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EFFECTS OF CORN SILAGE HYBRIDS AND DIETARY NONFORAGE FIBER SOURCES ON PRODUCTIVE PERFORMANCE IN EARLY LACTATING DAIRY COWS FED HIGH FORAGE DIETS

by

Michael Shane Holt

A thesis submitted in partial fulfillment
of requirements for the degree

of

MASTER OF SCIENCE

in

Dairy Science

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2010

ABSTRACT

Effects of Corn Silage Hybrids and Dietary Nonforage Fiber Sources on Productive Performance in Early Lactating Dairy Cows Fed High Forage Diets

by

Michael Shane Holt, Master of Science

Utah State University, 2010

Major Professor: Allen J. Young
Department: Animal, Dairy, and Veterinary Sciences

This experiment was conducted to determine the effects of corn silage hybrids and nonforage fiber sources (NFFS) in high forage diets formulated with high dietary proportion of alfalfa hay (AH) and corn silage (CS) on ruminal fermentation and productive performance by early lactating dairy cows. Eight multiparous Holstein cows (4 ruminally fistulated) averaging 36 ± 6.2 d in milk were used in a duplicated 4 × 4 Latin square design experiment with a 2 × 2 factorial arrangement of treatments. Cows were fed 1 of 4 dietary treatments during each of the four 21-d periods. Treatments were: 1) conventional corn silage (CCS)-based diet without NFFS, 2) CCS-based diet with NFFS, 3) brown midrib corn silage (BMRCS)-based diet without NFFS, and 4) BMRCS-based diet with NFFS. Diets were isonitrogenous and isocaloric. Sources of NFFS consisted of ground soyhulls and pelleted beet pulp to replace a portion of AH and CS in the diets. In vitro 30-h NDF degradability was greater for BRMCS than CCS (42.3 vs. 31.2%).

Neither CS hybrids nor NFFS affected intake of DM and nutrients. Digestibility of N, NDF, and ADF tended to be greater for cows consuming CCS-based diets. Milk yield was not influenced by CS hybrids and NFFS. However, a tendency for an interaction between CS hybrids and NFFS occurred with increasing milk yield due to feeding NFFS with the BMRCS-based diets. Yields of milk fat and 3.5% FCM decreased when feeding the BMRCS-based diet, and there was a tendency for an interaction between CS hybrids and NFFS by further decreased milk fat concentration because of feeding NFFS with BMRCS-based diet. Although feed efficiency (milk/DM intake) was not affected by corn silage hybrids and NFFS, there was an interaction between CS hybrids and NFFS because feed efficiency increased when NFFS was fed only with BMRCS-based diet. Total VFA production and individual molar proportion were not affected by diets. Dietary treatments did not influence ruminal pH profiles except that duration (h/d) of pH < 5.8 decreased when NFFS was fed in CCS-based diet but not in a BMRCS-based diet, causing a tendency for an interaction between CS hybrids and NFFS. Overall measurements in our study reveal that high forage NDF concentration (20% DM on average) may eliminate potentially positive effects of BMRCS. In the high forage diets, NFFS exerted limited effects on productive performance when they replaced AH and CS. Although the high quality AH provided adequate NDF (38.3% DM) for optimal rumen fermentative function, the low NDF concentration of the AH and the overall forage particle size reduced physically effective fiber and milk fat concentration.

(63 pages)

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M. Shane Holt

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LIST OF ABBREVIATIONS

ADF = acid detergent fiber

AH = alfalfa hay

AIA = acid insoluble ash

BMR = brown midrib

BMRCS = brown midrib corn silage

BW = body weight

CCS = conventional corn silage

CP = crude protein

CS = corn silage

DM = dry matter

DIM = days in milk

DMI = dry matter intake

ECM = energy corrected milk

EMPS = efficiency of microbial protein synthesis

F:C = forage to concentrate

FNDF = forage neutral detergent fiber

MP = metabolizable protein

NDF = neutral detergent fiber

NDFD = neutral detergent fiber degradability

NE_L = net energy for lactation

NFFS = nonforage fiber sources

NFNDF = nonforage neutral detergent fiber

pef = physically effectiveness factor

peNDF = physically effective neutral detergent fiber

PSPS = Penn State particle separator

RDP = rumen degraded protein

RUP = rumen undegraded protein

SEM = standard error of least square means

TMR = total mixed ration

WPCS = whole plant corn silage

INTRODUCTION

Forages are the foundation upon which good dairy nutritional programs are built, and corn silage and alfalfa are the main forages fed to dairy cattle in the United States. Typical lactating dairy diets in the intermountain west contain more alfalfa hay (AH) than corn silage (CS). Baled AH is commonly fed to provide 50 to 75% of the dietary forage with total forage levels averaging 45 to 55% of the dietary DM. However, dairy producers are increasingly asking the question, "Should I be growing and feeding more CS at the expense of alfalfa?" Although both forages provide the needed fiber components, alfalfa and CS complement each other from a nutritional perspective; CS is high in energy, whereas alfalfa is high in protein. Howard (1994) suggested that factors such as forage particle length, dietary DM, protein degradability, dietary starch concentration, and calcium levels are important factors to consider when determining the optimum balance of alfalfa and CS in rations.

In Utah, AH is grown in greater abundance than other forages. According to the Crop Production Summary Report (USDA, 2009), Utah has 7 acres of alfalfa grown for every acre of corn grown, whereas the ratio in Idaho is much closer at 2:1 of alfalfa to corn, with the majority of the corn being harvested as silage (Table 1). According to these data, CS has a greater return per acre than either corn grain or AH. Because CS is difficult to transport after ensiling, more dairies are dedicating their acres to growing CS and bringing in alfalfa from outside farms.

Making decisions between alfalfa and CS from a nutritional perspective is becoming more complicated, as many hybrids have been developed with specific plant traits that enhance their value as a nutrient source like the brown midrib (BMR) CS hybrid. High-quality CS hybrids have been developed through genetic selection for improved stover (stalk, leaves, husk, and cob) digestibility and grain yield. Fiber digestibility and grain yield have been research areas of interest for many years, because the two factors are not highly related (Hunt et al., 1992; Argillier et al., 1995).

Table 1. Recent major crop production in Utah and Idaho[1]

Crop	Acres	Yield	Price/unit	Income/acre
Utah				
Alfalfa hay	552 thousand	4.1 ton	$117/ton	$478
Corn grain	17.2 thousand	156 bushels	$3.38/bushel	$527
Corn silage	45 thousand	22 ton	$27/ton	$594
Idaho				
Alfalfa Hay	1,138 thousand	4.2 ton	$138/ton	$580
Corn grain	271 thousand	171 bushels	$3.73/bushel	$638
Corn silage	189 thousand	27 ton	$30/ton	$810

[1] Average of 5 years (2004 through 2008); source: USDA, National Agricultural Statistics Service, 2009.

Brown midrib CS (BMRCS) hybrid was developed in 1924 at the University of Minnesota (Jorgensen, 1931). The BMRCS are characterized by their lower lignin content and higher fiber digestibility than conventional CS (CCS; Oba and Allen, 1999a). The name “BMR” was attributed to this trait because of the reddish-brown coloration of the center midrib on the underside of the leaf. Eastridge (1999) reported that on average, the BMRCS contained 34% less lignin and had in vitro NDF degradability (NDFD) that were 19% higher than non-BMRCS.

Several experiments comparing BMRCS with its conventional counterpart reported improved animal performance for cows fed the BMR hybrid (Oba and Allen, 1999a). However, concerns with lower yield per acre of the BMR hybrid exist. Eastridge (1999) reported the yield for BMRCS was 10.4% (range = 2.8 to 16.9%) lower than for CCS among the studies reviewed (Table 2). However, the lower yield can be somewhat offset by the higher forage quality having more digestible fiber. This allows cows to be fed more forage and less concentrate, which will increase ruminal pH and improve overall rumen function.

Table 2. Agronomic principles and chemical composition of corn silages[1]

	BMRCS			CCS			BMRCS vs. CCS
	n	Mean	STD	n	Mean	STD	
Yield, ton/acre[2]	10	6.4	0.98	11	7.1	1.05	– 10.4%
Range		5.2 - 8.3			5.4 - 9.0		– 2.8 - + 16.9%
Chemical composition[3]							
DM, %	22	33.1	NR	23	34.6	NR	NR
CP	21	9.34	1.71	22	8.74	1.64	+ 0.07%
NDF	13	47.2	6.7	14	47.9	7.3	– 0.01%
ADF	21	24.0	3.2	22	25.1	3.9	– 0.05%
Lignin	14	2.80	1.33	15	3.75	1.40	– 33.9%
Ash	7	4.63	0.53	7	4.51	0.61	+ 0.03%
NDFD, %	8	55.8	9.3	9	47.0	8.7	+ 18.7%

[1] BMRCS = brown midrib corn silage; STD = standard deviation; CCS = conventional corn silage; NR = not reported.

[2] Data taken from Allen et al. (1997); Hutjens et al. (1998); and Qiu et al. (2003).

[3] Data taken form Colenbrander et al. (1972); Frenchick et al. (1976); Rook et al. (1977); Keith et al. (1979); Sommerfeldt et al. (1979); Block et al. (1981); Stallings et al. (1982); Allen et al. (1997); Hutjens et al. (1998); Hutjens et al. (1999); Oba and Allen (1999a); Qiu et al. (2003). Nutrient concentration was expressed as % of DM. NDFD = in situ or in vitro NDF degradability.

Previous studies on BMRCS were done with diets more typical of the midwestern and northeastern United States containing high levels of forage from corn silage. Forage to concentrate (F:C) ratios of 60 to 40 are not uncommon when BMR corn hybrids are fed; a minimum 55 to 45 of the F:C ratio is strongly advised by Mycogen Seeds (Eagan, MN). On majority of the studies done on BMRCS, lactating dairy cows were fed the hybrid CS from 31 to 85% of total dietary DM with 0 to 20% alfalfa silage in the rations. Only a couple of studies done with BMRCS have included any AH in the diet at all. For example, Kung et al. (2008) included AH at 5% in TMR, and Ebling and Kung (2004) fed 8% AH (DM basis). In the intermountain west, high quality AH is more readily available than CS, and therefore the AH is in greater abundance than CS. On the other hand, soyhulls and beet pulp are often added to rations as nonforage fiber sources (NFFS) to increase NDFD of the ration and reduce grain proportion on the rations.

Nonforage fiber sources are plant byproducts produced by extraction of starch, sugar, or other valuable nonfibrous constituents. These NFFS can have NDF content similar to coarse forages, but particle size similar to concentrates. The NFFS have been used as alternative feeds in many dairy operations based on their price and availability. Traditionally, NFFS have been used as sources of concentrate, because many NFFS have relatively high NE_L and moderate CP concentrations (Stern and Zeimer, 1995). However, in situations in which traditional forage sources have been in short supply because of drought or availability, NFFS have been successfully used to stretch forage supplies. Diets containing NFFS supported higher ruminal pH while supplying a fermentable substrate for cellulolytic bacteria (Cunningham et al., 1993). Fiber digestibility increased when soyhulls were substituted for cereal grains (Edionwe and Owne, 1989). Others have noted that total concentrations of VFA increased when soyhulls replaced either dietary forage or grain components (Sarwar et al., 1992). Beet pulp contains approximately 40% NDF, and is unique in its high concentration of neutral detergent soluble fiber, especially pectin substances (Voelker and Allen, 2003). Both soyhulls and beet pulp are popularly used by many dairy farmers in Utah. Although NFFS feedstuffs are excellent fiber sources, one must consider maintaining adequate physically effective NDF (peNDF) content of dairy cow diets due to their relatively small particle size, which may result in decline in ruminal pH and subsequently ruminal acidosis (Yang and Beauchemin, 2006). Fiber in dairy cow rations is essential for animal health, because it is required to support an appropriate rumen function and optimal fermentative condition. Dietary fiber promotes cud chewing which increases the buffering capacity of the rumen.

Overall research contained in this thesis will show that utilization of forages can alter ruminal fermentation and productive performance of lactating dairy cows. On the review of literature, development of BMRCS and its use as a main forage source in lactating dairy diets will be extensively discussed. Although BMRCS has been proved to be an effective forage to increase fiber digestibility, ruminal fermentable energy, and microbial protein synthesis, BMRCS with high quality AH may have limited impacts on ruminal fermentation and animal performance, which will be proved in the lactation experiment of this thesis.

REVIEW OF LITERATURE

Fiber in dairy cow rations is essential for animal health, since it is required to support an appropriate rumen function and physiology. The National Research Council (2001) recommends NDF to be maintained at 25% of dietary DM with at least 75% from forage for the NDF requirement. Therefore, there is room for up to 25% of the NDF from nonforage fiber sources (NFFS) to meet the NDF requirement. Although NFFS are less effective in stimulating chewing than normal forage fiber sources, they can be used as fiber sources in lactating diets when included at a certain proportion. However, the effectiveness of fiber within byproduct feeds and forages is variable because of differences in size distribution of fiber particles and the retention time of fiber in the rumen. Hence, chemical and physical characteristics alone should not be used as exclusive measures of fiber requirements, because ruminal fermentation of fiber is variable (Nocek and Tamminga, 1991), and adjustment of dietary fiber content affects fermentation acid production by dilution or concentration of the nonfibrous fraction of the diet.

Milk fat production of dairy cows has been used to determine NDF effectiveness for NFFS as a way of integrating these complex interactions (Clark and Armentano, 1993; Swain and Armentano, 1994; Armentano and Pereira, 1997). However, the effectiveness, as determined with this strictly empirical relationship, might have limited application because values of the effectiveness have not been repeatable across different types of diets (Clark and Armentano, 1993). Midlactation cows are typically used for this determination, because milk fat percentage of cows in early lactation is less responsive to dietary NDF. In addition, milk fat percentage might not be the most appropriate measure of fiber effectiveness for cows in early lactation; requirements for fiber and energy of cows in mid- and late lactation are easily met, but fiber requirements of early lactation cows are critical because their energy demand exceeds the energy consumed. Diets with lower fiber and higher starch contents are fed to increase energy intake by early lactation cows, which increases the risk of ruminal acidosis.

Ruminal pH is a more meaningful response variable for determining effectiveness of forage utilization by dairy cows in early lactation. Diets should be balanced to maintain adequate ruminal pH; as ruminal pH decreases, appetite, ruminal motility (Ash, 1959), microbial yield (Hoover, 1986), and fiber digestion (Terry et al., 1969) are reduced. Thus, low ruminal pH has direct, negative impacts on microbial fermentation and nutrient digestion, which are primary factors limiting production of high producing dairy cows. When ruminal pH is substantially reduced, severe health problems such as laminitis, ruminal ulceration, liver abscess, and even death could result (Slyter, 1976). Mackie and Gilchrist (1979) suggested an index that emphasized the time spent under the optimal ruminal pH by the magnitude of the deviation from this pH. Although this index might be better related to animal performance than is mean ruminal pH, variation in ruminal pH is more closely related to feeding management practices, and more influenced by meal frequency (Bragg et al., 1986) and diet adaptation (Counotte and Prins, 1981) than diet formulation. The effects of feeding management on variation in ruminal pH should be considered when choosing the optimal mean ruminal pH, which is lower when variation over time is minimized.

Allen (1997) reported the relationship between ruminal pH and forage NDF using 106 treatment means from 28 experiments in the literature. The author used only data from ruminally cannulated lactating dairy cows with pH determined as within-day means. The dataset included intake of DM or OM and dietary concentration of NDF and ADF in all or most of the experiments. However, the concentration of forage NDF was reported on only 6 experiments of the dataset. Ruminal pH was positively related to forage NDF on DM basis ($P < 0.01$; $r^2 = 0.63$). Ruminal pH was not related to ADF or NDF as a percentage of DM or to OM intake. A positive relationship between forage NDF and ruminal pH was expected because of the greater chewing and salivary buffer flow with increasing forage NDF. Because only 6 experiments included forage NDF, the dataset was limited (n = 26), and caution should be taken when these results are interpreted.

NONFORAGE NDF

Forages are usually the major source of fiber in dairy rations. However, if diets are formulated with a high quantity of forage NDF (FNDF), some portion of the FNDF may be replaced with nonforage NDF (NFNDF) when forages are in short supply, have low nutritive value, or have a high nutrient price relative to other feed sources. Nonforage fiber sources are plant byproducts produced by extraction of starch, sugar, or other valuable nonfibrous constituents such as soy hulls, beet pulp, wheat midds, and corn gluten. These NFFS can have NDF content similar to coarse forages, but particle size similar to concentrates. Forages that have been very finely ground may have similar physical function to NFFS.

Many NFFS have a relatively large pool of potentially degradable NDF, small particle size, and relatively high specific gravity (Batajoo and Shaver, 1994). The NFFS have similar or faster passage rates than most forages (Bhatti and Firkins, 1995). Therefore, a large proportion of the potentially available NDF from nonforages may escape ruminal fermentation, resulting in less acid production in the rumen (Firkins, 1997). In diets of low forage but high NDF content from NFFS, large intestinal fermentation may exert increased importance on fiber digestion compared with ruminal fermentation.

Diets that contain low FNDF (< 19% Diet DM) should contain high fiber byproducts to increase total dietary NDF and reduce nonfiber carbohydrates. Swain and Armentano (1994) reported that more NDF must be added from NFFS than from forage to achieve the same increase in milk fat yield. When feeding FNDF concentrations below 19% the NRC (2001) recommends increasing total dietary NDF by 2 percentage units for every 1 percentage unit decrease in FNDF (Table 3). In general, replacing forages and grains with high fiber byproducts has the effect of raising total dietary NDF and reducing nonfiber carbohydrates. Therefore, the direct, negative effect of starch on fiber digestion should be less for these high NDF diets due to their dilution effect on starch concentration and resultant prevention of decrease in pH from excessive starch fermentation in the rumen (Mould et al., 1983).

Most NFNDF does not stimulate chewing activity as effectively as FNDF, with thenotable exception of whole cottonseed (Pereira and Armentano, 2000). Decreased chewing activity when NFFS replace forage may decrease the flow of salivary buffer to the rumen, decreasing ruminal pH and NDF degradation (Grant and Mertens, 1992).

Chewing activity and ruminal pH of lactating dairy cows decreased when soyhulls replaced 42% of dietary forage in a diet containing 59% forage, although total NDF concentration increased from 28 to 34% on DM basis (Weidner and Grant, 1994). Supplementing sodium bicarbonate may be useful in increasing total tract NDF digestibility when cereal NFFS are a main component of low forage diets. Firkins et al. (1991) reported that sodium bicarbonate supplementation increased ruminal pH at 12 h post feeding and tended (*P* = 0.10) to increase total tract NDF digestibility when lactation cows were offered diets containing 20% corn silage, 15% alfalfa, and 20% corn gluten feed (38% NDF in the diet).

Table 3. NRC (2001) recommendation for forage NDF and dietary NDF and nonfiber carbohydrates (NFC)[1]

Minimum forage NDF[2]	Minimum dietary NDF	Maximum dietary NFC[3]
19[4]	25[4]	44[4]
18	27	42
17	29	40
16	31	38
15[4]	33	36

[1] Source: NRC (2001). Values in this table are based on the assumption that actual feed composition has been measured; values may not be appropriate when values from feed tables are used.

[2] All feeds that contain substantial amounts of vegetative matter are considered forage. For example, corn silage is considered a forage, although it contains significant amounts of grain.

[3] Nonfiber carbohydrate is calculated by difference 100- (% NDF + % CP + % fat + % ash).

[4] Diets that contain less fiber (forage NDF or total NDF) than these minimum values and more NFC than 44% should not be fed.

DIGESTIBILITY OF NDF

Neutral detergent fiber digestibility is a function of the potentially digestible fraction and its rate of digestion and passage. Digestibility of NDF is another important parameter of forage quality, because forage NDF varies widely in its degradability in the rumen, and NDF digestibility influences animal performance. Oba and Allen (1999b) reported in vitro degradability of NDF after 30 h of incubation ranged from less than 30% to 60% for corn silage and alfalfa. 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. Mertens (1997a) suggested that DMI of dairy cows can be predicted by dietary NDF, in part because of a positive relationship between NDF and the bulk density of feeds. Hence, enhanced NDF hydrolysis in the rumen may stimulate rapid disappearance of NDF from the rumen, reduce physical fill, and allow greater voluntary feed intake (Allen and Oba, 1996). Once the rumen's capacity for fill has been reached, movement of digesta out of the rumen must occur before feed intake can resume. Early work on this subject by Crampton (1957) showed that forages with the least digestibility of cellulose and hemicelluloses were retained the longest in the rumen of sheep. He postulated that this increase in retention time of the feed in the rumen was a major factor in decreasing voluntary intake. Grant et al. (1995) and Dado and Allen (1996) showed that increased NDF digestibility can alleviate the filling effect of NDF in the rumen at similar dietary NDF concentrations. Oba and Allen (2000c) fed lactating dairy cows silages with similar NDF and CP contents but different NDF digestibility. DMI and milk yield increased when cows were fed forages with higher NDF digestibility. The authors stated that increased NDF degradability can also increase the energy density of diets and stimulate microbial N production. Oba and Allen (1999b) reported that a one percentage unit increase in in vitro NDF degradability of forage elicited a 0.17 kg increase in DMI and a 0.25 kg increase in 4% FCM yield. Jung et al. (2004) reported that in diets containing corn silage (> 40% of the dietary DM), a one percentage unit increase in in vitro NDF degradability of corn silage resulted in a 0.12 kg/d increase in DMI and a 0.14 kg/d increase in 3.5% FCM yield. Thus, the increases in NDF digestibility of forage in vitro and in vivo have the potential to substantially improve the productivity of dairy cows fed diets containing relatively high concentrations of forages, and BMRCS can effectively improve lactational performance of dairy cows due to increased NDF digestibility.

PHYSICALLY EFFECTIVE NDF

An important aspect of fiber nutrition is that cows consuming sufficient NDF without a sufficient proportion of long particles can exhibit the same metabolic disorders as cows consuming a diet deficient in chemical fiber (Fahey and Berger, 1998). Negative responses due to lack of long particle fiber include subclinical ruminal acidosis, reduced fiber digestion, milk fat depression, displaced abomasums, lameness, and fat cow syndrome (NRC, 2001).

Mertens (1997b) defined effective NDF as the overall effectiveness of NDF for maintaining milk fat yield, whereas physically effective NDF (peNDF) as the specific effectiveness of NDF for stimulating chewing activity in relationship to particle size. The peNDF was introduced specifically to account for the physical characteristics of NDF (primarily particle size) that affects chewing activity and thus saliva secretion. This concept is based on the hypothesis that the fiber in long feed particles (> 1 cm) promotes chewing and saliva secretion which helps neutralize the acids produced during ruminal digestion of feeds (Beauchemin and Yang, 2005). The fiber that promotes chewing is considered physically effective. The peNDF content of the diet can be determined by multiplying the NDF concentration by the proportion of particles retained on a 1.18 mm sieve or by its physical effectiveness factor (pef).

Although various methods are available to measure particle size of diets, the Penn State Particle Separator (PSPS) has become widely accepted as a quick and practical method for routine use on-farm to evaluate particle size of forages and TMR (Lammers et al., 1996). Using the PSPS a particle distribution can be determined from 3 fractions: proportion of particles retained on the 19.0-mm sieve, proportions of particles that pass through the 19.0-mm sieve but are retained on the 8.0-mm sieve, and proportion of particles that pass through the 8.0-mm sieve (Lammers et al., 1996). The pef (ranging from 0 to 1) is calculated as the sum of the proportion of particles retained on both 19.0 and 8.0 mm sieves. Using this approach, the requirement for peNDF of dairy cows was determined to be 22% of ration DM to maintain an average ruminal pH of 6.0, and 20% of ration DM to maintain the milk fat percentage of early to midlactation Holstein cows at 3.4% (Mertens, 1997b).

Beauchemin and Yang (2005) conducted a study to investigate the effects of the peNDF content of dairy cow diets containing corn silages as the sole forage type on feed intake, meal patterns, chewing activity, and ruminal pH. The experiment was designed as a replicated 3 × 3 Latin square using 6 lactating dairy cows with ruminal cannulas. Diets were chemically similar, but varied in peNDF by altering corn silage particle length. That study showed that increased forage particle length increased intake of peNDF, but did not affect intake of DM and NDF. Number of chews (chews/d) and chewing time (eating + ruminating time) linearly increased with increasing dietary peNDF. However, increased chewing time did not necessarily reduce ruminal acidosis which can be explained by the fact that the concept of peNDF does not account for differences in fermentability of feeds, and thus it cannot predict differences in chewing and ruminal pH due to grain fermentability (Beauchemin and Yang, 2005).

EFFECT OF NDF ON FEED INTAKE

Digestibility of forage or forage-based diet is also dependent on the amount of feed intake for which given specific forage is consumed. Colucci et al. (1982) fed a low or high forage diet (corn silage and alfalfa silage based) with dietary NDF concentrations of 29.7 and 37.8%, respectively, to nonlactating and lactating cows. The lactating cows had greater DMI (30.1 and 19.2 g/kg BW) for the low or high forage diet, but lower DM and NDF digestibilities than the non-lactating cows within a diet. They observed that the intake of NDF was positively correlated with particulate matter passage and theorized that decreased digestibility of diets at the higher intake was caused by a faster rate of passage through the rumen.

Utilizing a 3 × 3 Latin square design, Shaver et al. (1986) evaluated the effects of various intake levels and forage particle sizes on the digestion and passage of legume hay in dairy cattle. They fed pre-bloom alfalfa hay, either long, chopped, or pelleted, in a 60:40 of hay:concentrate diet to 6 Holstein cows in early and midlactation within high and medium intake groups and in the dry period (low intake group). Dietary NDF and CP concentrations were similar for all treatments (30.8 and 17.4%, respectively). The authors observed a longer whole tract retention time of ytterbium-marked hay (26.4 vs. 15.6 h) and greater total tract NDF digestibility (42.5 vs. 36.5%) for the low intake group compared with the high intake group (Shaver et al., 1986). Like Colucci et al. (1982), Shaver et al. (1986) attributed the depression in NDF digestibility for the high intake group to the decreased ruminal retention time of the NDF. When the effect of particle size of the hay diets was evaluated, DMI was similar for all treatments, but the pelleted diet had lower total tract NDF digestibility and ruminal pH compared with the long and chopped diets (36.8 vs. 42.2% and 5.77 vs. 6.34, respectively). The authors theorized that with high quality forages like pre-bloom alfalfa, particle size was not the factor that limited DMI because rapid reduction in particle size due to mastication and rumination occurred relative to lower quality forages. Therefore, the authors speculated that an attempt to decrease rumen fill by reducing the particle size of high quality forage may not increase digestibility because smaller particles in the rumen could decrease rumination and total chewing, thereby causing a drop in ruminal pH and thus decreasing fiber digestibility.

Oba and Allen (1999b) reported the importance of the digestibility of NDF from forage on DMI and milk yield in lactating dairy cows. Thirteen sets of forage comparisons from 7 studies in the literature were evaluated. The database consisted of treatment means only from experiments that reported differences ($P < 0.10$) in the digestibilities of NDF among forages either in situ or in vitro. Not included in the database were experiments that compared legume with grass and experiments not reporting dietary NDF concentration, because dietary NDF concentration was used in the model as a covariate. Forages with high NDF digestibility were associated with greater milk yield (31.8 vs. 29.9 kg; $P < 0.01$) and 4% FCM yield (28.9 vs. 26.8 kg; $P < 0.02$). The authors concluded that enhanced NDF digestibility of forage significantly increased

DMI and milk yield. A one unit increase in NDF digestibility in vitro equated to a 0.17 kg/d increase in DMI and a 0.25 kg/d increase in 4% FCM yield (Oba and Allen, 1999b).

HISTORY OF BMRCS

Corn silage is a major source of NDF and NE_L in typical lactating dairy diets. Increasing the concentration of NDF in corn silage could mean that lesser amounts of other forages would have to be grown or purchased by the dairy farmer to meet NDF requirements (NRC, 2001). Several studies that have compared BMRCS with its conventional counterpart reported enhanced animal performance for cows fed the BMR hybrids (Oba and Allen 1999a).

The first BMR corn plants appeared in a 1-yr self pollinated line of northwestern dent corn at the University Farm, University of Minnesota, St. Paul, Minnesota in 1924. The BMR corn plants exhibited a reddish brown pigmentation of the leaf midrib that became visible in plants at the 4-6 leaf stage (Jorgenson, 1931). The name “BMR” was attributed to this trait because of the reddish-brown coloration of the center midrib on the underside of the leaf. The pigmentation appears in the stem with its lignifications visually associated with rind and vascular bundles. The coloration fades during maturing and may disappear on the leaves, but remains in the stalks. Four BMR mutants have been indentified: *bm1*, *bm2*, *bm3,* and *bm4* (Barrière and Argillier, 1993). These 4 genes occur as natural mutations. Whole plant corn containing any of the *bm* genes shows a reddish brown pigmentation of the leaf midrib.

Brown midrib hybrids are usually characterized by low lignin concentrations and high fiber digestibility. Incorporation of the BMR trait into forage genotypes has been of interest for many years because of the reduction in lignin content of the plant. The lower lignin content will increase digestibility of the forage, thereby resulting in forage with higher energy concentration. The BMR gene has little, if any, effect on the concentrations of CP, NDF, ADF, and ash in corn plants (Weller et al., 1984). The low lignin concentration is associated with changes in concentration of phenolic acids and alteration in enzymes involved in lignin biosynthesis (Cherney et al., 1991).

Reduction in fiber digestion due to higher concentration of lignin was thought to be the main reason for the shielding effect on cell wall polysaccharides (Akin, 1989). The unique difference in BMR compared to conventional corn hybrids comes from the mutation of certain enzymes involved in lignin biosynthesis. One mutation in *bm3* involves low concentration or lack of *o*-methyl transferase activity to complete methylation reaction of caffeic acid to ferulic acid, which is a lignin precursor (Cherney et al., 1991). Goto et al. (1994) showed lower concentrations of *p*-coumaric (4.3 vs. 7.4 g/kg DM) and ferulic acids (2.7 vs. 3.8 g/kg DM) for *bm3* compared to normal whole plant corn silage, respectively. Similarly, Hartley and Jones (1978) reported lower total concentration of phenolic compounds (10 vs. 16 mg/g of cell wall) for *bm*3 compared to normal whole plant corn silage.

Most BMR hybrids currently used by the hybrid seed industry have the *bm3* allele, which characteristically reduces lignin concentration and increases NDF digestibility to a greater extent than the other *bm* genes. Allen (1997) stated that the *bm3* mutation in corn hybrids decreased lignin content by 1.1 units and increased in vitro NDF digestibility after 30 h of incubation by 8.4 units compared with conventional control hybrids. There was no effect on the CP, NDF, ADF, or ash content of corn silage (Allen, 1997).

The BMR corn hybrids have been reported to have lower whole-plant DM yields than conventional corn silage. Miller et al. (1983) reported that *bm3* corn silage only averaged 77% of the grain yield and only 90% of the stover yield compared to CCS. Similarly, Barrière et al. (1998) reported 2.5 tonne/ha reduction in total DM yield for BMR compared to conventional corn plants. Overall BMR hybrids produce 10 to 15% less DM compared with their conventional counterparts (Miller et al., 1983).

PERFORMANCE OF DAIRY CATTLE FED BMRCS

Lactational Performance

Oba and Allen (1999a) showed that increased NDF digestibility observed for BMRCS in vitro did not necessarily correspond to similar NDF digestibility in vivo. Thirty two cows averaging 89 ± 27 DIM were fed BMR and CCS-based diets in a single crossover design with 28-d period. The digestibility of NDF that was estimated by 30 h of in vitro fermentation was 9.7 units higher for BMRCS than CCS (49.1 vs. 39.4%). However, when the corn silages were included in TMR diets at 45% of the diet DM, cows fed the BMRCS had only 2.2 percentage units greater apparent total tract NDF digestibility compared with cows fed the CCS-based diet ($P = 0.02$). Intake of DM was greater for cows fed the BMRCS diet compared with cows fed the CCS (25.6 vs. 23.5 kg/d). The authors hypothesized that the discrepancy of NDFD improvement between in vitro and in vivo to the two corn silage hybrids was a result of the increased DMI observed for the cows fed the BMRCS. The relationship between DMI and total tract NDF digestibility showed a negative correlation ($P < 0.01$); as DMI increased, NDF digestibility decreased. The authors speculated that this was because of faster passage from the rumen for the BMRCS as DMI increased (Oba and Allen, 1999a). Because a constant retention time was used to determine in vitro digestibility, the differences in NDF digestibility between BMRCS and CCS may have been inflated when the two corn silages were compared in vivo.

The increases in DMI and NDF digestibility observed by Oba and Allen (1999a) for cows fed the BMRCS treatment was accompanied by a milk yield response compared with cows fed the CCS treatment. Specifically, cows fed the BMRCS treatment yielded 2.8 kg/d more milk than cows on the CCS treatment and 2.6 kg/d more 3.5% FCM. Because this study was performed in a crossover design, the authors evaluated each animal's response to the BMRCS treatment. They plotted each animal's pre-trial milk yield against their milk yield responded to the BMRCS treatment and observed a positive correlation. This means cows that had the higher milk yields pre-trial had better response to the BMRCS treatment, and greater increases in DMI ($P = 0.06$) and milk yield ($P = 0.03$), whereas cows that had lower milk yields pre-trial had little or no responses to the BMRCS treatment. It is more challenging for high producing dairy cows to meet their energy requirement, and these results suggest that DMI of high producing cows is limited by ruminal fill to a greater extent than is that of low producing cows (Oba and Allen, 1999a).

Increase in milk yield has also been observed with cows fed BMRCS diets without increase in DMI. Keith et al. (1979) randomly assigned 12 lactating Holstein cows past peak lactation to one of 4 treatments in a double switchback design. The dietary treatments were BMRCS and CCS fed at two F:C ratios (75:25 and 60:40). Cows received their assigned diet for 5 wk, were randomly switched to a second treatment diet for 5 wk, and then were switched back to the originally assigned diet for 5 wk. Although both genotype of corn silage and F:C ratio did not affect DMI, milk yield was higher for cows fed the BMRCS treatment. Cows on the BMRCS treatment had 1.3 and 1.6 kg/d greater milk yield and 0.9 and 1.0 kg/d greater 4% FCM yield than cows fed the CCS treatment at F:C ratio of 75:25 and 60:40, respectively.

Oba and Allen (2000a) also fed cows BMRCS and CCS diets at two different dietary NDF concentrations (29 and 38% dietary NDF) and noted increase in DMI at both concentrations of fiber for cows on the BMRCS treatment. Along with the increased DMI, cows fed the BMRCS-based diets also had higher SCM yields regardless of the forage concentration. However, because no milk fat depression was observed for cows on the high forage BMRCS diet and SNF concentration was also greater for these cows compared with the BMRCS in low forage diet and CCS diet, the authors stated that the feeding of BMRCS was more beneficial in high forage diets when fed to high producing cows.

Frenchick et al. (1976) observed increase in milk yield for cows past peak lactation for a BMRCS-based diet compared with cows fed a CCS diet (22.5 vs. 21.7 kg/d) ($P = 0.05$). However, because cows fed the BMRCS treatment had a lower milk fat percentage, FCM yield between the two treatments were similar. Body weight gain was greater for cows fed the BMRCS treatment (+3.1 vs. -0.6 kg for the BMRCS and the CCS treatment, respectively).

Sommerfeldt et al. (1979) theorized that BW gains of cows fed BMRCS were due to partitioning of energy from milk production. In their study, cows (averaging 42 DIM) fed BMRCS-based diet had no advantages in DMI and milk yield compared with cows fed

CCS diet, but cows fed the BMRCS did have greater daily BW gain (+58.4 vs. -47.3 g/d). Rook et al. (1977) also observed increased BW gain with cows fed BMRCS-based diet from 42 to 91 DIM (49.6 vs.7.1 g/d), but there were also increase in DMI compared with cows fed CCS-based diet (20.2 vs. 18.6 kg/d).

The apparent partitioning of energy toward BW gain rather than milk production for cows fed BMRCS was also observed by Block et al. (1981). Cows fed BMRCS from 18 to 74 DIM increased BW (+10.2 kg), whereas cows fed CCS lost BW (-26.6 kg). Cows fed the BMRCS treatment produced more milk throughout the study, but this was not significant. The authors, however, noted that when the milk yield of the two groups were analyzed by week, cows receiving the BMRCS treatment produced more milk in wk 5, 6, and 8 compared to cows receiving the CCS treatment.

Effects of BMRCS on lactational performance have also been compared with other specialty hybrids. Ballard et al. (2001) fed late lactation cows (204 ± 104 DIM) corn silages from either leafy, BMR, or high grain yield corn hybrids. Because the leafy and BMR hybrids are considered as ones for making corn silage, they were compared with the grain hybrid and to each other. Direct contrast between the grain hybrid and either of the silage hybrids was not performed. They found that cows fed the silage hybrids produced 1.1 kg/d more milk compared with cows fed the grain hybrid, and that the BMRCS treatment increased milk yield over the leafy hybrid by 2.3 kg/d. Yield of 3.5% FCM was also greater for cows fed the BMRCS treatment compared with the leafy treatment (35.8 vs. 33.5 kg/d), but cows receiving the silage hybrids had similar 3.5% FCM yield compared to cows fed the grain hybrid treatment (34.7 vs. 33.3 kg/d). In a study using growing dairy heifers (Ballard et al., 2001), the silage hybrids allowed greater consumption of DM compared with the grain hybrid as a percent of BW (2.13 vs. 2.02%), but body condition and BW gain were similar between the treatments.

Transition cows have benefited by BMRCS-based diets. Santos et al. (2001) fed primiparous and multiparous dairy cows 3 different diets: 2 CCS-based diets at either 55:45 or 65:45 F:C ratios, and a BMRCS-based diet at a 65:45 of F:C ratio. The dietary treatments began an average of 23 d prior to calving and continued for 33 d postpartum. Post calving health and DMI were similar between treatments, but a tendency ($P = 0.09$) for increased milk yield was observed for muliparous cows receiving the BMRCS treatment (+ 2.2 kg/d).

Ruminal pH

Many studies have reported decreases in ruminal pH when cows were fed BMRCS-based diets compared to CCS-based diets. Oba and Allen (2000b) observed depressed ruminal pH in cows fed BMRCS compared to cows fed CCS (5.68 vs. 5.84), although chewing activity and OM truly fermented in the rumen were similar between the treatments. Similarly, Greenfield et al. (2001), Taylor and Allen (2005a), and Gehman et al. (2008) observed lower ruminal pH for BMRCS treatment compared with CCS treatment by 0.52, 0.22, and 0.28 pH units, respectively. In contrast, Qiu et al. (2003) and Weiss and Wyatt (2006) reported no effects of feeding between BMRCS- and CCS-based diets on ruminal pH.

In an attempt to explain ruminal pH differences by salivary buffering capacity without measuring saliva flow to the rumen directly, Oba and Allen (2000b) measured chewing activity and OM truly fermented in the rumen. In their study, no explanation for the depressed ruminal pH was evident. The authors speculated that factors other than chewing time, which may affect rate of absorption and passage along with the neutralization of fermentation acids, may explain the decreased ruminal pH with the BMRCS diet (Oba and Allen, 2000b).

Gehman et al. (2008) performed a lactation study using 20 cows in midlactation to investigate effects of type of corn silage and ionophore in a 4 × 4 Latin square design with a 2 × 2 factorial arrangement. Dietary treatments included BMRCS and CCS at two concentration of monensin (0 and 300mg/d). The authors reported that the inclusion of monensin in BMRCS-based diets increased ruminal pH by 0.14 units. The monensin supplementation had no effect on DMI, digestibility of any nutrients, and N metabolism, and there were no interactions between type of corn silage and monensin supplementation. However, treatments with BMRCS appeared to have negatively affected N digestibility. The BMRCS-based diet tended ($P = 0.08$) to increase DMI, but did not affect milk production. Reductions in the digestibility of some nutrients when cows consumed BMRCS-based diet may have been caused by increased DMI and possibly increased digestions in the lower gut. The increase in DMI appeared to have negatively affected N digestibility, but not NDF digestibility. This resulted in a greater amount of N excreted in feces, but did not affect total mass of manure N.

Microbial Protein Synthesis

Efficiency of microbial protein synthesis (EMPS), typically expressed as gram of bacterial N/kg of OM truly fermented in the rumen, might be reduced in diets with long ruminal retention times. As retention time increases, microbial autolysis and predation by protozoa increase, resulting in reduced EMPS (Wells and Russell, 1996). Oba and Allen (2000b) reported that, despite a decrease in ruminal pH, BMRCS increased EMPS, possibly because faster ruminal passage rate reduced microbial turnover. Conversely, lower ruminal pH might have reduced EMPS for BMRCS compared with CCS when DMI, and presumably rate of passage, was not affected by treatment (Greenfield et al., 2001). Because feeding BMRCS often reduces ruminal pH, its potential to increase EMPS might depend on the extent to which ruminal passage rate increases, resulting in a greater amount of N to be excreted into the feces (Gehman et al., 2008).

Weiss and Wyatt (2006) evaluated the effect of corn silage hybrid and metabolizable protein (MP) supply on N metabolism using 8 cows fed low (4.5%) or high concentration (7.1%) of RUP. The different RUP concentrations were achieved by the addition of fish meal and treated soybean meal. Diets contained 55% CCS or BMRCS on DM basis. Increasing the supply of MP greatly increased urine output and tended ($P = 0.13$) to increase total manure output, whereas diets with BMRCS tended ($P = 0.09$) to reduce manure output. At equal N intake, feeding BMRCS reduced N excretion by about 4%. The authors concluded that feeding BMRCS rather than CCS would have the same effect on manure N excretion as would feeding approximately 22 g/d less N. Although cows on the low MP treatments consumed an average of 125 g/d less N than those on the high MP treatments, average ruminal ammonia concentrations were not affected by treatment. Ruminal ammonia concentrations are dependent on supply of RDP and rate of bacterial growth. Oba and Allen (2000b) reported that rumen ammonia concentrations were reduced ($P < 0.09$) when BMRCS was fed, which they attributed to increased bacterial protein synthesis. A similar, albeit weak ($P < 0.15$), trend was observed by Weiss and Wyatt (2006).

Milk Composition

Effects of BMRCS-based diets on milk composition and yield have given mixed results. Several studies have shown no effect on concentration or yield of milk components with BMRCS diets (Tine et al., 2001; Ebling and Kung., 2004; Gehman et al., 2008). In other studies, milk fat yield was not affected by corn silage hybrid, but milk fat percentage was reduced when BMRCS was fed (Oba and Allen, 2000a; Qiu et al., 2003; Weiss and Wyatt, 2006).

Oba and Allen (2000a) conducted a lactation study to test 2 concentrations of dietary NDF with BMRCS and CCS hybrids fed to lactation cows in a 4 × 4 Latin square design with a 2 × 2 factorial arrangement of treatments. The authors observed lower milk fat concentration for cows fed BMRCS diet compared with CCS diet at low (29% DM), but not high (38% DM) NDF concentration. Milk fat concentration was depressed greatly for the BMRCS treatment compared with CCS treatment for the low NDF concentration diet (3.28 vs. 3.67%), but not for the high NDF concentration diet (3.86 vs. 3.90%). However, milk fat yield was similar among treatments (average of 1.24 kg/d). The milk fat depression observed for the BMR treatment in the low NDF concentration diet was hypothesized by the authors to be a dilution effect resulting from a greater rate of milk fluid synthesis relative to milk fat synthesis.

Taylor and Allen (2005b) reported that milk fat percentage was positively correlated with ruminal pH ($r = 0.58$; $P < 0.01$), and ruminal pH was greater for CCS-based diets compared with BMRCS-based diets (6.12 vs. 5.97). The decrease in milk fat concentration by BMRCS-diets might be because of increased ruminal biohydrogenation and lower flux of trans $C_{18:1}$ fatty acids from the rumen with higher ruminal pH (Taylor and Allen, 2005b). Many studies have shown a negative relationship between milk trans $C_{18:1}$ fatty acids and milk fat concentration (Bauman and Griinari, 2003), and higher ruminal pH might result in more complete biohydrogenation of $C_{18:1}$ fatty acids in the rumen. Acetate to propionate ratios of less than 2.0 are often associated with milk fat depression, and a positive relationship exists between ADF concentration and milk fat percentage (Erdman, 1988).

The effects of WPCS processing with CCS-based diets on milk fat are mixed. Bal et al. (2000) reported a 0.07 percentage unit and 0.07 kg/d increases ($P < 0.01$) in milk fat because of WPCS processing. Schwab et al. (2002) reported that processing BMRCS reduced milk fat percentage ($P < 0.01$) and yield ($P < 0.01$) by 0.25% and 0.08 kg/d, respectively. In contrast, Weiss and Wyatt (2006) reported that milk fat concentration in BMRCS-based diets increased by 0.23 percentage unit because of WPCS processing. No increases in milk fat percentage have been reported for an increase in WPCS chop length (Clark and Armentano, 1999; Bal et al., 2000; Schwab et al., 2002).

Several studies have shown no effect on protein and lactose concentration of milk by feeding BMRCS-based diets (Schwab et al. 2002; Taylor and Allen, 2005b; Gehman et al., 2008). However, Oba and Allen (1999a) observed increases in milk protein concentration and yield with cows fed BMRCS diets by 2.4 and 8.1%, respectively, compared with cows fed CCS diets. In a subsequent study, Oba and Allen (2000a) noted increase in milk protein yield for cows fed the BMRCS diet compared with those fed

CCS diet, but not for milk protein concentration. Oba and Allen (2000c) attributed the increased milk protein concentration and yield observed in these two studies to the greater microbial N production in cows fed the BMRCS treatment.

MATERIALS AND METHODS

The dairy cows used in this study were cared for according to the Live Animal Use in Research Guidelines of the Institutional Animal Care and Use Committee at Utah State University (approved protocol number: 1436). The study was conducted at the Caine Dairy Center (Wellsville, UT), Utah State University from November 2009 to February 2010.

Cows and Experimental Diets

Eight multiparous lactating Holstein cows were used; 4 cows were surgically fitted with ruminal cannulas. Days in milk ranged from 26 to 42 d and from 32 to 39 d for noncannulated and cannulated cows, respectively, at the start of the experiment. Average BW was 633 ± 83.6 kg at the beginning of the experiment and 666 ± 80.6 kg at the end of the experiment.

The design of the experiment was a double 4 × 4 Latin square with each period lasting 21 d (14 d of treatment adaptation and 7 d of data collection). The cows were allocated to squares by whether they were surgically cannulated, and the 2 squares were conducted simultaneously. Within square, cows were randomly assigned to a sequence of 4 diets. A 2 × 2 factorial arrangement was used; CCS or BMRCS was combined without or with NFFS to form 4 treatments: CCS-based diet without NFFS (CCS–NFFS), CCS-based diet with NFFS (CCS+NFFS), BMRCS-based diet without NFFS (BMRCS–NFFS), and BMRCS-based diet with NFFS (BMRCS+NFFS) (Table 4). The NFFS consisted of a 50:50 (DM basis) blend of ground soyhulls and pelleted beet pulp to replace a portion of AH and corn silage in the diets. The diets that contained

NFFS had 48.6% forage, 43.0% concentrate, and 8.4% NFFS, and the forage consisted of 48.5% alfalfa hay and 51.5% corn silage on DM basis (Table 4). The diets without NFFS had 57.0% forage and 43.0% concentrate with the forage consisting of 45.5% AH and 54.5% corn silage on DM basis (Table 5). The diets are typical to high producing dairy cows in northern Utah with the inclusion of Rumensin® (Elanco Animal Health, Greenfield, IN) and Megalac® (Church & Dwight Co., Inc., Princeton, NJ). Rations were formulated based on NRC (2001) recommendations to provide sufficient NE_L, protein, vitamins, and minerals to produce 40 kg/d of milk with 3.5% fat and 3.0% true protein.

Brown midrib corn hybrid (Mycogen F2F569, Mycogen Seeds, Indianapolis, IN) and conventional corn hybrid (Pioneer 37K84, Pioneer Hi-Bred International, Inc., Johnston, IA) were planted during spring 2009 on private property near Logan, UT. Corn silages were harvested using a self-propelled forage harvester (model 6850, John Deere, Moline, IL) which applied lactic acid bacteria containing 90,000 cfu/g (Promote® LC, Cargill, Minneapolis, MN) at a rate of 1.1 g/tonne of fresh forage. A theoretical chop length of 0.95 cm was used with mechanical processing during harvesting. Approximately 28 tonnes of each silage was placed in bag silos (Ag/Bag International Ltd., Warrenton, OR) and ensiled for 60 d.

Cows were housed in individual tie stalls fitted with rubber mattresses, bedded with straw, and were fed a TMR for ad libitum intake with at least 10% of daily feed refusal. All cows were individually fed twice daily at 0830 and 1500 h with approximately 70% and 30% of total daily feed allocation at each feeding, respectively. Feed offered and refused was recorded daily, and daily samples were collected to determine DMI. Cows had free access to water.

Table 4. Ingredient and chemical composition of experimental diets

	Experimental diets[1]			
	CCS		BMRCS	
Item	−NFFS	+NFFS	−NFFS	+NFFS
Ingredient, % of DM				
Alfalfa hay	26.0	23.6	26.0	23.6
BMRCS	-	-	31.0	25.0
CCS	31.0	25.0	-	-
Corn, flaked	20.0	20.0	20.0	20.0
Soyhulls	-	4.20	-	4.20
Beet pulp	-	4.20	-	4.20
Canola meal	5.89	5.89	5.89	5.89
Corn DDGS[2]	5.24	5.24	5.24	5.24
Soybean meal, 48% CP	5.04	5.04	5.04	5.04
Molasses	2.10	2.10	2.10	2.10
Megalac®	1.59	1.59	1.59	1.59
Blood meal	1.04	1.04	1.04	1.04
Sodium bicarbonate	0.68	0.68	0.68	0.68
Calcium	0.52	0.52	0.52	0.52
Salt	0.40	0.40	0.40	0.40
Urea	0.30	0.30	0.30	0.30
Magnesium oxide	0.14	0.14	0.14	0.14
Vitamins and trace minerals[3]	0.06	0.06	0.06	0.06
Chemical composition, % of DM				
DM, %	53.9 ± 0.98	55.6 ± 1.14	55.8 ± 2.24	54.4 ± 0.81
OM	91.6 ± 0.17	91.2 ± 0.28	91.5 ± 0.51	91.4 ± 0.19
CP	18.0 ± 1.03	18.1 ± 1.06	18.1 ± 1.06	18.3 ± 1.00
NDF	32.5 ± 2.32	32.4 ± 2.30	32.2 ± 1.21	32.2 ± 2.00
ADF	19.2 ± 1.60	19.7 ± 2.01	19.1 ± 1.37	19.0 ± 1.80
NE_L, Mcal/kg[4]	1.73	1.75	1.85	1.85

[1] CCS−NFFS = conventional corn silage (CCS)-based diet without nonforage fiber sources (NFFS); CCS+NFFS = CCS-based diet with NFFS; BMRCS−NFFS = brown midrib corn silage (BMRCS)-based diet without NFFS; and BMRCS+NFFS = BMRCS-based diet with NFFS.

[2] Dried distillers grains with solubles.

[3] Formulated to contain (per kg DM): 4.75 mg of Se (from sodium selenate), 182 mg of Cu (from copper sulfate), 732 mg of Zn (from zinc sulfate), 10,369 IU of Vitamin A , 1,185 IU of Vitamin D, 150 IU of vitamin E, and 175 mg of Rumensin® (Elanco Animal Health, Greenfield, IN).

[4] Based on tabular value (NRC, 2001).

Cows were milked twice daily at 0400 and 1600 h. Milk production was recorded daily throughout the experiment. Cows were turned outside to a dry-lot for exercise for at least 1 h daily in the morning after being milked. Milk was sampled during the a.m. and p.m. milkings on 2 consecutive days (d 16 to d 17) in each period. Milk samples were preserved with Broad Spectrum Microtabs II (D & F Control Systems Inc., San Ramon, CA), and were stored at 4°C. Individual milk samples were analyzed for fat, true protein, lactose, and MUN by the Rocky Mountain DHIA Laboratory (Logan, UT) with mid-infrared wave-bands (2 to 15 µm) procedures using an infrared instrument (Bentley 2000; Bentley Instruments, Chaska, MN) calibrated weekly using raw milk standards provided by Eastern Laboratory Services (Fairlawn, OH). An enzymatic procedure was used to determine MUN using a Chemspec 150 instrument (Bentley Instruments, Chaska, MN). Milk composition was expressed on weighted milk yield of a.m. and p.m. samples. Milk fat and protein yields were calculated by multiplying milk yield from the respective day by fat and protein content of the milk on an individual cow.

Feed Sampling

Corn silage, chopped AH, and concentrates were sampled weekly to determine DM content. Diets were adjusted weekly to account for changes in DM content. Corn silage samples were collected on d 20 and 21 for particle size analysis by using the Penn State Particle Separator (PSPS) as described by Kononoff et al. (2003) equipped with 3 sieves (19, 8, and 1.18 mm) and a pan. Physical effectiveness factor (pef) for corn silages was calculated as the sum of the proportion of DM retained on 2 sieves, 19 and 8 mm ($pef_{8.0}$;

Lammers et al., 1996). The peNDF content of the corn silage was calculated by multiplying NDF content of the feed (DM basis) by $pef_{8.0}$ ($peNDF_{8.0}$).

Samples of the TMR fed and orts for individual cows were collected daily during the data collection period, dried at 60°C for 48 h, ground to pass a 1-mm screen (standard model 4; Arthur H. Thomas Co., Philadelphia, PA), and stored for subsequent analyses.

Analytical DM content of samples was determined by oven drying at 135°C for 3 h; OM was determined by ashing, and N content was determined using an elemental analyzer (LECO TruSpec N, St. Joseph, MI) (AOAC, 2000). The NDF and ADF contents were sequentially determined using an $ANKOM^{200/220}$ Fiber Analyzer (ANKOM Technology, Macedon, NY) according to the methodology supplied by the company, which is based on the methods described by Van Soest et al. (1991). Sodium sulfite was used in the procedure for NDF determination and pre-treatment with heat stable amylase (Type XI-A from *Bacillus subtilis*; Sigma-Aldrich Corporation, St. Louis, MO). Acid detergent lignin was determined as outlined in AOAC (1990; method no. 973.18, procedure D); the samples were soaked in 12*M* sulfuric acid for 3 h and thoroughly washed with boiling distilled water.

Feed DM and nutrient digestibility was measured during the last week in each period using acid-insoluble ash (AIA) as an internal marker (Van Keulen and Young, 1977). Fecal samples (approximately 100 g, wet weight) were collected for all cows from the rectum once or twice daily at various times for 5 d beginning on d 15. Samples were composited across sampling times for each cow, dried at 60°C for 72 h, ground to pass a 1-mm screen (standard model 4), and stored for chemical analysis. Apparent total tract nutrient digestibilities were calculated from concentrations of AIA and nutrients in diets fed, orts, and feces using the following equation: apparent digestibility = 100 − [100 × (AIA_d/AIA_f) × (N_f/N_d)], where AIA_d = AIA concentration in the diet actually consumed, AIA_f = AIA concentration in the feces, N_f = concentration of the nutrient in the feces, and N_d = concentration of the nutrient in the diet actually consumed.

In Vitro NDF Degradation of Corn Silages

The Daisy II in vitro fermentation system (ANKOM Technology) was used to examine the NDF degradation of corn silages used in the lactation trial. Five hundred milligrams (± 20 mg) of CCS or BMRCS was weighed into artificial fiber bags (#F57, ANKOM Technology), which were then heat-sealed. Ruminal fluid was collected 4 h after the morning feeding (1100 h) from 2 ruminally cannulated, lactating Holstein cows fed a TMR composed of corn silage (22.4%), chopped alfalfa hay (43.2%), rolled corn grain (22.6%), and concentrate (11.8%) on a DM basis. To prepare the ruminal fluid, ruminal contents were obtained from various locations within the rumen and composited. The ruminal contents were placed in sealed containers, transported to the lab, and strained through a polyester screen (pore size 355 μm; B & S H Thompson, Ville Mont-Royal, QC, Canada) under a stream of oxygen-free CO_2. Four hundred milliliters of ruminal fluid (pH of 6.2) was then added to each ANKOM fermentation jar, together with 1,600 mL of anaerobic buffer, and fermentation was allowed to continue for 30 h at 39°C. Bags were removed in quadruplicate (plus one empty bag) at 30 h of incubation, and washed under cold tap water until excess water ran clear. Bags were dried at 55°C for 48 h, and NDF degradation was determined using the same procedure described in feed sampling. The experiment was replicated on four occasions.

Ruminal pH Measurement

Ruminal pH was continuously measured for 2 consecutive days starting on d 18 using the Lethbridge Research Centre Ruminal pH Measurement System (LRCpH; Dascor, Escondido, CA) as described by Penner et al. (2006). Readings in pH buffers 4 and 7 was recorded prior to placing the LRCpH system in the rumen. Ruminal pH readings were taken every 30 s and stored by the data logger. After about 48 h of continuous pH measurement, the LRCpH was removed from the rumen, washed in 39°C water, and millivolt readings were recorded in pH buffers 4 and 7. The daily ruminal pH data was averaged for each minute and summarized as minimum pH, mean pH, and maximum pH. In addition, daily episodes, duration (h/d), and area (pH × min) when ruminal pH was less than 5.8 were calculated. The threshold 5.8 was assigned because it has been defined by others (Nocek, 1997; Maekawa et al., 2002; Beauchemin and Yang, 2005) to cause ruminal acidosis.

Ruminal Fermentation Characteristics

Ruminal contents were sampled from cannulated cows 0, 3, and 6 h after the a.m. feeding on d 20 and 21. Approximately 1 L of ruminal contents was obtained from the anterior dorsal, anterior ventral, medial ventral, posterior dorsal, and posterior ventral locations within the rumen, composited by cow, and strained through a polyester screen (pore size 355 μm). Five milliliters of the filtered ruminal fluid was added to 1 mL of 1% sulfuric acid and samples were retained for ammonia-N (NH_3-N) determination. Concentration of NH_3-N in the ruminal contents was determined as described by Rhine et al. (1998). Another 5 mL of the filtered ruminal fluid was taken at 3 h after the a.m. feeding and added to 1 mL of 25% of meta-phosphoric acid, and the samples were retained for VFA determination. The VFA were quantified using a gas chromatograph (model 5890, Hewlett-Packard Lab, Palo Alto, CA) with a capillary column (30 m × 0.32 mm i.d., 1 μm phase thickness, Zebron ZB-FAAP, Phenomenex, Torrance, CA), and flame-ionization detection. The oven temperature was 170°C held for 4 min, which was then increased by 5°C/min to 185°C, and then by 3°C/min to 220°C, and held at this temperature for 1 min. The injector temperature was 225°C, the detector temperature was 250°C, and the carrier gas was helium.

Statistical Analyses

Data were summarized for each cow by measurement period. All data were statistically analyzed using the mixed model procedure in SAS (SAS Institute, 2001). Data for intake, digestibility, and milk production were analyzed with a model that included the effects of type of corn silage in the diet (CCS vs. BMRCS), group (noncannulated vs. cannulated cows), NFFS (without vs. with NFFS), and the interaction between type of corn silage and NFFS (CS × N). Cow, period, and cow by period by group were the terms of the random statement.

Data for VFA profiles were analyzed with a model that included the type of corn silage, NFFS, and the interaction between type of corn silage and NFFS. Cow and period were the terms of the random statement. Data for NH_3-N concentration were analyzed using the model described above except that the fixed effect of time after feeding was included using the repeated option. The covariance structure that resulted in the lowest values for the Akaike’s information criteria and Schwartz’s Bayesian criterion was used (Littell et al., 1998).

Residual errors were used to test main effects and interactions. Differences were considered significant at $P < 0.05$ and trends were discussed at $P < 0.15$. When the interaction between type of corn silage in the diet and NFFS was $P < 0.15$, contrasts were used to examine the effects of NFFS within type of corn silage. Contrasts were considered significant at $P < 0.05$. Results are reported as least square means.

RESULTS AND DISCUSSION

Table 5 lists the chemical composition of the forages fed during the experiment. On average, BMRCS had slightly higher DM concentration than CCS (35.6 vs. 34.0%). Mean concentrations of CP, NDF, and ADF were similar for the two silages at 7.3, 41.5, and 23.4% on DM basis, respectively. As expected, BMRCS had lower concentration of acid detergent lignin when compared with CCS (1.93 vs. 2.70% on DM basis).

A larger proportion of particles were present on the top screen (> 19 mm) for the CCS (3.2%) when compared with the BMRCS (2.4%; Table 5). A larger proportion of particles also remained on the middle screen (> 8 mm) for the CCS (79.4%) than for the BMRCS (76.1%). Thus, a smaller proportion of particles remained on the bottom screen (> 1.18 mm) for CCS (17.4%) than for the BMRCS (21.5%). Consequently, $pef_{8.0}$ and $peNDF_{8.0}$ were slightly higher for the CCS than the BMRCS.

Table 5. Chemical composition and particle size distribution of forages

	Forages[1]		
Item	CCS	BMRCS	Alfalfa hay
Chemical composition			
DM, %	34.0 ± 1.54	36.0 ± 1.11	90.0 ± 1.31
OM, % of DM	99.3 ± 0.93	98.4 ± 0.42	98.1 ± 0.88
CP, % of DM	7.36 ± 0.452	7.24 ± 0.330	21.3 ± 1.22
NDF, % of DM	41.2 ± 2.93	41.7 ± 2.92	38.3 ± 1.22
ADF, % of DM	23.4 ± 2.30	23.3 ± 2.96	26.7 ± 1.60
ADL[2], % of DM	2.70 ± 0.423	1.93 ± 0.330	ND[3]
Particle size distribution[3]			
19 mm	3.2 ± 0.93	2.4 ± 0.64	ND
8 mm	79.4 ± 1.72	76.1 ± 1.53	ND
1.18 mm	17.4 ± 1.20	21.5 ± 0.97	ND
Pan	0	0	ND
$pef_{8.0}$	82.6	78.5	ND
$peNDF_{8.0}$	34.0	32.7	ND

[1] CCS = conventional corn silage; BMRCS = brown midrib corn silage.
[2] ADL = acid detergent lignin.

[3] Particle size distribution was expressed as % DM retained on sieves using the Penn State Particle Separator (Kononoff et al., 2003). $pef_{8.0}$ = physical effectiveness factor determined as the proportion of particles retained on top 2 sieves (Lammers et al., 1996). $peNDF_{8.0}$ = physically effective NDF determined as NDF concentration (% DM) of corn silage multiplied by $pef_{8.0}$.

[3] Not determined.

Using corn silages, in vitro NDF degradability after 30 h of incubation was markedly higher for the BMRCS than the CCS (42.2 vs. 31.2%; Figure 1).

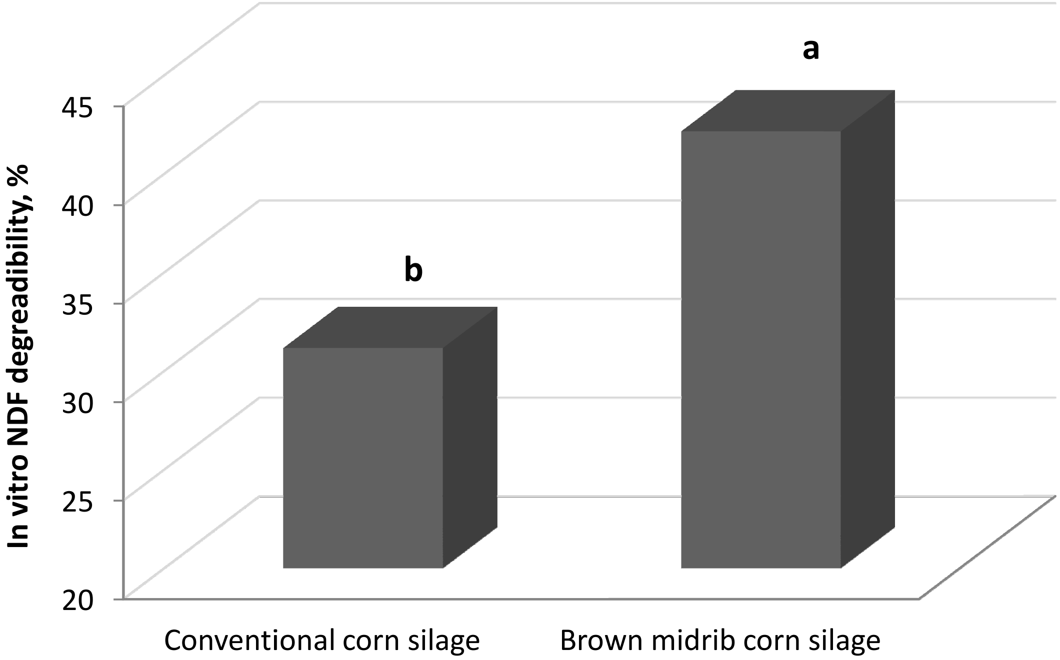

Figure 1. In vitro NDF degradability of corn silages used in lactation trial after 30 h of incubation with ruminal fluid (n = 4 for each mean). Bars within each corn silage having a different letter differ ($P < 0.05$; SE = 3.15).

The ingredients and chemical composition of experimental diets are listed in Table 4. Concentrations of CP, NDF, and ADF were similar across all dietary treatments. Two different forage levels were used for diets without or with NFFS being 57 or 48.6%, respectively. Diets with NFFS (CCS+NFFS and BMRCS+NFFS) had lower levels of corn silage and AH than diets without NFFS (CCS−NFFS and BMRCS−NFFS) (25.0 vs. 31.0% and 23.6 vs. 26.0% on DM basis, respectively).

Intake of DM averaged 26.8 kg/d across all treatment diets, and it was not affected by diets (Table 6). Additionally, source of corn silage and NFFS did not influence intake of OM, N, NDF, and ADF. Digestibilities of DM and OM were similar in response to diets. However, digestibilities of N ($P = 0.11$), NDF ($P = 0.14$), and ADF ($P = 0.06$) tended to increase by 2.8, 6.9, and 10.0%, respectively, by feeding the CCS-based diet compared with the BMRCS-based diet. Feeding NFFS did not affect the digestibilities.

Table 6. Nutrient intake and total tract digestibility of early lactation Holstein dairy cows fed conventional or brown midrib corn silage without or with nonforage fiber sources

	Diets[1]							
	CCS		BMRCS			Significance of effect[2]		
Item	−NFFS	+NFFS	B−NFFS	B+NFFS	SE	CS	N	CS × N
Intake, kg/d								
DM	26.5	26.2	27.7	26.6	1.43	0.20	0.27	0.56
OM	23.2	24.5	25.0	24.3	1.36	0.44	0.75	0.39
N	0.75	0.79	0.80	0.78	0.050	0.53	0.69	0.41
NDF	8.10	8.59	8.56	8.38	0.566	0.72	0.66	0.36
ADF	4.75	5.25	5.04	4.98	0.375	0.96	0.30	0.21
Digestibility, %								
DM	72.9	74.1	72.5	71.0	2.29	0.26	0.92	0.40
OM	74.3	75.1	73.9	72.5	2.27	0.32	0.82	0.47
N	75.7	76.8	74.7	73.7	1.73	0.11	0.94	0.40
NDF	53.0	54.8	51.4	49.4	3.75	0.14	0.96	0.42
ADF	49.9	53.2	48.2	45.6	4.12	0.06	0.88	0.23

[1] CCS−NFFS = conventional corn silage (CCS)-based diet without nonforage fiber sources (NFFS); CCS+NFFS = CCS-based diet with NFFS; BMRCS−NFFS = brown midrib corn silage (BMRCS)-based diet without NFFS; and BMRCS+NFFS = BMRCS-based diet with NFFS.

[2] CS = type of corn silage in the diet (conventional vs. brown midrib corn silage), N = nonforage fiber sources (without vs. with nonforage fiber source), and CS × N = interaction between CS and N.

Milk yield averaged 42.3 kg/d across all treatment diets, and it was not influenced by source of corn silage or NFFS (Table 7). Feeding NFFS to the CCS-based diet did not affect milk yield, whereas NFFS tended (*P* = 0.09) to increase milk yield when fed in the BMRCS-based diet, resulting in a tendency for a CS × N interaction (*P* = 0.06). Yields of milk fat and 3.5% FCM decreased by feeding the BMRCS-based diet. Diets did not affect milk protein yield. Feeding the BMRCS-based diet decreased milk fat concentration, and it was further decreased by feeding NFFS in the BMRCS-based diet, causing a tendency for a CS × N interaction (*P* = 0.07).

Table 7. Milk production and composition and efficiencies of DM and N use for milk production of early lactation Holstein dairy cows fed conventional or brown midrib corn silage without or with nonforage fiber sources

	Diets[1]							
	CCS		BMRCS			Significance of effect[2]		
Item	−NFFS	+NFFS	−NFFS	+NFFS	SE	CS	N	CS × N
Yield, kg/d								
Milk	42.6	41.5	41.6	43.3	2.14	0.53	0.64	0.06
Fat	1.23	1.24	1.13	1.04	0.110	< 0.01	0.25	0.20
Protein	1.18	1.19	1.17	1.21	0.070	0.69	0.23	0.34
Lactose	1.99	1.96	1.96^{b}	2.06^{a}	0.112	0.20	0.14	0.02
3.5% FCM	38.6	38.1	36.4	35.6	2.55	0.01	0.43	0.84
Milk composition, %								
Fat	2.91	2.97	2.71^{a}	2.40^{b}	0.203	< 0.01	0.19	0.07
Protein	2.80	2.84	2.82^{a}	2.78^{b}	0.039	0.17	0.82	0.04
Lactose	3.55	3.53	3.48^{b}	3.69^{a}	0.199	0.48	0.20	0.11
MUN, mg/dL	15.7	15.5	15.0	15.3	0.44	0.16	0.93	0.42
Efficiency								
Milk/DMI	1.62	1.55	1.55^{b}	1.63^{a}	0.058	0.79	0.77	< 0.01
3.5% FCM/DMI	1.47	1.41	1.34	1.33	0.059	< 0.01	0.26	0.31
Milk N/N intake[3]	0.26	0.26	0.26	0.27	0.014	0.96	0.76	0.26

[a,b] Means in the same row within CCS and BMRCS subgroups with different superscripts differ based on single degree of freedom contrasts ($P < 0.05$).

[1] CCS−NFFS = conventional corn silage (CCS)-based diet without nonforage fiber sources (NFFS); CCS+NFFS = CCS-based diet with NFFS; BMRCS−NFFS = brown midrib corn silage (BMRCS)-based diet without NFFS; and BMRCS+NFFS = BMRCS-based diet with NFFS.

[2] CS = type of corn silage in the diet (conventional vs. brown midrib corn silage), N = nonforage fiber sources (without vs. with nonforage fiber source), and CS × N = interaction between CS and N.

[3] Efficiency of use of feed N to milk N = ((milk true protein, kg/d ÷ 0.93) ÷ 6.38) ÷ N intake, kg/d.

Source of corn silage did not change concentrations of milk protein and lactose. However, feeding NFFS in the BMRCS-based diet decreased milk protein concentration, whereas NFFS in the BMRCS-based diet increased milk lactose concentration, resulting in an CS × N interaction or its tendency ($P = 0.11$), respectively. Concentration of MUN was not affected by diets.

Source of corn silage and NFFS did not affect feed efficiency expressed as milk yield per DMI (Table 7). However, NFFS in the CSS-based diet tended to decrease ($P = 0.08$) the feed efficiency, while NFFS in the BMRCS-based diet increased the feed efficiency, leading to an interaction of CS × N. The BMR-based diet increased feed efficiency when expressed as 3.5% FCM per DMI, but there was no effect due to NFFS. Dietary treatments did not influence efficiency of use of feed N to milk N.

Total VFA production and individual molar proportions were not affected by diets (Table 8). Concentration of NH_3-N tended ($P = 0.10$) to decrease due to feeding the BMRCS-based diet, which resulted from decreased NH_3-N by NFFS. Dietary treatments did not influence ruminal pH profiles (Table 9), except that duration of pH < 5.8 was reduced by feeding NFFS in the CCS-based diet, resulting in a tendency for a CS × N interaction ($P = 0.07$).

Table 8. Ruminal fermentation characteristics of early lactation Holstein dairy cows fed conventional or brown midrib corn silage without or with nonforage fiber sources

	Diet[1]							
	CCS		BMRCS			Significance of effect[2]		
Item	−NFFS	+NFFS	−NFFS	+NFFS	SE	CS	N	CS × N
Total VFA, m*M*	135.3	136.8	139.9	134.5	10.2	0.86	0.78	0.66
Individual VFA[3]								
Acetate (A)	54.0	52.1	51.9	51.7	2.87	0.27	0.41	0.48
Propionate (P)	27.9	27.9	28.4	28.4	2.16	0.46	0.98	1.00
Butyrate (B)	12.8	13.3	14.3	13.1	0.90	0.25	0.59	0.17
Valerate	2.91	2.82	3.10	3.31	0.778	0.23	0.83	0.61
Isobutyrate	1.10	1.36	1.11	1.52	0.800	0.79	0.33	0.79
Isovalerate	1.13	1.64	1.51	1.54	0.766	0.75	0.58	0.61
A:P	2.02	1.94	1.89	1.85	0.243	0.28	0.63	0.85
(A + B):P	2.48	2.45	2.38	2.33	0.292	0.35	0.73	0.91
NH_3-N, mg/dL	9.58	9.88	9.03	7.36	1.687	0.10	0.50	0.33

[1] CCS−NFFS = conventional corn silage (CCS)-based diet without nonforage fiber sources (NFFS); CCS+NFFS = CCS-based diet with NFFS; BMRCS−NFFS = brown midrib corn silage (BMRCS)-based diet without NFFS; and BMRCS+NFFS = BMRCS-based diet with NFFS.

[2] CS = type of corn silage in the diet (conventional vs. brown midrib corn silage), N = nonforage fiber sources (without vs. with nonforage fiber source), and CS × N = interaction between CS and N.

[3] Expressed as mol/100 mol.

Table 9. Ruminal pH profiles of early lactation Holstein dairy cows fed conventional or brown midrib corn silage without or with nonforage fiber sources

	Diet[1]							
	CCS		BMRCS			Significance of effect[2]		
Item	−NFFS	+NFFS	−NFFS	+NFFS	SE	CS	N	CS × N
Minimum pH	5.70	5.72	5.73	5.73	0.118	0.50	0.70	0.59
Mean pH	6.39	6.23	6.33	6.26	0.107	0.86	0.15	0.55
Maximum pH	7.28	7.08	6.86	7.14	0.185	0.38	0.84	0.25
pH < 5.8								
Daily episodes	19.5	12.8	10.8	30.8	8.96	0.64	0.51	0.21
Duration, h/d	3.53[a]	1.11[b]	0.87	2.37	1.044	0.48	0.64	0.07
Area, pH × min	13.1	7.42	1.04	10.6	6.549	0.55	0.79	0.31

[a,b] Means in the same row within CCS and BMRCS subgroups with different superscripts differ based on single degree of freedom contrasts ($P < 0.05$).

[1] CCS−NFFS = conventional corn silage (CCS)-based diet without nonforage fiber sources (NFFS); CCS+NFFS = CCS-based diet with NFFS; BMRCS−NFFS = brown midrib corn silage (BMRCS)-based diet without NFFS; and BMRCS+NFFS = BMRCS-based diet with NFFS.

[2] CS = type of corn silage in the diet (conventional vs. brown midrib corn silage), N = nonforage fiber sources (without vs. with nonforage fiber source), and CS × N = interaction between CS and N.

Characteristics of BMRCS and Experimental Diets

Reduced lignin concentration in BMRCS has been the most unique nutritive benefit, as it can increase NDF digestibility in vivo. In this study, concentration of lignin was reduced by 28.5% in BMRCS compared with CCS, and in vitro NDF degradability of BMRCS increased by 25.7%. The BMR corn hybrids have little impacts on the concentrations of CP, NDF, ADF, and ash in corn plants (Weller et al., 1984). Allen et al. (1997) reported that the BMR mutation in corn hybrids decreased lignin concentration by 1.1 unit percentages and increased in vitro NDF degradability after 30 h of incubation by 8.4 unit percentages compared with isogenic controlled hybrids with no effect on the NDF concentration of corn silage. Eastridge (1999) reported that lignin concentration was quite variable among BMR hybrids because of the different methods of analysis and variability within a method. Eastridge (1999) also reported that on average, BMRCS contained 34% less lignin and had 19% higher in situ or in vitro NDF degradability compared with non-BMR hybrids. Ebling and Kung (2004) reported a greater difference (55%) in the concentration of lignin and a higher increase (38%) in in vitro NDF degradability. In agreement with the data summarized by Eastridge (1999), we found no differences in nutrient components between CCS and BMRCS. In addition, although particle size distributions between CCS and BMRCS had different patterns, having slightly lower peNDF in BMRCS than CCS, the particle size estimates of both corn silages are within the recommendation by Kononoff et al. (2003).

Cows used in this study were fed a lower concentration of corn silages (25 and 31% DM) with higher concentrations of AH (23.6 and 26% DM) than diets fed in previous studies done with BMRCS (Taylor and Allen, 2005a; Weiss and Wyatt, 2006; Kung et al., 2008). What made our study unique was to consider typical lactating dairy diets in the intermountain west containing high concentrations of AH with corn silage. Only a couple of studies published with BMRCS included any AH in the diets at all; for example, Ebling and Kung (2004) fed 8% AH with 45% BMRCS and 10% alfalfa silage on DM basis, and in another study, Kung et al. (2008) fed 5% AH with 45% BMRCS and 5% alfalfa silage on DM basis. Other studies fed 31 to 60% BMRCS (DM basis), and alfalfa silage concentrations ranged from 10 to 12% with no AH in the diet at all.

The high quality AH used in our study was clean, bright green, and fine stemmed with a chemical composition of 21.3, 38.3, and 26.7% DM for CP, NDF and ADF, respectively (Table 5). Kung et al. (2008) used medium quality AH (16.8, 43.9, and 36.8% DM for CP, NDF, and ADF, respectively) in BMRCS TMR diets. Therefore, digestive and nutritive contribution by AH in the current study would be relatively high due to its large dietary concentration as well as high nutritive quality.

Nutrient Intake and Digestibility

Due to the sizable increase of in vitro NDF degradability of BMRCS (Figure 3-1), we expected that the BMRCS-based diet would improve DMI and nutrient digestibilities. However, we did not detect any response on intake of DM and nutrients. Rather, BMRCS in TMR tended to decrease ($P < 0.15$) N and fiber digestibilities. The negative impacts of BMRCS on the digestibilities were unexpected, highlighting the weaknesses of in vitro technique to predict in vivo response. Oba and Allen (2000b) reported that BMRCS TMR did not increase ruminal or total tract NDF digestibility. Additionally, Taylor and Allen (2005a) reported that, although in vitro NDF degradability was 12.6 percentage units higher for BMRCS, in vivo ruminal and postruminal NDF digestibility of BMRCS TMR did not increase. These results suggest that although in vitro NDF degradability can be improved by BMRCS, in vivo response depends upon integration of several factors; for instance, DMI and ruminal passage rate are important in determining ruminal residence time, influencing ruminal digestion. Therefore, mixed results from in vitro and in vivo experiments make it difficult to formulate any accurate predictions for animals fed BMRCS (Taylor and Allen, 2005a).

The mechanism whereby BMRCS TMR diets decreased N and fiber digestibility is difficult to explain. It is probable that greater passage of substrate from the rumen in the BMRCS-based diets may have increased hindgut fermentation and decreased apparent total tract N and fiber digestibilities (Taylor and Allen, 2005a). Another possibility may be the effects of the high quality of AH; relatively high nutritive quality of AH with chopping may increase passage rate, diluting potential effects of BMRCS in ruminal digestion as was seen in increased in vitro NDF degradability depicted in Figure 1.

Feeding NFFS in our dietary treatments did not affect intake and digestibility. Partial replacement of forage with NFFS resulted in similar ruminal NDF digestibility when diets contained equal NDF concentration (Cunningham et al., 1993; Feng et al., 1993; Van Vuuren et al., 1993). The NDF in NFFS has been considered to be of higher digestibility than that of forage NDF, and total tract NDF digestibility increased when soyhulls replaced forage or concentrate (Sarwar et al., 1991, 1992; Cunningham et al., 1993). However, if NFFS have a lower undigestible NDF fraction compared to forages, the amount of potentially degradable NDF leaving the rumen may be greater when NFFS replace forage (Pantoja et al., 1994; Bhatti and Firkins, 1995). In our case, we believe that high forage NDF concentration may eliminate potentially positive effects of NFFS. Forage NDF concentration in our study was 21.2 and 17.9%, respectively for diet without and with NFFS, and the forage NDF contributed to 65 and 55% of dietary NDF. Replacing forage NDF with NFFS for $\mathrm{pef}_{8.0}$ may vary with changing forage chop length and fiber level or composition. As the mean particle length or NDF content of the forage increases, ruminal retention time and forage mat formation in the rumen increase, which may slow the passage rate of NFFS, thus enhancing fiber digestibility (Clark and Armentano, 1997). However, it seems that the positive effects of NFFS may be ineffective when diets contain appropriate forage or dietary NDF such as the high quality forage diets used in our study. When feeding forage NDF under 19% DM, the NRC (2001) recommends increasing total dietary NDF by 2 percentage units for every 1 percentage unit decrease below 25% DM of total dietary NDF, and all diets tested in this study are within the NRC recommendation.

Milk Production and Composition and Feed Efficiency

Due to lack of effects of BMRCS TMR on intake and digestibility, we did not expect any positive effects due to feeding BMRCS TMR on milk production and feed efficiency. Productive performance of BMRCS diets have been inconsistent; milk yield and FCM yield were greater for cows consuming BMRCS TMR than those fed CCS TMR (Tine et al., 2001; Ebling and Kung, 2004; Weiss and Wyatt, 2006), whereas increased production has not been observed in other studies (Greenfield et al., 2001; Qiu et al., 2003; Gehman et al., 2008).

In previous studies, yield of milk fat was not affected by corn silage hybrid, but milk fat percentage was reduced when BMRCS was fed in some studies (Oba and Allen, 2000a; Qiu et al., 2003; Weiss and Wyatt, 2006). Oba and Allen (2000a) observed an interaction between concentration of dietary NDF and corn silage hybrid for milk fat percentage; milk fat concentration was reduced when BMRCS was included in diets with 28% NDF, but was not affected when diets contained 38% NDF. Milk fat depression due to low ruminal pH and acetate to propionate ratio is expected from cows consuming lower forage and diets of shorter particle size as observed by Grant et al. (1990) and Fischer et al. (1994). Diets in the present study contained approximately 32% NDF meeting NRC (2001) requirements, and mean ruminal pH was 6.2, indicating that all diets were adequate to maintain normal ruminal fermentation. However, the CCS-based diets produced an average of 0.15 kg/d more milk fat than the BMRCS-based diets. Therefore, lower peNDF of BMRCS and possibly resultant lower peNDF of the BMRCS-based diets may decrease milk fat concentration and yield.

Low milk fat concentration (2.75% on average) in the current study is noticeable. Fracturing the corn kernels in CS has been shown to improve starch digestibility (Bal et al., 2000; Weiss and Wyatt, 2006), and both CCS and BMRCS were mechanically processed prior to ensiling. The processed CS may enhance ruminal starch digestion, leading to lower acetate to propionate ratio. The acetate to propionate ratios of less than 2.0 are often associated with milk fat depression (Erdman, 1988), and in our study the ratio averaged 1.93.

There is limited information in the scientific literature on the effects of feeding a mixture of soyhulls and beet pulp as NFFS on milk production by dairy cows. Clark and Armentano (1997) reported increased milk yield, milk protein yield, and milk protein percentage, but lower milk fat percentage and fat yield for cows fed low forage diets (30% forage) with NFFS (mixture of whole cottonseed, distillers grains, and wheat middlings) than for cows fed high forage diets (60% forage). In the low forage diets, DMI, milk fat percentage, and milk fat yield all increased linearly as NDF concentration increased. Adding NDF from NFFS increased milk fat percentage and yield, but this increase was less than that expected compared to the increase of NDF from alfalfa silage. Pereira et al. (1999) reported that NFFS (mixture of wheat middlings, distillers grains, and corn gluten feed) were only 27% as effective as NDF from alfalfa silage in eliciting a milk fat concentration response. Hence, NFFS used in this study (8.4% DM) were not effectively used to affect milk composition due to high forage NDF. Rather, the NFFS exerted a negative impact on milk fat concentration when added in the BMRCS-based diet.

Rumen Fermentation Characteristics

In general, we did not find major impacts of feeding BMRCS TMR on ruminal fermentation. In previous studies, BMRCS has inconsistent effects on the proportion of acetate and propionate in the rumen. In some studies (Block et al., 1981; Taylor and Allen, 2005c), BMRCS TMR reduced the acetate to propionate ratio in the rumen compared with CCS TMR by decreasing the molar proportion of acetate and increasing propionate proportion. In contrast, BMRCS TMR did not affect molar proportion of acetate (Oba and Allen, 2000a; Greenfield et al., 2001), and only increased molar proportion of propionate in the experiment by Greenfield et al. (2001). Ruminal pH was similar among treatments in our study, but others reported that BMRCS TMR decreased ruminal pH (Oba and Allen, 2000a; Greenfield et al., 2001; Taylor and Allen, 2005c). In our study, minimum ruminal pH was maintained at least at 5.70, and pH less than 5.8 hardly occurred, signifying that all dietary treatments did not interfere with ruminal fermentation due to adequate supply of forage NDF and its particle size. Early lactation diets often contain high levels of fermentable carbohydrate and low levels of fiber to maximize energy intake. However, feeding a high concentrate diet typically results in reduced ruminal pH and subsequent dysfunctions of ruminal fermentation. High quality forages, particularly AH, used in the current study would provide efficient ruminal fermentation and digestibility. High quality AH is lower in NDF concentration and may not be adequate for milk fat production, but generally is thought to stimulate adequate rumination and saliva production and provide adequate natural buffering capacity to reduce the need for dietary buffers (Eickelberger et al., 1985). Experimental cows in this study maintained overall productive performance without any negative response on ruminal fermentation and digestibility, although we fed high forage diets to the early lactating dairy cows. Further research is needed on the effects of BMRCS and NFFS in high concentrate lactating diets that induce subacute ruminal acidosis to determine if they contribute to reducing the metabolic risk and maintain optimal ruminal fermentation in dairy cows.

Similar to our findings, Pereira and Armentano (2000) reported that the addition of NFFS had no effect on the ratio of acetate to propionate or total VFA concentration when

NFFS was used to replace a portion of forage and concentrate at 17.2 and 20% DM, respectively.

CONCLUSIONS

As we hypothesized, feeding BMRCS compared to CCS had limited impacts on intake, digestibility, and milk production when fed in high forage diets comprised of high quality AH. When fed with BMRCS, feeding NFFS increased feed efficiency (milk/DMI), whereas NFFS decreased milk fat concentration. Feeding NFFS did not affect any productive performance parameter when fed in CCS diet. Feeding different corn silage hybrids without or with NFFS resulted in similar ruminal fermentation patterns without any adverse effects on ruminal pH, indicating that total NDF and forage NDF concentrations were adequate to maintain normal ruminal fermentation. On the other hand, high quality AH and forage NDF concentration beyond NRC recommendation (2001) may dilute effects of corn silage hybrids and NFFS. However, one should be cautious on low milk fat concentration in this study. Although it is unclear why cows fed the highly nutritive quality diets had low milk fat concentration, it may be resulted from low NDF concentration of the AH and overall smaller particle size due to fine chopping of AH, possibly causing increased passage rate, decreasing ruminal digestion, and increasing hindgut fermentation of our experimental diets. Further research is needed to investigate the effect of high quality AH, chop length, and interaction with corn silage to determine optimal dietary proportion in lactating diets for milk production and components. In addition, it is warranted to investigate the effects of BMRCS and NFFS in high concentrate lactating diets by inducing subacute ruminal acidosis to measure the contribution of BMRCS to reducing metabolic risk and maintaining optimal ruminal fermentation in dairy cows.

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