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Stage of maturity, processing, and hybrid effects on ruminal in situ disappearance of whole-plant corn silage

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Abstract

Five in situ trials with whole-plant corn silage (WPCS) were conducted in two ruminally-cannulated Holstein cows to determine 24-h ruminal disappearance of dry matter (DM), starch, and neutral detergent fiber (NDF). In Trial 1, the effect of maturity of WPCS on ruminal nutrient disappearance was evaluated. Treatments were early dent (ED), 1/4 milk-line (1/4 ML), 2/3 milk-line (2/3 ML), and black-layer (BL) stage of maturity. Ruminal disappearance of DM was lower ($p<0.01$) for BL (474 g/kg) than ED (547 g/kg), 1/4 ML (579 g/kg), or 2/3 ML (530 g/kg). Ruminal starch disappearance was lower ($p<0.01$) for BL (862 g/kg) than ED, 1/4 ML, or 2/3 ML which averaged 950 g/kg. In Trial 2, the effect of mechanical processing of mature and immature WPCS and stover silage at harvest was evaluated. Processing increased ($p<0.01$) ruminal starch disappearance for both immature (844 vs. 664 g/kg) and mature (790 vs. 525 g/kg) WPCS. In Trial 3, two WPCS hybrids (grain vs. leafy) at two plant populations (low=59,000 or high=79,000 plants/ha) were evaluated. Type of hybrid or plant population did not affect DM or NDF disappearance. However, starch disappearance was higher ($p<0.01$) for the leafy hybrid (872 vs. 731 g/kg). In Trial 4, brown-midrib (BMR) corn harvested as WPCS was evaluated for ruminal nutrient disappearance versus a conventional grain hybrid. Ruminal DM (602 vs. 561 g/kg) and NDF (326 vs. 220 g/kg) disappearance were higher ($p<0.01$) for BMR. In Trial 5, ruminal nutrient disappearance of high- and low-NDF corn silage hybrids were compared. Ruminal DM (662 vs. 620 g/kg) and starch (987 vs. 950 g/kg) disappearance were higher, but NDF disappearance was lower (176 vs. 225 g/kg) for the low-NDF hybrid ($p<0.001$). In summary, delaying silage harvest to BL reduced ruminal nutrient disappearance. Mechanical processing increased ruminal disappear-

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ance of WPCS, primarily through greater ruminal starch disappearance. Ruminal starch and NDF disappearance were higher for leafy and BMR hybrids, respectively, relative to a conventional grain hybrid. Ruminal DM disappearance was increased for a low-NDF hybrid, but effects were positive for starch and negative for NDF disappearance.

Keywords: Corn silage; Dairy cows; Digestion; Rumen; Fiber; Starch

1. Introduction

Whole-plant corn harvested as silage (WPCS) often comprises 1/4 to 3/4 of dietary forage for lactating dairy cows in the United States. Corn silage is normally a high-energy forage with high dry matter (DM) yield relative to other forage crops (Coors, 1996). Recently, agronomists, nutritionists, and dairy producers have placed increased emphasis on factors affecting the nutritive value of WPCS.

The nutritive value of WPCS is affected by grain content, neutral detergent fiber (NDF) content of stalk, cob and leaves, NDF digestibility, starch content of grain, starch digestibility, oil content, and protein content. Delaying harvest of WPCS to black layer (BL) stage of maturity resulted in higher starch content and lower NDF content as grain comprises a higher proportion of the silage, but total-tract organic matter (OM), starch, and NDF digestion and milk production were reduced (Bal et al., 1997). Mechanical processing WPCS has been shown to increase total-tract starch digestion (Bal et al., 1998b) and milk production in some but not all trials (Satter et al., 1999).

Leafy and brown midrib (BMR) corn hybrids are marketed commercially for production of WPCS. Leafy hybrids are characterized by a greater number of leaves above the ear and higher kernel and whole-plant moisture relative to conventional grain hybrids (Shaver, 1983). Bal et al. (1998a) reported higher starch digestibility but lower NDF digestibility in the total tract for leafy versus grain hybrids harvested as WPCS. Brown midrib WPCS contains less lignin and its in vitro NDF digestibility is greater than for WPCS harvested from a non-BMR isogenic counterpart (Oba and Allen, 1999). Feeding brown midrib WPCS has increased DMI and milk yield (Oba and Allen, 1999).

In vitro digestion techniques are often used in evaluations of the nutritive value of WPCS (Nocek, 1988). These techniques involve drying and fine grinding of WPCS for analysis. This may minimize quality differences between WPCS samples related to physical form, such as grain hardness and particle size. A macro in situ technique using undried, unground WPCS has been used to evaluate ruminal nutrient disappearance (Doggett et al., 1998). This procedure may provide better estimates of differences in ruminal starch disappearance as influenced by maturity and hybrid than standard in vitro procedures, but because of particle size reduction during eating and rumination it may tend to overestimate the magnitude of mechanical-processing effects on ruminal starch disappearance and likely underestimates ruminal NDF disappearance.

The objectives of this study were to evaluate effects of maturity, mechanical processing, and hybrid on ruminal in situ DM, starch, and NDF disappearance of WPCS using a macro dacron-bag procedure. Most of the WPCS samples tested were obtained from feeding experiments with lactating dairy cows conducted by our laboratory. These

include early through late maturity (Bal et al., 1997), leafy and BMR vs. conventional hybrid (Bal et al., 1998a, 1999, respectively), and high-NDF hybrid vs. low-NDF hybrid (Al-Jobeile et al., 2000) WPCS samples. Samples of immature and mature WPCS and stover silage harvested with or without rolling were not obtained from a companion in vivo experiment.

2. Materials and methods

In Trial 1, Pioneer hybrid 3563 was harvested as WPCS at early dent (ED), 1/4 milkline (1/4 ML), 2/3 milkline (2/3 ML), and BL stages of maturity using a *Gehl* 8-knife chopper (Model 860) set for a 0.93 cm theoretical length of cut (TLC). Silage treatments were stored in silo bags (Ag Bag®; 2.7 m diameter×30.5 m length). Individual samples from each treatment WPCS composited across four monthly periods of a lactation trial were tested. In Trial 2, three separate in situ runs were conducted to evaluate effects of mechanical processing on ruminal nutrient disappearance of mature or immature WPCS (509 vs. 368 g/kg DM, respectively) and stover silage (417 vs. 294 g/kg DM, respectively). Silage treatments were harvested with or without rolling using a John Deere (Model 6910) self-propelled harvester set for 0.93 cm TLC. Silage treatments were stored in triplicate in PVC laboratory silos (10 cm diameter×36 cm height) for 30 days, and then composited by treatment. Silage treatments and their comparisons within in situ runs are presented in Table 1. In Trial 3, grain hybrid (Pioneer 3563) and leafy hybrid (Mycogen TMF 106) were planted at both low (59,000 plants per hectare) and high (79,000 plants per hectare) plant populations and harvested as WPCS at 1/2 milkline (1/2 ML) stage of maturity using a *Gehl* 8-knife chopper (Model 860) set for 0.93 cm TLC. Silage treatments were stored in silo bags (Ag Bag®; 2.7 m diameter×30.5 m length). Individual samples from each treatment WPCS composited across four monthly periods of a lactation trial were tested. In Trial 4, conventional (Pioneer 3563) and BMR (Cargill 657) corn hybrids were harvested as WPCS at 1/2 ML stage of maturity using a *Gehl* 8 knife chopper (Model 860) set for 0.93 cm TLC. Silage treatments were stored in upright concrete-stave silos (4.3 m diameter×15 m height). Individual samples from each treatment WPCS composited across two monthly periods of a lactation trial were tested. In Trial 5, high (Garst 8751) and low (Cargill 3677) NDF corn silage hybrids were harvested as WPCS at 1/2 ML stage of maturity using a *Gehl* chopper (Model 860) set for

Table 1
Treatment comparisons of whole-plant corn silage (WPCS) and stover silage harvested at immature or mature stage and with or without processing tested within in situ runs

In situ run	Treatment comparisons
1	Immature stover silage with (ISP) and without (ISNP) processing vs. mature stover silage with (MSP) and without (MSNP) processing
2	Immature WPCS with (IWP) and without (IWNP) processing vs. mature WPCS with (MWP) and without (MWNP) processing
3	Mature WPCS with (MWP) and without (MWNP) processing vs. re-wetted mature WPCS with (RMWP) and without (RMWNP) processing

1.25 cm TLC with a 2 mm roller mill clearance. Silage treatments were stored in silo bags (Ag Bag®; 2.7 m diameter×30.5 m length). Individual samples from each treatment WPCS composited across four monthly periods of a lactation trial were tested. All in situ digestion trials were conducted with two ruminally-cannulated multiparous Holstein cows in mid-lactation.

Cows were fed a total mixed ration (TMR; 180 g/kg CP, 320 g/kg NDF) containing 85 g/kg alfalfa hay (170 g/kg CP, 460 g/kg NDF), 186 g/kg alfalfa silage (224 g/kg CP, 449 g/kg NDF), 307 g/kg corn silage (92 g/kg CP, 442 g/kg NDF), and 422 g/kg concentrate mix (229 g/kg CP, 126 g/kg NDF) comprised of ground shelled corn, soybean meal, and corn gluten feed (DM basis). In situ bags were made of dacron polyester cloth (25×35 cm, 52±5μ pore size; R102 Marvelaire White, N. Erlanger, Blumgardt and Co. Inc. Broadway, NY). Twenty-five grams DM (30 mg DM/cm^2) samples (≈65–85 g as fed) of respective WPCS or stover silage treatments were incubated in duplicate within each cow for 24 h. Only one incubation time was used to keep the number of macro bags that were incubated within a cow to a minimum. The 24-h incubation period was used because ruminal starch disappearance was the main parameter of interest in this study. In situ bags for the respective treatments were placed in a nylon laundry bag (30×40 cm) and positioned in the ventral rumen. No more than eight sample bags were placed into the laundry bag. Two blank bags were also incubated in each laundry bag to allow correction for any infiltration of DM into sample bags. After 24 h of incubation, each laundry bag was removed at the same time and soaked in cold water before washing twice in a commercial washing machine with cold water for 12 min per cycle (Cherney et al., 1990). Bags were dried for 48 h at 60°C in a forced-air oven. Residues were then ground through a 1-mm Wiley mill screen (Arthur H. Thomas, Philadelphia, PA) for nutrient analyses. Residues from duplicate bags within each cow were composited for NDF (Van Soest et al., 1991) and starch analysis. Starch determination on WPCS treatments and in situ residues was as follows: (1) duplicate 0.1 g dried samples were weighed into 35 ml Pyrex glass centrifuge tubes and 20 ml of distilled water was added to each tube for vortexing; (2) 100 μl of α-amylase (Sigma No. A3306; Sigma, St. Louis, MO) was added to each tube and held for 1 h in a 93°C water bath with tubes being mixed every 15 min during this incubation; (3) tubes were cooled for 15 min, vortexed three times within the first 10 min, and then particles were allowed to settle to the bottom of the tubes; (4) 1 ml of supernatant was transferred to a new 35 ml Pyrex glass centrifuge tube and then 8 ml of 0.1 m sodium acetate buffer (pH 4.75) and 50 μl of amyloglucosidase (Sigma No. A3514; Sigma Chemical Co., St. Louis, MO) were added to each tube; (5) tubes were incubated in a 60°C water bath for 30 min, swirled every 10 min, and then 16 ml of distilled water was added to each tube to bring volume to 25 ml; and (6) glucose oxidase assay (Sigma No. 510-A; Sigma Chemical Co., St. Louis, MO) was done using 0.5 ml of sample from each sample tube. A pure corn starch sample (Sigma No. S-4126; Sigma Chemical Co., St. Louis, MO) was tested for every run to check recovery. Average pure starch recovery within runs was 981±11 g/kg. Dry matter, starch, and NDF disappearance at 24 h was determined. Data were analyzed using General Linear Models of SAS with cow by treatment as the error term (SAS, 1998). In Trial 2, orthogonal contrasts were used to evaluate the maturity effect and processing effects within immature and mature WPCS and stover silage and the re-wetting effect and processing effects within mature and

re-wetted mature WPCS. Trial 3 was analyzed as a 2×2 factorial with hybrid and plant population as main effects. Treatment comparisons were by least significant difference method (SAS, 1998) in Trials 1, 4, and 5.

3. Results and discussion

3.1. Trial 1

Whole-plant corn silage treatments harvested at ED, 1/4 ML, 2/3 ML, and BL stages of maturity were evaluated in this trial. Chemical composition and ruminal disappearance of WPCS treatments are presented in Table 2. Dry matter content (toluene distillation; Dewar and McDonald, 1961) increased from 301 to 420 g/kg as stage of maturity advanced from ED to BL. Both NDF and acid detergent fiber (ADF) concentrations declined as maturity progressed from ED to 2/3 ML. Starch content of WPCS increased as maturity advanced from ED to 2/3 ML. Ruminal DM disappearance was lower ($p<0.01$) for BL compared to ED, 1/4 ML, and 2/3 ML treatments. Bal et al. (1997) reported reduced apparent total-tract DM digestion for this BL treatment versus the ED, 1/4 ML, and 2/3 ML treatments in mixed diets fed to lactating dairy cows. Ruminal disappearance of NDF was higher for ED and 1/4 ML treatments than 2/3 ML and BL treatments ($p<0.01$). Bal et al. (1997) observed reduced total-tract NDF digestion with advancing maturity for these treatments in mixed diets fed to lactating dairy cows. Russell (1986) reported that in vitro DM digestibility of corn stover declined with advancing maturity. Overall, our ruminal NDF disappearance values were low relative to in vitro and in vivo measurements of NDF digestibility. This suggests that the 24-h incubation period was too short for measurement of NDF disappearance. Also, because of particle size reduction during eating and rumination this procedure may underestimate ruminal NDF disappearance. Ruminal starch disappearance was lower for BL than ED, 1/4 ML, and 2/3 ML treatments. Bal et al. (1997) reported reduced total-tract starch

Table 2
Chemical composition and 24-h ruminal disappearance of whole-plant corn silage (WPCS) at four stages of maturity[a]

Item	Treatment				SEM[b]
	ED	1/4 ML	2/3 ML	BL	
DM (g/kg)	301	324	351	420	–
NDF (g/kg) DM	520	444	405	413	–
ADF (g/kg) DM	320	271	239	242	–
Starch (g/kg) DM	182	287	372	374	–
Ruminal disappearance (g/kg)					
DM	547 a	579 a	530 a	474 b	14
NDF	249 a	209 a	152 b	138 b	18
Starch	938 a	952 a	956 a	862 b	5

[a] Means in same row with different letters differ ($p<0.01$).
[b] SEM: standard error of mean.

Table 3
Chemical composition of whole-plant and stover silage treatments

Treatment[a]	DM (g/kg)	NDF (g/kg) DM	Starch (g/kg) DM
ISP	313	566	ND[b]
ISNP	274	568	ND
MSP	408	661	ND
MSNP	425	633	ND
IWP	376	418	240
IWNP	360	416	256
MWP	485	431	260
MWNP	532	395	244
RMWP	436	431	258
RMWNP	463	380	226

[a] Refer to Table 1 for description of treatment abbreviations.
[b] Not determined.

digestion for this BL treatment versus the ED, 1/4 ML, and 2/3 ML treatments in mixed diets fed to lactating dairy cows. This could be related to harder texture kernels for the BL treatment (Philippeau and Michalet-Doreau, 1997). A quantitative comparison of our in situ and in vivo measurements is difficult, because the in vivo experiment (Bal et al., 1997) was with mixed diets (forage and concentrate) and post-ruminal digestion may affect differences between treatments.

3.2. Trial 2

Immature and mature WPCS and stover silage harvested with or without rolling were evaluated in this trial. Chemical composition of WPCS and stover silage treatments are presented in Table 3. Average DM contents of WPCS and stover silage were 141 and 123 g/kg higher, respectively, for mature compared to immature treatments. Differences in DM content between unprocessed and processed treatments were small and inconsistent. Re-wetting mature WPCS prior to ensiling lowered DM content by 59 g/kg, on average, resulting in final DM concentrations that fell between immature and mature WPCS treatments. Ideally the DM content of the re-wetted and immature WPCS treatments would have been similar, but this was not achieved. Concentration of NDF was higher for stover silage than WPCS and for mature stover silage than immature stover silage. Differences in NDF content between unprocessed and processed treatments were small and inconsistent. Starch content was similar for WPCS treatments averaging 247 g/kg.

Ruminal DM and NDF disappearance of stover silage treatments are presented in Table 4. Disappearance of DM was greater ($p<0.001$) for immature (468 g/kg) compared to mature (381 g/kg) stover silage. Johnson et al. (1985) reported a higher concentration of digestible nutrients for immature compared to mature stover silage. Processing increased ($p<0.001$) DM disappearance of immature stover silage but decreased ($p<0.01$) DM disappearance of mature stover silage. We have no explanation for this observation. Disappearance of NDF was similar for immature (193 g/kg) and mature (188 g/kg) stover

Table 4
Ruminal in situ DM and NDF disappearance of stover silage treatments harvested at immature or mature stage with or without processing

Treatment[a]	DM disappearance (g/kg)	NDF disappearance (g/kg)
ISP	490±7	212±10
ISNP	446	173
MSP	366	174
MSNP	396	201
Contrast (*p*-value)		
ISP vs. ISNP	0.001	0.01
MSP vs. MSNP	0.01	0.02
ISP, ISNP vs. MSP, MSNP	0.001	NS

[a] Refer to Table 1 for description of treatment abbreviations.

silage. Processing effects on stover silage NDF disappearance followed a pattern similar to that observed for DM disappearance. As previously discussed, our ruminal NDF disappearance values were low.

Ruminal DM, NDF, and starch disappearance of WPCS treatments are presented in Table 5. Higher ($p<0.02$) DM disappearance was observed for immature compared to mature WPCS. Processing increased ($p<0.01$) DM disappearance of WPCS about 100 g/kg for both immature and mature WPCS. Ruminal NDF disappearance was higher ($p<0.05$) for immature (314 g/kg on average) than mature (233 g/kg on average) WPCS, but was unaffected by processing. As previously discussed, our ruminal NDF disappearance values were low. Doggett et al. (1998) saw no effect of processing on 48-h macro in situ NDF disappearance of WPCS. Ruminal starch disappearance was about 100 g/kg higher, on average, for immature compared to mature WPCS. This can be explained by increased kernel hardness with advanced maturity (Philippeau and Michalet-Doreau, 1997). Processing increased ruminal starch disappearance 265 and 180 g/kg in mature ($p<0.01$) and immature ($p<0.001$) WPCS, respectively. Because of particle size reduction during eating and rumination, the magnitude of the effect of

Table 5
Ruminal in situ DM, NDF, and starch disappearance of whole-plant corn silage harvested at immature or mature stage with or without processing

Treatment[a]	DM disappearance (g/kg)	NDF disappearance (g/kg)	Starch disappearance (g/kg)
IWP	671±9	326±17	844±14
IWNP	581	302	664
MWP	622	251	790
MWNP	524	215	525
Contrast (*p*-value)			
IWP vs. IWNP	0.01	NS	0.001
MWP vs. MWNP	0.01	NS	0.01
IWP, IWNP vs. MWP, MWNP	0.02	0.05	0.01

[a] Refer to Table 1 for description of treatment abbreviations.

Table 6
Ruminal in situ DM, NDF, and starch disappearance of whole-plant corn silage harvested at mature stage or re-wetted with or without processing

Treatment[a]	DM disappearance (g/kg)	NDF disappearance (g/kg)	Starch disappearance (g/kg)
MWP	592±17	223±22	774±15
MWNP	474	243	476
RMWP	579	186	728
RMWNP	463	166	454
Contrast (p-value)			
MWP vs. MWNP	NS	NS	0.02
RMWP vs. RMWNP	0.06	NS	0.01
MWP, MWNP vs. RMWP, RMWNP	NS	NS	NS

[a] Refer to Table 1 for description of treatment abbreviations.

mechanical processing on ruminal starch disappearance may be overestimated with the macro in situ procedure. Also, post-ruminal starch digestion may minimize differences between treatments in total-tract starch digestibility compared to treatment differences for ruminal starch disappearance. These specific WPCS samples were not evaluated in an in vivo experiment, but increased total-tract starch digestion for immature compared to mature WPCS and due to processing have been reported by Bal et al. (1997) and Bal et al. (1998b), respectively, in mixed diets fed to lactating dairy cows.

The effect of re-wetting mature WPCS on ruminal DM, NDF, and starch disappearance is presented in Table 6. Although re-wetting reduced the average DM content of mature WPCS about 60 g/kg, there was no effect of re-wetting on ruminal nutrient disappearance. Whether further re-wetting to the DM content of the immature WPCS treatments would have elicited an effect can not be determined. Processing effects on ruminal starch disappearance were observed in both normal ($p<0.02$) and re-wetted ($p<0.01$) mature WPCS. This suggests that the negative affect of advancing WPCS maturity on ruminal starch disappearance was not simply a function of whole-plant DM content and was likely related to increased kernel hardness.

3.3. Trial 3

Whole-plant corn silage treatments produced from leafy and grain hybrids each at two plant populations were evaluated in this trial. Data on the chemical composition of WPCS treatments and ruminal nutrient disappearance appear in Table 7. The leafy WPCS contained 35 g/kg less DM, on average, than the grain WPCS. Concentrations of NDF and ADF were unaffected by type of corn hybrid or plant population. Starch content tended to be lower for the leafy WPCS at the high plant population (262 vs. 285–296 g/kg). Ruminal DM and NDF disappearance were not different among hybrids or plant populations averaging 578 and 298 g/kg, respectively. As previously discussed, our ruminal NDF disappearance values were low. Ruminal starch disappearance was greater ($p<0.01$) for leafy compared to grain WPCS (872 vs. 731 g/kg) and for high compared to low plant populations (821 vs. 781 g/kg). Bal et al. (1998a) reported increased total-tract

Table 7
Chemical composition and ruminal in situ disappearance of whole-plant corn silage differing by hybrid type (leafy vs. grain) and plant population (low=59,000 and high=79,000 plant/ha)

Item	Treatment[a]				SEM[b]
	GCL	GCH	LCL	LCH	
DM (g/kg)	354	364	329	319	–
NDF (g/kg) DM	446	457	455	465	–
ADF (g/kg) DM	268	280	279	277	–
Starch (g/kg) DM	285	286	296	262	–
Ruminal disappearance (g/kg)					
DM	577	569	577	588	16
NDF	333	299	274	283	26
Starch[c]	707	756	856	887	9

[a] GCL: grain corn hybrid at low plant population; GCH: grain corn hybrid at high plant population; LCL: leafy corn hybrid at low plant population; LCH: leafy corn hybrid at high plant population.
[b] SEM: standard error of mean.
[c] Hybrid and plant population effects ($p<0.01$).

starch digestibility for this leafy WPCS treatment compared to the grain WPCS treatment in mixed diets fed to lactating dairy cows. Increased starch disappearance for leafy WPCS may be related to reduced kernel hardness compared to the grain WPCS (Dwyer et al., 1995).

3.4. Trial 4

Whole-plant corn silage treatments produced from conventional and BMR hybrids were compared in this trial. Data on chemical composition of WPCS treatments and ruminal nutrient disappearance appear in Table 8. The brown midrib WPCS contained 21 g/kg less DM than the conventional WPCS. Lower whole-plant DM content for BMR

Table 8
Chemical composition and ruminal in situ disappearance of brown midrib (BMR) and conventional corn hybrids harvested at 1/2 ML stage of maturity as WPCS[a]

Item	Conventional dent corn hybrid	BMR corn hybrid	SEM[b]
DM (g/kg)	343	322	–
NDF (g/kg) DM	416	381	–
ADF (g/kg) DM	240	230	–
Starch (g/kg) DM	266	243	–
Ruminal disappearance (g/kg)			
DM	561 b	602 a	11
NDF	220 b	326 a	19
Starch	816 a	783 b	6

[a] Means in same row with different letters differ ($p<0.01$).
[b] SEM: standard error of mean.

vs. conventional WPCS was reported by Weller et al. (1985). Both NDF and ADF concentrations tended to be reduced for BMR compared to conventional WPCS. This trend has also been reported by others (Cherney et al., 1991; Cone and Engels, 1993). Starch content was 23 g/kg lower for BMR compared to conventional WPCS. This can be explained by reduced proportion of ear in the whole-plant for BMR compared to conventional WPCS (Weller et al., 1985). Weller et al. (1985) reported a 50 g/kg reduction in ear proportion for BMR.

Ruminal DM disappearance was 41 g/kg higher ($p<0.01$) for BMR compared to conventional WPCS. Allen et al. (1997) reported increased in vitro DM digestibility for BMR compared to isogenic normal WPCS (780 vs. 738 g/kg). Ruminal disappearance of NDF was 106 g/kg higher ($p<0.01$) for BMR compared to conventional WPCS. As previously discussed, our ruminal NDF disappearance values were low. Keith et al. (1979) reported 105 g/kg higher in vitro NDF digestibility for BMR compared to its isogenic normal counterpart WPCS. Oba and Allen (1999) reported 97 g/kg higher in vitro NDF digestibility for BMR compared to its isogenic normal counterpart WPCS. Ruminal starch disappearance was 33 g/kg lower ($p<0.01$) for BMR.

3.5. Trial 5

Whole-plant corn silage treatments produced from high- and low-NDF hybrids were compared in this trial. Data on chemical composition of WPCS treatments and ruminal nutrient disappearance appear in Table 9. The high- and low- NDF treatments differed in NDF and ADF contents by 64 and 38 g/kg, respectively. Starch concentration was 98 g/kg higher for the low-NDF treatment, suggesting a higher proportion of grain in the whole plant for this treatment.

Ruminal DM and starch disappearance were about 40 g/kg higher for the low-NDF treatment. However, 24-h ruminal NDF disappearance was about 60 g/kg lower for the low-NDF treatment. As previously discussed, our ruminal NDF disappearance values were low. The same pattern of ruminal nutrient disappearance noted for these WPCS

Table 9
Chemical composition and ruminal in situ degradation of high- and low-fiber whole-plant corn silage (WPCS) hybrids[a]

Item	High-NDF WPCS hybrid	Low-NDF WPCS hybrid	SEM[b]
DM (g/kg)	367	342	–
NDF (g/kg) DM	392	328	–
ADF (g/kg) DM	227	189	–
Starch (g/kg) DM	240	338	–
Ruminal degradation (g/kg)			
DM	620 b	657 a	5
NDF	225 a	160 b	9
Starch	950 b	991 a	6

[a] Means in same row with different letters differ ($p<0.001$).
[b] SEM: standard error of mean.

treatments, was also observed in the total-tract as reported by Al-Jobeile et al. (2000) from a feeding trial with mixed diets fed to lactating dairy cows.

4. Conclusion

Harvesting WPCS at BL stage of maturity reduced ruminal disappearance of DM and starch. Processing increased ruminal starch disappearance in both immature and mature WPCS. Ruminal starch disappearance was increased for the leafy WPCS. Ruminal NDF disappearance was increased for the brown midrib WPCS. Ruminal DM and starch disappearance were increased and NDF disappearance was decreased for the low-NDF hybrid. These findings were consistent with patterns in total-tract digestibility data for these treatments reported elsewhere in the literature. It appears that the macro dacron-bag procedure is a useful tool for evaluating differences in ruminal DM and starch disappearance of WPCS. But, the magnitude of the effect of mechanical processing on ruminal starch disappearance may be overestimated because of particle size reduction during eating and rumination. Low NDF disappearance, probably because of the short incubation period and particle size reduction during eating and rumination, precludes the use of this method for determining ruminal NDF disappearance. Variation in ruminal disappearance parameter estimates between trials suggests that this method should only be used to evaluate treatment differences in ruminal disappearance of WPCS within an experiment.

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