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IN SITU RUMINAL DEGRADATION KINETICS OF CORN SILAGE HYBRIDS HARVESTED PRIOR TO OR AT MATURITY IN DRY AND LACTATING DAIRY COWS

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ABSTRACT

The objective of this study was to assess *in situ* dry matter (DM) and neutral detergent fiber (NDF) degradation kinetics for two new pre-matured brown midrib varieties (pmBMR1 and pmBMR2) that can be double-cropped by harvesting at tassel, compared with a sole crop mature BMR (mBMR) and conventional corn silage (CCS) harvested at maturity in dry and lactating dairy cows. Potentially degradable DM fraction for the BMR hybrids were greater ($P<0.01$) than the CCS in both dry and lactating cows and was greatest for the mBMR in dry cows, while in lactating cows potentially degradable DM was greatest for the pmBMR1. Potentially degradable NDF fraction was greater ($P<0.01$) for BMR hybrids compared with CCS with the exception of the pmBMR2, which had the lowest potentially degradable NDF fraction in dry cows. Estimates of ruminal degradability of NDF were greater ($P<0.01$) for the pmBMR varieties compared to mature silages, and were greatest ($P<0.01$) for the pmBMR1 in both dry and lactating cows. Taken as a whole, this experiment indicates that rumen degradability may have been influenced more by hybrid than stage of maturity, as the pmBMR1 had the greatest degradability, and the pmBMR2 was not as degradable as the mBMR.

Keywords: brown midrib corn silage, conventional corn silage, dry matter disappearance kinetics, dairy cows.

INTRODUCTION

The expansion of livestock enterprises on many farms in USA is often limited by the amount of land available for producing high yielding feed crops for cattle. Double-cropping (DCP) land is one mean of increasing forage production per hectare. In such a system, two crops are harvested on the same land in a single year. An example of a DCP system might be to harvest a fall-seeded small grain by early summer, and then plant corn for harvest in the fall. The DCP system increases the amount of time land is used for crop production and can increase potential profit. Although a warm-season DCP may yield smaller returns than a full-season crop, the value of the combined crops makes this a practice more economically competitive in some areas (Brown, 2006). There are also ecological advantages to increasing the amount of time the land is in production. For example, a winter grain crop can act as a cover crop, with the potential to sequester soil N and prevent erosion (Snapp *et al.* 2005). Heggenstaller *et al.* (2008) reported that the use of well-adapted DCP systems can lower nitrate-N leaching in the spring and fall relative to present annual cropping systems. In addition, incorporating alternative crops in a DCP system can break pest cycles, thereby reducing the incidence of disease and insect outbreaks (Buntin *et al.* 2002).

Chemical and genetic approaches have been employed to improve forage fiber digestibility by decreasing the extent of lignin content or lignin cross-linking with cell wall carbohydrates. Brown midrib (BMR) forage genotypes usually contain less lignin and may have altered lignin chemical composition (Bucholtz *et al.* 1980; Cherney *et al.* 1991; Vogel and Jung, 2001). Corn breeding efforts have resulted in commercially available BMR hybrids mostly being targeted for silage. The characteristic reddish-brown to tan colored midribs of mutant leaf blades contrasts with the pale green midrib of wild-type leaf blades. Mutant plants also accumulate reddish-brown to yellow pigment in stalks and roots. This phenotype has been associated with decreased lignin content and altered lignin composition compared to wild-type. The BMR corn is generally viewed as being lower yielding than non-BMR corn, but feeding BMR silage has resulted in increased milk production of dairy cows due to its lower lignin content and associated increase in rumen degradability (Gencoglu *et al.* 2008; Sattler *et al.* 2010). Similarly, *in situ* and *in vitro* digestion studies have shown that BMR forages have a greater extent of NDF degradation than their conventional counterparts (Grant *et al.* 1995). Relatively new BMR corn hybrids have been introduced as highly rumen degradable corn forage crops that can be double-cropped in areas with shorter growing seasons by harvesting at tassel. Therefore, the objective of this study was to assess *in situ* dry matter (DM) and NDF degradation kinetics for these new pre-matured BMR (pmBMR) forages compared to a sole crop BMR (mBMR) and conventional corn silage (CCS) harvested at maturity. It was hypothesized that *in situ* DM and NDF degradation would be enhanced in the pmBMR compared to the mBMR and the CCS due mainly to stage of maturity.

MATERIALS AND METHODS

Corn production, forage samples and laboratory analysis: Three BMR hybrids and one CCS hybrid were grown and harvested on private property near Burley, ID, USA. Sole-crop corn hybrids of CCS (Dekalb DKC61-72; Monsanto Co., St. Louis, MO, USA) and mBMR (Mycogen F2F387; Mycogen Seeds, Indianapolis, IN, USA) were planted on a site that previously produced corn grown for silage. Sole-crop hybrids were seeded on May 2, 2011 with a planter (DB90, John Deere, Moline, IL, USA) that delivered approximately 99,010 seeds/ha in 56 cm rows. Approximately 396 ha of each hybrid were harvested at 30% DM on September 15, 2011 using a self-propelled forage harvester (model 7750, John Deere).

Double-crop pmBMR varieties were the MasterGraze^{TM} MC-BMR (pmBMR1; Masters Choice Inc., Anna, IL, USA) and the synthetic BMR84^{TM} (pmBMR2; Ray Brothers Seed Farms, Ironside, OR, USA) planted using the same planter described previously, but delivered approximately 173,267 seeds/ha in 56 cm rows. Double-crop varieties were planted on June 20, 2011 following the harvest of triticale planted in the fall of 2010. Triticale was selected as a winter cover crop due to its high yield potential in Idaho, USA (Brown, 2006). Because we sought to manage for total forage DM production rather than grain yield in the DCP system, corn to be harvested at tassel was planted at elevated densities relative to sole-crop corn. Approximately 198 ha of each DCP variety were harvested 75 d after planting on September 5, 2011. Corn plants were cut at tassel with a self-propelled windrower (model WR9770, Hesston, Duluth, GA, USA), allowed to wilt for approximately 28 h and chopped using the same forage harvester used for the CCS and the mBMR. All forages were blown directly from the harvester into a truck with a box-style wagon which had been previously calibrated for weight. Forages to be evaluated included CCS (control), mBMR, pmBMR1 and pmBMR2.

Corn plants were ensiled separately in bag silos (Ag/Bag International Ltd., Warrenton, OR, USA) for 90 d before representative samples were taken. Then, composite samples were prepared to determine *in situ* degradation kinetics. Forage samples were dried at 55°C, ground to pass through a 1.0-mm screen (standard model 4; Arthur H. Thomas Co., Swedesboro, NJ, USA) and stored for nutritive value determination. Analytical DM and organic matter contents of forage samples were determined by oven drying at 105°C for 3 h and by ashing at 550°C for 5 h, respectively, while N content was determined using an elemental analyzer (LECO TruSpec N, St. Joseph, MI, USA) according to AOAC (2000). Neutral detergent fiber and ADF contents, both inclusive of residual ash, were determined according to Van Soest *et al.* (1991), as modified for use with an ANKOM^{220} fiber analyzer (ANKOM Technology, Macedon, NY, USA). Sodium sulfite was used in the procedure for NDF determination and pre-treatment with heat stable α-amylase (Type XI-A from *Bacillus subtilis*; Sigma-Aldrich Corporation, St. Louis, MO, USA).

***In situ* incubation procedures:** Two nonlactating dry and two lactating Holstein dairy cows (multiparous) surgically fitted with ruminal cannula were used to incubate samples for *in situ* measurements of ruminal degradation kinetics of DM and NDF. The study was conducted at the Caine Dairy Research Center (Wellsville, UT, USA), Utah State University. Use of the animals was approved by the Utah State University Institutional Animal Care and Use Committee.

Cows were housed in group pens and had *ad libitum* access to both feed and water. Dry cows were fed a diet containing 511 g/kg alfalfa hay, 234 g/kg wheat straw, 215 g/kg oat hay, 26 g/kg CCS, 10 g/kg wheat midds, and 4.0 g/kg vitamin and trace mineral supplement, whereas the diet for lactating cows contained 476 g/kg alfalfa hay, 153 g/kg high moisture corn grain, 152 g/kg CCS, 74 g/kg corn dried distillers grains with solubles, 54 g/kg beet pulp, 32 g/kg whole cotton seed, 25 g/kg soybean meal, 9.0 g/kg fat supplement (EnerGII®, Virtus Nutrition, LLC, Corcoran, CA, USA), and 25 g/kg vitamin and trace mineral supplement (DM basis).

Dacron bags (10 × 20-cm; ANKOM Technology) with an average pore size of 50 µm were filled with 4.0 g (DM) of freeze-dried silage (FreeZone 12 L Freeze Dry Systems, Labconco Corp., Kansas City, MO, USA) ground through a 4.0-mm screen (standard model 4) to yield an approximate sample DM/surface area of 10 mg DM/cm^2. Within each cow, each forage tested was incubated in triplicated bags at each incubation time. This provided 3 bags/cow and 6 total bags/silage for each time point. Bags were heat-sealed and placed in mesh bags (43 × 39 cm; 12 *in situ* bags in a mesh bag) with 3 × 5-mm pores that permitted ruminal fluid to percolate freely. Three mesh bags in each cow were incubated in the ventral rumen. Samples were incubated for 0, 4, 8, 16, 24, 48 and 96 h. Upon removal, bags were rinsed in cold water to remove ruminal contents on the exterior and frozen until all bags had been collected. Bags were machine washed for 5 rinse cycles consisting of a 1-min agitation and a 2-min spin. Additional bags were also prepared and machine rinsed without ruminal incubation, thereby creating a 0-h incubation time. After rinsing, residues were dried at 55°C in a forced-air oven for 48 h and weighed to determine residual DM. Dried residues were ground to pass a 1-mm screen and analyzed for NDF degradation kinetics.

Statistical analysis: *In situ* ruminal DM and NDF degradation data were fitted to the first order exponential model with discrete lag (Mertens, 1977) using the iterative Marquardt method and the nonlinear regression procedure of SAS (SAS Institute, 2011). Because dry and lactating cows used for *in situ* degradation measurement were fed different diets, there was no statistical comparison of cow types. Therefore, all data were analyzed separately by stage of lactation on test cows (dry *vs.* lactating cows). For each cow and type of feed, the following model was fitted to the percentage of DM and NDF degradation:

$R_{(t)} = B \times (e^{-Kd\,(t-L)}) + C,$

where $R_{(t)}$ = indigested total residue at any time t, B = insoluble potentially digestible fraction, K_d = fractional rate of digestion of B, t = time of incubation in the rumen in h, L = discrete lag time in h, C = fraction not digested after 96 h of incubation. Effective ruminal degradability (extent of rumen degradation, ERD) was calculated using the model of Ørskov and McDonald (1979):

$ERD = A + \{B \times [K_d / (K_d + K_p)]\}$

where K_p = assumed ruminal passage rate of 4.0 %/h for dry cows and 6.0 %/h for lactating cows. The wash fraction A was the percentage of substrate washed out of the bag at 0 h.

Data was analyzed in a completely randomized design with the MIXED procedure of SAS (SAS Institute, Cary, NC, USA), and the model included the effect of corn silage hybrids. In addition, pre-planned orthogonal contrasts were tested: 1) CCS *vs*. BMR (mBMR + pmBMR1 + pmBMR2), 2) mBMR *vs.* pmBMR (pmBMR1 + pmBMR2) and 3) pmBMR1 *vs.* pmBMR2. Least square means are reported throughout. Significance was declared at P<0.05 and tendency at 0.05<P<0.10.

RESULTS AND DISCUSSION

Corn crop yield: Yields were determined by dividing the weight of each corn silage hybrid or triticale by the exact acreage from which it was harvested. Sole-crop corn plants harvested at maturity yielded 53.6 and 52.0 Mg/ha, respectively, for the CCS and the mBMR. Double-cropping corn plants harvested at tassel yielded 24.7 and 24.9 Mg/ha, respectively, for the pmBMR1 and the pmBMR2.

Nutrient profiles of silages: Contents of CP, NDF, and ADF were greater in the pre-matured BMR silages compared with the CCS and the mBMR, whereas the pre-matured BMR contained lower contents of starch and non-fiber carbohydrates (NFC; Table 1). Nutrient composition between the pmBMR1 and the pmBMR2 was similar. A decline in fiber content with increasing maturity can be attributed to the dilution effect created by the increasing content of grain in corn as the crop matures (Coors *et al*. 1997; Darby and Lauer, 2002). Additionally, CP content has been shown to decline with increasing maturity (Sheperd and Kung, 1996). For the forages tested in this study, increased starch contents were associated with decreased contents of CP and fiber. A similar effect may have occurred with the content of acid detergent lignin. The pre-mature BMR varieties had similar or greater acid detergent lignin content compared with the CCS, and as expected, the mBMR was 24% less in acid detergent lignin than the CCS. Decreased lignin contents in BMR have been the hybrid's most notable nutritive benefit. Lesser lignin synthesis decreases the degree of cross-linking that occurs among lignin and digestible structural carbohydrates, thus increasing plant digestibility (Casler and Jung, 1999; Vogel and Jung, 2001). The lack of starch in the pmBMR silages could have been attributed to the increase in lignin as well as CP and NDF contents. Lignin-to-NDF ratio was greatest in the CCS (0.063) but was similar between BMR silages (0.046 on average). In addition, *in vitro* NDF degradability measured at 30 h of incubation was similar across BMR silages and was greaterthan that of the CCS (66.9 *vs.* 56.6%). Immature plants generally have greaterNDF digestibility than mature plants, as the plant matures the indigestible NDF fraction increases and rate of NDF digestion decreases (Smith *et al.* 1972).

***In situ* ruminal degradation kinetics of DM and NDF:** Kinetics of DM degradation is reported in Table 2. The CCS had the greatest wash fraction compared with the BMR hybrids in dry and lactating cows. The DM wash fraction represents the percentage of DM available immediately in the rumen. The high DM fraction in the CCS may have resulted from greater contents of water-soluble carbohydrates compared with the BMR hybrids. An accumulation of various solutes, including sugars and starch, is observed in corn plants, as they mature, and consequently this result was expected because NFC content of the CCS exceeded 47% of the total forage DM.

The potentially degradable DM fraction generally exhibited responses that were mirror-opposites to that observed for the wash fraction. As expected, differences of the potentially degradable DM fraction between the BMR hybrids and the CCS were greater in dry cows compared to lactating cows (19 *vs.* 20%, respectively) compared with BMR hybrids. This is due largely to the differences in the undegradable fraction for the CCS in dry and lactating cows (15.9 and 23.0%, respectively). The potentially degradable DM fraction was greatest for the mBMR in dry cows, while in lactating cows this fraction was greatest for the pmBMR1. Different fractional rates of particulate passage between dry and lactating cows (assumed to be 4.0 *vs.* 6.0 %/h) may result in the different responses in the potentially degradable DM fraction between the test cows. In addition, it is likely that the different overall nutrient compositions on BMR corn silage varieties would interact with the different fractional passage rates between the test cows.

As expected, the CCS had the greatest undegradable fraction in lactating cows, but surprisingly, the greatest undegradable fraction in dry cows was found in the pmBMR2. Because of the high wash fraction and rapid degradability of the CCS at the early incubation time points, estimates of ERD of DM were greatest for the CCS in lactating cows followed by the pmBMR1 in dry cows.

All lag times were relatively low (approximately < 1 h) with no distinct patter in dry cows except for the pmBMR1 which took 5.6 h. There was no apparent explanation for the greater lag time of the pmBMR1 in dry cows. In lactating cows, however, lag time for the pmBMR1 was < 1 h, while both the CCS and the mBMR averaged 7.0 h in lag time. Estimates of rate of degradation (K_d) for DM were greater for the BMR hybrids compared with the CCS and were noticeably greater for the pmBMR varieties than the mBMR in dry cows (8.08 *vs.* 2.97 %/h). Estimates of K_d for DM were much smaller in lactating cows compared to dry cows due to increased fractional rate of particulate passage. In the lactating cows, the BMR hybrids had a smaller K_d than the CCS (1.89 *vs.* 2.80 %/h).

Patterns of DM degradability in dry cows revealed that the pmBMR2 ceased further degradation in the rumen by 48 h of incubation, peaking at 79%, whereas the CCS continued to degrade, reaching 84% by 96 h of incubation (Fig. 1). This interaction was not seen in lactating cows where the pmBMR2 started lower at early incubation time points and remained lower through 96 h of incubation.

Results for NDF degradation kinetics are reported in Table 3. The wash fraction for NDF comprised a relatively small percentage of the total NDF pool, ranging from 5.2 to 15.6% in dry and lactating cows. Theoretically, NDF is insoluble in water (Van Soest, 1982) and therefore should be completely recovered at 0 h in *in situ* bags. In practice, recovery is rarely complete but is commonly > 90% for small cereal grain forages (Coblentz *et al.* 2000), and is often unreported (Bargo *et al.* 2001), or correction procedures are used to set disappearance of NDF to 0% at l h (Hackmann *et al.* 2010). However, substantial losses of NDF at l h were reported for immature perennial cool-season grasses, such as timothy (*Phleum pretense*; Hoffman *et al.* 1993) or tall fescue (*Festuca arundinacea* Schreb.; Flores *et al.* 2007) that have ranged up to 29.4% of the NDF pool. In the present study, the wash fraction was greatest for the pmBMR varieties ranging from 11.9 to 15.5% in dry and lactating cows. This may be attributed to greater contents of pectin in the plant cell walls of the pmBMR silages. The polysaccharide components of plant cell walls are cellulose, hemicellulose and pectin. Cellulose is composed of β-1, 4 linked glucose, whereas hemicellulose and pectin are composed of mixtures of both hexose and pentose sugars with a variety of linkage types (Hatfield, 1993). Most of the pectin in the cell wall is lost by solubilization during the first step of the detergent system where NDF is isolated. The net result is that NDF considerably underestimates cell wall content when high contents of pectin exist (Vogel and Jung, 2001).

The potentially degradable NDF fraction comprised large percentages of the NDF pool ranging from 61.0 to 89.8% and 47.7 to 59.4% for dry and lactating cows, respectively. As expected, the BMR hybrids had greater potentially degradable NDF fraction compared with the CCS with the exception of the pmBMR2 which had the least potentially degradable NDF fraction in dry cows.

Patterns of NDF degradability in dry cows indicated that degradation of the pmBMR2 rapidly declined after 24 h of incubation (Fig. 2). As a result, the undegradable NDF fraction was greatest for the pmBMR2 in dry cows as opposed to the CCS in lactating cows. Estimates of ERD of NDF were greater for the pmBMR varieties compared with mature silages (Table 3), and were greatest for the pmBMR1 in both dry and lactating cows (58.9 and 38.7%, respectively). The decrease in the ERD of NDF for lactating cows compared to dry cows was expected; however, it is interesting to point out that ERD of NDF was 4.5, 10 and 20% smaller for the mBMR, the CCS and the pmBMR varieties, respectively. This can partially be explained by the difference in K_d between the test cows. Estimates of K_d decreased dramatically for the pmBMR varieties, only slightly for the CCS, but increased for the mBMR. Estimates for lag time were < 0.06 h in dry cows, whereas in lactating cows lag times were similar for the CCS and the pmBMR varieties, but nearly double for the mBMR (11.0, 10.8 and 20.7 h, respectively). The effects of lag time on NDF degradability for the mBMR are depicted in Fig. 2. Results for true NDF degradability should be interpreted with caution, because correction procedures to calculate degradability of NDF to 0% at l h were not used in our study.

Although dairy cows require forage NDF in diets for maximum productivity, excess dietary NDF often limits voluntary feed intake because of physical fill in the rumen. Enhanced NDF degradability in the rumen may stimulate rapid degradation of NDF from the rumen, reduce physical fill and allow greater voluntary feed intake (Allen and Oba, 1996). *In situ* degradation of NDF was greater for all BMR hybrids compared with the CCS. Among BMR hybrids total degradation of NDF was greatest for the pmBMR1 and greater for the mBMR than the pmBMR2, indicating that *in situ* NDF degradation may have been influenced more by hybrid than stage of maturity.

In conclusion, incorporating alternative crops in a DCP system has the potential to improve continuous cycling of nutrients between livestock and land without decreasing forage yields. However, lack of NFC in silage corn harvested at tassel may require additional supplementation of grains to provide nutrient requirements for high producing dairy cows. The lack of starch in the pmBMR silages could have attributed to increased CP, NDF and lignin contents. Increased degradability of the pmBMR varieties should produce more VFA and may provide an efficient energy source for dry cows and heifers. In the lactating cows, however, extent of DM degradation for the pmBMR2 was not as great as the CCS. In addition, the higher content of starch in mature corn silages (CCS and mBMR) would provide more energy available for rumen microorganisms, which can increase microbial population and microbial protein synthesis available for the host animal. Feeding the mBMR to high-producing cows may allow for lesser grain to be fed, whereas feeding the pmBMR silage may need to be supplemented with additional energy in high-producing cows.

Table 1. Chemical composition (means ± SD) of forages (n = 3)

	Corn silage hybrid[1]			
Item, % of DM	**CCS**	**mBMR**	**pmBMR1**	**pmBMR2**
DM, %	29.8 ± 0.53	28.2 ± 0.93	26.0 ± 1.00	36.8 ± 3.21
OM	94.6 ± 0.21	94.6 ± 0.37	94.7 ± 0.43	94.2 ± 0.33
CP	6.5 ± 0.57	7.8 ± 0.45	11.8 ± 1.20	10.7 ± 1.46
Fat	2.8 ± 0.82	2.9 ± 0.69	2.3 ± 0.52	1.9 ± 0.60
NDF	39.5 ± 0.99	47.1 ± 0.64	56.4 ± 0.75	53.5 ± 0.60
IVNDFD,[2] %	56.6 ± 0.71	67.7 ± 0.71	67.7 ± 0.79	65.2 ± 0.84
ADF	23.0 ± 0.71	26.1 ± 1.20	34.8 ± 1.11	33.9 ± 1.05
Starch	32.5 ± 1.91	25.8 ± 1.48	1.1 ± 0.42	2.2 ± 0.55
NFC[3]	47.1 ± 1.90	39.2 ± 1.67	17.9 ± 2.99	22.9 ± 2.51
ADL[4]	2.5 ± 0.50	1.9 ± 0.33	2.5 ± 0.57	3.0 ± 0.66

[1] CCS = conventional corn silage; mBMR = brown midrib corn silage harvested at maturity; pmBMR1 = brown midrib corn silage 1 harvested prior to maturity; and pmBMR2 = brown midrib corn silage 2 harvested prior to maturity.

[2] IVNDFD = *in vitro* NDF degradability measured at 30 h of incubation.

[3] Non-fibre carbohydrates = 100 – CP – NDF – fat– ash.

[4] Acid detergent lignin.

Table 2. Kinetics of in situ ruminal DM degradation of corn silage hybrids in dry and lactating dairy cows.

	Treatments[1]					Contrasts[2]		
Item	**CCS**	**mBMR**	**pmBMR1**	**pmBMR2**	**s.e.m.**	**1**	**2**	**3**
Dry cows[3]								
Wash fraction (%)	51.7^{a}	42.9^{b}	42.1^{c}	43.4^{b}	0.12	< 0.01	0.63	< 0.01
Potentially degradable fraction (%)	32.4^{d}	47.4^{a}	45.4^{b}	36.8^{c}	0.25	< 0.01	< 0.01	< 0.01
Undegradable fraction (%)	15.9^{c}	9.7^{c}	12.5^{c}	19.8^{a}	0.29	< 0.01	< 0.01	< 0.01
Extent of rumen degradation (%)	67.2^{b}	62.9^{c}	74.0^{a}	66.5^{b}	0.37	< 0.01	< 0.01	< 0.01
Lag time (h)	1.38^{b}	0.00	5.65^{a}	0.80^{d}	0.195	0.03	< 0.01	< 0.01
K_d (%/h)[4]	3.70^{c}	2.97^{d}	9.44^{a}	6.72^{b}	0.110	< 0.01	< 0.01	< 0.01
Lactating cows[5]								
Wash fraction (%)	51.6^{a}	43.0^{b}	37.6^{c}	43.1^{b}	0.06	< 0.01	< 0.01	< 0.01
Potentially degradable fraction (%)	25.4^{d}	43.2^{b}	51.7^{a}	38.7^{c}	0.68	< 0.01	< 0.01	< 0.01
Undegradable fraction (%)	23.0^{a}	13.8^{c}	10.7^{d}	18.2^{b}	0.62	< 0.01	0.43	< 0.01
Extent of rumen degradation (%)	59.5^{a}	53.6^{b}	50.8^{d}	51.6^{c}	0.16	< 0.01	< 0.01	< 0.01
Lag time (h)	7.77^{c}	6.64^{c}	0.00	3.54^{b}	0.443	< 0.01	< 0.01	< 0.01
K_d (%/h)[4]	2.80^{a}	1.97^{b}	2.05^{b}	1.72^{b}	0.073	< 0.01	0.15	0.11

$^{a-d}$Within a row, means with different superscript differ ($P<0.05$).

[1] CCS = conventional corn silage; mBMR = brown midrib corn silage harvested at maturity; pmBMR1 = brown midrib corn silage 1 harvested prior to maturity; and pmBMR2 = brown midrib corn silage 2 harvested prior to maturity.

[2] Contrasts: 1 = CCS *vs.* BMR (mBMR + pmBMR1 + pmBMR2); 2 = mBMR *vs.* pmBMR (pmBMR1 + pmBMR2); and 3 = pmBMR1 *vs.* pmBMR2.

[3] Fractional passage rate of dry cows was assumed to be 4.0 %/h.

[4] Rate of DM degradation.

[5] Fractional passage rate of lactating cows was assumed to be 6.0 %/h.

Table 3. Kinetics of in situ ruminal NDF degradation of corn silage hybrids in dry and lactating dairy cows.

	Treatments[1]					Contrasts[2]		
Item	CCS	mBMR	pmBMR1	pmBMR2	s.e.m.	1	2	3
Dry cows[3]								
Wash fraction (%)	8.3^{c}	5.2^{d}	15.6^{a}	11.9^{b}	0.13	< 0.01	< 0.01	< 0.01
Potentially degradable fraction (%)	66.9^{c}	89.8^{a}	70.2^{b}	61.0^{d}	0.30	< 0.01	< 0.01	< 0.01
Undegradable fraction (%)	24.9^{b}	5.0^{d}	14.2^{c}	27.1^{a}	0.32	< 0.01	< 0.01	< 0.01
Extent of rumen degradation (%)	36.2^{c}	36.3^{c}	58.9^{a}	47.0^{b}	0.39	< 0.01	< 0.01	< 0.01
Lag time (h)	0.03^{c}	0.02^{d}	0.06^{a}	0.05^{b}	0.001	< 0.01	< 0.01	< 0.01
K_d (%/h)[4]	2.12^{d}	2.92^{c}	6.49^{a}	5.45^{b}	0.001	< 0.01	< 0.01	< 0.01
Lactating cows[5]								
Wash fraction (%)	7.0^{d}	7.8^{c}	13.2^{a}	12.9^{b}	0.11	< 0.01	< 0.01	0.34
Potentially degradable fraction (%)	47.7^{c}	55.5^{b}	59.4^{a}	54.3^{b}	1.31	< 0.01	0.28	0.10
Undegradable fraction (%)	45.3^{a}	36.8^{b}	27.4^{c}	32.8^{b}	1.20	< 0.01	< 0.01	0.05
Extent of rumen degradation (%)	20.8^{d}	31.8^{b}	38.7^{a}	27.3^{c}	0.41	< 0.01	< 0.01	< 0.01
Lag time (h)	11.0^{bc}	20.7^{a}	12.3^{b}	9.2^{c}	0.70	0.01	< 0.01	0.02
K_d (%/h)[4]	2.57^{b}	4.67^{a}	4.51^{a}	2.45^{b}	0.001	< 0.01	< 0.01	< 0.01

[a-d] Within a row, means with different superscript differ ($P<0.05$).

[1] CCS = conventional corn silage; mBMR = brown midrib corn silage harvested at maturity; pmBMR1 = brown midrib corn silage 1 harvested prior to maturity; and pmBMR2 = brown midrib corn silage 2 harvested prior to maturity.

[2] Contrasts: 1 = CCS *vs.* BMR (mBMR + pmBMR1 + pmBMR2); 2 = mBMR *vs.* pmBMR (pmBMR1 + pmBMR2); and 3 = pmBMR1 *vs.* pmBMR2.

[3] Fractional passage rate of dry cows was assumed to be 4.0 %/h.

[4] Rate of NDF degradation.

[5] Fractional passage rate of lactating cows was assumed to be 6.0 %/h.

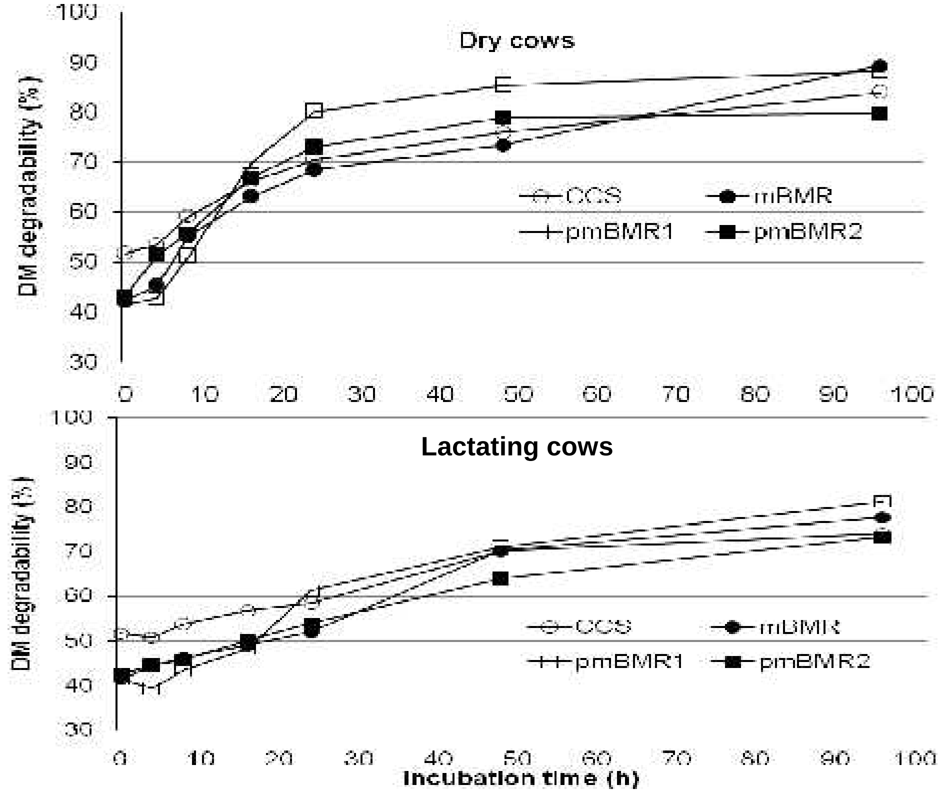

Fig. 1. ***In situ*** **degradability of DM in dry and lactating dairy cows measured at 0, 4, 8, 16, 24, 48 and 96 h.** CCS = conventional corn silage, mBMR = brown midrib corn silage harvested at maturity, pmBMR1 = brown midrib corn silage 1 harvested prior to maturity and pmBMR2 = brown midrib corn silage 2 harvested prior to maturity. In dry cows, effect of type of silage, incubation time and the interaction between type of silage and incubation time were $P<0.01$, $P<0.01$ and $P<0.01$, respectively, with s.e.m. = 0.86. In lactating cows, effect of type of silage, incubation time and the interaction between type of silage and incubation time were $P<0.01$, $P<0.01$ and $P<0.01$, respectively, with s.e.m. = 0.62.

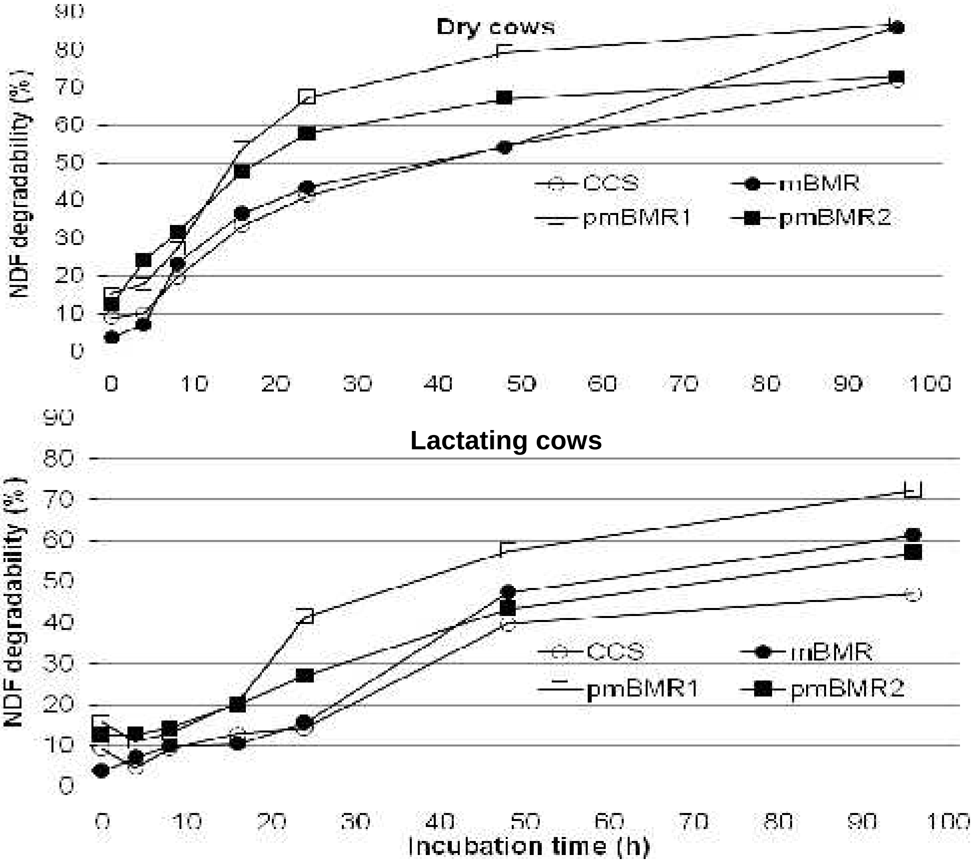

Fig. 2. *In situ* degradability of NDF in dry and lactating dairy cows measured at 0, 4, 8, 16, 24, 48 and 96 h. CCS = conventional corn silage, mBMR = brown midrib corn silage harvested at maturity, pmBMR1 = brown midrib corn silage 1 harvested prior to maturity and pmBMR2 = brown midrib corn silage 2 harvested prior to maturity. In dry cows, effect of type of silage, incubation time and the interaction between type of silage and incubation time were $P<0.01$, $P<0.01$ and $P<0.01$, respectively, with s.e.m. = 1.21. In lactating cows, effect of type of silage, incubation time and the interaction between type of silage and incubation time were $P<0.01$, $P<0.01$ and $P<0.01$, respectively, with s.e.m. = 1.12.

Conclusion: Increases in *in situ* NDF degradability of the brown midrib hybrids (sole crop as well as double crop) have the potential to substantially improve the productivity of dairy cows fed diets containing relatively high contents of forage without negatively influencing feed intake due to increased NDF degradability. However, *in situ* NDF degradation is insufficient for estimating the nutritional value of such types of forage because of differences in rate of degradability. More research is needed to determine the effects of feeding double-cropped pre-matured brown midrib-based diets on NDF digestibility, feed intake and lactation performance of dairy cows.

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