Crop Processing and Chop Length of Corn Silage: Effects on Intake, Digestion, and Milk Production by Dairy Cows

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ABSTRACT

Effects of corn silage crop processing and chop length on intake, digestion, and milk production were evaluated. Corn silage treatments were harvested at one-half milkline stage of maturity (65% whole-plant moisture content) and at 0.95-cm theoretical length of cut without processing (control) or 0.95-, 1.45-, or 1.90-cm theoretical length of cut with processing at a 1-mm roll clearance. Twenty-four multiparous Holstein cows averaging 71 d in milk at trial initiation were in a replicated 4 × 4 Latin square design with 28-d periods; one square was comprised of ruminally cannulated cows for rumen measurements. Corn silage treatments were fed in total mixed rations containing 50% forage (67% corn silage and 33% alfalfa silage) and 50% corn and soybean meal based concentrate (dry matter basis). Dry matter intake (25.9 vs. 25.3 kg/d) and milk (46.0 vs. 44.8 kg/d) and fat (1.42 vs. 1.35 kg/d) yields were higher for the processed corn silage treatments compared with the control corn silage. Within the processed corn silage treatments, there were no chop length effects on intake, milk production, or milk composition. Chewing activity was not different among the four corn silage treatments averaging 12 h/d. Total tract digestion of dietary starch was lower for control corn silage (95.1%) compared with fine, medium, and coarse processed corn silage treatments, which averaged 99.3%. Total tract digestion of dietary NDF was reduced for fine-processed corn silage compared with control corn silage and coarse-processed corn silage (28.4% vs. 33.9 and 33.7%, respectively). Processing corn silage improved dry matter intake, starch digestion, and lactation performance. Under the conditions of this study and with theoretical lengths of cut ranging from 0.95 to 1.90 cm, length of chop effects were minimal in processed corn silage.
(**Key words:** corn silage, processing, particle size, milk production)

Abbreviation key: FPR = fine-processed corn silage, **MPR** = medium-processed corn silage, **CPR** = coarse-processed corn silage, **TLC** = theoretical length of cut, **WPCS** = whole-plant corn silage.

INTRODUCTION

Recently, interest in the feeding of processed (rolled) corn silage to lactating dairy cows has increased. Currently, crop processors are available on both self-propelled and pull-type harvesters. Research in North America has shown that processing whole-plant corn silage (**WPCS**) improves total-tract starch digestion in dairy cows (4) and beef steers (22) and milk production by dairy cows (13). Satter et al. (24) summarized WPCS processing trials for response in milk production, and found 0.5 kg/d higher milk production for processed compared with unprocessed WPCS. In two studies (4, 22), total-tract starch digestion was increased 5 percentage units for processed compared with unprocessed WPCS diets.

There has been little research to evaluate effects of WPCS chop length on lactation performance and digestion by dairy cows. Kuehn et al. (16) saw no DMI or milk production difference between long (0.87 cm) or short (0.32 cm) theoretical length of cut (**TLC**) unprocessed WPCS. Stockdale and Beavis (28) evaluated fine, medium, and coarse TLC unprocessed WPCS, and reported no differences in milk production or apparent total-tract nutrient digestion. Feeding trials that have evaluated chop length effects in processed WPCS are lacking.

The objectives of this experiment were to evaluate the effects of processing WPCS and chop length of processed WPCS on intake, digestion, and milk production by dairy cows.

MATERIALS AND METHODS

Pioneer corn hybrid 3563 (Pioneer Hi-Bred International, Des Moines, IA) was harvested as WPCS at one-half milkline stage of maturity with an experimental pull-type harvester fitted with on-board rollers. Corn silage treatments were harvested at 0.95 cm TLC without processing (control), or 0.95-cm (fine processed;

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FPR), 1.45-cm (medium processed; **MPR**), and 1.90-cm (coarse processed; **CPR**) TLC with processing at a 1-mm roll clearance. The four WPCS treatments were harvested in 1 d, and they were stored in separate 2.7-m diameter silo bags. Alternate loads of each WPCS treatment were sampled at the bagger to determine moisture content; preensiling moisture content of WPCS treatments was similar, averaging 66%.

Twenty-four multiparous Holstein cows were randomly assigned to treatments in a replicated 4 × 4 Latin square design with 28-d periods. Four cows in one square were ruminally cannulated to allow measurement of ruminal pH, VFA, mat consistency, and in situ nutrient disappearance from Dacron bags. The first 14 d of each period were for diet adaptation, and sampling occurred during d 15 to 28 of each period. Cows averaged 71 DIM (range: 44 to 99 d) at trial initiation. All cows were injected with bovine somatotropin (Posilac, Monsanto Company, St. Louis, MO) every 14 d starting on d 1 of the experiment. The corn silage treatments, alfalfa silage, and concentrate mix comprised 34, 16, and 50 of diet DM, respectively, and were fed as TMR once daily. Diets were formulated to contain 17.5% CP (DM basis) and to meet or exceed NRC (21) requirements for minerals and vitamins. Dry matter content of WPCS treatments and alfalfa silage were measured weekly using 60°C forced-air oven for adjustment of as-fed ratios of diet ingredients. The amounts of TMR offered and refused were recorded daily. Cows were fed ad libitum, and diet refusals were maintained at approximately 10%. The WPCS treatments, alfalfa silage, and concentrate mixture were sampled on d 15 and 22 of each period and each was composited by period for nutrient analysis. Refusal samples were collected on d 26 to 28 of each period and composited by cow within period. Feed and refusal composites were dried for 48 h in a 60°C forced-air oven and ground to pass a 1-mm Wiley mill screen (Arthur H. Thomas, Philadelphia, PA). Samples were analyzed for DM, OM, and CP (2), ADF (10), NDF using α-amylase (Sigma no. A3306; Sigma Chemical Co., St. Louis, MO) and sodium sulfite (30), and lignin (30). Starch was measured on feed and refusal composites as follows. 1) Aliquots (0.1 g) were weighed into duplicate 35-ml Pyrex glass centrifuge tubes, 20 ml of distilled water was added to each tube, and tubes were vortexed. 2) α-Amylase (100 μl; Sigma no. A3306; Sigma Chemical Co., St. Louis, MO) was added to each tube and tubes were held for 1 h in a 93°C water bath (tubes were vortexed every 15 min during this incubation). 3) Tubes were cooled for 15 min and vortexed three times within the first 10 min, then particles were allowed to settle to the bottom of the tubes. 4) Supernatant (1 ml) was transferred to a new 35-ml Pyrex glass centrifuge tube and then 8 ml of 0.1 *M* sodium acetate buffer (pH 4.75) and 50 μl of amyloglucosidase (Sigma no. A3514; Sigma Chemical Co., St. Louis, MO) was added to each tube. 5) Tubes were incubated in a 60°C water bath for 30 min (tubes were swirled every 10 min) before adding 16 ml of distilled water to each tube to bring the volume to 25 ml. 6) Glucose oxidase (Sigma no. 510-A; Sigma Chemical Co., St. Louis, MO) was assayed with 0.5 ml of sample from each sample tube and absorbance was read with a micro-assay plate reader at 450 nm. A pure corn starch sample (Sigma no. S-4126; Sigma Chemical Co., St. Louis, MO) was included in each run to check starch recovery, and sample values were adjusted for starch recovery in that run. Average pure starch recovery within nine runs was 100.2 ± 2.5%. The WPCS treatments were analyzed for pH, lactic acid, and VFA as described by Muck and Dickerson (20). The particle size of WPCS treatments and their corresponding TMR was determined in duplicate using an oscillating screen particle separator according to American Society of Agricultural Engineers standard S424 (1).

Cows were milked twice daily, and production was recorded at each milking. Milk samples taken from a.m. and p.m. milkings on three consecutive days during wk 3 (d 15, 16, and 17) and 4 (d 22, 23, and 24) of each period were analyzed for milk fat, CP, MUN, and lactose by infrared analysis (AgSource Milk Analysis Laboratory, Menomonie, WI). Milk composition was calculated as an average of a.m. and p.m. samples using the proportion of daily production at that milking as a weighting factor. Body weights were recorded for three consecutive days at the start of trial and on d 26 to 28 of each period.

Twenty-four hour ruminal in situ DM and starch disappearance of WPCS treatments were determined in the ruminally cannulated cows on d 27 of each period. In situ bags were made of Dacron polyester cloth (25 × 35 cm, 52 ± 5 μm pore size). The WPCS treatments were each incubated with triplicate bags per cow and matching incubation WPCS with diet WPCS by cow and period. Twenty-five grams of DM was weighed into each bag (30 mg/cm^2, sample size to surface area ratio) and incubated without drying or grinding at 2 h after the morning feeding (1000 h) for 24 h. To minimize sampling error for these as-fed samples, a large sample size was used, each treatment was incubated in triplicate in each cow, and the treatments were remixed between each subsampling. In situ bags were placed in a nylon laundry bag and positioned in the ventral rumen. Duplicate blank bags were incubated in each laundry bag to correct for influx of DM into the sample bags. In situ bags were washed in a commercial washing machine with cold water for two cycles of 12 min each (5). Bags and residue were then dried at 60°C for 48 h to determine DM disappearance. Residues were then composited for each WPCS by period and analyzed for starch as described previously to measure starch disappearance.

Ruminal fluid was sampled immediately before the morning feeding (0800 h) and at 3, 6, 9, and 12 h after feeding on d 25 of each period. Samples were taken from five different locations in the rumen via the cannula using a custom made metal filter probe and pH was determined (twin pH meter Model B-213, Spectrum Technologies Inc., Plainfield, IL). Duplicate 10-ml samples of rumen fluid were acidified with 0.2 ml of 50% H_2SO_4 and frozen until analysis for VFA. These samples were prepared for analysis as follows: 1) Sample tubes were thawed and centrifuged at 2000 × g, 4°C for 15 min. 2) Supernatant (1 ml) was transferred into a microfuge tube, 0.2 ml of 25% metaphosphoric acid was added, and the mixture was vortexed before incubating at room temperature for 30 min. 3) Supernatant was transferred into a GLC sample vial for analysis by using GLC (Varian 2100, Sunnyvale, CA) with GP 10% SP-1200/1% H_3PO_4 on 80/100 Chromasorb WAW column packing (Supelco, Bellefonte, PA). Separate duplicate 10-ml samples of rumen fluid were acidified with 0.2 ml of 50% trichloroacetic acid solution and frozen until analysis for ammonia concentration. These samples were centrifuged at 1400 × g, 4°C for 20 min and the supernatant was diluted 1:10 with distilled water. Four milliliters of reagent A (50 mg of sodium nitroprusside, 8.25 g of sodium tungstate, and 11 ml of 90% liquified phenol per liter) and reagent B (25 g of disodium phosphate, 5 g of reagent grade sodium hydroxide, and 50 ml of 5.25% sodium hypochlorite per liter) were added to 100 μl of ruminal fluid. Tubes were incubated at room temperature for 1 h and absorbance was subsequently read at 625 nm as described by Sievert and Shaver (27).

Ruminal mat consistency was measured in the ruminally cannulated cows 5 h after the morning feeding (1300 h) on d 26 of each period. The method described by Welch (31) was used for this measurement. Three replicate measurements for each cow by period were taken at 30-min intervals. Times spent eating and ruminating were measured during the last day of each period by recording the chewing action of each cow every 5 min for 24 h.

Total-tract nutrient digestibilities were measured using La as an external marker. Lanthanum solution (12) was sprayed onto a wheat middlings carrier. Each cow received 114 g of wheat middlings labeled with 1 g of La solution that was mixed in the TMR on d 18 through 28 of each period to provide 35 mg/kg of La in total diet DM. Fecal grab samples were collected daily at 0800, 1400, and 2000 h during the last 3 d of each period. One gram of Yb solution (25) was sprayed onto 500 g (DM basis) of each WPCS treatment to estimate solids passage rate. The labeled WPCS was fed to each ruminally cannulated cow according to its respective diet immediately before the morning feeding (0800 h) on d 25 of each period. Fecal grab samples were collected before dosing and at 12, 18, 24, 36, 48, 60, and 72 h after dosing. Samples were dried in a forced-air oven at 60°C for 96 h and then ground to pass a 1-mm Wiley mill screen. The fecal samples taken to determine total-tract nutrient digestibilities were composited for each cow by period, ground to pass a 1-mm Wiley mill screen, and analyzed for DM, OM, CP, ADF, NDF, and starch as described previously. The fecal concentration of La was determined in duplicate by direct current plasma emission spectroscopy (7) after dry-ashing at 500°C for 16 h. Total-tract nutrient digestibilities were calculated from La and nutrient concentrations in diet (orts adjusted) and feces. Solids passage rate was determined by regressing the natural logarithm of Yb concentration from the declining portion of the fecal excretion curve versus time.

Data were analyzed by using the general linear models procedure of SAS (23) for a replicated Latin square design. The model used for the lactation performance data was:

$$Y_{ijkl} = \mu + P_i + S_j + C_k(S)_j + T_l + (SP)_{ji} + (ST)_{jl} + e_{ijkl}$$

Y = dependent variable,
μ = population mean,
P_i = effect of period i,
S_j = effect of square j,
$C_k(S)_j$ = effect of cow k nested within square j,
T_l = effect of treatment l,
$(SP)_{ji}$ = interaction of square j and period i,
$(ST)_{jl}$ = interaction of square j and treatment l, and
e_{ijkl} = residual error, normally and independently distributed.

All terms were tested using the residual mean square error. Square × period and square × treatment terms were not significant. Therefore, they were removed from the model and pooled with the residual error. A contrast statement was also included to test the processing effect (control vs. FPR, MPR, and CPR). Ruminal pH and VFA data were analyzed using PROC MIXED of SAS (18) for repeated measures; time was used as a repeated measure with first-order auto regressive covariance structure. All mean comparisons were by least significant difference method after a significant (P < 0.05) treatment effect.

RESULTS AND DISCUSSION

Silage and Diet Composition and Particle Size

Chemical composition and fermentation characteristics of WPCS treatments are presented in Table 1 (data not statistically analyzed). Moisture content of WPCS was at a desirable level for good silage fermentation, digestibility, and lactation performance (3); it averaged 65%, with little variation among treatments. Both NDF and ADF concentrations were lower for FPR and MPR silages compared with control and CPR silage (36 to 38% vs. 41% NDF and 21 to 22% vs. 24% ADF). Starch concentration (27.3%) was highest for FPR silage. It is unlikely that this variation in fiber and starch concentrations among treatments was related to harvest practices, because the field was subdivided into quadrants for harvest with an equal portion of each quadrant harvested for each treatment, the harvest was completed in one day, and the same height of cutter head was used for the harvest of all treatments. Variation in fiber and starch concentrations among treatments was possibly due to more uniform sampling of the fine chopped, processed WPCS. Sudweeks et al. (29) reported lower ADF and NDF concentrations (3 and 7% units, respectively) for fine (0.62-cm TLC) vs. coarse (1.91-cm TLC) chopped WPCS. Lower fiber but higher starch concentrations for processed versus unprocessed WPCS were reported by Rojas-Bourrillon et al. (22). Lactate concentration and pH were indicative of a desirable silage fermentation (19). Lactate and acetate concentrations were higher for FPR silage (5.05 and 1.29% of DM) versus an average of 4.69 and 1.11% of DM, respectively, for control, MPR, and CPR silage. This could be due to greater packing density and carbohydrate availability for the processed (22), fine-chopped (28) WPCS. The high propionate concentration (0.4 to 0.5% of DM) was partially related to the application of a buffered propionic acid preservative (Ultra-Curb, Kemin Industries, Des Moines, IA) to the silo face of each WPCS treatment during feed-out.

The ingredient and nutrient composition of experimental diets is presented in Table 2 (data not statistically analyzed). Diet nutrient concentrations are presented on an orts-adjusted basis. Dietary CP concentration was 0.6% units lower than as formulated because of lower than anticipated CP content of the soybean meal. Diet NDF concentration for control (24.3%) and CPR (24.6%) was at the minimum NRC (21) allowance. This was a function of the relatively low WPCS and alfalfa silage NDF concentrations and our formulation to a 50:50 forage:concentrate ratio. Diet NDF for FPR and MPR averaged 23.3% (DM basis). The lower NDF content for these two diets was related to the lower concentration of NDF measured in the corresponding WPCS treatments.

Particle size of WPCS treatments and their corresponding TMR is presented in Table 3 (data not statistically analyzed). Percentage of as-fed sample retained on first and second screens was highest for CPR and lowest for FPR silage. Mean particle length was lowest for FPR silage. Percentage of as-fed sample retained on third and fourth screens was lower for CPR (57.6%) than FPR (70.2%) or control (80.3%) silage. The percentage of as-fed sample retained on the fifth screen and pan was highest for FPR silage. The low percentage retained on screens 1 and 2 and the high percentage retained on screen 5 and pan for FPR silage reflects the effects of fine chopping (0.95-cm TLC) and processing on particle size. Increasing length of chop to 1.90-cm TLC without changing roll clearance increased percentage retained on screens 1 and 2, and decreased the percentage retained on screens 3 and 4 as well as screen 5 and pan. Visual inspection of the screens showed that there were no unbroken kernels or cob pieces greater than

Table 1. Chemical composition and fermentation characteristics of whole-plant corn silage treatments.[1]

Item	Control	FPR	MPR	CPR
Moisture, %	64.4	65.6	64.5	65.0
DM basis				
CP, %	7.3	7.7	7.4	7.4
NDF, %	40.6	35.9	38.0	40.9
ADF, %	23.9	20.6	21.9	23.6
Lignin, %	2.5	2.2	2.4	2.4
Starch, %	24.0	27.3	25.5	25.0
pH	3.83	3.82	3.81	3.81
Lactate, %	4.59	5.05	4.74	4.74
Acetate, %	1.16	1.29	1.10	1.08
Propionate, %	0.42	0.50	0.39	0.52

[1]Control corn silage was unprocessed and had a 0.95-cm theoretical length of cut (TLC); FPR = fine processed corn silage (0.95-cm TLC with 1-mm roll clearance), MPR = medium processed corn silage (1.45-cm TLC with 1-mm roll clearance), and CPR = coarse processed corn silage (1.90-cm TLC with 1-mm roll clearance).

Table 2. Ingredient and nutrient composition of TMR.[1]

Item				
	% of DM			
Ingredient				
Corn silage	33.6			
Alfalfa silage[2]	16.4			
Shelled corn	28.0			
Soybean meal, solvent[3]	8.9			
Soybean meal, expeller[3]	9.0			
Urea	0.3			
Limestone	1.2			
Dicalcium phosphate	0.7			
Magnesium oxide	0.2			
Salt	0.3			
Dynamate[4]	0.2			
Sodium bicarbonate	0.8			
Trace-mineralized salt[5]	0.2			
Vitamin premix[6]	0.2			
	Control	FPR	MPR	CPR
Nutrient, % of DM[7]				
OM	92.1	92.1	92.0	92.1
CP	16.9	17.1	16.8	16.9
NDF	24.3	22.8	23.7	24.6
ADF	15.6	14.4	15.0	15.5
Starch	30.5	31.9	31.0	30.8

[1]Control diet contained unprocessed corn silage at a 0.95-cm theoretical length of cut (TLC); FPR = fine processed corn silage diet (0.95-cm TLC with 1-mm roll clearance), MPR = medium processed corn silage diet (1.45-cm TLC with 1-mm roll clearance), and CPR = coarse processed corn silage diet (1.90-cm TLC with 1-mm roll clearance).

[2]Contained 25.2% CP, 32.9% ADF, and 36.7% NDF (DM basis).

[3]Soy Plus, West Central Cooperative, Ralston, IA.

[4]18% K, 11% Mg, 22% S. Pitman Moore, Inc. (Mundelein, IL).

[5]0.55% Mn, 0.55% Zn, 0.35% Fe, 0.14% Cu, 0.008% I, 0.006% Se, and 0.002% Co.

[6]2665 IU of vitamin A/g, 900 IU of vitamin D/g, and 3.52 IU of vitamin E/g.

[7]Orts-adjusted basis.

one-eighth of a concentric ring of sliced cob for the processed WPCS. Conversely, for control WPCS quarter, half and whole sliced cobs were found on screens 1 and 2, and cob pieces one-eighth to one-half of a concentric ring of sliced cob and intact kernels were found on screens 3 and 4. This resulted in greater sorting in the feed manger for the control TMR. Feed refusals were analyzed for CP and NDF content to evaluate sorting. Lower CP ($P < 0.02$) and higher NDF ($P < 0.001$) concentrations were measured in refusal samples for cows receiving control TMR (15.1% CP and 33.8% NDF) compared with cows receiving FPR (16.0% CP and 30.3% NDF), MPR (16.0% CP and 31.3% NDF), or CPR (15.5% CP and 31.7% NDF) TMR (data not presented in tables). Particle size distribution of TMR reflected trends observed for corresponding WPCS treatments. Percentage as-fed TMR retained on screens 1 and 2 for control and MPR diets, respectively, was similar to the average coarse particle fraction observed by Lammers et al. (17) for TMR samples.

Intake, BW, and Chewing Activities

Body weight and orts-adjusted DM and NDF intake data are presented in Table 4. Body weight averaged 8 kg higher for cows fed processed versus control WPCS. Because of the short-term Latin square design used in this trial it is difficult to attribute this observation to actual differences in BW change due to treatment. However, Young et al. (33) reported increased average daily gain (1.45 vs. 1.32 kg/d) for replacement heifers fed processed versus unprocessed WPCS. Dry matter intake was 0.6 kg higher ($P < 0.01$) for processed versus control WPCS diets. Johnson et al. (13) also reported higher DMI for processed compared with unprocessed WPCS. Intake of DM was similar among chop lengths of processed WPCS. Lack of effect of chop length on DMI has been observed by others (6, 8, 16). De Boever et al. (8) reported no effect of chop length on DMI in dairy cows fed unprocessed WPCS harvested at 0.4, 0.8 and 1.6 cm TLC. Kuehn et al. (16) reported no effect of chop length on DMI in dairy cows fed unprocessed WPCS harvested at 0.32- or 0.87-cm TLC. Similarly, Clark and Armentano (6) saw no chop length effect on DMI in two trials with unprocessed WPCS when average mean particle length for coarse- and fine-chopped WPCS were 7.6 and 3.4 mm, respectively. Orts-adjusted intake of NDF was lowest for FPR and MPR diets, reflecting the lower NDF concentration in these diets. Cows fed CPR diet had the highest intake of NDF reflecting higher diet NDF versus FPR and MPR and lower ort NDF versus control.

Eating, rumination, and total chewing times were not affected by either processing or chop length averaging 239, 482, and 721 min per day, respectively (data not presented in tables). Eating time per kilogram of DMI was lower ($P < 0.03$) for diet FPR versus control (9.0 vs. 9.9 min/kg of diet DMI). There were no differences among the treatments for rumination or total chewing time per kilogram of DMI. De Boever et al. (8) found that eating index (min/kg of silage DMI) decreased when TLC of WPCS was reduced from 1.6 to 0.8 cm (22 vs. 19 min/kg of silage DMI), but reduction in TLC from 0.8 to 0.4 cm did not change eating index further. They also found that rumination index was not affected by increasing TLC of WPCS from 0.8 to 1.6 cm, but reducing TLC from 0.8 to 0.4 cm caused reduction in rumination index (36 versus 38 min/kg of silage DMI). Recent studies (6, 16) saw no effect of chop length on chewing activity of dairy cows fed unprocessed corn silage.

Table 3. Particle size of whole-plant corn silage treatments and corresponding TMR determined using Oscillating Screen Particle Separator (1).

	Screen[1] (% of sample on screen)			
Treatment	1 and 2	3 and 4	5 and pan	MPL,[2] mm
WPCS[3]				
Control	7.5	80.3	12.2	9.4
FPR	1.5	70.2	28.3	6.7
MPR	9.9	72.4	17.7	8.9
CPR	21.5	57.6	20.9	9.2
TMR[4]				
Control	6.1	48.9	45.0	4.7
FPR	3.0	46.5	50.5	4.1
MPR	6.0	45.8	48.2	4.4
CPR	10.5	41.0	48.5	4.5

[1]Screen size: No. 1, 26.9 mm; No. 2, 18.0 mm; No. 3, 8.98 mm; No. 4, 5.61 mm; No. 5, 1.65-mm square-hole diagonal.

[2]Geometric mean particle length determined by screen size as described by the American National Standards Institute (1).

[3]Control corn silage was unprocessed and had a 0.95-cm theoretical length of cut (TLC); FPR = fine processed corn silage (0.95-cm TLC with 1-mm roll clearance), MPR = medium processed corn silage (1.45-cm TLC with 1-mm roll clearance), and CPR = coarse processed corn silage (1.90-cm TLC with 1-mm roll clearance).

[4]Contained 33.6% whole-plant corn silage treatment, 16.4% alfalfa silage, and 50% concentrate mixture (DM basis).

Milk Yield and Composition

Milk production data are presented in Table 5. Milk and FCM production were 1.2 kg/d ($P < 0.02$) and 1.5 kg/d higher ($P < 0.001$), respectively, for processed WPCS diets versus control. Higher milk production for processed WPCS has been reported by others (13, 14, 15). Processing WPCS at black-layer maturity increased milk production 0.9 kg/d versus unprocessed WPCS, but FCM yield was not affected (14). The TMR with processed WPCS had a higher estimated NE_L content (1.55 Mcal/kg) than TMR with unprocessed WPCS (1.45 Mcal/kg) when WPCS was harvested at two-thirds milkline stage of maturity (15). However, Bal et al. (4) found no effect of processing on milk production in WPCS harvested at one-half milkline stage of maturity. There was no effect of chop length on milk and FCM production in this trial. This lack of response has been observed by others (6, 16, 28). Milk fat percentage and yield were increased ($P < 0.001$) by processing WPCS. Lower milk fat percentage and yield for control was somewhat surprising and was possibly due to greater sorting for this treatment. This was supported by the higher NDF content of the orts for control TMR. Milk fat percentage and yield did not differ between FPR and CPR. Other researchers (6, 28) have not found an

Table 4. Effects of crop processing and chop length on BW, DMI, and NDF intake.

	Treatment[1]					*P* <	
Item	Control	FPR	MPR	CPR	SEM	Treatment[2]	Processing[3]
BW, kg	657	668	665	663	1.8	NS[4]	0.001
DMI, kg/d	25.3	25.9	25.9	25.8	0.2	NS	0.01
DMI, % of BW	3.9	3.9	3.9	3.9	0.03	NS	NS
NDF intake, kg/d	6.2	5.9[c]	6.1[b]	6.3[a]	0.06	0.001	NS
NDF intake, % of BW	0.95	0.87[c]	0.92[b]	0.97[a]	0.01	0.001	0.02

[a,b,c]Chop length means within the same row with different superscripts differ.

[1]Control diet contained unprocessed corn silage at a 0.95-cm theoretical length of cut (TLC); FPR = Fine processed whole-plant corn silage diet (0.95 cm TLC with 1 mm roll clearance), MPR = Medium processed whole-plant corn silage diet (1.45 cm TLC with 1 mm roll clearance), and CPR = Coarse processed whole-plant corn silage diet (1.90 cm TLC with 1 mm roll clearance).

[2]Chop length effect.

[3]Comparison of Control versus FPR, MPR, and CPR.

[4]NS = $P > 0.10$.

Table 5. Effects of crop processing and chop length on milk and milk component production and milk composition.

	Treatment[1]					P<	
	Control	FPR	MPR	CPR	SEM	Treatment[2]	Processing[3]
Production, kg/d							
Milk	44.8	46.5	45.4	46.1	0.4	NS[4]	0.02
4% FCM	38.2	40.2	39.0	39.8	0.4	NS	0.001
Fat	1.35	1.44[a]	1.39[b]	1.42[ab]	0.02	0.001	0.001
Protein	1.42	1.47	1.45	1.47	0.02	NS	NS
Lactose	2.16	2.27	2.20	2.26	0.03	NS	0.01
Milk composition							
Fat, %	3.06	3.13	3.11	3.14	0.02	NS	0.001
Protein, %	3.24	3.21	3.25	3.23	0.04	NS	NS
Lactose, %	4.89	4.92	4.87	4.92	0.01	NS	NS
MUN, mg/dl	18.6	19.0	18.9	19.5	0.4	NS	NS

[a,b]Chop length means within the same row with different superscripts differ.

[1]Control diet contained unprocessed corn silage at a 0.95-cm theoretical length of cut (TLC); FPR = Fine processed whole-plant corn silage diet (0.95 cm TLC with 1 mm roll clearance), MPR = Medium processed whole-plant corn silage diet (1.45 cm TLC with 1 mm roll clearance), and CPR = Coarse processed whole-plant corn silage diet (1.90 cm TLC with 1 mm roll clearance).

[2]Chop length effect.

[3]Comparison of Control versus FPR, MPR, and CPR.

[4]NS = $P > 0.10$.

effect of chop length of WPCS on milk fat. There were no effects of processing or chop length on milk protein percentage or yield, which is in contrast to other trials that reported increased milk protein yield due to processing (14) or fine chopping (6, 28) of WPCS. In our study, lack of milk protein response to processing can not be explained especially in light of improved ruminal (Figure 1) and total-tract (Table 6) starch digestion observed with processing. However, lower NDF digestion (Table 6) for FPR and MPR may have counteracted the positive effects on starch digestion observed with processed WPCS. Milk lactose and MUN concentrations were not affected by treatment. Yield of milk lactose increased with processing in relationship to increased milk yield.

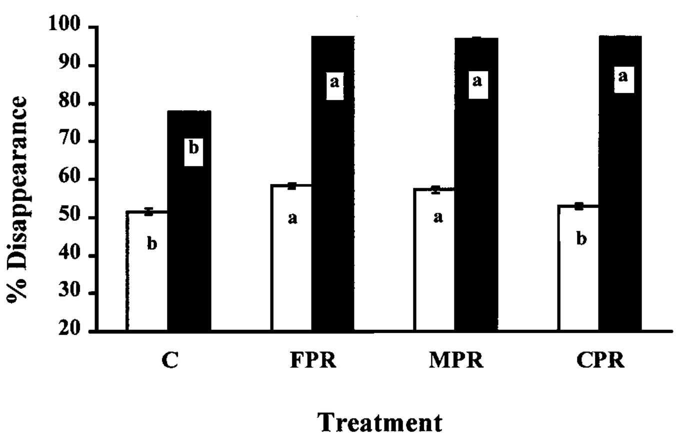

Figure 1. The 24-h ruminal in situ DM (white bars, pooled SEM = 0.8) and starch (black bars, pooled SEM = 0.2) disappearance of whole-plant corn silage treatments. Different letters on each bar for each variable indicate a difference ($P < 0.05$) for effects of processing or chop length. C = Control whole-plant corn silage [0.95-cm theoretical length of cut (TLC) without processing], FPR = fine processed whole-plant corn silage (0.95-cm TLC with 1-mm roll clearance), MPR = medium processed whole-plant corn silage (1.45-cm TLC with 1-mm roll clearance), and CPR = coarse processed whole-plant corn silage (1.90-cm TLC with 1-mm roll clearance).

Digestion

Total-tract nutrient digestibilities and fractional rates of passage are presented in Table 6. Digestibilities of DM, OM, and CP were not affected by treatment. Lack of effect of processing WPCS on digestibilities of DM and OM has been observed by others (22, 33). This may be due to higher starch but lower fiber digestibilities for processed WPCS versus unprocessed WPCS as observed by Rojas-Bourrillon et al. (22) and in this trial. Lack of effect of WPCS chop length on total tract digestibilities of DM and OM was observed by Sudweeks et al. (29). Total-tract digestibilities of ADF and NDF were 5.6 ($P < 0.01$) and 5.3 ($P < 0.04$) percentage units lower, respectively, for FPR versus CPR. Processing reduced ($P < 0.01$) total-tract digestion of ADF (31.7% on average vs. 37.0%), with most of this reduction caused by the FPR and MPR treatments. Reduction in total-tract ADF and NDF digestibilities have also been observed with fine chopping of alfalfa hay and silage (25, 32). Total-tract starch digestibility increased by 4.2 percentage units on average for processed WPCS versus control WPCS diets ($P < 0.001$). Bal et al. (4) reported higher total-tract starch digestibility for processed WPCS ver-

Table 6. Effects of crop processing and chop length on total tract nutrient digestion and solids fractional rate of passage.

	Treatment[1]				SEM	$P <$	
	Control	FPR	MPR	CPR		Treatment[2]	Processing[3]
Digestibility							
DM, %	66.7	67.4	66.5	67.5	0.7	NS[4]	NS
OM, %	68.8	69.7	68.9	69.8	0.6	NS	NS
CP, %	64.5	65.6	64.6	65.8	0.7	NS	NS
NDF, %	33.9	28.4[b]	30.2[ab]	33.7[a]	1.5	0.04	NS
ADF, %	37.0	29.1[c]	31.4[bc]	34.7[a]	1.6	0.01	0.01
Starch, %	95.1	99.4	99.2	99.3	0.3	NS	0.001
Solids passage rate							
h^{-1}	0.059	0.066	0.058	0.059	0.003	NS	NS

[a,b,c]Chop length means within the same row with different superscripts differ.

[1]Control diet contained unprocessed corn silage at a 0.95-cm theoretical length of cut (TLC); FPR = Fine processed whole-plant corn silage diet (0.95 cm TLC with 1 mm roll clearance), MPR = Medium processed whole-plant corn silage diet (1.45 cm TLC with 1 mm roll clearance), and CPR = Coarse processed whole-plant corn silage diet (1.90 cm TLC with 1 mm roll clearance).

[2]Chop length effect.

[3]Comparison of Control versus FPR, MPR, and CPR.

[4]NS = $P > 0.10$.

sus unprocessed WPCS diets (87.9 vs. 83.8%) in lactating dairy cows. Higher starch but lower fiber digestibility for FPR was also observed by Rojas-Bourrillon et al. (22) for processed versus unprocessed WPCS chopped at 0.95-cm TLC fed in 90% corn silage diets. In our study, chopping processed WPCS at 1.90-cm TLC prevented the depression of fiber digestibility observed at 0.95-cm TLC while still achieving improved starch digestibility due to processing. This suggests a negative associative effect of fine chopping of processed WPCS on fiber digestion, but our data on milk fat content (Table 5) and rumen fermentation (Table 7) do not support this premise. Ruminal passage rate of WPCS was unaffected by treatment.

Twenty-four-hour ruminal in situ DM and starch disappearance of WPCS treatments are presented in Figure 1. Ruminal DM disappearance was improved by processing and averaged 56.1% for processed WPCS versus 51.5% for control WPCS. This was associated with improved ruminal starch disappearance for processed WPCS (97.1% on average vs. 77.6%). Increased ruminal starch disappearance for the processed WPCS treatments is consistent with the total-tract starch digestion data presented in Table 6. Ruminal disappear-

Table 7. Effects of crop processing and chop length on ruminal pH, ammonia, and VFA.

	Treatment[1]					$P <$	
Item	C	FPR	MPR	CPR	SEM	Treatment[2]	Processing[3]
pH	5.99	6.07	6.05	6.04	0.07	NS[4]	NS
NH_3, mg/dl	18.7	19.0	18.1	18.2	1.6	NS	NS
Total VFA, m*M*	121.2	124.3	126.0	128.7	6.5	NS	NS
VFA, mol/100 mol							
Acetate	44.6	46.0	46.7	45.2	2.6	NS	NS
Propionate	30.3	29.2	29.7	32.5	2.5	NS	NS
Butyrate	16.4	16.3[a]	15.9[ab]	14.6[b]	0.9	0.001	0.01
Others[5]	8.7	8.5	7.7	7.7	0.9	NS	NS
Acetate:propionate	1.6	1.6	1.7	1.4	0.2	NS	NS

[a,b]Chop length means within the same row with different superscripts differ.

[1]Control diet contained unprocessed corn silage at a 0.95-cm theoretical length of cut (TLC); FPR = fine processed whole-plant corn silage diet (0.95-cm TLC with 1-mm roll clearance), MPR = medium processed whole-plant corn silage diet (1.45-cm TLC with 1-mm roll clearance), and CPR = coarse processed whole-plant corn silage diet (1.90-cm TLC with 1-mm roll clearance). Values are mean of samples taken at 0, 3, 6, 9, and 12 hours postfeeding.

[2]Chop length effect.

[3]Comparison of C vs. FPR, MPR, and CPR.

[4]NS = $P > 0.10$.

[5]Isobutyrate, isovalerate, and valerate.

ance of DM, but not starch, was lower for CPR versus FPR and MPR. This was likely related to lower NDF disappearance from coarsely chopped particles in CPR. Particle size reduction through normal mastication during eating may make this observation moot. Doggett et al. (9) reported greater ruminal in situ disappearance (30- × 35-cm macro bags with unground samples) of DM and starch after 8, 16, 24, and 48 h incubations for processed versus unprocessed WPCS.

Data on ruminal mat consistency are presented in Figure 2. The time necessary for the weight to ascend from the bottom of the rumen to the surface (31) was our measure of mat consistency. Ascension time was longer ($P < 0.001$) for control and CPR (10 and 11 min, respectively) versus FPR and MPR (7 and 8 min, respectively). Longer ascension time for control and CPR was likely related to the higher percentage of WPCS on screens 1 and 2 and 3 and 4 of the particle separator (Table 3).

Ruminal pH data at 0, 3, 6, 9, and 12 h postfeeding appear in Figure 3. Ruminal pH nadir was observed at 9 h postfeeding. There was no effect of processing or chop length of WPCS on ruminal pH. The trend for lower ruminal pH at some time points for control may have been related to sorting for this treatment. Rojas-Bourrillon et al. (22) found slightly lower ruminal pH (6.21 vs. 6.29) for processed versus unprocessed WPCS chopped at 0.95-cm TLC. No effect of chop length of WPCS on ruminal pH was reported by Stockdale and Beavis (28). Total VFA concentration was not affected by treatment, averaging 125 m*M* (Table 7). Molar percentages of acetate and propionate and ratio of acetate to propionate were not affected by treatment averaging 45.6 mol/100 mol, 30.4 mol/100 mol, and 1.57, respectively. The low acetate to propionate ratio reflects the low milk fat test (3.06 to 3.14%) and low dietary ADF (14.4 to 15.6%) and NDF (22.8 to 24.6%) observed in this trial (11). Ruminal ammonia concentration was also not affected by treatment (18.5 mg/dl on average), which coincides with MUN observations. Stockdale and Beavis (28) saw no effect of WPCS chop length on ruminal acetate and propionate molar percentage or ammonia concentration.

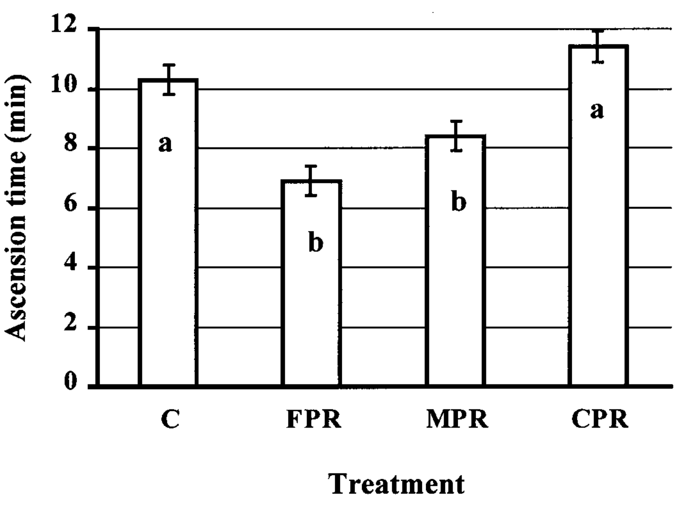

Figure 2. Effect of processing and chop length of whole-plant corn silage treatments on ruminal mat consistency measured as ascension time (min). Different letters on each bar indicate a difference ($P < 0.05$) for effects of processing or chop length. Pooled SEM = 0.6. C = Control whole-plant corn silage diet [0.95-cm theoretical length of cut (TLC) without processing], FPR = fine processed whole-plant corn silage diet (0.95-cm TLC with 1-mm roll clearance), MPR = medium processed whole-plant corn silage diet (1.45-cm TLC with 1-mm roll clearance), and CPR = coarse processed whole-plant corn silage diet (1.90-cm TLC with 1-mm roll clearance).

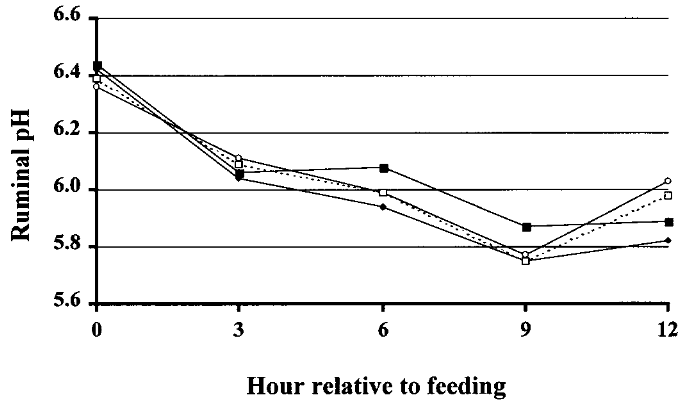

Figure 3. Effect of processing and chop length of whole-plant corn silage treatments on postfeeding ruminal pH for: Control diet (◆); fine processed whole-plant corn silage diet (0.95 cm TLC with 1 mm roll clearance) (■); medium processed whole-plant corn silage diet (1.45 cm TLC with 1 mm roll clearance) (○); coarse processed whole-plant corn silage diet (1.90 cm TLC with 1 mm roll clearance) (□). Pooled SEM = 0.07.

CONCLUSIONS

Processing one-half milkline, 65% moisture WPCS increased milk and FCM production 1.2 and 1.5 kg/d, respectively. This was related to increased DMI, ruminal starch disappearance, and total-tract starch digestibility for processed WPCS. Chop length effects within processed WPCS on lactation performance were minimal, but ruminal mat consistency was improved for CPR silage (1.90-cm TLC) versus FPR and MPR silage in relationship to its large coarse particle fraction. Improved ruminal mat consistency elicited no cow health benefits here, but may have in a longer-term study or in early lactation cows. Also, chopping processed WPCS at 1.90-cm TLC prevented the depression of fiber digestibility observed at 0.95-cm TLC while still achieving improved starch digestibility with processing. Shinners et al. (26) reported similar machine throughput and power requirements for 1.90-cm TLC processed WPCS versus 0.95-cm TLC unprocessed WPCS but power requirements were greatest for 0.95-cm TLC processed WPCS. Our results and the findings of Shinners et al. (26) support a 1.90-cm TLC recommendation for processed WPCS. Results also suggest less sorting and cob refusal in the feed manger for TMR containing processed WPCS.

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