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# Influence of Mechanical Processing on Utilization of Corn Silage by Lactating Dairy Cows[1]

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## ABSTRACT

We conducted three experiments to determine the influence of mechanical processing on corn silage utilization by lactating dairy cows. Total mixed rations contained either unprocessed or processed corn silage harvested between 1/4 and 3/4 milk line. In trial 1, 12 multiparous Holstein cows were used in a replicated double switchback design with 21-d periods. Intake of dry matter (DM) was increased 1.2 kg/d by processing, but milk yield was unaffected. Processing did not affect apparent total-tract DM digestibility, but processing tended to lower starch and corn excretion in feces and reduced concentration of sieved corn kernel particles in feces. In trial 2, 42 Holstein cows were used in an 18-wk randomized complete-block design. Intake of DM and milk yield were unaffected by processing, but milk fat percent was increased 0.35 percentage units by processing. Processing tended to increase total-tract digestibility of starch, but reduced organic matter, crude protein, and neutral detergent fiber digestibilities. In trial 3, 30 Holstein cows were used in a 15-wk randomized complete block design. There was no influence of mechanical processing on intake or lactation performance in this trial. Despite indications of increased starch digestion in two trials and increased DM intake in one trial, effects of processing corn silage on lactation performance were minimal with corn silage at the maturity and moisture contents used in these trials.

(**Key words:** corn silage, mechanical processing, digestion, milk production)

**Abbreviation key: BL** = black layer, **ML** = milkline, **MPL** = mean particle length, **TLC** = theoretical length of cut.

## INTRODUCTION

Although common in Europe for more than a decade, interest in the feeding of processed (rolled) corn silage is recent in North America. The heightened interest in mechanical processing is partially related to recent research showing reduced starch digestion and lactation performance by dairy cows fed corn silage harvested at the black-layer (**BL**) stage of maturity (3, 10). Also involved is an increase in custom harvesting with self-propelled machines and the recent commercial availability of pull-type harvesters fitted with mechanical processors. Despite the growing popularity, research that confirms the benefits of mechanical processing on the utilization of corn silage is limited (20).

Rojas-Bourrillon et al. (18) observed greater total-tract starch digestibility (96.1 vs. 90.7%) in growing steers for processed than for unprocessed BL corn silage, but feedlot performance was not improved. Bal et al. (4) reported increased ruminal in situ (25 g of DM of undried and unground corn silage in 25- × 35-cm Dacron bags) starch degradation for processed over unprocessed corn silage harvested at both 1/2 milkline (**ML**) and BL stages of maturity, but total tract starch digestion was not measured. Johnson et al. (13) reported increased milk yield and fat test and reduced percentage of corn grain in the feces for processed versus unprocessed BL corn silage in dairy cows. Bal et al. (5) reported increased DMI, milk yield, and fat test for processed versus unprocessed 1/2 ML corn silage in dairy cows.

The studies of Bal et al. (5) and Johnson et al. (13) involved switchback designs with short periods of 2 to 4 wk. The objective of our experiments was to further

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[1]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 USDA or an endorsement over products not mentioned.

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**Table 1**. Diet ingredient and nutrient composition for trials 1, 2, and 3.

| | Trial 1 | | Trial 2 | | Trial 3 | |
|---|---|---|---|---|---|---|
| Ingredient, % of DM | Control | Processed | Control | Processed | Control | Processed |
| Control corn silage | 30.0 | . . . | 34.0 | . . . | 37.0 | . . . |
| Processed corn silage | . . . | 30.0 | . . . | 34.0 | . . . | 37.0 |
| Alfalfa silage | 20.0 | 20.0 | 16.0 | 16.0 | 18.0 | 18.0 |
| High-moisture ear corn | 27.0 | 27.0 | 27.0 | 27.0 | 20.5 | 20.5 |
| Roasted soybeans[1] | 14.3 | 14.3 | 12.0 | 12.0 | 12.0 | 12.0 |
| Soybean meal | 7.0 | 7.0 | 8.0 | 8.0 | 5.0 | 5.0 |
| Soybean meal, expeller processed[2] | . . . | . . . | . . . | . . . | 5.0 | 5.0 |
| Calcium carbonate | 0.6 | 0.6 | 1.0 | 1.0 | 0.7 | 0.7 |
| Dicalcium phosphate | 0.4 | 0.4 | 0.7 | 0.7 | 0.5 | 0.5 |
| Magnesium oxide | 0.05 | 0.05 | 0.2 | 0.2 | 0.2 | 0.2 |
| TM salt[3] | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Sodium bicarbonate | 0.2 | 0.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| Vitamin supplement[4] | trace | trace | trace | trace | trace | trace |
| Nutrient | | | | | | |
| DM, % | 60.8 | 60.3 | 52.6 | 52.3 | 55.0 | 56.1 |
| CP, % of DM | 17.2 | 17.2 | 16.2 | 16.3 | 19.0 | 18.8 |
| NDF, % of DM | 26.6 | 25.6 | 27.8 | 28.4 | 28.6 | 28.5 |
| ADF, % of DM | 18.3 | 17.7 | 16.7 | 16.9 | 19.1 | 18.8 |
| $NE_L$[5], Mcal/kg of DM | 1.71 | 1.71 | 1.69 | 1.69 | 1.65 | 1.65 |

[1]Soybeans were roasted at146°C and steeped for 30 min with a Jet-Pro Roaster (Jet Pro Co., Springfield, OH).

[2]Soy Plus (West Central Cooperative, Ralston, IA).

[3]Trace-mineralized salt: NaCl – 92.5 to 95.5%; not less than 0.55% Zn, 0.55% Mn, 0.35% Fe, 0.14% Cu, 0.008% I, 0.006% Se, and 0.002% Co.

[4]Vitamin supplement was added to provide vitamins A, D, and E at 150,000, 50,000 and 500 IU/d per cow.

[5]Calculated using NRC (16) $NE_L$ values.

evaluate the influence of crop processing on corn silage utilization by lactating dairy cows.

## MATERIALS AND METHODS

### Trial 1

Twelve multiparous Holstein dairy cows (four ruminally cannulated and eight intact) were used in this trial. Cows were blocked into three groups; two groups of intact cows and one group of ruminally cannulated cows. Cows within each block were randomly assigned to either unprocessed or processed corn silage treatments. The experimental design was a replicated double switchback with 21-d periods. The first 14 d of each period were for diet adaptation, and the last 7 d of each period were for data collection. At trial initiation, cows averaged 110 DIM (SD = 33; range 61 to 157 d) and 38.2 kg/d of milk (SD = 4.6; range 29.5 to 44.0 kg/d). Diet ingredient composition is presented in Table 1. Diets contained forage and concentrate in a 50:50 ratio (DM basis) and were fed as TMR once a day. Cows were housed in tie stalls and were fed individually for at least 5 to 10% refusal (as-fed basis).

Corn silage was harvested with a conventional chopper and was left unprocessed or processed at ensiling with an Automatic roller mill (Automatic Equipment Mfg. Co., Pender, NE; 1-mm roll clearance). Corn silage for both treatments was harvested September 15, 1995, from the same field. Processed corn silage was harvested first, followed by control silage within 1 d. Unprocessed and processed corn silage treatments were harvested at 3/4 ML stage of maturity. The corn hybrid was Dekalb 512 (DeKalb Genetics, DeKalb, IL), a 101-d variety. Unprocessed and processed corn silage treatments were stored in separate silo bags (2.7 × 30.5 m).

Daily amounts of feed offered and orts for individual cows were weighed and recorded. Orts were mixed for each treatment and a representative composite sample was frozen. Daily samples of silage were frozen and weekly composite samples of silage and orts were used for chemical analysis. Samples of individual ingredients in the treatment diets were taken once weekly. Sample DM content was determined by oven drying at 60°C for 48 h. Diet formulations were adjusted weekly when necessary to account for changes in silage DM content.

Dried composite feed samples were ground through a 1-mm Wiley mill screen (Arthur H. Thomas, Philadelphia, PA) and were analyzed for NDF (23), ADF (8), and CP with a Leco N-analyzer (Model FP-2000, Leco, Leco Corporation, St. Joseph, MI). These feed samples were further dried at 105°C for 8 h to determine absolute DM. Chemical analyses were expressed on an abso-

lute DM basis. Average daily DMI was calculated for individual cows by subtracting the weekly mean of orts DM from the weekly mean of DM offered. Diet $NE_L$ content was calculated with $NE_L$ values from NRC (16) for individual ingredients. Water extracts of corn silage were prepared from samples collected during each period for determination of pH (15).

Daily milk weights were recorded. Milk samples (with bronopol-$B_2$ preservative) were collected from two consecutive a.m. and p.m. milkings during the last week of each period. Milk samples were analyzed for fat and CP by AgSource Cooperative Services (Milk Analysis Laboratory, Menomonie, WI) using infrared procedures with a Fossmatic-605 utilizing a B filter (Foss Electric, Hillerød, Denmark). Final milk composition was expressed based on weighted a.m. and p.m. milk yields. Daily fat and CP yields were calculated by multiplying the milk yield by fat and protein concentrations from the respective week on an individual cow basis.

Apparent total-tract DM digestibility was determined using acid detergent lignin as an internal marker. During the last week of each period, six fecal grab samples were collected within 48 h from each cow. Fecal sampling times were 0900, 1500, 2100, 0600, 1200, and 1800 h. Fecal samples were dried at 60°C for 48 h and ground through a 1-mm Wiley mill screen. Composite fecal samples from each cow and samples of diet ingredients from each period were analyzed for acid detergent lignin (8). Dry matter digestibility was calculated as 1 minus (concentration of acid detergent lignin in DM consumed/concentration of acid detergent lignin in the feces) × 100. Composite fecal samples from each cow were analyzed for starch content (22). Daily starch excretion was calculated by multiplying fecal starch concentration by fecal output for each cow.

During the last 2 d of each period, a fecal grab sample (200 to 220 g, wet-weight basis) from each cow was washed with water through a set of sieves (4.75, 3.35, 1.18, 0.6 mm) to collect corn particles. Residue that was retained on each screen was dried at 60°C, and sieved corn particles were separated manually. Corn particles were expressed as grams of sieved corn particles excreted per kilogram of fecal DM.

During the last 2 d of each period, 15-ml blood samples were collected in heparinized Vacutainers from the coccygeal vein or artery at 5 h postfeeding. Blood samples were centrifuged on the same day at 2200 × $g$ for 15 min at 4°C to separate plasma. Blood plasma was stored at –20°C for further analysis. Glucose and urea concentrations were determined colorimetrically in blood plasma samples by the Industrial Method Numbers 120-71A and 856-87T, respectively, on an Auto Analyzer (Bran + Luebbe Inc., Buffalo Grove, IL).

Ruminal fluid samples were collected from ruminally cannulated cows during the last 2 d of each period at 0, 1, 2, 3, 6, 9, 12, 18, and 24 h postfeeding. Digesta samples were collected from the ventral sac of the rumen and squeezed through two layers of cheesecloth for immediate pH determination. Fifty-milliter samples of strained rumen fluid were preserved by the addition of 1 ml of 50% (vol/vol) sulfuric acid, and stored at –20°C for further analysis. Samples were then thawed and centrifuged at 30,000 × $g$ for 20 min at 4°C; supernatants were analyzed for ammonia and free AA using an alkaline phenol-hypochlorite colorimetric procedure (6). Ten-milliter samples of strained rumen fluid were acidified with formic acid (1:1) and stored at –20°C before preparation and analysis for VFA. Acidified rumen fluid samples were centrifuged at 10,000 × $g$ at 4°C for 20 min and analyzed for VFA (7) with a Varian Vista 6000 gas chromatograph (Varian Instrument Group, Walnut Creek, CA).

Data were analyzed as a double switchback experiment using the general linear models procedure of SAS (19). The basic model included block, cow within block, period, block × period interaction, treatment, and block × treatment interaction. Block × treatment was used as an error term. Rumen fermentation parameters were analyzed as a single-block double switchback experiment with treatment, period, cow, hour, and treatment × hour interaction included in the model. Least squares means were compared using protected least significant difference. Significance was declared at $P < 0.05$ unless otherwise noted.

## Trial 2

Forty-two Holstein cows (13 primiparous and 29 multiparous) were used in an 18-wk lactation trial (2-wk pretreatment period followed by a 16-wk treatment period). Cows were blocked by parity and randomly assigned to either unprocessed or processed corn silage treatments. At trial initiation, cows averaged 48 DIM (SD = 11; range 30 to 66 d) and 39.0 kg/d of milk (SD = 7; range 24.0 to 53.1 kg/d).

The corn silage variety was DeKalb 580, a 108-d variety, harvested on October 2 to 3, 1996. Silage was harvested with a John Deere self-propelled model 6910 harvester (Deere & Co., Moline, IL) fitted with an onboard roller mill that was either engaged (processed treatment) or removed from the path of feed flow (unprocessed treatment). The theoretical length of cut (**TLC**) setting on the harvester was not recorded, but it is normally set at 0.95 cm for unprocessed corn silage. The TLC was increased for harvest of the processed corn silage. Again, the precise TLC was not recorded, but it is normally set at 1.27 to 1.91 cm for processed

corn silage. The roll clearance was set at 1 mm. Unprocessed and processed corn silage treatments were harvested at 1/2 ML stage of maturity and stored in separate concrete-stave upright silos (6.1 × 21.3 m). Both silos were filled over 2 d with processed corn silage harvested during a.m. of d 1 and p.m. of d 2 and unprocessed corn silage harvested during p.m. of d 1 and a.m. of d 2. Both control and processed corn silage were obtained from the same field in alternating strips.

Diet ingredient composition is presented in Table 1. Diets contained forage and concentrate in a 50:50 ratio (DM basis) and were fed as TMR once a day. Cows were housed in tie stalls and were fed individually for at least 5 to 10% refusal (as-fed basis). During the 2-wk pretreatment period, cows were fed the processed corn silage diet. Data collected during this period were used as covariables to estimate least square means for their corresponding variables collected during the treatment period.

Feed sampling and analyses were as described for trial 1. Unprocessed and processed corn silages were measured for particle size with a forage particle separator (1). The separator consists of five screens with square-hole diagonal opening of 26.9, 18.0, 9.0, 5.6, and 1.7 mm (from top to bottom) and a catching pan at the bottom. Mean particle length (**MPL**) and particle distribution were obtained on a wet basis.

Measurement of DMI, milk yield, milk composition, and component yields was as described for trial 1. Samples were collected to determine milk composition every other week during the trial. Body weights were recorded on three consecutive days at the same time each day every other week during the trial. Body condition scores (24) were recorded at weighing on the last day of both the pretreatment and treatment periods.

Total-tract digestibilities of OM, CP, NDF, and starch were determined using Yb as an external marker. A solution containing 499 g of Yb (21) was sprayed onto 1016 kg of soybean meal, and the labeled meal was added to the TMR for 10 d during wk 8 and 9 of the trial to provide 40 mg of Yb/kg of ration DM. During the ninth week of the trial, nine fecal grab samples were collected within a 72-h period from each cow. Sampling times were distributed across the 24-h cycle. Fecal samples were dried at 60°C for 48 h and ground through a 1-mm Wiley mill screen. Analysis of composite fecal samples from each cow for Yb concentration was as described by Bal et al. (3). Composite fecal and ort samples from each cow and composites of daily feed samples taken during the collection period were analyzed for OM (2), CP, and NDF as previously described, and for starch (11). Nutrient digestibilities in the total tract were calculated with Yb and nutrient concentrations in diet, ort, and fecal samples.

Data were analyzed as a randomized complete-block design using the PROC MIXED procedure of SAS (14). Parity (primiparous vs. multiparous cows) was the blocking factor. Data collected during the 2-wk pretreatment period were used as a covariate term in the model. Cow was a random effect in the model. Week and week × treatment interaction were included as repeated effects in the model for intake and lactation data. Least squares means were compared using protected least significant difference. Significance was declared at $P < 0.05$ unless otherwise noted.

### Trial 3

Thirty Holstein cows (14 primiparous and 16 multiparous) were used in a 15-wk lactation trial (2-wk pretreatment period followed by a 13-wk treatment period). Cows were blocked by parity and randomly assigned to either unprocessed or processed corn silage treatments. At trial initiation, cows averaged 130 DIM (SD = 50; range 37 to 186 d) and 36.5 kg/d of milk (SD = 4; range 27.8 to 45.9 kg/d).

The corn silage variety was DeKalb 527, a 101 to 103-d variety, and it was harvested on September 2, 1997, between 1/4 and 2/3 ML. A modified New Holland (New Holland North America, New Holland, PA) forage harvester fitted with a roller mill harvested the processed silage. A Case (Case Corporation, Racine, WI) forage harvester was used for the control forage. Control corn silage was chopped at 0.95 cm TLC, and processed silage at 1.9 cm theoretical length of chop. The silages were stored in separate concrete-stave silos (3.1 × 21.3 m).

Diet ingredients and nutrient composition are presented in Table 1. Diets contained forage and concentrate in a 55:45 ratio (DM basis) and were fed as TMR once a day. Cows were housed in tie stalls and were fed individually for at least 5 to 10% refusal (as-fed basis). During the 2-wk pretreatment period, the TMR contained 18.5% unprocessed corn silage and 18.5% processed corn silage (DM basis). Data collected during this period were used as covariates in the estimation of least square means for their corresponding variables collected during the treatment period.

Feed sampling and analyses and measurement of DMI, milk yield, milk composition, and component yields were as described for trial 1. Samples were collected to determine milk composition every other week during the trial. Body weights were recorded on two consecutive days at the same time each day during the last week of both the pretreatment and treatment periods. Body condition scores (24) were recorded at weighing on 1 d of both the pretreatment and treatment periods. On 1 d during wk 12 of the trial, a.m. and p.m.

**Table 2**. Chemical composition and particle size of corn silage fed in trials 1, 2, and 3.

| | Trial 1 | | Trial 2 | | Trial 3 | |
|---|---|---|---|---|---|---|
| Item | Control | Processed | Control | Processed | Control | Processed |
| DM, % | 40.7 | 39.2 | 38.5 | 38.3 | 32.4 | 35.5 |
| pH | 3.9 | 3.8 | 3.8 | 3.8 | 3.9 | 5.7 |
| CP, % of DM | 6.7 | 6.7 | 7.1 | 7.0 | 9.0 | 8.4 |
| NDF, % of DM | 38.2 | 34.6 | 39.4 | 38.2 | 39.6 | 39.3 |
| ADF, % of DM | 23.2 | 21.2 | 23.7 | 23.0 | 25.9 | 25.2 |
| MPL[1], mm | ND[2] | ND | 9.9 | 9.8 | 9.8 | 9.6 |
| Percentage of particles on sieves 1 and 2[3] | ND | ND | 15.6 | 15.9 | 19.9 | 35.2 |

[1]Mean particle length determined with a oscillating screen particle serparator (1).

[2]Not determined.

[3]Sieves 1 and 2 on oscillating screen particle separator (consisting of five sieves and a catching pan at the bottom (1); had square-hole diagonal openings of 26.9 and 18.0 mm, respectively. Values were obtained on a wet-weight basis.

fecal grab samples (200 to 220 g, wet weight basis) were taken from each cow and washed through a set of sieves (4.75, 3.35, 1.18, 0.6 mm) to count whole kernels.

Data were analyzed as a randomized complete-block design using the general linear models procedure of SAS (19). Parity (primiparous vs. multiparous cows) was the blocking factor. Data collected during the 2-wk pretreatment period were used as a covariate term in the model. Least squares means were compared using protected least significant difference. Significance was declared at $P < 0.05$ unless otherwise noted.

## RESULTS AND DISCUSSION

### Trial 1

Dry matter content of the corn silage averaged 40.0%, with little difference between treatments (Table 2). Silage pH was indicative of a normal fermentation for both treatments. Contents of CP, NDF, and ADF in the corn silage were low relative to NRC (16) feed tables. Contents of NDF and ADF were 3.6 and 2.0 percentage units lower, respectively, for processed compared to unprocessed corn silage. The alfalfa silage was good quality; 51.4% DM, 18.5% CP, and 41.4% NDF (DM basis). Diet estimated $NE_L$ and CP did not vary by treatment (Table 1). Contents of dietary NDF and ADF were at NRC (16) minimums and were slightly lower for the processed corn silage treatment, reflecting the lower NDF and ADF concentrations found in the processed corn silage.

Intake of DM was 1.2 kg/d higher for the processed versus unprocessed corn silage treatment (Table 3). This is in agreement with Bal et al. (5). Johnson et al. (13) could not evaluate DMI because cows were group fed. Higher DMI for processed corn silage could be related to improved silage fermentation (18), but pH values of processed and unprocessed corn silage were similar (Table 2).

Milk yield, composition, and component yields were unaffected by processing (Table 3). Body weight change was not measured in this experiment because of the short-term switchback design that was employed. We speculate that higher DMI for processed corn silage with no change in milk production likely would result in an increase in BW gain, but have no data to support this premise.

Apparent total-tract DM digestibility was unaffected by processing (Table 4). This finding agrees with data observed for steers (18), in which processing did not affect DM digestibility, but increased starch digestibility and tended to reduce NDF digestibility. We observed a tendency ($P = 0.10$) for processing to lower starch and corn excretion in feces. Processing reduced the concentration of sieved corn particles in the feces (55 vs. 90 g/kg of fecal DM). Because daily feed intake was slightly higher for cows on the processed corn silage (25.2 vs. 24.0 kg), the differences noted in starch excretion and fecal corn particles (Table 4) tend to underestimate the real differences between treatments. Our observations regarding the effect of processing on fecal excretion of corn particles are similar to those of Johnson et al. (13). The combined effects of slightly lower starch digestion and slightly higher DM digestibility for the control diet suggest that digestibility of the fibrous portion of the control diet may have been increased slightly. Cows fed the control diet may have selected a more digestible diet by sorting and leaving the poorly digested cobs.

Processing tended ($P = 0.06$) to increase ruminal VFA concentration and reduced ruminal pH (Table 4). Acetate (mol/100 mol total VFA) was reduced and propionate was increased for the processed corn silage treatment. Processing also reduced ruminal ammonia concentration. These findings are consistent with increased

**Table 3**. Effects of mechanical processing on DMI and lactation performance by dairy cows in Trials 1, 2, and 3.

| | Trial 1 | | | | Trial 2 | | | | Trial 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | C[1] | PR[2] | SEM | *P* | C | PR | SEM | *P* | C | PR | SEM | *P* |
| BW, kg | ND[3] | ND | . . . | . . . | 619 | 621 | 6 | 0.73 | 636 | 622 | 14 | 0.35 |
| DMI, kg/d | 24.0 | 25.2 | 0.1 | 0.01 | 24.8 | 24.9 | 0.3 | 0.67 | 22.7 | 23.4 | 0.5 | 0.39 |
| Milk yield, kg/d | 35.7 | 36.4 | 0.8 | 0.58 | 42.6 | 41.3 | 0.7 | 0.10 | 36.8 | 36.1 | 0.6 | 0.41 |
| Milk fat, % | 2.97 | 3.00 | 0.07 | 0.84 | 3.53 | 3.88 | 0.09 | 0.01* | 3.73 | 3.83 | 0.1 | 0.47 |
| Milk fat, kg/d | 1.05 | 1.08 | 0.02 | 0.35 | 1.53 | 1.58 | 0.05 | 0.37 | 1.38 | 1.41 | 0.04 | 0.73 |
| Milk protein, % | 3.11 | 3.10 | 0.02 | 0.77 | 3.08 | 3.08 | 0.03 | 0.90 | 3.09 | 3.22 | 0.08 | 0.28 |
| Milk protein, kg/d | 1.11 | 1.13 | 0.03 | 0.68 | 1.32 | 1.27 | 0.02 | 0.05 | 1.15 | 1.18 | 0.03 | 0.43 |

[1]C = Control corn silage treatment.

[2]PR = Processed corn silage treatment.

[3]ND = Not determined.

*Treatment × parity effect ($P = 0.05$).

rumen-available starch (17) for the processed corn silage treatment. Increased ruminal starch digestion for processed over unprocessed corn silage has been observed in situ (4) and in vivo (18). Blood plasma glucose and urea concentrations were not different between treatments.

## Trial 2

Dry matter content of the corn silage averaged 38.4% with little difference between treatments (Table 2). Silage pH was indicative of normal fermentation for both treatments. Contents of CP, NDF, and ADF in the corn silage were low relative to NRC (16) feed tables, and there was little difference between treatments. The starch contents of unprocessed and processed corn silage were 30.2 and 31.5% (DM basis), respectively. The MPL and percent coarse particles (% retained on 26.9 and 18.0-mm screens) measured with wet material were similar for unprocessed and processed corn silage treatments. Jirovec et al. (12) reported similar MPL for processed corn silage that was harvested at a longer TLC than unprocessed corn silage, presumably due to sheering action of the processor on the stalk material. The percentage of visibly damaged kernels was 82 and 99% of total recoverable kernel mass for unprocessed and processed corn silage, respectively. The alfalfa silage contained 30.4% DM, 16.9% CP, and 41.9% NDF (DM basis). Diet estimated $NE_L$ and CP did not vary by treatment (Table 1). Contents of dietary NDF and ADF were slightly above NRC (16) minimums. Contents of dietary starch were 29.6 and 30.0% (DM basis) for unprocessed and processed corn silage treatments, respectively.

**Table 4**. Total tract digestibility, ruminal fluid parameters, and blood plasma metabolite concentrations in cows fed control and processed corn silage in trial 1.

| | Control | Processed | SEM | *P* |
|---|---|---|---|---|
| Total tract digestion | | | | |
| DM digestibility, % | 62.0 | 61.5 | 0.3 | 0.36 |
| Starch excretion, g/d | 442 | 336 | 27 | 0.10 |
| Corn excretion, g/d | 631 | 480 | 19 | 0.10 |
| Sieved corn particles in feces, g/kg of fecal DM | 90 | 55 | 4.0 | 0.02 |
| Ruminal fluid parameters | | | | |
| pH | 5.85 | 5.73 | 0.02 | 0.01 |
| $NH_3$, m*M* | 13.1 | 10.1 | 0.4 | 0.01 |
| Free AA, m*M* | 0.90 | 0.87 | 0.09 | 0.81 |
| Total VFA, m*M* | 132.3 | 137.3 | 1.9 | 0.06 |
| VFA, mol/100 mol | | | | |
| Acetate | 59.7 | 57.1 | 0.3 | 0.01 |
| Propionate | 23.5 | 26.3 | 0.4 | 0.01 |
| Butyrate | 11.7 | 12.1 | 0.2 | 0.13 |
| Isovalerate | 2.1 | 1.8 | 0.03 | 0.01 |
| Valerate | 2.0 | 1.9 | 0.05 | 0.03 |
| Blood plasma metabolites | | | | |
| Glucose, mg/dl | 68.4 | 69.9 | 2.0 | 0.64 |
| Urea, m*M* | 4.8 | 4.4 | 0.2 | 0.32 |

**Table 5**. Apparent total tract nutrient digestibility (%) in cows fed control and processed corn silage in Trial 2.

| Measurement | Control | Processed | SEM | *P* |
|---|---|---|---|---|
| OM | 66.1 | 62.1 | 0.7 | 0.01 |
| CP | 64.8 | 58.7 | 0.6 | 0.01 |
| NDF | 36.8 | 32.1 | 1.2 | 0.01 |
| Starch | 84.3 | 87.4 | 1.0 | 0.09 |

The DMI and milk yield were unaffected by processing (Table 3). Milk fat was 0.35 percentage units higher ($P < 0.01$) for processed than for unprocessed corn silage treatment. Increased ($P < 0.05$) milk fat percentage in response to processing corn silage has been reported by others (5, 13). This was not supported by the ruminal fermentation data in trial 1 but could be related to less sorting and refusal of cob fiber in the feed manger for the processed corn silage treatment. The CP content of orts averaged 13.7 and 14.6% (DM basis), respectively, for the unprocessed and processed corn silage treatments. The NDF content of orts averaged 32.5% and 31.1% (DM basis), respectively, for unprocessed and processed corn silage treatments. Comparing these values for orts to diet CP and NDF concentrations suggests that sorting occurred, but it does not appear that there was enough difference in sorting between the two treatments to explain the observed difference in milk fat percentage. Also, differences in chewing activity between the two treatments that might affect milk fat percentage would not be expected given the similar particle size of unprocessed and processed corn silage (Table 2). A treatment × parity interaction ($P = 0.05$) for milk fat percent was observed. Processing increased milk fat 0.60 percentage units in primiparous cows and only 0.10 percentage units in multiparous cows. The cause of this difference in response between parity groups is unclear.

Total-tract OM, CP, and NDF digestibilities were lower for the processed corn silage treatment (Table 5). Total-tract digestibility of starch tended ($P = 0.09$) to be higher for the processed corn silage treatment, which agrees with Bal et al. (5). Reduced fecal excretion of corn particles has been reported (13). Rojas-Bourrillon et al. (18) reported that processing did not affect total-tract DM digestibility, but increased starch digestibility and tended to reduce NDF digestibility by steers. Reduction in total-tract NDF digestion related to processing of corn silage could be due to negative associative effects of greater rumen-available starch on ruminal NDF digestion (9), or to less sorting of the poorly digested corn cobs. Processing reduced ruminal pH, acetate (mol/100 mol of total VFA), and ammonia (m*M*) and increased propionate in trial 1. There was no treatment effect for BW change (0.5 kg/d for both processed and unprocessed corn silage) or BCS. Reduced NDF digestion may have counteracted potential benefits of increased starch digestion on milk yield in this trial. Also, the high percentage of cracked and broken kernels for the unprocessed corn silage may have precluded a better response to processing in this trial.

## Trial 3

Average DM content of the processed corn silage was higher than that for the unprocessed corn silage (35.5 vs. 32.4%), but both percentages were lower than the average DM content of the corn silage used in trials 1 and 2 (Table 2; 40.0 and 38.4%, respectively). Maturity, based on position of ML did not differ significantly from corn silage used in trials 1 and 2. Silage pH indicated a normal fermentation for both treatments. The higher pH value for the processed silage resulted from elevated pH during the last one third of the trial, where some spoilage occurred. The content of NDF in the corn silage was low relative to NRC (16) feed tables, and there was little difference between treatments. The MPL measured at feeding did not differ with processing, with values smaller than those measured at ensiling (13.2 and 12.2 mm for unprocessed and processed corn silages, respectively). Percent coarse particles (% wet-weight) retained on 26.9 and 18.0-mm screens were higher for the processed than the unprocessed corn silage due to the longer TLC. Rolling decreased percent particles retained on the 9.0-mm screen (25.4 vs. 44.8%) and increased the portion recovered on the smallest screen (1.7 mm) and the bottom pan (25.3 vs. 19.6%). The alfalfa silage averaged 31.1% DM, 23.0% CP, and 42.8% NDF (DM basis). Diet estimated $NE_L$ and CP varied little by treatment and contents of dietary NDF and ADF were above NRC (16) minimums (Table 1).

Intake of DM and lactation performance were unaffected by processing (Table 3). Body weight change averaged 434 and 533 g/d for unprocessed and processed corn silage treatments, respectively, but was not different ($P = 0.62$). Initial (3.60 and 3.56) and final (3.65 and 3.64) BCS and change in BCS for unprocessed and processed corn silage treatments, respectively, were not affected by processing. Lack of response to processing may have been related to the low DM content of the corn silage evaluated in this trial. Bal et al. (3) observed higher apparent total tract OM and starch digestibilities for corn silage with 30 to 35% DM (early dent to 2/3 ML maturity) than corn silage with 42% DM (BL maturity). Therefore, the potential benefits of processing may increase as corn silage maturity advances and DM content increases. Johnson et al. (13) and Rojas-Bourrillon et al. (18) observed lactation performance and digestion responses, respectively, to pro-

cessing BL corn silage. Dry matter content of our corn silage averaged 40.0 and 38.4% in trials 1 and 2, respectively, versus 34.0% in trial 3 (Table 2). The concentration of whole kernels in the feces tended to be lower for processed than unprocessed corn silage treatments (14 vs. 53 kernels/kg of fecal DM). Concentrations of corn particles, including intact and partially broken, were 26 and 38 g/kg of fecal DM for processed and unprocessed corn silage treatments, respectively.

## CONCLUSIONS

Results from these trials suggest that mechanical processing of corn silage improved starch digestibility. This appeared to compromise fiber digestion, as evidenced by measurement of ruminal fluid parameters (trial 1) and total-tract NDF digestibility (Trial 2), under the conditions of these experiments with diets containing 30 to 37% corn silage and 26 to 29% NDF (DM basis). Except for an increase in DMI in trial 1, no differences were observed in DMI or milk yield of cows fed either processed or unprocessed corn silage. The maturity of corn silage harvested for all three trials was between one-fourth and three-fourths ML. More mature corn silage with drier and harder kernels might be expected to benefit more from processing. The impact of corn silage hybrid, maturity, and DM content on the response to processing remains to be elucidated.

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