Results of this study should in no way be construed to imply that the kernel processing score and particle size measured and reported herein cannot be produced when using another brand of harvester and processor by adjusting the length of cut, roll-gap, and roll-speed differential settings. Mention of companies, trade names, or products solely for the purpose of providing specific information and does not imply recommendation, endorsement or exclusion. R.D. Shaver.

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Effect of Corn Shredlage on lactation performance and total tract starch digestibility by dairy cows

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ABSTRACT

The objective of this trial was to determine the effect of feeding a TMR containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS) on lactation performance by dairy cows. The KPCS was harvested using conventional rolls (3-mm gap) and set at a 19-mm theoretical length of cut. The SHRD was harvested using novel cross-grooved rolls (2.5-mm gap) and set at a 30-mm length of cut. One hundred twelve cows stratified by DIM, milk yield, breed, and parity were randomly assigned to 14 pens with 8 cows. Pens were randomly assigned to 2 treatment TMR in a completely randomized design. A 2-wk covariate period with cows fed a 50:50 mixture of treatment diets was followed by an 8-wk treatment period with cows fed their assigned treatment diet. The TMR contained (DM basis) KPCS or SHRD (50%), alfalfa silage (10%), and concentrate mixture (40%). Data were analyzed using Proc Mixed in SAS with covariate, treatment, week, and the treatment × week interaction as fixed effects and pen within treatment as a random effect. Cows fed SHRD tended to consume 0.7 kg/d more DM. Milk yield and composition were similar between treatments. The 3.5% FCM yield tended to be 1.0 kg/d greater for cows fed SHRD. A treatment × week interaction was detected for 3.5% FCM yield; as during wk 2, a tendency was observed for SHRD to be greater during wk 4 and 6 and greater for SHRD at wk 8. Ruminal in situ digestibility of starch was greater for SHRD than for KPCS. Feeding SHRD tended to increase DMI and 3.5% FCM yield.

Key words: Corn Shredlage, corn silage, dairy cow, starch digestibility

INTRODUCTION

Shaver and Kaiser (2011) observed that forage constitutes 50 to 60% of TMR DM in Wisconsin high-producing dairy herds. In addition, these authors reported that whole-plant corn silage (**WPCS**) constitutes 40 to 70% of the forage DM; thus, corn silage is an important source of both physically effective NDF (**peNDF**) and energy in dairy cattle diets.

Greater peNDF can be achieved by increasing the theoretical length of cut (**LOC**) of WPCS, and is thought to be important for ruminal mat consistency, rumination activity, rumen buffering and digestion, and milk fat content (Allen, 1997; Mertens, 1997). However, in a recent review, Ferraretto and Shaver (2012) reported minimal benefits of greater LOC of WPCS on lactation performance by dairy cows. Furthermore, longer forage particles may limit intake through reduced ruminal passage rate and increased fill (Mertens, 1987) and may increase diet sorting (Leonardi and Armentano, 2003) by dairy cows. A novel method of harvesting WPCS, Corn Shredlage (**SHRD**; Shredlage LLC, Tea, SD, http://www.shredlage.com/), has generated much recent interest by dairy producers and their nutritionists. The SHRD is harvested with a commercially available self-propelled forage harvester (**SPFH**) fitted with after-market cross-grooved crop-processing rolls, and the SPFH is set for a longer LOC than commonly used. The cross-grooved rolls used for producing SHRD may cause greater damage to the coarse stover particles sufficient to allow for greater digestibility of the NDF (Johnson et al., 1999) and thus attenuate the negative effects of long forage particles on DMI (Oba and Allen, 1999).

High-producing dairy cows require a high intake of energy to support milk production and body condition requirements (Zebeli et al., 2012). Starch accounts for approximately

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half of the WPCS energy value (calculated from NRC, 2001). Therefore, improving WPCS starch utilization through kernel breakage may increase lactation performance (Ferraretto and Shaver, 2012) and reduce feed costs, especially during periods of high corn prices. Ferraretto and Shaver (2012) suggested that the degree of kernel processing may be reduced at a very long LOC, possibly by the longer stover portion causing greater roller spread as the WPCS passes through. The novel rolls used for producing SHRD may attenuate this effect by causing greater damage to the kernels at a longer LOC.

Corn Shredlage is a recent development with limited information available related to feeding and nutrition, and to our knowledge, reports from controlled experiments do not exist in the literature. Therefore, the objective of this study was to determine the effect of feeding a TMR containing Corn Shredlage compared with conventionally processed corn silage (**KPCS**) on intake, lactation performance, and total tract starch digestibility by dairy cows.

MATERIALS AND METHODS

A dual-purpose hybrid (DKC 57-79; Monsanto Company, St. Louis, MO) was planted in a University of Wisconsin–Arlington Agricultural Research Station (Arlington, WI) field (8 ha; 84,000 seeds/ha; 76-cm row spacing) on May 7, 2011. Half of the field was harvested as SHRD and the other half was harvested as KPCS on September 8 and 9, 2011, respectively. The SHRD and KPCS were stored in separate side-by-side 2.5-m-diameter × 61-m-long silo bags and allowed to ferment for approximately 6 wk before commencing the feeding trial on October 20, 2011. Packing density of the silo bags was similar and averaged 272 kg of DM/m^3. The SHRD was harvested using an SPFH (Claas Jaguar; Claas of America Inc., Omaha, NE) equipped with the SHRD processing rolls (Scherer Design Engineering Inc., Tea, SD) set for a 30-mm LOC by removing half of the knives and with the processor gap spacing set at 2.5-mm. The SHRD harvest was done by a custom operator (Kutz Farms, Jefferson, WI), and the SPFH was set up by a Scherer Design Engineering Inc. representative. Harvest of the KPCS was done using the University of Wisconsin–Arlington Agricultural Research Station SPFH (JD 6910; John Deere, Moline, IL) set for a 19-mm LOC and equipped with conventional processing rolls set for a 3-mm gap spacing. Neither the SHRD nor the KPCS was treated with a silage inoculant.

One hundred twelve cows were stratified by milk yield, DIM (116 ± 36 DIM), breed [Holstein (102) or Holstein-Jersey crossbreds (10)], and parity [first (52) or second lactation and greater (60)] and randomly assigned to 14 pens of 8 cows each in the University of Wisconsin sand-bedded free-stall barn and milking parlor dairy (Emmons Blaine Dairy Research Center, Arlington, WI). Pens were randomly assigned to 1 of 2 treatments in a completely randomized design for a 10-wk continuous-lactation feeding trial; 2-wk covariate adjustment period with cows fed a 50:50 mixture (DM basis) of the SHRD and KPCS diets, followed by an 8-wk treatment period with cows fed their assigned treatment diet. Ingredient compositions of the experimental diets are provided in Table 1. Experimental diets contained 50% (DM basis) of either SHRD or KPCS. The same concentrate mixture, prepared at the University of Wisconsin Feed Mill (Arlington, WI) was used in both diets. Diets were fed as a TMR mixed once daily at 0800 h for 5% refusals, with daily DMI determined on individual pens throughout the 10-wk experiment. Daily pen DMI was measured by the difference of as-fed feed and as-is orts by using the Feed Supervisor software (Supervisor Systems, Dresser, WI). The scale was accurate to 2.2 kg, introducing 0.45% error per pen to the measurement of DMI.

The animal research was conducted under a protocol approved by the Institutional Animal Care and Use Committee of the College of Agricultural and Life Sciences of the University of Wisconsin–Madison. All cows were injected with bovine somatotropin (Posilac; Elanco Animal Health, Greenfield, IN) every 14 d, commencing on d 1 of the covariate period. Body weight and BCS (1 to 5 in 0.25 increments; Wildman et al., 1982) were recorded on individual cows at the end of the covariate period and every other week during the treatment period. Body weight change (**BWC**) was determined by regression of the treatment period BW measurements over time. Milk yield was recorded daily (DairyComp 305; Valley Agricultural Software, Tulare, CA) on individual cows milked 2× daily in a double-16 parlor (Metatron P21; GEA Farm Technologies, Bakel, the Netherlands) throughout the 10-wk trial and composited by pen before statistical analysis. Milk samples were obtained from all cows every other week on the same 2 consecutive days from the morning and evening milkings throughout the 10-wk trial, composited by pen by week, and composites were analyzed for fat, true protein, lactose, and milk urea nitrogen concentrations and SCC was analyzed by infrared analysis (AgSource Milk Analysis Laboratory, Menomonie, WI) using a Foss FT6000 instrument (Foss Electric, Hillerød, Denmark), with average daily yields of fat and protein calculated from these data for each week. Yields of 3.5% FCM, solids-corrected milk (**SCM**), and energy-corrected milk (**ECM**) were calculated according to NRC (2001) equations. Actual milk, 3.5% FCM, SCM, and ECM feed conversions were calculated by week using average daily yield and DMI data. Estimated dietary energy concentrations were calculated by summing the megacalories of NE_l from milk production required for maintenance and in BW change (NRC, 2001), and then dividing the sum by DMI.

Samples of TMR, KPCS, SHRD, alfalfa silage, and concentrate mix were obtained weekly and composited for the covariate period and every 2 wk during the treatment period for

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

Item	COV[2]	SHRD	KPCS
Ingredient, % of DM			
Forage			
Corn silage	25.0	—	50.0
Corn Shredlage	25.0	50.0	—
Alfalfa silage[3]	10.0	10.0	10.0
Concentrate[4]			
Dry-ground, shelled corn	10.3	10.3	10.3
Soybean meal, expeller	9.0	9.0	9.0
Soybean meal, solvent	6.9	6.9	6.9
Corn gluten feed, dried	7.4	7.4	7.4
Energy Booster 100[5]	1.85	1.85	1.85
Calcium carbonate	1.48	1.48	1.48
Sodium bicarbonate	0.74	0.74	0.74
Potassium carbonate[6]	0.46	0.46	0.46
Urea	0.28	0.28	0.28
Magnesium oxide	0.22	0.22	0.22
Magnesium-potassium-sulfur[7]	0.19	0.19	0.19
Mono-calcium phosphate	0.10	0.10	0.10
Trace mineral salt[8]	0.42	0.42	0.42
Vitamin premix[9]	0.19	0.19	0.19
Rumensin premix[10]	0.13	0.13	0.13
Smartamine-M[11]	0.02	0.02	0.02
Nutrient, % of DM			
DM, % of as fed	45.1	46.4	46.6
OM	91.9	91.9	92.0
CP	17.3	17.2	17.3
Ether extract	4.7	4.8	4.5
NDF	28.2	28.1	28.3
Nonfiber carbohydrates	43.5	43.5	43.6
Starch	25.5	25.4	25.5

[1]Treatments were the diet containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS).

[2]COV = covariate period diet, formulated to provide 50% of each experimental corn silage.

[3]Contained 23.0% CP, 34.4% ADF, and 37.9% NDF (DM basis).

[4]Contained 27.7% CP, 6.2% ADF, 14.4% NDF, and 20.1% starch (DM basis).

[5]Minimum of 98% total fatty acids (MSC Company, Dundee, IL).

[6]DCAD Plus (minimum of 48.5% K; Church & Dwight Co. Inc., Princeton, NJ).

[7]Dynamate (11% magnesium, 18% potassium, 22% sulfur; The Mosaic Co., Plymouth, MN).

[8]Contained 88% sodium chloride, 0.002% cobalt, 0.2% copper, 0.012% iodine, 0.18% iron, 0.8% manganese, 0.006% selenium, and 1.4% zinc (Vita Plus, Madison, WI).

[9]Vitamin A, 3,300,000 IU/kg; vitamin D, 1,100,000 IU/kg; vitamin E 11,000 IU/kg (Country Mix Inc., Madison, WI).

[10]Rumensin (Elanco Animal Health, Greenfield, IN).

[11]Smartamine-M (Adisseo, Alpharetta, GA).

analysis. Samples of KPCS, SHRD, alfalfa silage, and concentrate mix for determination of nutrient composition were dried at 60°C for 48 h in a forced-air oven to determine DM content, ground to pass a 1-mm Wiley mill screen (Arthur H. Thomas, Swedesboro, NJ), and composited as described before being sent to Dairyland Laboratories Inc. (Arcadia, WI) for analysis. Absolute DM was determined by oven-drying at 105°C for 72 h. All samples were analyzed for DM, OM (method 942.05; AOAC, 2006), CP (method 990.03; AOAC, 2006), ether extract (method 2003.05; AOAC, 2006), NDF using α-amylase and sodium sulfite (Van Soest et al., 1991), starch (Bach Knudsen, 1997; YSI Biochemistry Analyzer; YSI Inc., Yellow Springs, OH), and particle size. Particle sizes of TMR, KPCS, SHRD, and alfalfa silage samples were determined as described by Kononoff et al. (2003a). Particle size of the concentrate mixture was determined by dry sieving using a Tyler Ro-Tap Shaker Model RX-29 (W. S. Tyler, Mentor, OH) with sieves of 4,760-, 2,380-, 1,191-, 595-, 297-, 149-, and 63-µm apertures plus a bottom pan; mean particle size was calculated using a log normal distribution (Baker and Herrman, 2002). Ruminal in vitro NDF (30 h) and starch (7 h) digestibility on KPCS and SHRD samples were determined at Dairyland Laboratories Inc. The 30-h in vitro NDF digestibility on dried 1-mm screen-ground samples was performed using an Ankom Daisy Incubator (Ankom Technology Corporation, Fairport, NY) as described by Holden (1999). Ruminal in vitro starch digestibility on dried 4-mm screen-ground samples was determined using procedures modified from Richards et al. (1995) for an Ankom Daisy II System (Ankom Technology Corporation). Using undried, unground samples of SHRD and KPCS, corn silage processing score (**CSPS**; Ferreira and Mertens, 2005) and fermentation profile (Muck and Dickerson, 1988) were determined at Dairyland Laboratories Inc., and fragility was determined at the William H. Miner Agricultural Research Institute (Chazy, NY) as described by Grant (2010).

Total tract starch digestibility (**TTSD**) was determined using the following equation: TTSD % = [100 × (0.9997 − 0.0125 × fecal starch, % DM)]; $R^2 = 0.94$. This equation was developed using fecal starch concentrations, and associated TTSD data were determined using digesta markers from a database containing 506 fecal samples (Bal et al., 1997; Bal et al., 2000a,b; Schwab et al., 2002; Lopes et al., 2009; Gencoglu et al.,

Table 2. Chemical composition and fermentation characteristics of whole-plant corn silage[1]

Item	SHRD	KPCS
Nutrient		
DM, % as fed	35.0 ± 1.9	34.7 ± 1.4
OM, % of DM	95.8 ± 0.5	96.1 ± 0.1
CP, % of DM	7.7 ± 0.2	7.8 ± 0.2
Ether extract, % of DM	3.9 ± 0.5	3.4 ± 0.2
NDF, % of DM	37.0 ± 1.7	37.4 ± 1.9
ADF, % of DM	21.8 ± 0.9	21.4 ± 1.1
Lignin, % of DM	2.9 ± 0.5	2.9 ± 0.2
30-h in vitro NDF digestibility, % of NDF	50.9 ± 4.0	50.8 ± 2.2
Starch, % of DM	34.4 ± 2.6	34.7 ± 1.7
7-h in vitro starch digestibility, % of starch	78.5 ± 4.0	75.4 ± 2.6
Sugars, % of DM	2.4 ± 1.1	2.0 ± 1.3
Fermentation profile		
pH	3.59 ± 0.05	3.61 ± 0.03
Lactate, % of DM	5.96 ± 0.86	5.08 ± 0.41
Acetate, % of DM	0.95 ± 0.14	1.01 ± 0.13
Propionate, % of DM	<0.01	<0.01
Butyrate, % of DM	<0.01	<0.01
Ethanol, % of DM	<0.01	0.59 ± 0.07
Ammonia, % of CP	4.74 ± 0.83	4.83 ± 0.82

[1]Treatments were the diet containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS).

2010). A rectal grab fecal sample was collected from each cow and then composited by pen during wk 5 and 8 of the treatment period, and samples were dried, ground, and analyzed for starch content as described previously.

Feed sorting was evaluated for 3 consecutive days during wk 3 and 7 of the treatment period. Individual daily pen samples (TMR and orts) were analyzed for particle size as described by Kononoff et al. (2003a). Dry matter of each fraction was measured after separation by drying at 60°C for 48 h in a forced-air oven. Sorting was calculated as the actual DMI of each fraction expressed as a percentage of the predicted DMI, as described by Leonardi and Armentano (2003); values <100% indicate selective refusals, those >100% indicate preferential consumption, and those equal to 100% indicate no sorting.

Three cows (1 from the SHRD group and 2 from the KPCS group) had truncated records in the latter weeks of the trial because of a shoulder or knee injury that would not allow then to continue on the trial.

Data were analyzed as a completely randomized design, with data from the preliminary period as a covariate using PROC MIXED (SAS Institute, 2004), with week of treatment as the repeated measure using the first-order autoregressive covariance structure, which provided the best fit according to Sawa's Bayesian information criterion. Pen was used as the experimental unit. The model included treatment, week, and the treatment × week interaction as fixed effects and pen within treatment as a random effect. Degrees of freedom were calculated using the Kenward-Roger option. Interaction effects were partitioned using the SLICE option (SAS Institute, 2004). Statistical significance and trends were declared at $P \leq 0.05$ and $P > 0.05$ to $P < 0.10$, respectively.

A subsequent in situ trial was conducted in the University of Wisconsin tie-stall barn (Dairy Cattle Center, Madison, WI) using 3 ruminally cannulated midlactation, multiparous Holstein cows fed a TMR containing (DM basis) alfalfa silage (44.5%), corn silage (26.8%), alfalfa hay (10.7%), wheat straw (6.5%), and concentrate mixture (11.5%). Individual samples from each treatment, composited across 2-wk periods of the lactation trial, were evaluated for starch (12- and 24-h) and NDF (24-h) in situ digestibilities. Dacron polyester cloth bags (9 × 18 cm) containing 5-g DM samples (approximately 15 g as fed) of the respective treatments were incubated in duplicate within each cow. Samples were not dried or ground before incubation to evaluate the effects of processing done during harvest most accurately (Johnson et al., 1999). The in situ bags for the respective treatments for each time point were placed in a nylon laundry bag (30 × 40 cm) and then positioned in the ventral rumen. Bags were moistened in warm water before incubation. Each laundry bag contained a blank bag to allow correction for any infiltration of DM into sample bags. Samples for the 12-h time point were incubated 12 h after the 24-h time point samples to allow all bags to be removed and washed at the same time. After removal, samples were soaked in cold water before washing twice in a commercial washing machine with cold water during 12-min cycles. Two bags for each treatment (0-h bags) were soaked for 30 min in warm water and washed with the rest of the sample bags. The bags were dried in a forced-air oven at 60°C for 48 h. Residues were ground through a 1-mm Udy mill screen (Udy Corp., Boulder, CO) for nutrient analysis. Bags from different weeks within cows were composited into 1 sample before nutrient analysis. Samples were sent to Dairyland Laboratories Inc. (Arcadia, WI) and analyzed for starch and NDF as described previously. Data were analyzed using PROC MIXED (SAS Institute, 2004). The model included treatment as a fixed effect and cow as a random effect. Statistical significance and trends were declared at $P \leq 0.05$ and $P > 0.05$ to $P < 0.10$, respectively.

RESULTS AND DISCUSSION

Diet nutrient composition, as measured by sample analysis, is presented

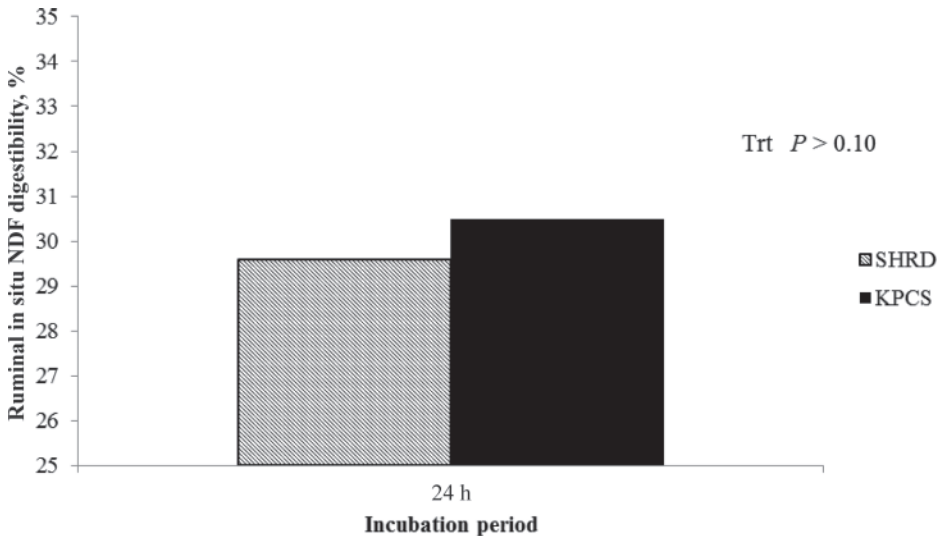

Figure 1. Effect of treatment on ruminal in situ NDF digestibility (%) least squares means. Treatments were Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS). Treatment effects ($P > 0.10$); SEM = 4.5. Trt = treatment.

in Table 1; nutrient composition was similar for the 2 diets. Data from laboratory analyses of SHRD and KPCS are presented in Table 2; both were of good quality (Kung and Shaver, 2000; NRC, 2001) and of similar nutrient composition and fermentation profile. Results for SHRD, KPCS, and the corresponding TMR physical characteristics and feed-sorting behavior by dairy cows are presented in Table 3. The CSPS (% of starch passing through a 4.75-mm screen) was greater for SHRD than KPCS (75.0 vs. 60.3% on average), which suggests greater kernel breakage for SHRD. Ferreira (2002) reported that CSPS was increased by 40 percentage units (90 vs. 50% on average) and TTSD in dairy cows was increased by 6 percentage units with kernel processing of WPCS. Fragility was similar for SHRD and KPCS, averaging 76.5%. Grant (2010) suggested that fragility is related to NDF digestibility; thus, the fragility results are in agreement with ruminal 30-h in vitro (Table 2) and 24-h in situ (Figure 1) NDF digestibility measurements, which were also similar for SHRD and KPCS. The proportion of coarse particles was greater for SHRD than KPCS for samples collected during feed-out from the silo bags throughout the feeding trial (averaged 31.5 vs. 5.6% of as-fed material retained on the 19-mm screen). A unique aspect to SHRD was greater kernel breakage at longer LOC compared with KPCS. Ferraretto and Shaver (2012) reported that conventional processing was less effective at greater LOC.

The proportion of coarse particles was greater for TMR prepared with SHRD than KPCS (averaged 15.6 vs. 3.5% of as-fed material retained on the 19-mm screen). Feeding diets containing a greater proportion of coarse particles is positively related to chewing and rumination activity, rumen buffering, fiber digestibility, and milk fat content (Mertens, 1997; Zebeli et al. 2012) but may also increase diet sorting (Leonardi and Armentano, 2003) by dairy cows. Feed sorting was minimal and did not differ ($P > 0.10$) between treatments. Kononoff et al. (2003b) reported that sorting behavior increased for dairy cows fed unprocessed WPCS harvested at 22.3-mm compared with 4.8-mm LOC. More modest differences in LOC between treatments and processing effects on cob particle size (Shinners, et al., 2000) may explain the lack of sorting observed in the present study.

Table 3. Particle size of whole-plant corn silage (WPCS) treatments and corresponding TMR[1]

Item	SHRD	KPCS	SEM	*P*-value
WPCS processing score[2]				
Starch passing a 4,750-μm sieve, %	75.0 ± 1.9	60.3 ± 1.9		
Fragility,[3] %	78.3 ± 1.9	74.7 ± 1.9		
WPCS particle size,[4] % of as fed retained				
19.0 mm	31.5 ± 5.7	5.6 ± 2.0		
8.0 mm	41.5 ± 3.9	75.6 ± 2.6		
1.18 mm	26.2 ± 2.0	18.4 ± 1.6		
TMR particle size,[4] % of as fed retained				
19.0 mm	15.6 ± 2.9	3.5 ± 1.4		
8.0 mm	38.2 ± 1.2	52.9 ± 1.8		
1.18 mm	38.9 ± 1.9	35.8 ± 2.6		
TMR sorting, % of predicted[5,6]				
19.0 mm	99.3	99.5	0.3	0.72
8.0 mm	99.7	99.8	0.2	0.66
1.18 mm	100.1	99.7	0.2	0.09
Pan	102.1	101.7	0.3	0.54

[1]Treatments were the diet containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS).

[2]Processing score was measured as described by Ferreira and Mertens (2005).

[3]Fragility was measured as described by Grant (2010).

[4]Particle size was measured using the Penn State Particle Size Separator (Nasco, Fort Atkinson, WI) as described by Kononoff et al. (2003a).

[5]TMR sorting % = 100 × (observed DMI particle size/predicted DMI particle size).

[6]Week and week × treatment interaction ($P > 0.10$).

Table 4. Effect of treatment on covariate-adjusted least squares means for DM and nutrient intakes[1,2,3,4]

Intake	SHRD	KPCS	SEM	*P*-value
DM, kg/d	25.4	24.7	0.2	0.08
DM, % of BW	3.55	3.56	0.03	0.74
OM, kg/d	23.4	22.7	0.2	0.06
NDF, kg/d	7.2	7.0	0.1	0.10
NDF, % of BW	1.01	1.00	0.01	0.47
Starch, kg/d	6.5	6.3	0.1	0.08
CP, kg/d	4.4	4.3	0.1	0.09

[1]Treatments were diet containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS).

[2]Week effect ($P < 0.001$) for all parameters, except NDF intake as a percentage of BW ($P < 0.01$).

[3]Week × treatment interaction effect ($P < 0.05$) for DMI as a percentage of BW.

[4]Covariate effect ($P < 0.001$) for all parameters.

Treatment effects on covariate-adjusted least squares means for DM and nutrient intakes are presented in Table 4. Cows fed SHRD tended ($P < 0.08$) to consume 0.7 kg/d more DM than cows fed KPCS. The DMI response to LOC of WPCS is equivocal in the literature. Increased DMI was reported for cows fed KPCS with a 28- or 40-mm LOC compared with an 11-mm LOC (Johnson et al., 2003b), whereas decreased DMI was reported for KPCS with a 32-mm compared with 19-mm LOC (Schwab et al., 2002; Onetti et al., 2003). The greater DMI for SHRD than KPCS could suggest improved NDF digestibility (Oba and Allen, 1999) for SHRD resulting from the modified rolling action; however, neither fragility (Table 3) nor ruminal in situ NDF digestibility (Figure 1) results support this premise. Further research is required to elucidate the mechanism by which SHRD may increase DMI. Similar to DMI, nutrient intakes (OM, NDF, starch, and CP) tended ($P < 0.08$) to be greater for cows fed SHRD than KPCS.

Table 5. Effect of treatment on covariate-adjusted least squares means for lactation performance[1,2,3,4]

Item	SHRD	KPCS	SEM	*P*-value
Yield				
Milk, kg/d	43.6	42.8	0.3	0.14
3.5% FCM, kg/d	45.5	44.5	0.4	0.07
SCM, kg/d	41.9	41.3	0.3	0.24
ECM, kg/d	45.1	44.2	0.4	0.10
Milk component				
Fat, %	3.74	3.70	0.06	0.66
Fat, kg/d	1.64	1.59	0.02	0.13
Protein, %	3.18	3.21	0.02	0.29
Protein, kg/d	1.40	1.38	0.01	0.34
Lactose, %	4.93	4.95	0.01	0.25
Lactose, kg/d	2.16	2.13	0.02	0.36
MUN, mg/dL	13.9	13.6	0.2	0.48

[1]Treatments were diet containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS).

[2]Week effect ($P < 0.001$) for all parameters, except milk fat content ($P > 0.10$) and yield ($P < 0.07$) and milk protein yield ($P > 0.10$).

[3]Week × treatment interaction effect ($P < 0.05$) for milk, 3.5% FCM, energy-corrected milk (ECM), milk fat yield, and milk urea nitrogen (MUN). SCM = solids-corrected milk.

[4]Covariate effect ($P < 0.001$) for all parameters.

Treatment effects on covariate-adjusted least squares means for lactation performance measurements are presented in Table 5. Milk yield averaged 43.2 kg/d per cow for SHRD and KPCS, and although no difference ($P > 0.10$) was observed overall between the treatments, milk yield was greater ($P < 0.05$) for SHRD during wk 3, 4, and 8 of treatment ($P < 0.01$, week × treatment interaction). Yields of 3.5% FCM and ECM tended ($P < 0.07$ and $P < 0.10$, respectively) to be 1.0 and 0.9 kg/d per cow, respectively, greater for SHRD than KPCS. A week × treatment interaction was detected ($P < 0.03$) for 3.5% FCM and ECM yields. For 3.5% FCM yield, during the treatment period no difference was observed between treatments at wk 2, 3.5% FCM yield tended ($P < 0.10$) to be greater for SHRD at wk 4 and 6, and 3.5% FCM yield was greater ($P < 0.01$) by 2.0 kg/d per cow for SHRD than KPCS at wk 8 (Figure 2). The ECM and 3.5% FCM responses over time were similar (ECM data not shown in a figure). Increased 3.5% FCM and ECM yields for SHRD could be related to greater nutrient intakes (Table 4), improved rumination activity and rumen function resulting from a greater proportion of coarse TMR particles (Mertens, 1997), or both, although rumination activity and ruminal parameters were not measured in the present study. Milk fat, protein, lactose, and urea nitrogen concentrations were unaffected ($P > 0.10$) by treatment and averaged 3.72%, 3.20%, 4.94%, and 13.8 mg/dL, respectively. Milk component concentrations were unaffected by the LOC of WPCS in

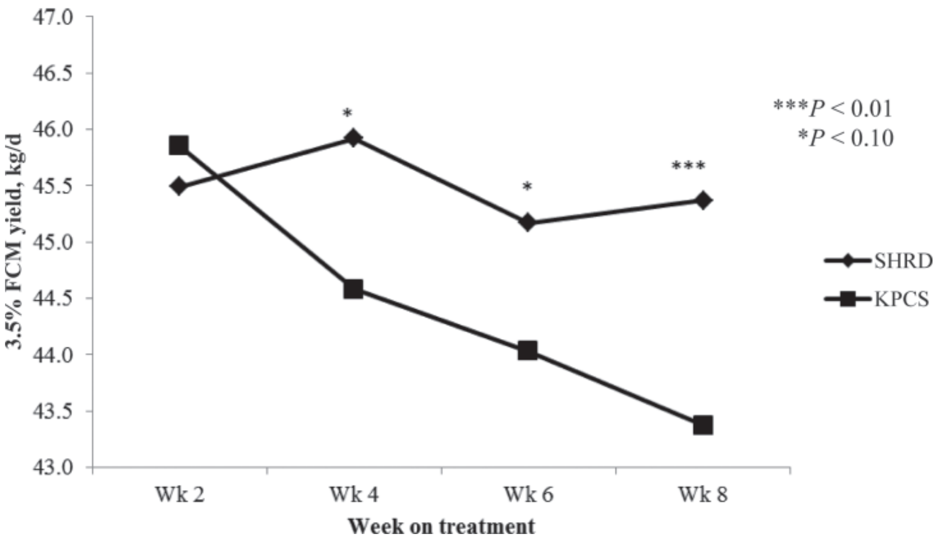

Figure 2. Effect of treatment on 3.5% FCM (kg/d) covariate-adjusted least squares means by week on treatment. Treatments were diet containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS).Week and week × treatment interaction effects ($P < 0.001$ and $P < 0.03$, respectively); SEM = 0.4.

a recent meta-analysis by Ferraretto and Shaver (2012). Yields of milk fat, protein, and lactose did not differ ($P > 0.10$) between the SHRD and KPCS treatments. Similar milk fat, protein, and lactose yields were reported when the LOC of KPCS increased from 19 to 32 mm (Schwab et al., 2002; Onetti et al., 2003).

Treatment effects on covariate-adjusted least squares means for BW, BCS, and feed conversions and unadjusted means for BWC and estimated diet energy concentrations are presented in Table 6. Body weight, BWC, and BCS were unaffected by treatment ($P > 0.10$). Feed conversion (kg of milk/kg of DMI) was similar ($P > 0.10$) among treatments, although a week × treatment interaction was detected ($P < 0.03$), with a trend ($P < 0.10$) for greater and greater ($P < 0.01$) feed conversions at wk 3 to 4 and wk 5, respectively. The 3.5% FCM, SCM, and ECM feed conversions were unaffected ($P > 0.10$) by treatment. Estimated diet energy content (Mcal NE_l/kg of DM), calculated using ECM, BW, BWC, and DMI data, did not differ ($P > 0.10$) by treatment.

Least squares means for TTSD at wk 5 and 8 of the treatment period are presented in Figure 3. Cows fed SHRD had 1.5 percentage units greater ($P < 0.001$) diet TTSD than did cows fed KPCS. This response may be explained by greater kernel breakage during passage through rollers and a corresponding increased surface area (Shinners et al., 2000; CSPS data in Table 3) allowing for enhanced bacterial attachment and digestion (Huntington, 1997). From a meta-analysis of published experiments, Ferraretto and Shaver (2012) observed that kernel processing of WPCS failed to improve starch digestibility when harvested at very long LOC. In the present trial, starch digestibility was increased when harvest was done at a greater LOC for SHRD than KPCS. Likewise, WPCS ruminal in situ starch digestibility tended to be ($P < 0.06$) 17 percentage units and was ($P < 0.02$) 7 percentage units greater for SHRD than KPCS at 12 and 24 h of incubation, respectively (Figure 4). The 7-h ruminal in vitro starch digestibility was similar between SHRD and KPCS (Table 2). The lack of difference for in starch digestibility for the in vitro procedure is likely related to sample grinding (Ferreira and Mertens, 2005) and suggests that the in vitro procedure may not be reliable when evaluating starch digestibility for samples differing in particle size at harvest.

Table 6. Effect of treatment on covariate-adjusted least squares means for BW, BCS, and feed conversion, and unadjusted means for BW change, locomotion score, and estimated diet energy concentrations[1,2,3,4]

Item	SHRD	KPCS	SEM	*P*-value
BW, kg	712.8	706.1	4.0	0.29
BW change, kg/d	0.28	0.31	0.11	0.84
BCS	3.03	3.04	0.02	0.90
Locomotion score	1.55	1.64	0.11	0.53
Feed conversion				
kg of milk/kg of DMI	1.73	1.72	0.01	0.74
kg of 3.5% FCM/kg of DMI	1.77	1.79	0.02	0.65
kg of SCM/kg of DMI	1.63	1.66	0.02	0.28
kg of ECM/kg of DMI	1.76	1.77	0.02	0.50
Estimated diet energy content,[5] Mcal/kg of DMI	1.78	1.80	0.03	0.59

[1]Treatments were diet containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS).

[2]Week effect for kilograms of milk/kilograms of DMI ($P < 0.001$), BW ($P < 0.04$), and BCS ($P < 0.001$).

[3]Week × treatment interaction effect ($P < 0.001$) for kilograms of milk/kilograms of DMI.

[4]Covariate effect ($P < 0.001$) for all parameters.

[5]Calculated by summing the megacalories of NE_l from milk production, required for maintenance, and in BW change (NRC, 2001) and then dividing the sum by DMI.

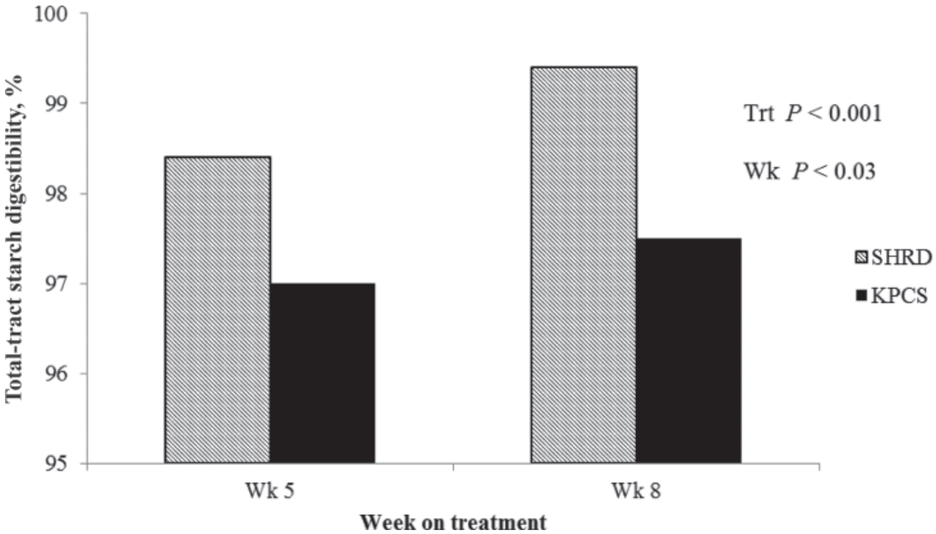

Figure 3. Effect of treatment on total tract starch digestibility (%) least squares means by week on treatment. Treatments were diet containing Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS). Week and week × treatment interaction effects ($P < 0.03$ and $P < 0.46$, respectively); SEM = 0.1. Trt = treatment; wk = week.

Ruminal in situ NDF digestibility did not differ ($P > 0.10$) among treatments, concurring with the 30-h ruminal in vitro NDF digestibility (Table 2) and fragility (Table 3) results. Johnson et al. (2003a) incubated undried, unground samples of WPCS harvested at 11-, 28-, and 40-mm LOC in dairy cows not receiving treatment WPCS in the diet. These authors reported greater 24-h in situ NDF digestibility for the short compared with the medium and long LOC WPCS. Likewise, Bal et al. (2000b) incubated undried, unground WPCS that was harvested at 9.5-mm compared with 1.95-mm LOC. Cows in this experiment were fed the incubated WPCS. Reduced 24-h in situ NDF digestibility was observed for the 9.5-mm compared with the 1.95-mm LOC WPCS. Although NDF digestibility was unaffected by treatment in the current study, further evaluation of NDF digestibility for SHRD is warranted.

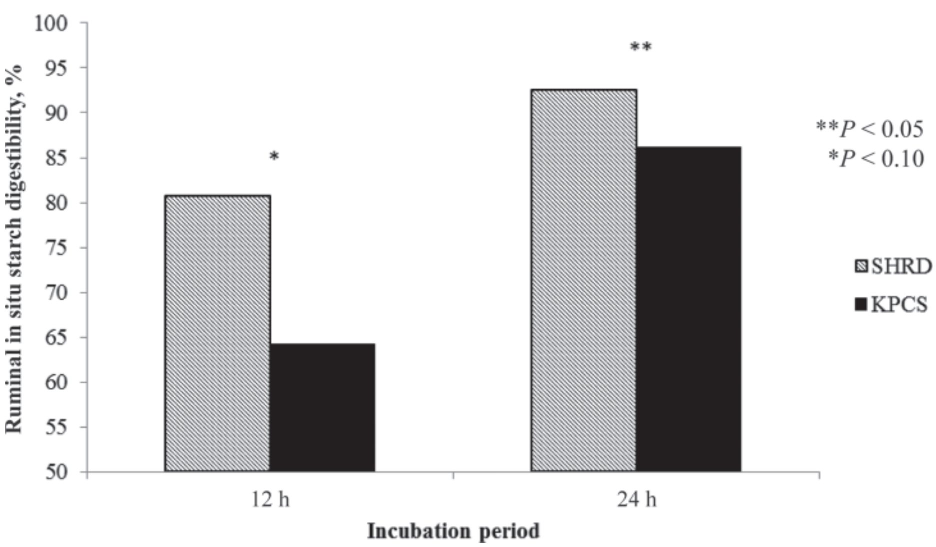

Figure 4. Effect of treatment on ruminal in situ starch digestibility (%) least squares means. Treatments were Corn Shredlage (SHRD; Shredlage LLC, Tea, SD) or conventionally processed corn silage (KPCS). Treatment effects for 12 and 24 h of incubation ($P < 0.06$ and $P < 0.02$, respectively); SEM = 4.3 and SEM = 1.1 for 12 and 24 h, respectively.

IMPLICATIONS

Under the conditions of this study, cows fed Corn Shredlage tended to consume more DM and produce more FCM and ECM than did cows fed KPCS. Furthermore, feeding Corn Shredlage increased total tract starch and may be a potential tool for dairy producers and their nutritionists desiring to feed higher corn silage diets without compromising kernel breakage and energy availability for WPCS chopped at a greater LOC. More research is needed to better evaluate fiber digestibility and peNDF of Corn Shredlage to allow for better decisions on how best to use it in dairy cattle diets relative to other ingredients.

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LITERATURE CITED

Allen, M. S. 1997. Relationship between fermentation acid production in the rumen and the requirement for physically effective fiber. J. Dairy Sci. 80:1447–1462.

AOAC. 2006. Official Methods of Analysis. 18th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Bach Knudsen, K. E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Feed Sci. Technol. 67:319–338.

Baker, S., and T. Herrman. 2002. Evaluating particle size. Publ. MF-2051. Kansas State Univ. Coop. Ext. Serv., Manhattan.

Bal, M. A., J. G. Coors, and R. D. Shaver. 1997. Impact of the maturity of corn for use as silage in the diets of dairy cows on intake, digestion, and milk production. J. Dairy Sci. 80:2497–2503.

Bal, M. A., R. D. Shaver, H. Al-Jobeile, J. G. Coors, and J. G. Lauer. 2000a. Corn silage hybrid effects on intake, digestion, and milk production by dairy cows. J. Dairy Sci. 83:2849–2858.

Bal, M. A., R. D. Shaver, A. G. Jirovec, K. J. Shinners, and J. G. Coors. 2000b. Crop processing and chop length of corn silage: Effects on intake, digestion, and milk production by dairy cows. J. Dairy Sci. 83:1264–1273.

Ferraretto, L. F., and R. D. Shaver. 2012. Meta-analysis: Impact of corn silage harvest practices on intake, digestion and milk production by dairy cows. Prof. Anim. Sci. 28:141–149.

Ferreira, G. 2002. Nutritive evaluation of corn silage: Factors affecting corn silage digestibility and their effects on performance by lactating dairy cows. MS Thesis. University of Wisconsin–Madison.

Ferreira, G., and D. R. Mertens. 2005. Chemical and physical characteristics of corn silages and their effects on in vitro disappearance. J. Dairy Sci. 88:4414–4425.

Gencoglu, H., R. D. Shaver, W. Steinberg, J. Ensink, L. F. Ferraretto, S. J. Bertics, J. C. Lopes, and M. S. Akins. 2010. Effect of feeding a reduced-starch diet with or without amylase addition on lactation performance in dairy cows. J. Dairy Sci. 93:723–732.

Grant, R. 2010. Forage fragility, fiber digestibility, and chewing response in dairy cattle. Pages 27–40 in Proc. Tri-State Dairy Nutr. Conf. Accessed May 7, 2012. http://tristatedairy.osu.edu/Proceedings%202010/Rick%20Grant%20paper.pdf.

Holden, L. A. 1999. Comparison of methods of in vitro dry matter digestibility for ten feeds. J. Dairy Sci. 82:1791–1794.

Huntington, G. B. 1997. Starch utilization by ruminants: From basics to the bunk. J. Anim. Sci. 75:852–867.

Johnson, L., J. H. Harrison, C. Hunt, K. Shinners, C. G. Doggett, and D. Sapienza. 1999. Nutritive value of corn silage as affected by maturity and mechanical processing: A contemporary review. J. Dairy Sci. 82:2813–2825.

Johnson, L. M., J. H. Harrison, D. Davidson, C. Hunt, W. C. Mahanna, and K. Shinners. 2003a. Corn silage management: Effects of hybrid, maturity, chop length, and mechanical processing on rate and extent of digestion. J. Dairy Sci. 86:3271–3299.

Johnson, L. M., J. H. Harrison, D. Davidson, W. C. Mahanna, and K. Shinners. 2003b. Corn silage management: Effects of hybrid, chop length, and mechanical processing on digestion and energy content. J. Dairy Sci. 86:208–231.

Kononoff, P. J., A. J. Heinrichs, and D. R. Buckmaster. 2003a. Modification of the Penn State forage and total mixed ration particle separator and the effects of moisture content on its measurements. J. Dairy Sci. 86:1858–1863.

Kononoff, P. J., A. J. Heinrichs, and H. A. Lehman. 2003b. The effect of corn silage particle size on eating behavior, chewing activities, and rumen fermentation in lactating dairy cows. J. Dairy Sci. 86:3343–3353.

Kung, L., and R. Shaver. 2000. Interpretation and use of silage fermentation analysis report. Accessed May 9, 2012. http://www.uwex.edu/ces/crops/uwforage/fermentation.pdf.

Leonardi, C., and L. E. Armentano. 2003. Effect of quantity, quality and length of alfalfa hay on selective consumption by dairy cows. J. Dairy Sci. 86:557–564.

Lopes, J. C., R. D. Shaver, P. C. Hoffman, M. S. Akins, S. J. Bertics, H. Gencoglu, and J. G. Coors. 2009. Type of corn endosperm influences nutrient digestibility in lactating dairy cows. J. Dairy Sci. 92:4541–4548.

Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. J. Anim. Sci. 64:1548–1558.

Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80:1463–1481.

Muck, R. E., and J. T. Dickerson. 1988. Storage temperature effects on proteolysis in alfalfa silage. Trans. ASABE 31:1005–1009.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington D.C.

Oba, M., and M. S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci. 82:589–596.

Onetti, S. G., R. D. Shaver, S. J. Bertics, and R. R. Grummer. 2003. Influence of corn silage particle length on the performance of lactating dairy cows fed supplemental tallow. J. Dairy Sci. 86:2949–2957.

Richards, C. J., J. F. Peterson, R. A. Britton, R. A. Stock, and C. R. Krehbiel. 1995. In vitro starch disappearance procedure modifications. Anim. Feed Sci. Technol. 55:35–45.

SAS Institute. 2004. SAS/STAT 9.1 User's Guide. Version 9.1 ed. SAS Inst. Inc., Cary, NC.

Schwab, E. C., R. D. Shaver, K. J. Shinners, J. G. Lauer, and J. G. Coors. 2002. Processing and chop length effects in brown-midrib corn silage on intake, digestion, and milk production by dairy cows. J. Dairy Sci. 85:613–623.

Shaver, R., and R. Kaiser. 2011. Top producing dairy herds in Wisconsin feed more forage than you may think. Accessed March 5, 2012. http://www.uwex.edu/ces/dairynutrition/documents/mfaforagefocusnov-2011shaver.pdf.

Shinners, K. J., A. G. Jirovec, R. D. Shaver, and M. A. Bal. 2000. Processing whole-plant corn silage with crop processing rolls on a pull-type forage harvester. Appl. Eng. Agric. 16:323–331.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Wildman, E. E., G. M. Jones, P. E. Wagner, R. L. Boman, H. F. Troutt, and T. N. Lesch. 1982. A dairy-cow body condition scoring system and its relationship to selected production characteristics. J. Dairy Sci. 65:495–501.

Zebeli, Q., J. R. Aschenbach, M. Tafaj, J. Boguhn, B. N. Ametaj, and W. Drochner. 2012. Invited review: Role of physically effective fiber and estimation of dietary fiber adequacy in high-producing dairy cattle. J. Dairy Sci. 95:1041–1056.