latin square experimental design using the general linear models and mixed models procedures of SAS (1999–2000). The general linear model used for analyzing dietary composition included treatment and period. The general linear model used for analyzing production variables included square, cow within square, period, treatment, period × square interaction, square × treatment interaction, and residual error. The mixed model used for analyzing rumen fermentation measurements included cow, hour, treatment, period, hour × treatment interaction. Least squares means were compared using protected least significant difference. Treatment means were also compared by selected orthogonal contrasts: 1) FG-1× and FG-4× vs. SF-1× and SF-4× (processing effects; FGC vs. SFC), and 2) FG-1× and SF-1× vs. FG-4× and SF-4× (frequency of feeding effects; 1× vs. 4×). Significance was declared at $P < 0.05$ unless otherwise noted. Significance at $P < 0.01$ was mentioned as $P = 0.01$ to simplify the tables. Square × treatment and hour × treatment interaction effects were nonsignificant ($P < 0.05$) for production variables and rumen fermentation measurements, respectively. The interaction between corn processing and frequency of feeding was nonsignificant for all the variables reported. Therefore, orthogonal contrasts were used to compare effects of corn processing and frequency of feeding.

RESULTS AND DISCUSSION

Diet Composition

Experimental diets were formulated to be identical in chemical composition. The actual analysis showed that diets had similar DM, CP, and RUP content (Table 1). The diets containing FGC and SFC had higher calculated NE_L concentration than CGC because of the higher energy value of processed corn used in the diet (NRC, 1989). The NDF and ADF contents were higher in diets containing SFC compared with diets containing coarse or FGC. However, NDF and ADF contents of the diets were within the recommended range (NRC, 1989) for lactating cows.

Corn Processing Effects

The mean DMI across treatments ranged from 24.4 to 25.9 kg/d (Table 2). Despite slightly higher energy content of diets containing FGC and SFC, the intakes of energy and DM were not different among treatments. Theurer et al. (1999a) summarized six trials and reported no difference in DMI between cows fed steam-rolled corn and those fed SFC. Intakes of CP and NDF

Table 2. Influence of corn processing and frequency of feeding on nutrient intake and digestibility in dairy cows.

	Treatment[1]						Significance[2]			
Item	CG-1×	FG-1×	SF-1×	FG-4×	SF-4×	SEM	*P1*	*P2*	*P3*	*P4*
Intake										
DM, kg/d	25.9	25.8	24.9	24.8	24.4	0.5	0.10	0.18	0.11	0.56
NE_L, Mcal/kg	43.0	44.6	43.1	42.0	42.3	0.8	0.20	0.46	0.04	0.27
CP, kg/d	4.4	4.4	4.3	4.1	4.2	0.1	0.10	0.59	0.04	0.33
RUP, kg/d	1.56[a]	1.53[a]	1.48[ab]	1.43[b]	1.45[b]	0.03	0.03	0.58	0.06	0.28
NDF, kg/d	6.7	6.6	6.3	6.6	6.4	0.2	0.56	0.25	0.93	0.91
Starch, kg/d	7.1[ab]	7.3[a]	6.5[b]	6.8[ab]	6.4[b]	0.2	0.01	0.01	0.11	0.47
Starch excretion in feces, kg/d	0.46[a]	0.29[b]	0.05[c]	0.30[b]	0.05[c]	0.05	0.01	0.01	0.96	0.91
Total tract digestibility, %										
DM	76.5[ab]	75.5[b]	73.3[b]	78.9[a]	79.2[a]	1.1	0.01	0.36	0.01	0.24
Starch	93.6[c]	96.1[b]	99.1[a]	95.6[b]	99.2[a]	0.7	0.01	0.01	0.72	0.76
NDF	53.2[ab]	49.1[bc]	45.9[c]	57.6[a]	55.6[ab]	2.8	0.04	0.37	0.01	0.83

[a,b,c]Means in the same row with different superscripts differ significantly for overall treatment effect (*P1*).

[1]Cows were fed a diet containing coarsely ground corn once daily (CG-1×), finely ground corn fed once daily (FG-1×), steam-flaked corn fed once daily (SF-1×), finely ground corn fed four times daily (FG-4×), and steam-flaked corn fed four times daily (SF-4×).

[2]*P1* = Overall treatment effect; *P2* = processing of corn into finely ground corn (FGC) vs. steam-flaked corn (SFC); *P3* = frequency of feeding (1× vs. 4×); *P4* = corn processing by frequency of feeding interaction.

were similar for cows in all treatments. The RUP intake was lower in FG-1× and SF-4× treatments compared with CG-1× and FG-1× treatments. Lower RUP intake in FG-1× and SF-4× treatments was probably due to observed decrease in DMI of cows in these treatments. Processing of corn had no influence on NDF intake.

There was a significant influence of processing of corn on starch intake (Table 2). Starch intake of cows fed SFC was lower than cows fed FGC. This decrease in starch intake was probably due to slightly lower starch content of SFC compared with coarse and FGC (68 vs. 71% of DM), and a numerical decrease in feed intake of cows fed SFC (Table 2). Cows fed SFC excreted 410 and 245 g/d less starch in feces compared with cows fed diets containing CGC and FGC, respectively. The starch excretion in feces, as a percentage of dietary starch intake, was 6.5, 4.2, and 0.8% in cows fed diets containing CGC, FGC, and SFC, respectively. These results suggest that steam flaking of corn reduced the excretion of starch in feces compared with coarse or fine grinding. Decreasing the mean particle size of corn from 1650 microns (CGC) to 1130 microns (FGC) reduced the fecal excretion of starch by 36%. Reduction in fecal starch excretion means improved efficiency of starch utilization in an animal.

Processing of corn into FGC or SFC had no influence on DM and NDF digestibility (Table 2). Processing corn into SFC increased the digestibility of starch by 6 and 3 percentage units compared with CGC and FGC, respectively. Apparent digestibility of starch in the rumen typically was increased by steam flaking of corn in other studies (Theurer et al., 1999a; Joy et al., 1997). Steam flaking of corn improves the total tract starch digestibility by increasing the proportions of dietary starch digested within the rumen and by increasing digestibility of the smaller amount of starch reaching the small intestine. Improved starch digestibility in the rumen increases the energy supply to the rumen microorganisms and enhances the amount of microbial protein supply to the small intestine for digestion and absorption.

Cows fed FGC or SFC produced 4% more milk than cows fed CGC (Table 3). Fat content was higher in milk from cows fed CGC than in milk from cows in FG-1×, SF-1×, and SF-4× treatments. Feeding SFC to cows reduced the milk fat content by an average of 7% compared with feeding FGC. In other studies, feeding SFC reduced milk fat content by 4 to 5%, but not fat yield (Theurer et al., 1999a). In the present study, due to reduction in fat content, cows fed SFC produced 70 g/d less milk fat compared with cows fed diets containing FGC.

Fat-corrected milk yield, energy-corrected milk yield, and efficiency of milk production (FCM/DMI) did not differ among treatments (Table 3). In a study reported by Theurer et al. (1999a) efficiency of milk production was not changed by methods used for corn processing, but was improved (+5%) by feeding steam-flaked sorghum compared with dry-rolled.

Feeding SFC to cows improved milk protein content by 3% and protein yield by 6%, and decreased milk urea N content compared with feeding CGC or FGC. Milk lactose content was not different among treatments in the present study. The SNF content was higher in milk from cows fed SFC or FGC compared with cows fed

Table 3. Influence of corn processing and frequency of feeding on milk yield and milk composition of dairy cows.

Item	Treatment[1]					SEM	Significance[2]			
	CG-1×	FG-1×	SF-1×	FG-4×	SF-4×		*P1*	*P2*	*P3*	*P4*
Milk yield, kg/d	36.6[c]	38.0[ab]	38.1[ab]	37.4[b]	38.6[a]	0.4	0.01	0.09	0.86	0.18
3.5% FCM[3], kg/d	35.2	35.6	34.2	35.4	35.1	0.5	0.30	0.09	0.42	0.27
ECM[4], kg/d	35.0	35.7	35.1	35.6	35.7	0.5	0.72	0.61	0.56	0.45
FCM/DMI	1.36	1.38	1.44	1.44	1.44	0.03	0.34	0.96	0.08	0.85
Fat, %	3.34[a]	3.17[b]	2.89[c]	3.21[ab]	3.02[bc]	0.06	0.01	0.01	0.18	0.50
Fat yield, kg/d	1.20[a]	1.18[a]	1.09[b]	1.19[a]	1.14[ab]	0.03	0.02	0.01	0.32	0.46
Protein, %	3.09[c]	3.15[b]	3.19[b]	3.15[b]	3.24[a]	0.02	0.01	0.01	0.09	0.07
Protein yield, kg/d	1.11[d]	1.19[bc]	1.21[ab]	1.17[c]	1.24[a]	0.01	0.01	0.01	0.73	0.06
Lactose, %	4.86	4.88	4.86	4.89	4.87	0.01	0.48	0.11	0.49	0.90
SNF, %	8.70[c]	8.80[b]	8.82[b]	8.81[b]	8.90[a]	0.02	0.01	0.01	0.06	0.15
Milk urea N, mg/dl	17.3[a]	16.4[ab]	15.3[b]	17.1[a]	15.7[b]	0.4	0.01	0.01	0.20	0.65

[a,b,c,d]Means in the same row with different superscripts differ significantly for overall treatment effect (*P1*).

[1]Cows were fed a diet containing coarsely ground corn once daily (CG-1×), finely ground corn fed once daily (FG-1×), steam-flaked corn fed once daily (SF-1×), finely ground corn fed four times daily (FG-4×), and steam-flaked corn fed four times daily (SF-4×).

[2]*P1* = Overall treatment effect; *P2* = processing of corn into finely ground corn (FGC) vs. steam-flaked corn (SFC); *P3* = frequency of feeding (1× vs. 4×); *P4* = corn processing by frequency of feeding interaction.

[3]3.5% FCM = 0.432 (kg of milk) + 16.2 (kg of fat).

[4]ECM = 0.327 × milk (kg) + 12.95 × fat (kg) + 7.20 × protein (kg) (Tyrrell and Reid, 1965).

CGC. Processing corn into SFC improved the SNF content of milk compared with FGC, probably due to increased milk protein content. The milk composition results from this study are consistent with earlier reports (Theurer et al., 1990, 1999a). The amount of microbial protein reaching the small intestine increased 10 to 18% when feedlot cattle and lactating cows were fed SFC or sorghum compared with dry-rolled grain. This could account, in part, for the tendency for increased protein retention in growing steers (Theurer et al., 1990) and increased milk protein yield by cows fed SFC or sorghum (Theurer et al., 1999a).

Santos et al. (1997) observed decreased milk urea N by feeding moderate density steam-flaked sorghum grain compared with dry-rolled or fine-flaked sorghum. The concentrations of milk urea N were lower in cows fed SFC than cows fed cracked corn (Dann et al., 1999). Milk urea N has been used as an indicator of protein utilization and a predictor of N excretion. Low milk urea N of cows fed SFC in the present study compared with cows fed FGC suggests that more dietary N directed towards milk protein and away from urine (Jonker et al., 1998) due to steam flaking of corn. Others have reported similar improvements in protein utilization from grain processing (Ekinci and Broderick, 1997).

There was an increase in the proportions of $C_{12:0}$ to $C_{15:0}$, *trans*-$C_{18:1}$, $C_{18:3}$, total unsaturated fatty acids, and a decrease in the proportion of total saturated fatty acids in milk fat from cows fed SFC compared with milk fat from cows fed FGC (Table 4). Milk fat from cows fed high grain diets has been shown to have high levels of *trans*-$C_{18:1}$ fatty acid (Romo et al., 1996). The reduction in the fat content of milk from cows fed SFC could be related to the increased *trans*-$C_{18:1}$ fatty acid in these cows (Griinari et al., 1998). There were no significant changes in the proportion of other milk fatty acids due to processing of corn. The average concentration of conjugated linoleic acid (*cis*-9, *trans*-11 $C_{18:2}$ isomer) across treatments was 0.46% of total fatty acids, which is similar to that observed by others in the milk fat from cows fed high grain diets (Dhiman et al., 1999, 2000).

The average ruminal pH values did not differ among treatments (Table 5). The NH_3 concentration in the ruminal fluid was lower in cows fed SFC corn than cows fed FGC. Decrease in the ruminal NH_3 in cows fed SFC is also an indication of increased capture of NH_3 by the rumen microbes and thus improved N utilization in the rumen.

Processing of corn into SFC decreased the proportion of acetate and increased propionate in the rumen compared with CGC and FGC (Table 5). The proportions of other VFA were not affected by treatments. The processing of corn into SFC resulted in lower acetate-to-propionate ratio in the ruminal fluid than CGC and FGC. In a study reported by Joy et al. (1997), ruminal fluid pH was not affected by corn processing, but steam-flaking decreased the molar percentage of acetate and increased the molar percentage of propionate. Other researchers (Dann et al., 1999; Ekinci and Broderick, 1997) also have reported a decrease in the ruminal acetate-to-propionate ratio and an increase in propionate when cows were fed rapidly degradable starch. The

Table 4. Influence of corn processing and frequency of feeding on milk fatty acid composition, % of total fatty acid reported.

	Treatment[1]						Significance[2]			
Item	CG-1×	FG-1×	SF-1×	FG-4×	SF-4×	SEM	*P1*	*P2*	*P3*	*P4*
$C_{8:0}$	1.21	1.15	1.13	1.17	1.14	0.03	0.27	0.38	0.52	0.90
$C_{10:0}$	1.02	0.98	1.0	1.01	1.01	0.02	0.62	0.66	0.27	0.71
$C_{12:0}$	2.9[ab]	2.8[b]	3.0[ab]	2.9[ab]	3.0[a]	0.1	0.04	0.01	0.18	0.69
$C_{14:0}$	3.5[b]	3.8[ab]	4.0[a]	3.8[a]	4.1[a]	0.1	0.01	0.02	0.30	0.88
$C_{14:1}$	12.1[b]	12.2[ab]	12.5[ab]	12.3[ab]	12.7[a]	0.1	0.03	0.02	0.24	0.80
$C_{15:0}$	1.4[c]	1.5[bc]	1.7[a]	1.5[bc]	1.6[b]	0.1	0.01	0.02	0.42	0.52
$C_{16:0}$	34.8	34.8	34.6	34.7	34.5	0.4	0.96	0.58	0.81	0.98
$C_{16:1}$	1.3	1.4	1.4	1.3	1.4	0.1	0.31	0.07	0.53	0.87
$C_{17:1}$	0.2	0.3	0.2	0.2	0.2	<0.1	0.19	0.99	0.05	0.23
$C_{18:0}$	11.3	11.0	10.2	11.5	10.6	0.4	0.26	0.06	0.32	0.97
Trans-$C_{18:1}$	3.0	3.2	3.6	3.1	3.4	0.2	0.14	0.04	0.49	0.70
Cis-$C_{18:1}$	21.9	21.6	21.2	21.2	20.8	0.3	0.07	0.17	0.17	0.92
$C_{18:2}$	3.8	3.8	3.9	3.7	3.8	<0.1	0.12	0.12	0.03	0.75
$C_{18:3}$	0.68	0.68	0.73	0.69	0.68	0.02	0.22	0.04	0.28	0.80
CLA[3]	0.43	0.48	0.48	0.41	0.49	0.02	0.06	0.08	0.21	0.10
Cis-8, 11, 14 $C_{20:3}$	0.18	0.16	0.17	0.17	0.19	0.01	0.30	0.18	0.18	0.68
Cis-11, 14, 17 $C_{20:3}$	0.19	0.19	0.20	0.20	0.21	0.01	0.73	0.48	0.31	0.96
SFA[4]	56.1	56.1	55.6	56.7	56.0	0.3	0.07	0.03	0.04	0.76
UFA[5]	43.9	43.9	44.4	43.3	44.0	0.3	0.07	0.03	0.04	0.76

[a,b,c]Means in the same row with different superscripts differ significantly for overall treatment effect (*P1*).

[1]Cows were fed a diet containing coarsely ground corn once daily (CG-1×), finely ground corn fed once daily (FG-1×), steam-flaked corn fed once daily (SF-1×), finely ground corn fed four times daily (FG-4×), and steam-flaked corn fed four times daily (SF-4×).

[2]*P1* = Overall treatment effect; *P2* = processing of corn into finely ground corn (FGC) vs. steam-flaked corn (SFC); *P3* = frequency of feeding (1× vs. 4×); *P4* = corn processing by frequency of feeding interaction.

[3]Conjugated linoleic acid, *cis*-9, *trans*-11 $C_{18:2}$ isomer.

[4]Saturated fatty acids, sum of $C_{8:0}$, $C_{10:0}$, $C_{12:0}$, $C_{14:0}$, $C_{15:0}$, $C_{16:0}$, and $C_{18:0}$.

[5]Unsaturated fatty acids, sum of $C_{14:1}$, $C_{16:1}$, $C_{17:1}$, *trans*-$C_{18:1}$, *cis*-$C_{18:1}$, $C_{18:2}$, $C_{18:3}$, *cis*-9, *trans*;-11 $C_{18:2}$, and $C_{20:3}$.

higher proportion of ruminal propionate in the present study suggests that more starch was digested in the rumen of cows fed SFC compared with cows fed CGC and FGC, and that more glucogenic precursors may have been available for milk production. However, limited observations on glucose levels in the present study suggest that blood serum glucose concentrations of cows fed CGC, FGC, and SFC were not different.

Frequency of Feeding Effects

Frequency of feeding did not influence the intakes of DM, energy, starch, and NDF in cows fed FGC or SFC in the present study (Table 2). A tendency for decreased feed intake of cows fed four times daily resulted in decreased CP intake compared with cows fed once daily. Increasing the frequency of feeding from 1× to 4× improved DM digestibility but did not alter the starch digestibility or excretion of starch in feces from cows fed FGC or SFC. The digestibility of NDF ranged from 45.9 to 57.6% across treatments. Increasing the frequency of feeding in cows fed FGC and SFC increased the digestibility of NDF by 19%. In other studies, the total tract digestibility of NDF was decreased by an average of 16% for lactating cows fed SFC compared with dry-rolled, coarse cracked, or steam-rolled corn (Theurer et al., 1999a). Studies that showed a decrease in fiber digestibility often had an average ruminal pH below 6.0 (Dann et al., 1999). Increasing frequency of feeding generally improves the ruminal pH, and this may be the reason for improved fiber digestibility in the present study.

There was no significant influence of frequency of feeding on milk yield, FCM, energy-corrected milk, and FCM/DMI. Feeding SFC to cows reduced the milk fat content, and feeding diets containing SFC or FGC four times daily did not improve the milk fat content compared with feeding once daily. Milk fat yield, protein content, protein yield, lactose, SNF, and urea N contents were not affected by increasing the frequency of feeding from 1× to 4×. Increasing the frequency of feeding from 1× to 4× decreased the proportion of $C_{17:1}$, $C_{18:2}$, total unsaturated fatty acids, and increased the proportion of total saturated fatty acids in milk (Table 4). However, the proportion of other fatty acids was not affected by frequency of feeding.

Increasing the frequency of feeding from 1× to 4× in cows fed FGC or SFC had no influence on average rumi-

Table 5. Influence of corn processing and frequency of feeding on ruminal fluid fermentation characteristics in dairy cows.

	Treatment[1]						Significance[2]			
Item	CG-1×	FG-1×	SF-1×	FG-4×	SF-4×	SEM	*P1*	*P2*	*P3*	*P4*
pH	6.16	6.05	6.01	6.16	6.07	0.06	0.26	0.23	0.16	0.71
NH_3, m*M*	6.9[a]	7.1[a]	4.4[b]	6.2[a]	4.4[b]	0.4	0.01	0.01	0.26	0.23
Total VFA, m*M*	136.5	141.5	142.8	136.2	137.4	3.6	0.59	0.74	0.15	0.99
VFA, mol/100 mol										
Acetate (A)	64.5[a]	63.0[ab]	59.5[c]	62.6[ab]	60.7[bc]	1.0	0.01	0.01	0.68	0.37
Propionate (P)	20.6[c]	22.3[bc]	26.0[a]	23.2[bc]	24.7[ab]	1.1	0.01	0.01	0.86	0.28
Iso-butyrate	0.7	0.7	0.7	0.7	0.6	<0.1	0.40	0.20	0.45	0.71
Butyrate	11.3	10.9	11.0	10.8	11.1	0.3	0.80	0.44	0.94	0.73
Iso-valerate	0.9	1.0	0.8	0.7	0.8	0.1	0.09	0.21	0.07	0.14
Valerate	2.0	2.1	2.1	2.0	2.1	0.1	0.59	0.31	0.92	0.54
A:P	3.2[a]	2.9[ab]	2.3[c]	2.8[ab]	2.5[bc]	0.2	0.01	0.01	0.79	0.29
Blood serum glucose, mg/dl	55.0	56.9	58.2	58.5	56.7	1.4	0.38	0.84	0.99	0.26

[a,b,c]Means in the same row with different superscripts differ significantly for overall treatment effect (*P1*).

[1]Cows were fed a diet containing coarsely ground corn once daily (CG-1×), finely ground corn fed once daily (FG-1×), steam-flaked corn fed once daily (SF-1×), finely ground corn fed four times daily (FG-4×), and steam-flaked corn fed four times daily (SF-4×).

[2]*P1* = Overall treatment effect; *P2* = processing of corn into finely ground corn (FGC) vs. steam-flaked corn (SFC); *P3* = frequency of feeding (1× vs. 4×); *P4* = corn processing by frequency of feeding interaction.

nal pH, total VFA concentrations, molar proportions of individual VFA, and on acetate-to-propionate ratio in the ruminal fluid (Table 5).

The results from the present study suggest that based on milk yield and fecal starch excretion response, it is economically beneficial to process corn by steam flaking or fine grinding for dairy cows compared with coarse grinding. The decision to process corn for dairy cows should be based on processing costs and returns in terms of milk and milk components. Using the average component pricing for milk in the United States during the year 2000 of $2.50 per kilogram of milk protein, the value of the increased yield of protein due to steam-flaking was $0.29 and $0.11 per cow/d compared with CGC and FGC, respectively. Theurer et al. (1999b) reported a value of $0.22 per cow/d more for SFC compared with steam-rolled or dry-rolled corn. The breakeven price of flaking corn in this study was $32 and $12/metric tonne compared with coarse or fine-ground corn, respectively. According to the results from the present study, it is of no value to flake corn above these breakeven prices. A telephone survey with eight corn processors in the country revealed that the price of flaking corn in the United States ranged from $7 to $22/metric tonne during year 2000.

CONCLUSIONS

Processing of corn into FGC or SFC had no influence on DMI of lactating dairy cows. Processing corn into SFC increased the digestibility of starch by 6 and 3 percentage units compared with CGC and FGC, respectively. Cows fed SFC and FGC produced 4% more milk with reduced milk fat content than cows fed CGC. Reduction in milk fat content resulted in similar FCM yield and FCM/DMI in cows fed CGC, FGC, and SFC. Cows fed diets containing SFC improved protein utilization and increased the yield of milk protein by 115 and 45 g/d per cow compared with protein yield from cows fed CGC and FGC, respectively. Reducing the mean particle size of corn from 1650 (CGC) to 1130 (FGC) microns resulted in 6.3% improvement in milk protein yield.

Increasing the feeding frequency had no influence on DMI of lactating dairy cows; however, the digestibility of NDF was improved by 19% when feeding frequency was increased from 1× to 4× in cows fed FGC and SFC. Feeding SFC to cows reduced the milk fat content and feeding diets containing SFC or FGC four times daily did not improve the milk fat content compared with feeding once daily. Results from present study suggest that it is economically beneficial to process corn by steam flaking or fine grinding for dairy cows compared with coarse grinding.

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