A Comparison of Processed Conventional Corn Silage to Unprocessed and Processed Brown Midrib Corn Silage on Intake, Digestion, and Milk Production by Dairy Cows*

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ABSTRACT

We studied the effects of mechanical processing and type of hybrid on the nutritive value of corn silage for lactating cows. Treatments were brown midrib (BMR) corn silage that was unprocessed (U-BMR), BMR corn silage that was processed (P-BMR), and a conventional corn silage that was processed (P-7511). All silages were harvested at a theoretical chop length of 19 mm. The chemical compositions of the silages were similar among treatments except that BMR silages were lower in lignin and higher in protein than P-7511. Brown midrib silages had greater 30-h in situ and in vitro NDF digestion than did P-7511, and processing had no effect on 30-h in situ and in vitro fiber digestion, but it increased in situ starch digestion after 3 and 12 h of incubation. Both processed silages had a smaller proportion of particles >1.91 cm and fewer whole corn kernels compared with unprocessed silage. Lactating cows were fed a total mixed ration (TMR) consisting of 42% of each silage type, 40% concentrate, 10% alfalfa silage, and 8% alfalfa hay (DM basis). Cows fed TMR containing P-BMR ate more DM and produced more milk than cows fed P-7511. At feeding, the TMR containing U-BMR had a larger proportion of particles >1.91 cm when compared with the TMR of cows fed processed silages, and after 24 h the difference was even greater, indicating that cows fed unprocessed corn silage sorted more. Cows fed TMR with P-7511 and P-BMR had greater total tract digestibility of organic matter, crude protein, and starch compared with cows fed U-BMR. In vivo digestibility of neutral detergent fiber was greatest for cows fed P-BMR when compared with the other treatments.

(Key words: mechanical processing, brown midrib, corn silage)

Abbreviation key: BMR = brown midrib, P-7511 = processed 7511 corn silage, P-BMR = processed BMR corn silage, U-BMR = unprocessed BMR corn silage.

INTRODUCTION

Selection of corn hybrids with high nutritive values and mechanical processing of the whole corn plant are 2 methods that have been extensively studied in recent years to improve the utilization of corn silage. Specifically, brown midrib (**BMR**) hybrids have a lower concentration of lignin throughout the plant because of a reduction in the activity of the enzyme *O*-methyltransferase (Barriere and Argillier, 1993). Lower concentrations of lignin in corn silage have resulted in improved fiber digestion (Lechtenberg et al., 1972; Oba and Allen, 1999, 2000) and, in several instances, increased animal performance (Eastridge, 1999). Mechanical processing increases the nutritive value of the corn plant by exposing the starch in the corn kernel to rumen bacteria for digestion (Johnson et al., 2003) and improves packing density of silage (Johnson et al., 2002). Processed silage offers the potential for better nutrient utilization by the lactating cows and can increase animal performance (Bal et al., 2000b; Andrae et al., 2001).

We know of only one other published study evaluating the nutritive value of processed BMR silage (**P-BMR**) (Schwab et al., 2002) and could find no comparisons between processed conventional corn silage and P-BMR. Thus, we evaluated the effectiveness of mechanical processing on the composition and nutritive value of BMR corn silage for lactating cows. We also compared P-BMR and unprocessed BMR corn silage (**U-BMR**) to a conventional corn silage hybrid that was processed. Evaluations were made via in situ and in vitro methods for digestibility and by feeding the silages to lactating cows and comparing their effects on intake, digestion, and production.

MATERIALS AND METHODS

Corn Silage

Two varieties of corn silage were used in this study: 7511FQ (Mycogen Seeds, Indianapolis, IN), a medium-

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tall, forage quality hybrid (115 d relative maturity), and 867 (Mycogen Seeds), a BMR variety (118 d relative maturity). Corn was planted at the University of Delaware Dairy in fields of silt loam soil at a theoretical planting density of 72,500 seeds/ha (29,000 seeds/A) in 0.76 m (30 in.) rows. The site had been managed as corn-alfalfa rotation every 4 yr for at least 12 yr. In the last year of each alfalfa rotation, alfalfa was harvested in the spring then followed by no-till planting of corn using Round-Up (Monsanto Co., St. Louis, MO) or Gramoxone (Syngenta Crop Protection, Inc., Greensboro, NC). Small grain planting (typically barley or wheat) followed in the fall of each year. Management strategies included application of sheep, beef, and horse manure, and tandem disk harrow-cultivation followed by a field finisher applied with rolling basket and tines. Dry fertilizer starter (10-20-20, N-P₂O₅-K₂O; Milford Fertilizer, Milford, DE) was applied at a rate of 112 kg/ha, as was Broad Strike-Dual herbicide (Dow Elanco, Indianapolis, IN) and a 30% urea ammonium nitrate solution (UAN; CF Industries, Inc., Long Grove, IL). Plants were harvested at about 35% DM and one-half milk line with a New Holland FP230 (New Holland, PA) pull-type harvester equipped with a mechanical processor. Treatments at harvest were U-BMR, P-BMR, and processed 7511FQ (P-7511). The roller clearance was set at 2 mm, and the theoretical length cut was set at 19 mm for processed silages. The deflector screen, which diverts the forage to the rollers, was removed, and the theoretical length cut was unchanged for the unprocessed corn silage. Approximately 50 tonnes of each treatment were ensiled in farm-scale bag silos (Ag/Bag International, Ltd., Warrenton, OR) and stored for 7 mo before feed out.

Diets and Cows

Twenty-four multiparous and 6 primiparous Holstein cows averaging 143 ± 32 DIM (average milk production of about 43 kg/d) were housed in a free stall barn with Calan gates (American Calan, Northwood, NH). During a 14-d pretreatment period, cows were fed a TMR at 105% of their expected intake for ad libitum consumption once daily at 0800 h. The TMR contained (DM basis) 14% P-7511, 14% P-BMR, 14% U-BMR, 10% alfalfa silage, 8% chopped alfalfa hay, and 40% of a pelleted concentrate (Table 1). The amount of feed offered and refused was measured daily for each cow. At the end of the pretreatment period, cows were blocked by milk yield, DIM, and parity and randomly allocated to 1 of the 3 treatment TMR containing P-7511, P-BMR, or U-BMR. The TMR (Table 2) contained 42% (DM basis) of the respective corn silage, 10% alfalfa silage, 8% chopped alfalfa hay, and 40% pelleted concentrate.

Table 1. Composition (% DM) of the concentrate fed to lactating cows.

Ingredient	%
Corn meal fine	20.4
Soybean meal, 47.5% CP	17.6
Distillers dried grains	12.3
Gluten feed	12.3
Soybean hulls	7.13
Soybean roasted	5.78
Corn gluten, 60% CP	5.02
Wheat middlings	3.97
Fat blend ¹	3.06
Soybean meal, extruded	2.81
Limestone, (37% Ca)	2.54
Molasses blend ²	2.04
Sesquicarbonate	2.05
Salt	1.06
Protein blend ³	0.66
Dicalcium phosphate ⁴	0.50
Urea	0.41
Magnesium oxide	0.21
Selenium, (0.06% Se)	0.11
Trace minerals ⁵	0.04
Vitamins ⁶	0.04

¹Feed grade combination of tallow, poultry, and porcine fats.

²Contained (DM basis) 0.5% Ca, 0.03 g of Cu/kg, 5.0% crude fat, 3.0 % CP, 0.50 g of I/kg, 0.40% Mg, 1.49 mcal/kg NEL, 45.5% non-structural carbohydrates, 3.2% K, 0.70% S, 63% TDN, 0.50% P, 0.01g of Zn/kg.

³Dried blood meal, hydrolyzed poultry feathers, fishmeal, calcium carbonate, and ethoxyquin.

⁴Contained (DM basis) 27% Ca and 20% P.

⁵2.1% Ca, 1.6 g of Co/kg, 40 g of Cu/kg, 4.0 g of I/kg, 6.0 g of Fe/kg, 150 g of Mn/kg, 13.0% S, and 160 g of Zn/kg.

⁶Contained (DM basis) 26,400 kIU of vitamin A/kg, 8800 kIU/kg of vitamin D, and 165,000 IU of vitamin E/kg.

Cows were fed their respective diets for a 6-wk treatment period. All cows had been treated with recombinant bST (Posilac bST, Monsanto Co.) every 2 wk starting 4 wk before and throughout the study. Fresh water was available at all times, and the care of animals was via accepted protocols for animal research (Anonymous, 1989).

Cows were milked twice daily at 0700 and 1900 h, and production was recorded at each milking. In addition, milk was sampled proportionately to yield once weekly from consecutive p.m. and a.m. milkings and analyzed for percentage of fat, protein, and lactose by infrared analysis (method 972.160; AOAC, 2000) (Mid-East Milk Laboratory Services, Inc., Hagerstown, MD).

Milk composition was calculated by adding together the compositions after being weighted for the proportion of milk produced at each milking. Cows were weighed on 2 consecutive d at the start and the end of the treatment period.

Feed Analyses

Samples of the corn silages, alfalfa haylage, and TMR were sampled 3 times weekly and composited prior to

Table 2. Chemical and physical composition of the TMR fed to lactating dairy cows.¹

Item	P-7511 ²	P-BMR ³	U-BMR ⁴
DM, %	51.9	49.8	49.6
	(% of DM)		
NEI, ⁵ Mcal/kg	1.61	1.61	1.61
CP, %	16.3	17.1	17.3
ADF, %	23.0	21.0	21.8
NDF, %	33.9	33.5	33.8
Starch, %	20.9	20.2	19.0
Ca, %	0.86	0.84	0.87
P, %	0.35	0.36	0.37
Mg, %	0.24	0.26	0.27
K, %	1.38	1.57	1.70
S, %	0.22	0.24	0.21
Fe, ppm	207	246	254
Mn, ppm	58	52	52
Zn, ppm	50	52	53
Cu, ppm	21	22	21
Particle size distribution ⁶	(% of wet weight)		
>1.91 cm	6	6	11
0.79 to 1.91 cm	40	39	41
<0.79 cm	54	55	48

¹Average analyses of 6 weekly samples. Minerals were analyzed on a single composite sample from 6 wk.

²TMR included processed conventional corn silage (7511FQ; Mycogen Seeds, Indianapolis, IN).

³TMR included processed brown midrib (BMR) corn silage.

⁴TMR included unprocessed BMR corn silage.

⁵NRC (2001).

⁶Feed particle size distribution of the fresh TMR prior to feeding using a Penn State forage particle separator.

weekly analyses. The chopped hay and pelleted concentrate were sampled once weekly for analyses. Composites samples from each week were dried in a 60°C forced-air oven for 48 h for the determination of DM. The dried feed samples were ground through a 1-mm screen using a Cyclone Sample Mill (UDY Corp., Fort Collins, CO). Samples were analyzed for laboratory DM by placing 0.5 g into a 100°C oven for 24 h. Samples were also analyzed for NDF by using sulfite and amylase (Van Soest et al., 1991), ADF (Robertson and Van Soest, 1981) using an Ankom²⁰⁰ Fiber Analyzer (Ankom Technology, Fairport, NY), and acid detergent lignin following ADF analysis using 72% H₂SO₄. Crude protein was calculated by multiplying total N by 6.25 after total combustion (Leco CNS 2000 Analyzer, St. Joseph, MI). Ash content was determined by placing 0.5 g of sample into a 600°C furnace for 4 h. Starch concentration was analyzed by the procedure described by Hall (2000).

Silages were also analyzed for fermentation end products. Twenty-five grams of the weekly silage composite samples were homogenized for 1 min in 225 mL of sterile quarter-strength Ringer solution (Oxoid BR52; Unipath, Basingstoke, UK). The pH of the water extract

was determined. A portion of the water extract was filtered through Whatman 54 filter paper (Whatman, Clifton, NJ), acidified with 50% H₂SO₄, and frozen prior to further analysis. Water extracts were analyzed for ammonia N by using the phenol-hypochlorite procedure described by Weatherburn (1967). A portion of the extracts was also acidified with 25% m-phosphoric acid (5:1, vol/vol) and analyzed for VFA by gas chromatography using a Hewlett Packard 5890 gas chromatograph (Hewlett Packard, Avondale, PA) with a 530 μ m Carbowax 20M column and flame ionization detector. The chromatograph oven was programmed as follows: 70°C for 1 min, 5°C increase/min until 100°C was reached, then 45°C increase/min to 170°C, and maintained a final holding time of 5 min. The water extracts were also analyzed for D- and L-lactic acids using an enzymatic kit (kit 826-UV; Sigma Aldrich, St. Louis, MO). For analysis of D-lactic acid, L-lactic dehydrogenase was replaced with a similar amount of D-lactic dehydrogenase (Sigma L-9636). L-lactic acid (Sigma L-2250) and D-lactic acid (Sigma L-1000) were used as standards for their respective assays. Lactic acid was reported as the sum of L- and D-lactic acid.

Fresh weekly composite samples (250 g) of each corn silage and their respective TMR were subjected to particle size analysis (Lammers et al., 1996) using the Pennsylvania State Separator box (Nasco, Fort Atkins, WI). The proportion of sample collected on each section and the number of whole kernels were determined. Weekly composite corn silage samples were also analyzed for in vitro and in situ digestibility. A 30-h in vitro NDF digestibility was determined by weighing 0.25 g of sample into F57 bags (acetone washed) placed in a Daisy^{II} Incubator (Ankom Technology) following the general procedure of Goering and Van Soest (1970). Dry matter, NDF, and starch digestibility were determined by a macro in situ method (Joanne Siciliano-Jones, personal communication, 2002), which was conducted at the FARME Institute, Inc. (Homer, NY). Samples were prepared by simulating the chewing action of the cow via manual crushing. Approximately 5 g (DM basis) of sample were weighed (triplicate for each treatment) into rumen in situ filter bags (Ankom Technology) that measured 10 × 20 cm with a pore size of 50 μ . Bags were heat-sealed and placed into small, mesh laundry bags before inserting the bags into a cannulated lactating Holstein cow. The bags were removed after 3, 12, and 30 h of incubation. The donor cow was fed 20.5 kg/d (DM basis) of a diet formulated to meet NRC (2001) requirements. The ration was comprised of 28.3% corn silage, 14.9% alfalfa silage, 3.8% alfalfa hay, and 53.0% concentrate. Starch and fiber were analyzed as previously described.

Digestion Trial

The 8 highest yielding lactating cows from each treatment group were used to measure *in vivo* apparent digestibility during wk 5 of the treatment period. Fecal samples were collected every 8 h to obtain 12 samples per cow and were placed into a freezer (-20°C) for later analyses. Three hundred grams of wet feces from each collection point were mixed to form a single composite sample of feces for each cow. Two hundred fifty grams of each fecal composite were screened for kernel content. Fecal pH was determined by mixing 10 g of sample into 100 mL of deionized H_2O . Dry matter was determined by placing 300 g of sample into an aluminum pan in a 60°C forced-air oven for 72 h. Dried samples were ground through a 1-mm screen using a Cyclone Sample Mill (UDY Corp.) and analyzed for laboratory DM, NDF, ADF, CP, starch, and ash (as described previously). Indigestible NDF was determined on the NDF residue after 120 h of *in vitro* fermentation in the Daisy^{II} Incubator and was used as a marker for total tract digestibility (Oba and Allen, 1999). Indigestible NDF for each TMR and each component of the TMR was determined using samples collected during the period of fecal collection.

Evaluation of TMR Sorting

On the second to last day of the trial, all cows were fed 120% of their expected intake to provide TMR samples throughout a 24-h collection period to monitor sorting. Upon the completion of feeding at 0700 h, 1 kg of the TMR was sampled every 6 h (0, 6, 12, 18, and 24 h) for each cow. The weight of the remaining feed was recorded and placed back into the bunk. The proportion of particles on each section of the Pennsylvania State Separator box (Nasco) was determined as previously described.

Statistical Analysis

Chemical data are presented on a DM basis. Digestibility data from the *in vivo* digestion trial was analyzed as a completely randomized design. Data from the last 7 d of the pretreatment period from the lactation trial were used in a covariate analysis. Production data from the lactation trial were analyzed as a completely randomized design with weekly observations as repeated measurements using the analysis of variances procedure by the General Linear Models procedure of SAS (SAS Inst., Inc., Cary, NC). Differences among means were tested using Tukey's Test (Snedecor and Cochran, 1980). An α level of $P < 0.05$ was deemed significant.

Table 3. Nutrient composition (% DM) and particle size of corn silages fed to lactating cows.¹

Item	P-7511 ²	P-BMR ³	U-BMR ⁴
DM, %	37.7	33.7	33.5
CP, %	6.19	8.37	8.21
ADF, %	24.0	24.5	24.0
NDF, %	41.6	41.8	41.0
Lignin, %	2.25	1.02	0.87
Starch, %	31.7	28.4	27.4
pH	3.51	3.63	3.59
Lactic acid, %	3.04	3.56	3.69
Acetic acid, %	1.24	1.48	1.53
Propionic acid, %	0.36	0.08	0.36
Particle size distribution ⁵	(%)		
>1.91 cm	3	8	14
0.79 to 1.91 cm	56	60	63
<0.79 cm	41	32	23
Whole kernels ⁶	9	7	39

¹Average analyses of 6 weekly composite samples.

²Processed conventional corn silage (7511FQ; Mycogen Seeds, Indianapolis, IN).

³Processed brown midrib (BMR) corn silage.

⁴Unprocessed BMR corn silage.

⁵Feed particle size distribution of the fresh TMR prior to feeding using a Penn State forage particle separator.

⁶Per 250 g of wet forage.

RESULTS

Silage Composition

The nutrient composition and size of forage particles for the 3 corn silages is presented in Table 3. On average, BMR corn silages had a DM content of 33.6%, whereas P-7511 was slightly drier, with a DM content of 37.7%. The CP concentration was similar for the BMR corn silages (average of 8.29%, DM basis) but was lower for P-7511 (6.19%). No differences were found in the NDF (average of 41.5%) and ADF (average of 24.2%) concentrations of the 3 corn silages. As expected, P-BMR (1.02%) and U-BMR (0.87%) had lower concentrations of lignin when compared with P-7511 (2.25%). The concentration of starch was 27.4% in U-BMR, 28.4% in P-BMR, and 31.7% in P-7511. The P-7511 had the lowest pH (3.51) and the lowest concentration of lactic (3.04%) and acetic acid (1.24%) when compared with the other 2 silages. A larger proportion of particles >1.91 cm was present in the U-BMR (14%) when compared with P-BMR (8%) and P-7511 (3%). A larger proportion of particles also remained on the middle screen (0.79 to 1.91 cm) for U-BMR (63%) than for P-BMR (60%) and P-7511 (56%). Thus, a smaller proportion of particles (<0.79 cm) remained on the bottom screen for U-BMR (23%) than for P-BMR (32%) and P-7511 (41%). A greater number of whole, intact kernels remained in U-BMR (n = 39) than in the processed silages (n = 7 to 9).

Table 4. In vitro and in situ digestion (% DM basis) of a processed conventional corn silage hybrid (7511FQ; Mycogen Seeds, Indianapolis, IN; P-7511; P-7511), a processed brown midrib hybrid (P-BMR), or an unprocessed brown midrib hybrid (U-BMR).

Item	Time of incubation (h)	Corn silage		
		P-7511	P-BMR	U-BMR
In vitro digestion ¹				
NDF	30	39.9 ^b	54.0 ^a	51.0 ^a
In situ digestion ²				
DM	3	46.1 ^a	46.3 ^a	41.3 ^b
	12	52.1 ^a	52.7 ^a	47.2 ^b
	30	62.6 ^b	66.9 ^a	66.6 ^a
Starch	3	73.9 ^{cd}	77.9 ^c	69.9 ^d
	12	85.7 ^a	89.4 ^a	74.2 ^b
	30	97.4	97.2	90.7
NDF	3	0	0	0
	12	7.0	6.9	3.2
	30	22.7 ^b	31.9 ^a	35.5 ^a

^{a,b}Means with unlike superscripts differ ($P < 0.05$).

^{c,d}Means with unlike superscripts differ ($P < 0.06$).

¹NDF digestibility after 30 h of in vitro fermentation.

²Using a macro in situ digestion technique.

In Vitro and In Situ Digestion

Digestibility of NDF after 30 h of in vitro digestion (Table 4) was markedly higher for P-BMR (51.0%) and U-BMR (54.0%) when compared with P-7511 (39.9%). Digestibility of nutrients was also measured by a macro in situ technique. Dry matter digestibility at 3 h was lower for the unprocessed silage (41.3%) compared with the processed silages (average of 46.2%). By 12 h, the digestibility of the unprocessed silage (47.2%) remained lower than the processed silages (average of 52.4%). However, by 30 h, the DM digestibility of both BMR silages was greater (average of 66.8%) by 4 percentage units than the P-7511 (62.6%). Processing BMR corn silage tended to improve ($P < 0.06$) starch digestion when compared with U-BMR after 3 h of incubation. After 12 h of incubation, both processed silages had more starch digestion than U-BMR, but these differences were not found after 30 h of incubation. No differences were found in NDF digestibility at 3 or 12 h among the silages. However, after 30 h of digestion, NDF digestion was greater in both BMR silages when compared with P-7511 (35.5% and 31.9% vs. 22.7%, respectively).

Lactation and Digestion

Milk production, milk composition, and DMI of cows fed TMR containing P-7511, P-BMR, or U-BMR are presented in Table 5. Dry matter intake was greatest for cows fed a TMR that contained P-BMR (25.9 kg/d) when compared with those fed P-7511 (23.4 kg/d). Cows fed the former also tended ($P < 0.12$) to eat more DM

Table 5. Performance of dairy cows fed a processed conventional corn silage hybrid (7511FQ; Mycogen Seeds, Indianapolis, IN; P-7511), a processed brown midrib hybrid (P-BMR), or an unprocessed brown midrib hybrid (U-BMR).

Item	P-7511	P-BMR	U-BMR	SE
DMI, kg/d	23.4 ^b	25.9 ^a	24.5 ^{ab}	0.6
Milk, kg/d	41.4 ^b	44.3 ^a	42.5 ^{ab}	0.8
Milk fat				
%	3.16	2.94	3.17	0.13
kg/d	1.29	1.32	1.34	0.04
Milk protein				
%	2.79	2.76	2.75	0.03
kg/d	1.15	1.22	1.17	0.03
3.5% FCM, kg/d	38.8 ^d	40.8 ^c	40.0 ^{cd}	0.8
FCM/DMI, kg/d	1.78	1.74	1.75	0.04

^{a,b}Means with unlike superscripts differ ($P < 0.05$).

^{c,d}Means with unlike superscripts differ ($P < 0.08$).

than those fed U-BMR. Dry matter intake was not different between cows fed U-BMR and P-7511. Milk yield was also greater from cows fed P-BMR (44.3 kg/d) when compared with cows fed P-7511 (41.4 kg/d), and it was also numerically greater than from cows fed U-BMR. Milk fat and protein did not differ among treatments. Yield of 3.5% FCM yield tended to be greater ($P < 0.08$) for cows fed a TMR with P-BMR compared with P-7511.

Fecal characteristics and apparent nutrient digestion from the total tract is presented in Table 6. Fecal pH was lowest for cows fed U-BMR, and these cows also had the largest amount of whole kernels excreted in the feces. Cows fed diets with processed silages (P-7511 and P-BMR), on average, had a greater OM (65.1% vs. 56.5%), CP (65.0% vs. 58.2%), and starch (98.9% vs. 88.5%) digestibility compared with cows fed U-BMR. However, cows fed P-BMR had a greater ADF (39.6%) and NDF (42.1%) digestibility than cows fed either P-7511 (32.8 and 34.1%, respectively) or U-BMR (32.1 and 30.0%, respectively) in a TMR.

Table 6. Fecal characteristics and apparent in vivo total tract digestibility from cows fed a processed conventional corn silage hybrid (7511FQ; Mycogen Seeds, Indianapolis, IN; P-7511), a processed brown midrib hybrid (P-BMR), or an unprocessed brown midrib hybrid (U-BMR).

Item	P-7511	P-BMR	U-BMR	SE
Fecal pH	6.92 ^a	6.97 ^a	6.81 ^b	0.15
Whole kernels/250 g of wet feces	4 ^b	3 ^b	20 ^a	3
	(% DM)			
OM	64.2 ^a	66.0 ^a	56.5 ^b	1.1
DM	61.7 ^a	63.8 ^a	54.0 ^b	1.1
CP	64.2 ^a	65.7 ^a	58.2 ^b	1.4
ADF	32.8 ^b	39.6 ^a	32.1 ^b	2.4
NDF	34.1 ^b	42.1 ^a	30.0 ^b	1.9
Starch	99.0 ^a	98.7 ^a	88.5 ^b	0.7

^{a,b}Means in rows with unlike superscripts differ ($P < 0.05$).

Table 7. The effect of mechanical processing and corn hybrid on particle size distribution (%) of TMR fed to dairy cows.

Item	P-7511 ¹	P-BMR ²	U-BMR ³
At feeding			
>1.91 cm	6.4 ^b	6.9 ^b	9.6 ^a
0.79 to 1.91 cm	34.3 ^b	39.9 ^a	39.4 ^a
<0.79 cm	58.7 ^a	52.6 ^b	50.4 ^b
6 h after feeding			
>1.91 cm	6.7 ^b	7.4 ^b	11.4 ^a
0.79 to 1.91 cm	34.4 ^b	35.3 ^{ab}	36.7 ^a
<0.79 cm	58.9 ^a	57.3 ^a	51.9 ^b
12 h after feeding			
>1.91 cm	10.9 ^b	9.4 ^b	13.8 ^a
0.79 to 1.91 cm	34.6 ^b	36.9 ^{ab}	37.7 ^a
<0.79 cm	54.5 ^a	53.7 ^a	48.5 ^b
18 h after feeding			
>1.91 cm	10.3 ^b	11.3 ^b	12.8 ^a
0.79 to 1.91 cm	34.9 ^b	37.8 ^{ab}	38.9 ^a
<0.79 cm	54.8 ^a	50.9 ^b	48.3 ^b
24 h after feeding			
>1.91 cm	9.9 ^b	11.3 ^b	19.4 ^a
0.79 to 1.91 cm	36.2 ^b	38.2 ^a	37.9 ^{ab}
<0.79 cm	53.9 ^a	50.5 ^b	42.7 ^c

^{a,b,c}Means with unlike superscripts differ ($P < 0.05$).

¹Processed conventional corn silage (7511FQ; Mycogen Seeds, Indianapolis, IN).

²Processed brown midrib (BMR) corn silage.

³Unprocessed BMR corn silage.

At initial feeding, cows offered a TMR containing U-BMR had a greater proportion of feed particles that were >1.91 cm compared with cows fed P-BMR and P-7511 (Table 7). Cows fed the BMR TMR had more and less particles on the 0.79- to 1.91-cm screen and < 0.79-cm bottom pan than cows fed P-7511, respectively. In general, similar trends were observed through 18 h of feeding. After 24 h, the proportion of particles >1.91 cm was still greatest for cows fed U-BMR (19.4%) compared with cows fed P-BMR (9.9%) and those fed P-7511 (11.3%) silage.

DISCUSSION

In the present study, the theoretical chop length of forages was 19 mm because previous work from our laboratory has shown that amount of forage retained on the screen that represents particles >1.91 cm decreases by 10 to 15 percentage units after freshly chopped corn forage has gone through a silo bagging machine (J. Neylon and L. Kung, unpublished data, University of Delaware, 2002). Some caution should also be taken when comparing the effects of processing of corn silage, as studies have not been consistent in adjusting for theoretical chop length. In the current study, all silages were harvested at the same theoretical chop length. However, in general, the effects of processing BMR corn silage were similar to those found

with conventional hybrids (Shinners et al., 2000; Andrae et al., 2001; Johnson et al., 2002). For example, processing decreased the number of whole, intact corn kernels in silage (from 39 to <10 per 250 g of silage) and decreased the proportion of particles >1.91 cm from 14% in U-BMR to 8 and 3% in P-BMR and P-7511, respectively. The P-7511 hybrid had a smaller proportion of particles >1.91 cm and a larger proportion of particles <0.79 cm than did either P-BMR or U-BMR, possibly because of the slightly higher DM content (37.7%) than in the BMR silages (average of 33.6%). Because processing crushed or cracked the majority of corn kernels in corn silage, there were fewer whole corn kernels in the manure of cows fed processed silages compared with that found in cows fed U-BMR. Cows fed processed silages also had a higher fecal pH than cows fed U-BMR, most likely because there was more starch digestion in the rumen than in the hindgut. Similar to the results of Bal et al. (2000a), we found that in the macro in situ incubations, where whole, wet forages were used, processed corn silages (P-BMR and P-7511) had similar and more rapid disappearance of starch after 3 and 12 h of incubation than did U-BMR. Cows fed diets with P-BMR and P-7511 also had higher total tract digestion of starch than those cows fed U-BMR. Similar findings have been reported by Schwab et al. (2002) specifically with BMR corn silage and by others with conventional corn silage hybrids (Dhiman et al., 2000; Weiss and Wyatt, 2000). Improvements in in situ and in vivo starch digestion supported the fact that processing increased the availability of starch in the corn kernel to microbial attachment and digestive enzymes.

The effect of processing on the digestion of fiber in corn silage has been variable. Johnson et al. (2003) and Schwab et al. (2002) reported decreases in fiber digestion from processing, but Rojas-Bourrillon et al. (1987) reported that processing increased the digestion of fiber from whole plant corn. In our study, processing had no effect on the extent of fiber digestion in BMR corn silage measured in vitro or via a macro in situ technique, which supports previous research by Bal et al. (2000a) and Doggett et al. (1998). In contrast to the in vitro and in situ results, apparent in vivo total tract digestion of fiber in our study was greater in cows fed P-BMR when compared with those fed U-BMR. However, total tract digestion of fiber from cows fed U-BMR was not different from that of cows fed P-7511, which might indicate that fiber digestion was depressed in cows fed U-BMR, possibly because of a lack of energy in the rumen attributable to the abundance of intact kernels in the diet. This finding is in contrast to data reported by Schwab et al. (2002) and Dhiman et al. (2000), who observed a reduction in total tract NDF digestion when

cows were fed diets containing processed vs. unprocessed corn silages.

In a review of the literature, Eastridge (1999) reported that, on average, BMR corn silages contained 34% less lignin and had an in situ or in vitro NDF digestibility that was 19% higher when compared with non-BMR hybrids. In this study, there was a greater difference in the concentration of lignin (55% less) between BMR corn silages and P-7511, which resulted in a proportional higher increase (38%) in in vitro NDF digestion. In agreement with the data summarized by Eastridge (1999), we generally found no differences between other nutrient components of the silages with the exception of a higher concentration of CP in the P-BMR, but our conventional hybrid was not the isogenic hybrid of BMR.

Pretrial estimates of the CP content of P-7511 were higher than what was sampled during the actual lactation study. Thus, cows fed P-7511 had a TMR with a slightly lower protein content than cows fed the BMR silages, but protein intake was in excess of NRC requirements and should not have been a limiting factor. In general, cows produced milk with a moderate to low fat test, probably because of the high concentration of corn silage in the diets and because effective fiber might have been limiting. The proportion of particles from the TMR that were >1.91 cm ranged from 6 to 11%, which is slightly lower than recommended levels (Lammers et al., 1996). Processing BMR silage tended to increase DMI (+1.4 kg/d; $P < 0.12$) and milk production (+ 1.8 kg/d; $P < 0.13$) when compared with cows fed U-BMR. In the only other comparison that we know of where BMR corn silage was subjected to processing, Schwab et al. (2002) reported no effect on intake or milk production from processing. In past studies, processing has had variable effects on milk production (Satter et al., 1999), because variables such as stage of corn maturity, cow productivity, and percentage of corn silage in the diet can affect production responses to treatment. When compared with cows fed P-7511, those animals fed P-BMR consumed 2.5 more kg of DM/d and produced 2.9 more kg of milk/d. In a summary of 9 lactation studies, Eastridge (1999) reported that cows fed BMR corn silage, on average, produced 0.95 kg more milk/d than cows fed a non-BMR silage, but positive effects were not seen in all studies. Although numerically greater, cows fed U-BMR did not eat more DM or produce more milk than those fed P-7511.

The proportion of TMR particles >1.91 cm was not different between cows fed diets with processed silages throughout the 24-h feeding period. However, the TMR containing unprocessed silage had a consistently larger proportion of particles in this category than did either TMR containing processed silages at all sampling

points. After 24 h in the feed bunk, this difference was greatest, suggesting that more sorting occurred between 18 and 24 h of feeding. Extensive sorting of feed particles in TMR has been reported by Kononoff et al. (2003), Leonardi and Armentano (2003), and Martin (1999), and the data from the current study suggests that mechanical processing of corn silage may decrease this problem, especially for cows fed only once daily.

CONCLUSION

Mechanical processing of whole-plant BMR corn silage resulted in smaller forage particles but a decreased number of whole, intact kernels in silage and in the manure of cows. Processing had no effect on in vitro or in situ fiber digestion, but it improved early in situ digestion and in vivo digestion of starch. Cows fed P-BMR ate more and produced more milk than did those fed the processed conventional corn silage. Cows fed processed BMR corn silage also tended to eat and produced more milk with a similar composition than did cows fed U-BMR. These data show that feeding cows P-BMR results in enhanced production over cows fed processed conventional corn silage. Including processed corn silage (regardless of hybrid type) into the TMR fed to cows once daily resulted in less sorting between 18 and 24 h of access to feed.

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