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Processing and Chop Length Effects in Brown-Midrib Corn Silage on Intake, Digestion, and Milk Production by Dairy Cows

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ABSTRACT

In this experiment, we evaluated the influence of increasing chop length and mechanical processing of whole-plant brown-midrib corn silage on intake, digestion, and milk production by dairy cows. Corn silage treatments were harvested at three-quarter milk line stage of maturity at 13- and 19-mm theoretical chop length without processing, or at 19- and 32-mm theoretical chop length with processing at a 2-mm roll clearance. Twenty-four multiparous Holstein cows that averaged 102 ± 17 d in milk at trial initiation were randomly assigned to treatments in a replicated 4 × 4 Latin square design with 28-d periods. Preplanned orthogonal contrasts were used to evaluate effects of processing (19 processed vs. 19 mm unprocessed) and chop length (13 vs. 19 mm unprocessed and 19 vs. 32 mm processed). Treatments were fed in total mixed rations containing 60% forage (67% corn silage and 33% alfalfa silage) and 40% shelled corn and soybean meal-based concentrate (dry matter basis). Milk yield was unaffected by treatment. Dry matter intake was unaffected by corn silage processing, but increasing corn silage chop length reduced dry matter intake in unprocessed (26.6 vs. 25.5 kg/d) and processed (25.9 vs. 25.1 kg/d) chop length contrasts. Processing reduced milk fat content (3.36 vs. 3.11%) and yield (1.43 vs. 1.35 kg/d), increased total-tract starch digestion (92.9 vs. 97.4%), and decreased total-tract neutral detergent fiber digestion (51.0 vs. 41.8%). Total chewing time (min/d) was unaffected by treatment. Masticate mean particle length was unaffected by chop length in unprocessed and processed corn silage treatments. In this study with brown-midrib corn silage fed to dairy cows producing 43 kg/d of milk, there were no benefits from crop processing or increasing chop length on lactation performance.

(**Key words:** brown-midrib, chop length, corn silage, processing)

Abbreviation key: ***bm3*** = brown-midrib corn hybrid or silage, **MPL** = geometric mean particle length, **TCL** = theoretical chop length, **WPCS** = whole-plant corn silage, **13UP** = 13-mm TCL unprocessed corn silage or diet, **19UP** = 19-mm TCL unprocessed corn silage or diet, **19PR** = 19-mm TCL processed corn silage or diet, **32PR** = 32-mm TCL processed corn silage or diet.

INTRODUCTION

Whole-plant corn silage (**WPCS**) is an important fiber and energy source in diets for lactating dairy cows. Increased use of WPCS harvesters fitted with on-board processors (roller mills; Johnson et al., 1999) and interest in forage and TMR particle size (Lammers et al., 1996) has fueled recent research into the effects of WPCS processing and chop length on lactation performance by dairy cows. The results of WPCS processing trials have been mixed. Bal et al. (2000a) reported a 1.2 kg/d increase in milk production and a 4.2 percentage unit increase in total-tract starch digestion for diets that contain processed versus unprocessed WPCS. In contrast, Dhiman et al. (2000) found no advantage to processing WPCS on milk production or starch digestibility by dairy cows in two of three studies. The results of WPCS chop length experiments are more consistent. Clark and Armentano (2000) and Bal et al. (2000a) evaluated increased chop length in unprocessed and processed WPCS, respectively; both reports showed no or minimal improvements in lactation performance by dairy cows.

Because of its consistently lower lignin content and correspondingly higher fiber digestibility (Cherney et al., 1991), there has been much recent interest in the brown-midrib (***bm3***) hybrid. Oba and Allen (1999) reported a 2.8 kg/d increase in milk yield and a 2.2 percentage unit increase in total-tract NDF digestibility for dairy cows fed diets containing unprocessed *bm3* WPCS versus its unprocessed isogenic control. In a subsequent study, Oba and Allen (2000) included unprocessed *bm3* WPCS or its unprocessed isogenic control in diets containing either 29 or 38% NDF. Replacing the isogenic WPCS silage with *bm3* WPCS increased milk production 3.4 kg/d on

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average for both low and high NDF diets. Experiments have been conducted to evaluate the effects of processing and chop length in conventional WPCS, and to evaluate *bm3* WPCS versus its isogenic counterpart. However, we found no experiments in the literature in which were examined the effects of processing and chop length in *bm3* WPCS on lactation performance or digestion by dairy cows.

The objectives of this experiment were to evaluate the effects of processing and chop length in *bm3* WPCS on intake, digestion, and milk production by dairy cows.

MATERIALS AND METHODS

Corn Silage

On April 30, 1999, Cargill corn hybrid F657, which contains the *bm3* mutation, was planted at a seeding density of 79,000 seeds/ha at the University of Wisconsin Arlington Research Station (Arlington, WI) in one 6.4-ha plot. Corn silage treatments were harvested at three-quarter milk-line stage of maturity, September 13, 1999, by using an experimental pull-type harvester fitted with an on-board crop processor set at a 2-mm roll clearance. Theoretical chop lengths (**TCL**) were 13 and 19 mm for unprocessed WPCS treatments (**13UP** and **19UP**), and 19 and 32 mm for the processed WPCS treatments (**19PR** and **32PR**). The 13-mm unprocessed TCL and 19-mm processed TCL were chosen because these TCL are commonly used machine settings by dairy producers for unprocessed and processed WPCS, respectively. The 19-mm unprocessed TCL and 32-mm processed TCL were chosen to evaluate the effects of increasing TCL in unprocessed and processed WPCS, respectively. Approximately 60 tonne (as fed) of each treatment were stored in individual 2.4-m-diameter silo bags with application of a buffered acid preservative containing 82% total acids, which included propionic, acetic, benzoic, and sorbic acids (Ultra Curb™; Kemin Inc., Des Moines, IA) at 2 kg/tonne to minimize differences in aerobic stability of the WPCS treatments during feed out. Alternate loads of each treatment were sampled during filling to determine DM content, which averaged approximately 40% DM across the four treatments.

Diets and Cows

The WPCS treatments, alfalfa silage, and concentrate comprised 40, 20, and 40% of diet DM, respectively, and were fed as a TMR twice daily at 1100 and 1600 h. Diets were formulated for 18% CP (DM basis) and to meet or exceed NRC (1989) requirements for vitamins and minerals. Cows were fed individually and ad libitum by using a drum-type mixer (Data Ranger; American Calan, Inc., Northwood, NH). Amounts of TMR offered and refused were recorded daily to maintain refusals at approximately 10%. The WPCS treatments and alfalfa silage were sampled weekly and dried at 60°C for 48 h in a forced-air oven to determine DM content for adjustment of as-fed ratios of dietary ingredients. The WPCS treatments, alfalfa silage, and concentrate were sampled on d 16 of each period for nutrient analysis. Orts were collected on d 24 to 27 of each period and composited by cow within period. Feed and ort 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). All samples were analyzed for DM, OM (AOAC, 1990), NDF by using a-amylase and sodium sulfite (Van Soest et al., 1991), and starch (Bal et al., 2000a). Feed samples were also analyzed for ADF (Goering and Van Soest, 1970) and CP (AOAC, 1990), and WPCS samples were analyzed for lignin (Goering and Van Soest, 1970) and pH, lactic acid, and VFA (Bal et al., 1997). All fiber analyses were done by using the ANKOM^{200} Fiber Analyzer (Ankom Technology, Fairport, NY).

Twenty-four multiparous Holstein cows were randomly assigned to treatments in a replicated 4 × 4 Latin square design with 28-d periods. Two squares were comprised of rumen-cannulated cows to allow for sampling of ruminal contents for pH, VFA, ammonia determination, measurement of rumen fill, and for collection of WPCS masticates. The first 14 d of each period were for diet adaptation, and sampling occurred on d 15 through 28. Cows averaged 102 ± 17 DIM at trial initiation and were injected with bovine somatotropin (Posilac; Monsanto Company, St. Louis, MO) every 14 d starting on d 1 of the experiment. All cows were weighed for three consecutive days at the start of the trial and on d 26 to 28 of each period. Cows were milked twice daily with production recorded at each milking. Milk samples taken at a.m. and p.m. milkings during wk 3 (d 16, 17, and 18) and wk 4 (d 23, 24 and 25) were analyzed for milk fat, CP, lactose, and urea nitrogen (AgSource Milk Analysis Laboratory, Menomonee, WI) by using infrared analysis with a Fossmatic-605 with a B filter (Foss Electric, Hillerød, Denmark). Times spent eating and ruminating were measured on d 21 of each period by observation at 5-min intervals for a period of 24 h. Total time spent chewing was calculated as the sum of the time spent eating and ruminating. Before the a.m. feeding on the last day of each period, rumen fill (kg) was determined by complete rumen evacuation. Masticates were collected from the cannulated cows on d 28 of each period after rumen evacuation. The cannulated cows were offered approximately 35 kg (as-fed basis) of their respective WPCS treatments and allowed to eat for 5 min, after which four to five masticates were collected at the cardia for mean particle length (**MPL**) determination. An intact cow was removed from the experiment on d 6 of period 3 because

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

Item	13UP	19UP	19PR	32PR
DM, %	43.9 ± 0.4	39.0 ± 1.1	37.8 ± 0.4	37.6 ± 0.5
DM basis				
CP, %	7.1 ± 0.4	7.2 ± 0.4	7.1 ± 0.4	6.8 ± 0.3
NDF, %	36.6 ± 3.2	39.5 ± 2.5	34.5 ± 1.4	36.7 ± 2.2
ADF, %	22.4 ± 2.4	23.9 ± 2.0	20.8 ± 1.0	23.4 ± 1.8
Starch, %	31.8 ± 2.6	26.8 ± 1.7	30.6 ± 1.6	29.2 ± 1.4
pH	3.99 ± 0.03	3.88 ± 0.02	3.92 ± 0.06	3.91 ± 0.01
Lactate, %	3.85 ± 1.5	4.14 ± 0.7	3.99 ± 0.7	4.27 ± 0.6
Acetate, %	0.88 ± 0.4	1.00 ± 0.2	0.74 ± 0.2	1.03 ± 0.2
Propionate, %	ND[2]	ND	ND	ND

[1]13UP = 13-mm theoretical chop length (TCL) without processing, 19UP = 19-mm TCL without processing, 19PR = 19-mm TCL processed with 2-mm roll clearance, and 32PR = 32-mm TCL processed with 2-mm roll clearance. Data are mean ± SD values.

[2]ND = Not detected.

of a digestive disorder with corresponding data treated as missing observations. The experimental protocol was approved by the Research Animal and Resource Center of the College of Agriculture and Life Sciences, University of Wisconsin-Madison.

Particle Size

The MPL of as-fed WPCS treatments was determined in duplicate by using an oscillating screen particle separator (ANSI, 1993). Samples of treatment WPCS (25 g as fed) and masticates (35 g of wet weight) were wet-sieved in duplicate for 10 min with a vibrating sieve shaker with a continuous water spray on the top sieve. Seven 20-cm diameter sieves were used with nominal sieve openings of 19.0, 12.5, 9.52, 6.30, 3.35, 1.18, and 0.15 mm. The MPL was determined according to ANSI (1995).

Rumen Sampling

Ruminal fluid was sampled on d 15 and 22 of each period immediately before the a.m. feeding and at 3, 6, 9, and 12 h after feeding. Samples were collected from the ventral sac of the rumen by using a metal filter probe and pH was determined (Twin pH-meter Model B-213; Spectrum Technologies Inc., Plainfield, IL). Duplicate 1-ml samples of ruminal fluid were acidified with 20 μl of 50% H_2SO_4 and frozen until prepared and analyzed for VFA by GLC (Perkin Elmer AutoSystem, Perkin Elmer Instruments, Shelton, CT) with GP 10% SP-1200/1% H_3PO_4 on 80/100 Chromasorb WAW column packing (Supelco, Bellefonte, PA) as described by Bal et al. (2000a). Separate duplicate 1-ml samples were acidified with 20 μl of 50% trichloroacetic acid solution and frozen until prepared and analyzed for ammonia concentration (Bal et al., 2000a).

Digestion Measurements

Total-tract nutrient digestibilities were measured by using lanthanum as an external marker. Lanthanum oxide solution (Hartnell and Satter, 1979) was sprayed onto a wheat middlings carrier. Each cow received 57 g of wheat middlings labeled with 0.5 g of lanthanum solution that was mixed in the TMR on d 18 through 27 of each period to provide approximately 16 mg/kg of lanthanum in total diet DM. Fecal grab samples were collected daily at 1100 and 2300 h on d 24 through 26. Ytterbium chloride (1-g Yb; solids passage marker; Shaver et al., 1986) and chromium-EDTA (3-g Cr; liquids passage marker; Binnerts et al., 1968) solutions were sprayed on to WPCS treatments (500 g of DM) and concentrate (450 g of DM), respectively. Concentrate and WPCS treatments labeled with their respective markers were fed before the a.m. feeding on d 24 of each period. Fecal grab samples were collected at 0, 12, 18, 24, 36, 48, 60, and 72 h post dose for measurement of rates of passage. Fecal grab samples were dried at 60°C for 72 h and ground through a 1-mm Wiley mill screen (Arthur H. Thomas, Philadelphia, PA). Fecal samples taken to determine total-tract nutrient digestibilities were composited by cow and period and analyzed for DM, OM, NDF, and starch as previously described. Duplicate 1-g fecal samples were weighed into 30-ml beakers and ashed in a muffle furnace (Thermolyne 30400; Barnstead/Thermolyne Corp., Dubuque, IA) at 500°C for 16 h. After ashing, 15 ml of hydrochloric acid was added to each beaker and allowed to stand for 1 h. Beaker contents were then diluted to 50 g in standard 120-cc specimen cups with LiOH * H_2O solution (121 g LiOH * H_2O added to 20 L of distilled water) added as an internal standard. Samples were then transferred to 17 × 100 mm polystyrene test tubes. The fecal concentrations of lanthanum, chromium, and ytterbium were determined by inductively coupled plasma mass spectroscopy at the University of Wisconsin-Madison Soil and Plant Analysis Laboratory (Madison, WI) by using a PQ2 Turbo Plus ICP-MS (VG Plasma Quad; Fision, Loughborough, Leicestershire, UK) with a concentric type nebulizer and double-pass Scott-type spray chamber water-cooled at 8°C. Nebulizer, auxiliary, and coolant gas flow rates were 0.83, 0.60, and 14.0 L/min, respectively. Ion lens setting was optimized on ^{115}In. Total-tract nutrient digestibilities were calculated from lanthanum and nutrient concentrations in orts-adjusted diet and feces. Liquid and solids rates of passage were determined by regressing the natural logarithm of chromium and ytterbium concentration from the declining portion of the fecal excretion curve versus time (Prange, 1981).

Statistical Analysis

Data were analyzed as a replicated Latin square by using the mixed procedure of SAS/STAT (1999). The model used for the lactation performance data was as follows:

$$Y_{ijkl} = \mu + P_i + S_j + C_k(S_j) + T_l + e_{ijkl}$$

where

Y_{ijkl} = dependent variable,
μ = population mean,
P_i = fixed effect of period i,
S_j = fixed effect of square j,
$C_k(S_j)$ = random effect of cow k nested within square j,
T_l = fixed effect of treatment l,
e_{ijkl} = random residual error, assumed to be normally distributed.

All terms were tested by using the residual mean square error. Preplanned orthogonal contrast statements were included to test the effects of processing (19PR vs. 19UP) and TCL in unprocessed (13UP vs. 19UP) and processed (19PR vs. 32PR) WPCS. Ruminal pH, VFA, and ammonia data were analyzed for repeated measures; time was used as a repeated measure with the first-order covariance structure. A diet by time interaction was included in the model, and diet by period by cow within square was included in the random statement. All mean comparisons were by the least significant difference method after a significant ($P < 0.05$) treatment effect.

RESULTS AND DISCUSSION

Silage and Diet Composition

Chemical composition and fermentation characteristics (mean ± standard deviation) of WPCS treatments are presented in Table 1. Dry matter content of WPCS treatments averaged 39.6 ± 2.9%. The 19PR and 32PR treatments were harvested on September 13, 1999, with the 19UP treatment harvested the following day. The 13UP treatment was not harvested until 2 d after the 19UP treatment because of mechanical problems with the harvester; this could explain the higher DM content of the 13UP treatment. Whereas TCL increased in both the 13UP versus 19UP and the 19PR versus 32PR contrasts, NDF and ADF concentrations increased and starch content decreased. Bal et al. (2000a) reported increasing NDF and ADF and decreasing starch concentrations (35.9 to 40.9% NDF; 20.6 to 23.6% ADF; and 27.3 to 25.0% starch) as chop length was increased from 0.95 to 1.9 cm in processed WPCS. Lower fiber (Bal et al., 2000a; Dhiman et al., 2000; Rojas-Bourrillon et al., 1987) and higher starch (Bal et al., 2000a; Rojas-Bourrillon et al., 1987) concentrations for processed than unprocessed WPCS have been reported. As discussed by Bal et al. (2000a), the variation in fiber and starch concentrations among treatments could be caused by more uniform sampling of finely chopped and processed WPCS treatments. Lignin content (data not presented in tables) averaged 1.4 ± 0.2% across the WPCS treatments. Silage pH values and lactate concentrations in treatment WPCS were indicative of adequate preservation (McDonald et al., 1991). Despite the higher DM content of the 13UP WPCS treatment, its fermentation parameters were similar to the other WPCS treatments.

Ingredient and nutrient compositions of experimental diets (mean ± standard deviation) are presented in Table 2. Dietary CP concentrations were lower than formulated because actual CP contents of the alfalfa silage and soybean meal were lower than values used for formulation before the start of the trial. However, dietary CP concentrations were similar for the four treatments and averaged 15.2% of DM. Dietary ADF concentrations averaged 16.2% of DM and were below minimum NRC (1989) guidelines, whereas dietary NDF concentrations averaged 25.5% of DM and just met minimum NRC (1989) guidelines. Although the diets contained 60% forage (DM basis), the relatively low dietary ADF and NDF concentrations reflect the high quality (low fiber) of the *bm3* WPCS. Dietary starch content averaged 25.3% of DM.

Particle Size

Particle size distribution (mean ± standard deviation) and MPL of the WPCS treatments is presented in Table 3. Percentage of as-fed sample retained on the first and second screens was highest for 32PR and lowest for 13UP. Of the as-fed sample retained on the third and fourth screens, the greatest percentage was observed for 13UP and lowest for 32PR. Percentage of as-fed sample

Table 2. Ingredient and nutrient composition of the diets.[1]

Item	% of DM			
Forage				
Corn silage	40.0			
Alfalfa silage[2]	20.0			
Concentrate[3]				
Corn (fine ground)	21.47			
Soybean meal (47.5% CP)	6.36			
Soybean meal, expeller[4]	7.55			
Urea	0.38			
Trace-mineralized salt[5]	0.51			
Magnesium oxide	0.15			
Dicalcium phosphate	0.73			
Calcium carbonate	1.02			
Dynamate[6]	0.15			
Sodium bicarbonate	0.65			
Vitamin premix[7]	0.13			
Animal fat	0.91			
	13UP	19UP	19PR	32PR
Nutrient, % of DM[8]				
OM	92.3 ± 0.3	92.8 ± 0.1	92.8 ± 0.2	92.8 ± 0.3
CP	15.2 ± 0.4	15.3 ± 0.4	15.2 ± 0.4	15.1 ± 0.3
NDF	25.5 ± 1.5	26.6 ± 1.5	24.6 ± 0.7	25.4 ± 1.1
ADF	16.1 ± 0.8	16.7 ± 0.8	15.4 ± 0.2	16.5 ± 0.9
Starch	26.2 ± 0.8	24.2 ± 0.7	25.7 ± 0.3	25.2 ± 0.7

[1]13UP = 13-mm theoretical chop length (TCL) without processing, 19UP = 19-mm TCL without processing, 19PR = 19-mm TCL processed with 2-mm roll clearance, and 32PR = 32-mm TCL processed with 2-mm roll clearance.

[2]Contained 18.9% CP, 26.5% ADF, and 34.0% NDF (DM basis).

[3]Contained 21.6% CP, 4.5% ADF, and 10.0% NDF (DM basis).

[4]Soy Plus, West Central Soy, Ralston, IA.

[5]0.55% Mn, 0.55% Zn, 0.35% Fe, 0.14% Cu, 0.0008% I, 0.006% Se, and 0.002% Co.

[6]18% K, 11% Mg, and 22% S (Pitman Moore, Inc., Mundelein, IL).

[7]3308 IU of vitamin A/g, 1103 IU of vitamin D/g, and 11.03 IU of vitamin E/g.

[8]Data are mean ± SD values.

retained on the fifth screen and pan was highest and similar for 19PR and 32PR treatments. After visual inspection of 13UP and 19UP treatments, cobs and husks were retained on screens 1 and 2, with kernels and leaves retained primarily on screen 3. For 19PR and 32PR treatments, no cobs were observed on screens 1 through 3. Mean particle length was lowest for 13UP and highest for the 19UP treatments. Processing reduced MPL by 19% (19UP vs. 19PR). This reduction in particle size because of processing falls within the range of 15 to 30% provided by Johnson et al. (1999). Processing also shifted the percentage of as-fed sample retained on screens 1

Table 3. Particle size distribution and mean particle length of whole-plant corn silage treatments determined by using the Oscillating Screen Particle Separator (ASAE, 1993).

	Screen[1] (% of sample retained on screen)						
Treatment[2]	1	2	3	4	5	Pan	MPL,[3]mm
13UP	2.9 ± 1.1	13.9 ± 1.3	55.2 ± 2.5	10.3 ± 1.5	11.7 ± 1.2	6.0 ± 1.6	9.65 ± 0.08
19UP	8.1 ± 1.9	24.6 ± 3.5	44.5 ± 2.9	8.9 ± 0.9	9.8 ± 0.9	4.1 ± 1.8	11.98 ± 1.1
19PR	3.6 ± 0.6	22.3 ± 2.1	38.2 ± 0.9	15.9 ± 0.7	15.5 ± 0.8	4.5 ± 0.8	9.73 ± 0.4
32PR	11.2 ± 2.0	22.9 ± 0.9	29.5 ± 3.1	16.4 ± 1.0	16.1 ± 1.2	3.9 ± 1.7	10.84 ± 0.2

[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 diagonal square hole opening. Data are mean ± SD values.

[2]13UP = 13-mm theoretical chop length (TCL) without processing, 19UP = 19-mm TCL without processing, 19PR = 19-mm TCL processed with 2-mm roll clearance, and 32PR = 32-mm TCL processed with 2-mm roll clearance.

[3]MPL = Geometric mean particle length determined by screen size (ASAE, 1993).

Table 4. Effects of corn silage crop processing and chop length on BW and nutrient intakes.

Item	Treatment[1]				SEM	Contrasts, P value		
	13UP	19UP	19PR	32PR		13UP vs. 19UP	19UP vs. 19PR	19PR vs. 32PR
BW, kg	667	667	671	667	7.6	NS[2]	NS	NS
DMI, kg/d	26.6	25.5	25.9	25.1	0.7	0.002	NS	0.03
DMI, % of BW	4.0	3.8	3.9	3.8	0.08	0.0005	NS	0.09
NDF intake, kg/d	6.6	6.6	6.3	6.2	0.18	NS	0.002	NS
NDF intake, % of BW	1.0	1.0	0.9	0.9	0.02	NS	0.0001	NS
FNDF intake, kg/d[3]	5.6	5.7	5.3	5.4	0.15	NS	0.0002	NS
FNDF intake, % of BW	0.84	0.9	0.8	0.8	0.02	NS	<0.0001	NS
Starch intake, kg/d	7.1	6.2	6.7	6.3	0.17	<0.0001	<0.0001	0.003

[1]3UP = 13-mm theoretical chop length (TCL) without processing, 19UP = 19-mm TCL without processing, 19PR = 19-mm TCL processed with 2-mm roll clearance, and 32PR = 32-mm TCL processed with 2-mm roll clearance.

[2]NS = $P > 0.10$.

[3]fNDF = Forage NDF based on forage NDF of the diet and not corrected for refusals.

and 2 to screen 5 and the pan. Increasing the TCL of processed WPCS from 19 to 32 mm increased MPL by 1.1 mm. This suggests that increasing TCL for processed WPCS is an appropriate recommendation for maintaining MPL.

The MPL of WPCS treatments as determined by wet-sieving (data not presented in tables) followed a pattern similar to that observed with the dry-sieving procedure. Wet-sieving MPL (mean ± standard deviation) of the 13UP, 19UP, 19PR, and 32PR treatments was 6.4 ± 0.3, 7.6 ± 0.5, 5.8 ± 0.3, and 7.1 ± 1.5 mm, respectively. The lower MPL of WPCS treatments for wet-sieving compared with dry-sieving (Table 3) can be attributed to finer mesh screens being used in the wet-sieving procedure. There was no TCL effect on MPL of WPCS masticates in either the 13UP versus 19UP (3.5 vs. 3.8 mm) or 19PR versus 32PR (3.2 vs. 3.5 mm) TCL contrasts. This lack of effect of TCL on MPL of WPCS masticates or material entering the rumen may explain TCL responses yet to be discussed. Processing reduced ($P = 0.04$) the MPL of WPCS masticates (3.8 vs. 3.2 mm for 19UP vs. 19PR; pooled SEM = 0.2). Mastication during eating of the WPCS treatments reduced MPL (mean ± standard deviation) of the 13UP, 19UP, 19PR, and 32PR treatments by 46.0% ± 6.2%, 48.6% ± 9.7%, 44.3% ± 8.6%, and 47.9% ±13.9%, respectively. Shaver et al. (1988) reported similar results for masticates of chopped versus long alfalfa hay fed to dairy cows.

Body Weight and Feed Intake

The body weight and intake data are presented in Table 4 and BW averaged 668 kg across the four treatments. Increasing TCL decreased DMI by 1.1 kg/d ($P = 0.002$) and 0.8 kg/d ($P = 0.03$) for the 19UP versus 13UP and 32PR versus 19PR contrasts, respectively. De Boever et al. (1993) evaluated unprocessed WPCS harvested at the dough stage of maturity and reported a 1.4 kg/d reduction in DMI when chop length was increased from 4 to 8 mm. Conversely, Bal et al. (2000a) reported no differences in DMI between dietary treatments that contained processed WPCS harvested at 9.5-, 14.5-, or 19.0-mm chop length. In two trials, Clark and Armentano (1999) reported no effect of chop length in unprocessed corn silage on DMI when average MPL of coarse- and fine-chopped WPCS were 7.6 and 3.4 mm, respectively. Intake of DM was similar for the 19UP versus 19PR contrast, averaging 25.7 kg/d and 3.85% of BW. Using WPCS harvested at 9.5-mm chop length, Dhiman et al. (2000) reported no effect of processing on DMI in two trials with either early- or mid-lactation cows. Weiss and Wyatt (2000) examined processing effects in both high-oil and conventional WPCS hybrids and reported no differences in DMI between unprocessed and processed WPCS for either hybrid. In contrast, Bal et al. (2000a) observed a 0.6 kg/d increase in DMI caused by processing WPCS between the unprocessed control and processed treatments. Orts-adjusted NDF intakes were unaffected by TCL, averaging 6.6 kg/d and 1.0% of BW for the 13UP versus 19UP contrast and 6.3 kg/d and 0.9% of BW for the 19PR versus 32PR contrast. However, processing reduced NDF intake by 0.3 kg/d ($P = 0.002$) and 0.1% of BW ($P = 0.0001$) for the 19UP versus 19PR contrast. Likewise, intakes of forage NDF (kg/d and % of BW) were reduced by processing ($P = 0.0002$ and $P < 0.0001$, respectively). These effects of processing can be attributed to the lower NDF concentration of the 19PR diet, because DMI was not affected by processing. Starch intake was reduced for the 13UP versus 19UP ($P < 0.0001$) and 19PR versus 32PR contrast ($P = 0.003$) by 0.9 and 0.4 kg/d, respectively, because of reduction in DMI and lower dietary starch concentrations observed for the longer TCL treatments. Processing increased ($P < 0.0001$) starch intake by 0.5 kg/d, because of the higher dietary starch concentration of the 19PR compared with the 19UP treatment.

Milk Yield and Composition

Milk production data are presented in Table 5. Milk and 3.5% FCM production were unaffected by treatment and averaged 43.2 and 41.2 kg/d, respectively. Experimental periods were too short to measure BW change in this trial. But, long-term continuous lactation trials may have revealed adverse effects of the long TCL WPCS treatments on BW change and (or) milk production related to the decline in DMI observed for these treatments (Table 4). Other researchers (Bal et al., 2000a; Clark and Armentano, 1999) have reported no effect of increasing WPCS chop length on milk production, but these were also switchback trials with short period duration. No effect of processing on milk production was observed by Weiss and Wyatt (2000) or in the three trials of Dhiman et al. (2000). In contrast, Bal et al. (2000a) reported an average increase of 1.4 kg/d in milk and FCM production because of processing. Variability in the benefit of processing on milk production has been documented (Satter et al., 1999). The effects of WPCS processing on milk fat are mixed. Bal et al. (2000a) reported 0.07 percentage unit and 0.07 kg/d increases ($P < 0.001$) in milk fat because of WPCS processing. Weiss and Wyatt (2000) reported that milk fat tended to increase by 0.23 percentage units because of WPCS processing. Dhiman et al. (2000) observed no affect of processing on milk fat percentage or yield in two trials, yet milk fat percentage increased by 0.35 percentage units ($P = 0.01$) in another trial. Bal et al. (2000a) attributed the milk fat response from WPCS processing to the possibility of sorting against fiber in the control WPCS diet that was prevented in the processed WPCS. Weiss and Wyatt (2000) theorized that because the processed WPCS treatments had increased particle size relative to the unprocessed WPCS treatments, cows receiving processed WPCS may have chewed longer and had increased saliva production and rumen buffering. In the experiment of Dhiman et al. (2000), the increase in milk fat percentage because of processing was greater in primiparous cows (0.60 percentage units) than in multiparous cows (0.10 percentage units). In the present experiment, processing reduced milk fat percentage ($P < 0.0001$) and yield ($P = 0.002$) by 0.25% and 0.08 kg/d, respectively. Acetate/propionate ratios of less than 2.0 are often associated with milk fat depression and a positive relationship exists between ADF concentration and milk fat percentage (Erdman, 1988). The ADF concentrations of the diets in this experiment were low relative to NRC (1989) guidelines, and the acetate/propionate ratio was reduced ($P = 0.01$) for the 19PR versus 19UP contrast (Table 6). The reduction in milk fat percentage and production in the processed contrast was not alleviated by increasing TCL (19PR vs. 32PR contrast). As was observed in the present experiment, other researchers (Bal et al., 2000a; Clark and Armentano, 1999) have reported no increases in milk fat percentage with an increase in WPCS chop length. Milk CP and lactose concentrations were not affected by either processing or TCL. Processing reduced ($P < 0.0001$) milk urea N concentration by 1.2 mg/dl, possibly because of an increase in the use of RDP by rumen microbes as more fermentable starch may have been available in the rumen for microbial protein synthesis (Nocek and Russell, 1988). The decrease ($P = 0.01$) in milk urea nitrogen in the 13UP versus 19UP contrast may be

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

	Treatment[1]					Contrasts, P value		
	13UP	19UP	19PR	32PR	SEM	13UP vs. 19UP	19UP vs. 19PR	19PR vs. 32PR
Production, kg/d								
Milk	42.7	43.0	43.5	43.7	0.9	NS[2]	NS	NS
3.5% FCM	41.4	41.7	40.6	41.2	0.9	NS	0.07	NS
Fat	1.41	1.43	1.35	1.37	0.05	NS	0.002	NS
Protein	1.35	1.36	1.39	1.39	0.03	NS	NS	NS
Lactose	2.05	2.06	2.09	2.10	0.05	NS	NS	NS
Milk composition								
Fat, %	3.32	3.36	3.11	3.18	0.13	NS	<0.0001	NS
Protein, %	3.17	3.18	3.20	3.20	0.05	NS	NS	NS
Lactose, %	4.79	4.80	4.80	4.80	0.03	NS	NS	NS
MUN[3], mg/dl	11.9	11.2	10.0	10.6	0.4	0.01	<0.0001	0.04

[1]13UP = 13-mm theoretical chop length (TCL) without processing, 19UP = 19-mm TCL without processing, 19PR = 19-mm TCL processed with 2-mm roll clearance, and 32PR = 32-mm TCL processed with 2-mm roll clearance.

[2]NS = $P > 0.10$.

[3]Milk urea nitrogen.

Table 6. Effects of corn silage crop processing and chop length on ruminal pH, ammonia, and VFA.[1]

	Treatment[2]					Contrasts, P value		
Item	13UP	19UP	19PR	32PR	SEM	13UP vs. 19UP	19UP vs. 19PR	19PR vs. 32PR
pH	5.96	5.99	5.92	6.01	0.07	NS[3]	NS	NS
NH_3, mg/dl	15.5	13.7	13.4	12.8	1.2	NS	NS	NS
Total VFA, m*M*	104.1	101.9	107.0	101.6	3.0	NS	NS	NS
VFA, mol/100 mol								
Acetate	52.3	51.3	49.5	50.3	0.9	NS	NS	NS
Propionate	26.0	26.7	30.2	27.7	1.0	NS	0.01	0.04
Butyrate	15.8	15.8	14.4	16.1	0.8	NS	NS	NS
Others[4]	5.8	6.0	5.6	5.7	0.2	NS	NS	NS
Acetate/propionate	2.1	2.0	1.7	1.9	0.1	NS	0.01	0.10

[1]Average of rumen fluid samples taken at 0, 3, 6, 9, and 12 h postfeeding.

[2]13UP = 13-mm theoretical chop length (TCL) without processing, 19UP = 19-mm TCL without processing, 19PR = 19-mm TCL processed with 2-mm roll clearance, and 32PR = 32-mm TCL processed with 2-mm roll clearance.

[3]NS = $P > 0.10$.

[4]Isobutyrate, isovalerate, and valerate.

caused by greater ruminal starch availability in relationship to the lower DM content of the 19UP WPCS compared with the 13UP WPCS (39.0 vs. 43.9% DM, respectively) treatments. Bal et al. (2000b) reported reduced ruminal in situ starch disappearance with increasing WPCS DM content. Increasing TCL in the 19PR versus 32PR contrast resulted in an increase ($P = 0.04$) in milk urea nitrogen concentration. This may be caused by the lower starch intake for 32PR compared with 19PR treatment (refer to Table 4). Differences in ruminal acetate/propionate ratio between treatments (Table 6) tends to support the premise of differences in ruminal starch availability, which may have impacted ruminal microbial protein synthesis and the milk urea nitrogen differences that were observed. Differences in ruminal ammonia concentrations between treatments tend to support this premise numerically but not statistically (Table 6). Despite these changes in milk urea nitrogen concentration, there were no differences in milk CP concentrations (Tables 5 and 6).

Digestion

Apparent total-tract nutrient digestibilities, rumen fill, and fractional rates of passage are presented in Table 7. Digestibilities of DM and OM were unaffected by treatment. No effect of processing on total-tract DM or OM was reported by Bal et al. (2000a) and Weiss and Wyatt (2000) in lactating dairy cows or Rojas-Bourillion et al. (1987) in growing steers. Dhiman et al. (2000), however, reported a 4.0 percentage unit reduction in total-tract OM digestibility for diets containing processed versus unprocessed WPCS. Increasing TCL in both the 13UP versus 19UP and 19PR versus 32PR contrasts had no affect on DM or OM digestibility, which is in agreement with the results of Sudweeks et al. (1979). Processing reduced ($P < 0.0001$) total-tract NDF digestibility by 9.2 percentage units. Dhiman et al. (2000) also reported lower total-tract NDF digestibility for diets containing processed WPCS, which they attributed to possible negative associative effects of greater rumen-available starch on NDF digestion (Grant and Mertens, 1992). The possibility that the reduction in total-tract NDF digestion observed in the present trial was caused by increased ruminal starch availability is supported by the rumen fermentation data (Table 6) and milk composition data (Table 5); processing increased ($P = 0.01$) the molar proportion of ruminal propionate, decreased ($P = 0.01$) the ruminal acetate/propionate ratio, and reduced ($P = 0.0001$) milk fat percentage. It is also possible that increasing ruminal starch availability altered the rumen microflora such that the numbers of cellulolytic bacteria were decreased, thereby inhibiting fiber digestion (Mould et al. 1983). Processing increased ($P = 0.0001$) total-tract starch digestibility by 4.5 percentage units. Bal et al. (2000a) and Weiss and Wyatt (2000) observed, respectively, 4.2 and 4.4 percentage unit increases in starch digestibility because of processing. Higher starch along with lower fiber digestibilities in the total-tract was also reported by Bal et al. (2000a) and Rojas-Bourrillon et al. (1987) for processed versus unprocessed WPCS. This may explain the similar total-tract DM and OM digestibilities for diets containing processed versus unprocessed WPCS reported in these studies and observed in the present study. Increasing TCL had no affect on total-tract NDF or starch digestion. Bal et al. (2000a) reported increased total-tract NDF digestibility, by increasing chop length from 0.95 to 1.9 cm, and no effect of chop length on starch digestibility. Rumen fill averaged 8.1 kg of DM and was unaffected by treatment. Ruminal

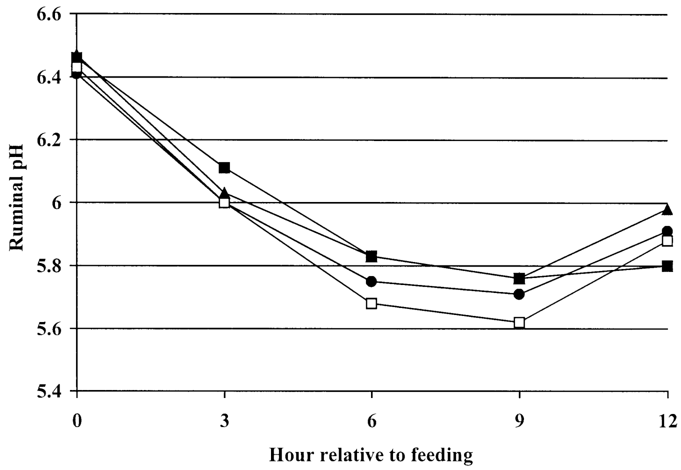

Figure 1. Effect of brown-midrib corn silage crop processing and chop length on postfeeding ruminal pH for 13UP (13-mm TCL without processing) (●); 19UP (19-mm TCL without processing) (■); 19PR (19-mm TCL processed with 2-mm roll clearance) (□); and 32PR (32-mm TCL processed with 2-mm roll clearance) (▲). Pooled SEM = 0.07. TCL = Theoretical chop length.

passage rate of ytterbium applied to WPCS was unaffected by treatment. Processing increased ($P = 0.04$) passage rate of the Cr-EDTA liquid marker from 7.4 to 8.2 %/h. Rate of passage measurements by use of rare earth markers should be interpreted with caution. Because the marker applied to the feedstuff can become attached to ruminal microbial cells (Combs et al., 1992) error could occur in measuring particulate passage rate. Therefore, passage rates are expressed in terms of the element used and the means represent relative not absolute measurements.

Ruminal pH, ammonia, and VFA data are presented in Table 6. There was no treatment × time interaction, so the data presented in the table represent average values from the five sampling times. There were no WPCS processing or TCL effects on ruminal pH or ammonia and total VFA concentrations. Bal et al. (2000a) also reported no processing or chop length effects on these parameters. However, Dhiman et al. (2000), with the use of a more intensive rumen-sampling regimen, reported significant decreases in both ruminal pH and ammonia concentration because of processing. As reported by Bal et al. (2000a), ruminal pH nadir was observed at 9 h post feeding (Figure 1). Processing increased ($P = 0.01$) the molar proportion of propionate by 3.5 mol/100 and decreased ($P = 0.01$) the acetate/propionate ratio. Dhiman et al. (2000) reported an increase in the molar proportion of propionate along with a decrease in the molar proportion of acetate because of WPCS processing. The molar proportion of propionate was decreased ($P = 0.04$) for the 19PR versus 32PR contrast. Bal et al. (2000a) reported no effect of chop length on ruminal acetate or propionate molar proportions.

Chewing Activities

Chewing activities are presented in Table 8. Increasing TCL had no effect on time spent eating. In a similar manner, Clark and Armentano (1999) and Bal et al. (2000a) both reported no effect of chop length on time spent eating in cows fed unprocessed and processed WPCS, respectively. No effect on time spent ruminating was observed for the 13UP versus 19UP contrast, which is in agreement with Clark and Armentano (1999). However, for the 19PR versus 32PR contrast, time spent ruminating was reduced ($P = 0.002$) when expressed as min/kg of dietary NDF. These results are surprising and no definitive explanation can be given. Research with alfalfa hay (Grant et al., 1990; Shaver et al., 1988) and WPCS (De Boever et al., 1993) has reported increases in time spent ruminating as the particle length of the respective treatments increased. The results observed in the present trial may be caused in part by the trend ($P = 0.06$) for increased apparent total-tract NDF digestibility (Table 7) for the 32PR versus 19PR contrast. Because of increased NDF digestibility, the cows may have needed to spend less time ruminating per unit of NDF intake to allow for sufficient particle size reduction for passage from the rumen. Increasing TCL in unprocessed WPCS (13UP vs. 19UP) did not affect the minutes per day of total chewing time, but increased ($P = 0.02$) total chewing time expressed as min/kg of DMI, despite that DMI was reduced for the 19UP compared with the 13UP treatment. Total chewing time was unaffected by increasing chop length in the experiment of Clark and Armentano (1999). However, De Boever et al. (1993) reported increases in total chewing index with increasing WPCS chop length from 4 to 16 mm.

Processing reduced time spent eating by 20 min/d ($P = 0.03$) and by 0.9 min/kg of DMI ($P = 0.01$), which could be attributed to the 2.25-mm-shorter MPL of the 19PR compared with the 19UP treatment and possible sorting of the 19UP treatment. Bal et al. (2000a) reported a reduction in eating time of 0.9 min/kg of DMI for processed WPCS chopped at 9.5-mm versus the unprocessed control harvested at the same length. Replacing long and chopped hay with pelleted hay reduced time spent eating (min/d) in the experiment of Shaver et al. (1988). Processing did not affect ruminating time when expressed as min/d or min/kg of DMI. However, processing increased rumination time when expressed as min/kg of dietary NDF ($P = 0.01$). These results are surprising considering that the MPL of the 19PR WPCS and masticate was 2.25 and 0.6 mm shorter, respec-

Table 7. Effects of corn silage crop processing and chop length on apparent total-tract nutrient digestion, rumen fill, and passage rates.

	Treatment[1]					Contrasts, *P* value		
	13UP	19UP	19PR	32PR	SEM	13UP vs. 19UP	19UP vs. 19PR	19PR vs. 32PR
Digestibility								
DM, %	71.9	71.1	71.2	72.1	0.6	NS[2]	NS	NS
OM, %	70.8	70.3	70.6	71.2	0.6	NS	NS	NS
NDF, %	50.7	51.0	41.8	45.4	1.5	NS	<0.0001	0.06
Starch, %	92.1	92.9	97.4	97.3	0.5	NS	<0.0001	NS
Rumen fill, kg DM	8.5	7.4	8.3	8.3	0.7	0.06	NS	NS
Passage rate, %/h								
Yb[3]	6.1	5.9	6.5	6.1	0.5	NS	NS	NS
Cr-EDTA[4]	7.5	7.4	8.2	7.9	0.2	NS	0.04	NS

[1]13UP = 13-mm theoretical chop length (TCL) without processing, 19UP = 19-mm TCL without processing, 19PR = 19-mm TCL processed with 2-mm roll clearance, and 32PR = 32-mm TCL processed with 2-mm roll clearance.

[2]NS = $P > 0.10$.

[3]Respective corn silage treatment labeled with ytterbium.

[4]Grain mix labeled with chromium-EDTA.

tively, than that of the 19UP treatment. This effect of processing may also be a mathematical artifact of the higher NDF intake (Table 4) and numerically lower time spent ruminating (min/d) for the 19UP versus 19PR treatments.

CONCLUSIONS

There were no benefits from crop processing or increasing TCL in *bm3* WPCS on lactation performance by dairy cows. Increasing TCL in unprocessed and processed *bm3* WPCS reduced DMI. Processing *bm3* WPCS increased total-tract starch digestibility, and reduced total-tract NDF digestibility and milk fat percentage and yield possibly because of adverse effects of increased starch digestion on the rumen environment. Although the diets contained 60% forage (DM basis), increasing dietary NDF and (or) ADF concentrations and reducing the amount of fine ground corn in the diets may have alleviated the milk fat percentage and yield depression observed with the processing of *bm3* WPCS that was not alleviated by increasing TCL from 19 to 32 mm. As concluded from earlier research with a conventional hybrid (Bal et al. 2000a), a 19-mm chop length seems to be adequate for *bm3* WPCS. The small differences in MPL of material entering the rumen after mastication of WPCS treatments during eating may partially explain the lack of response to increased chop

Table 8. Effects of corn silage crop processing and chop length on chewing activities.

	Treatment[1]					Contrasts, *P* value		
Variable	13UP	19UP	19PR	32PR	SEM	13UP vs. 19UP	19UP vs. 19PR	19PR vs. 32PR
Eating								
Min/d	236	244	224	224	8.2	NS[2]	0.03	NS
Min/kg of DMI	9.2	9.8	8.9	9.2	0.4	0.07	0.01	NS
Min/kg of dietary NDF	36.6	37.3	36.7	34.2	1.9	NS	NS	NS
Ruminating								
Min/d	374	387	405	384	11.5	NS	NS	0.09
Min/kg of DMI	14.6	15.6	16.1	15.7	0.7	0.08	NS	NS
Min/kg of dietary NDF	58.4	60.0	66.6	57.7	2.8	NS	0.01	0.002
Total chewing time								
Min/d	610	633	629	608	15.4	NS	NS	NS
Min/kg of DMI	23.8	25.4	25.0	25.0	1.0	0.02	NS	NS
Min/kg of dietary NDF	95.0	97.6	103.3	92.0	4.2	NS	0.08	0.002

[1]13UP = 13-mm theoretical chop length (TCL) without processing, 19UP = 19-mm TCL without processing, 19PR = 19-mm TCL processed with 2-mm roll clearance, and 32PR = 32-mm TCL processed with 2-mm roll clearance.

[2]NS = $P > 0.10$.

length. Because of its higher fiber digestibility, special attention must be given to dietary fiber and starch concentrations when feeding *bm3* WPCS.

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