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Brown Midrib Sorghum Silage for Midlactation Dairy Cows[1]

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ABSTRACT

Brown midrib sorghum silage was compared with alfalfa, corn, and normal sorghum silages for its effect on performance, ruminal metabolism, and digestive kinetics of Holstein dairy cows in midlactation. Twelve cows averaging 90 ± 5 DIM were assigned to one of four diets in replicated 4 × 4 Latin squares with 4-wk periods. Additionally, 3 ruminally fistulated cows (95 ± 20 DIM) were assigned to the same diets in a 3 × 4 Youden square for measurement of ruminal characteristics. Diets were fed as isonitrogenous TMR that contained 65% silage (DM basis). The DMI was greater for the corn and brown midrib sorghum (4% of BW/d) than for the alfalfa and normal sorghum diets (3.4% of BW/d). The brown midrib sorghum supported FCM production that was similar to that of cows on corn and alfalfa diets (25.8 kg/d), but cows fed normal sorghum produced less milk and fewer milk components. Source of silage had no effect on eating time, but rumination was least for the alfalfa diet. Ruminal pH and ammonia concentrations were similar for all diets. Total VFA concentrations were greatest for the corn and brown midrib sorghum diets. The brown midrib sorghum had greater in situ extent of ruminal NDF digestion than did the normal sorghum, which agreed with in vitro data. The brown midrib sorghum used in this experiment supported FCM production similar to the corn and alfalfa silages commonly fed to dairy cows in midlactation.

(**Key words**: sorghum, brown midrib, lactation, digestion)

Abbreviation key: **BMR** = brown midrib.

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench.] has become an increasingly important forage crop for dairy producers in the midwestern and plains region of the US. In Kansas and Nebraska alone, nearly 102,000 ha of sorghum were harvested for silage in 1992, producing approximately 2,500,000 tonnes of silage [as fed (21)]. Forage sorghum can be planted later than corn (*Zea mays* L.), uses water much more efficiently, and, when exposed to summer drought, still produces acceptable silage yields.

Most comparisons of forage sorghum with corn have shown that cows fed sorghum consume less digestible DM and produce less milk (14). Very little research concerning brown midrib (**BMR**) sorghum has been conducted with lactating cows. Lusk et al. (16) found no significant difference between cows fed BMR sorghum and normal corn silages in DM digestibility and milk production. In addition, Broderick (2) concluded that high quality al-

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falfa (*Medicago sativa* L.) silage is comparable with corn silage for milk production. However, no research has compared BMR sorghum silage with corn and alfalfa silages, the two most common forages for lactation diets in the midwestern US.

Previous research has compared the digestibility of BMR mutant sorghums and their normal counterparts (4). With the current diversity of available sorghum hybrids significant differences in NDF digestibility exist among sorghum hybrids. The objective of this research was to compare simultaneously a typical normal sorghum silage with an advanced BMR sorghum hybrid, corn, and alfalfa silages. Measurements included lactational performance, chewing activity, ruminal metabolism, and fiber digestibility determined in vitro and in situ.

MATERIALS AND METHODS

Forage Harvesting and Ensiling

All forages for this experiment were harvested during summer 1992 at Mead, Nebraska. Second-cutting alfalfa (Agripro Dart; Agripro Seeds, Shawnee Mission, KS) was harvested in the bud stage. A uniform stand of alfalfa was cut with a mower-conditioner and allowed to wilt to approximately 40% DM prior to ensiling. Knives on the field chopper were adjusted to a .64-cm theoretical length of cut. Alfalfa yielded 10,086 kg/ha (DM basis).

Corn silage (Hoegemeyer 2715; Hoegemeyer Hybrids, Inc., Hooper, NE) was harvested at physiological maturity (35% DM) using a field chopper with knives adjusted to a 1-cm theoretical length of cut. Corn silage yielded 12,551 kg/ha (DM basis).

The normal and BMR forage sorghums were grown in adjacent 1.6-ha fields. The normal and BMR sorghum hybrids (Greentreat II and SSX87; Vista Seeds, Webster City, IA) were harvested at the late dough stage of maturity (30% DM). The sorghum hybrids were harvested using a field chopper with knives adjusted to a 1-cm theoretical length of cut. Both sorghums yielded 16,000 kg/ha (DM basis). No differences in lodging between the two hybrids were noted at harvest.

All four forages were ensiled in separate silage bags prior to the lactation experiment.

Cows and Treatments

Twelve Holstein cows, averaging 90 DIM (± 5 SD), were assigned randomly to one of four diets in replicated 4 × 4 Latin squares with 4-wk periods to measure DMI and milk production. Additionally, 3 ruminally fistulated Holstein cows (95 ± 20 DIM) were assigned randomly to the same diets in a 3 × 4 Youden square design (5) with 4-wk periods to measure ruminal digestion, passage of fiber, and concentrations of VFA and ammonia. All cows used in this experiment were fistulated and housed under conditions described in animal use protocols approved by the Institutional Animal Care and Use Committee at the University of Nebraska.

Dietary treatments were 1) alfalfa silage, 2) corn silage, 3) BMR sorghum silage, and 4) normal sorghum silage as the sole dietary forage. All diets contained 65% silage (DM basis) and 35% of a concentrate mixture comprising soybean meal, dry rolled corn, and a mineral and vitamin premix (Table 1). Diets were formulated to be isonitrogenous (17.0% CP in DM) and fed as TMR twice daily in amounts to ensure 10% orts. Cows were housed in a tiestall barn equipped with individual feed boxes and were removed twice daily for milking, exercise, and estrus detection for a total of 5 to 6 h daily.

Sample Collection and Analysis

Samples of silages and TMR were composited weekly for analyses. Silage pH was measured weekly on fresh silage samples, and fermentation acids (acetic, propionic, butyric, and lactic) were determined on 4-wk composite samples using the procedures described by Moon et al. (18). Weekly composite samples of silages and TMR were oven-dried (60°C), ground through a Wiley mill (1-mm screen; Arthur H. Thomas Co., Philadelphia, PA), and analyzed for CP (1), NDF modified by α-amylase (26), ADF (26), and permanganate lignin (26). Alkali-labile phenolic monomers, released from neutral detergent residues of each silage using 1 *M* NaOH, were extracted and quantified using procedures described by Fritz et al. (9). Neutral sugars were also quantitated using the procedures described by Fritz et al. (9). A vertically oscillating sieve shaker (W. S. Tyler, Inc., Mentor, OH) was used to deter-

TABLE 1. Ingredient and nutrient composition of experimental diets.

Item	Normal sorghum	BMR[1] Sorghum	Alfalfa	Corn
	(% of DM)			
Ingredient				
Normal sorghum silage	65.0	...	...	...
BMR Sorghum silage	...	65.0	...	...
Alfalfa silage	...	...	65.0	...
Corn silage	...	...	...	65.0
Soybean meal, 44% CP	21.5	21.5	...	21.5
Shelled corn	10.7	10.7	32.1	10.7
Mineral-vitamin mixutre[2]	2.8	2.8	2.9	2.8
Composition				
DM, %	51.4	51.3	57.0	59.0
CP	16.9	16.9	17.4	17.0
RUP[3]	5.4	5.4	5.4	5.6
ADF	31.0	30.0	21.9	20.8
NDF	41.6	40.0	30.3	40.1

[1]Brown midrib.

[2]A mineral and vitamin mixture was added to all diets to meet or slightly exceed nutrient requirements of NRC (20).

[3]Calculated using values of NRC (20).

mine particle distributions of the dried silages. Mean particle size was calculated for each silage from the particle distributions (12).

Daily milk production was recorded electronically for all cows. Composite a.m. and p.m. milk samples were collected twice during wk 4 of each period and analyzed for percentage of fat, protein, and lactose (Milko-Scan Fossomatic; Foss Food Technology Corp., Eden Prairie, MN). Calculation of milk composition was weighted according to a.m.-p.m. milk production. Body weight was measured weekly immediately after the a.m. milking.

Total chewing, eating, and ruminating times were determined during wk 4 of each period for all cows. The chewing action of individual cows was observed and recorded every 5 min during 24 h. Although not an absolute measurement, this method of scan sampling has yielded reliable estimates given the short interval between observations (30). Chewing activity (minutes per kilogram of NDF intake) was calculated.

Samples of ruminal fluid were collected during wk 4 of each period from ruminally fistulated cows at 4-h intervals for 24 h. The pH of ruminal fluid was measured immediately using a portable pH meter, and concentrations of VFA were determined by GLC (7). The VFA samples were analyzed using a gas chromatograph (model 5890; Hewlett Packard, Wilmington, DE) with a 2-mm i.d. column that was 2.4 m in length and packed with SP 1200 (Supelco, Inc., Bellefonte, PA). The rate of N_2 flow was 20 ml/min, injection temperature was 170°C, column temperature was 120°C, and the flame ionization detector temperature was 200°C. Ruminal ammonia concentration was determined according to the procedure of Broderick and Kang (3), using an autoanalyzer.

Fractional rate of NDF digestion of each silage was measured using the in situ bag technique in which dacron bags containing 5 g of substrate were incubated in triplicate within the rumen of each cow for 0, 6, 12, 24, 36, 48, 72, and 96 h. Dacron bags (Ankom, Fairport, NY) were 10 cm × 20 cm with a mean pore size of 53 μm. Prior to ruminal incubation, dried silage samples were ground through a 2-mm screen using a Wiley mill. After removal from the rumen and rinsing (29), all bags were dried at 60°C and weighed. Contents were analyzed for ash-free NDF (26), and values within time were pooled. The kinetics of NDF digestion and apparent extent of ruminal fiber digestion were calculated as described by Grant (11).

Fractional passage rate of each silage from the rumen was determined using a rare earth marker. Each silage was soaked directly in a solution containing 50 mg of Er-acetate/g of DM in 5 to 10 ml of distilled water for 24 h and then soaked in 10 ml of .1 *M* acetic acid/g of DM for 6 h. Each fistulated cow consumed 100 g (DM basis) of labeled silage containing 260 mg of Er at the a.m. feeding. Ruminal digesta samples were collected from the ruminal mat at 0, 6, 12, 24, 36, 48, 72, and 96 h postdosing. The samples were dried in a forced-air oven at 60°C to constant weight and ground through a 1-mm screen using a Wiley mill. Erbium concentration for each silage and time combination was determined with an air-acetylene flame using atomic absorption spectroscopy. Fractional passage rate of marked silage particles from the rumen was calculated using the techniques described by Llamas-Lamas and Combs (15).

Apparent total tract fiber digestibility was measured during wk 4 of each period for the fistulated cows only. Feed samples and rectal grab samples of feces were taken daily at the a.m. feeding for indirect estimates of digestibility using the protocol of Nakamura and Owen (19). All feed and fecal samples were frozen and later composited prior to chemical analyses. The apparent digestibilities of ADF and NDF were determined using the acid-insoluble ash ratio technique (25).

In Vitro Fiber Digestion Kinetics

The basic in vitro procedure was described by Grant (11). The buffer solution was that of Goering and Van Soest (10). Fermentation times were the same as for the in situ procedure. Tubes were swirled gently immediately after inoculation and at 6-h intervals for 24 h and every 12 h thereafter. Ash-free NDF was measured at each time (26). The ruminal fluid inoculum was obtained from a steer fed medium quality alfalfa hay. At collection, the mean pH of the ruminal fluid was 6.30 (± .20 SE) for all three replicates of the in vitro experiment. Calculation of lag time, fractional digestion rate, and extent of NDF digestion was described in detail by Grant (11).

Statistical Analysis

Data from the intact cows were analyzed as replicated 4 × 4 Latin squares using the general linear models procedure of SAS (23). Ruminal pH, VFA, ammonia, and fiber digestion and passage data from the fistulated cows were analyzed using a model for a 3 × 4 Youden square design (5). Differences among treatment means for significant main effects were determined using Student-Newman-Keuls multiple range test (23). Significance was declared at $P < .10$ unless otherwise noted.

RESULTS AND DISCUSSION

Silage and Dietary Composition

Normal sorghum silage contained more permanganate lignin than BMR sorghum, alfalfa, or corn silages (Table 2). Concentrations of ADF and NDF were similar for the normal and BMR sorghums. In contrast, Fritz et al. (9) observed that BMR sorghum-sudangrass contained lower NDF concentrations than the normal counterpart; however, a review of BMR research (4) indicated that substantial variation existed in fiber composition among normal and BMR sorghum hybrids. Two distinct genetic lines of sorghum were examined in our study, a normal sorghum that is currently available and an advanced BMR hybrid that is anticipated to be in commercial production soon. Use of these two hybrids enhanced our chances of observing significant performance responses to the BMR mutation.

Alfalfa silage contained the most CP and the least NDF (Table 2). Corn silage contained the least ADF, and the NDF concentration was intermediate to those of alfalfa and the sorghum silages. Silage particle size, as measured by dry sieving, was equivalent for the two sorghums and largest for the corn silage.

The two sorghums were similar in the monosaccharide composition of the neutral detergent residue (Table 2). Fritz et al. (9) also found no differences in neutral sugars between BMR and normal sorghum-sudangrass hybrids. Alfalfa contained a lower concentration of xylose and greater concentrations of mannose and glucose than the other silages. Corn silage contained the greatest amount of xylose.

The phenolic acid composition of the four experimental silages corroborates results of previous studies that have shown that BMR sorghums generally have lower concentrations of *p*-coumaric acid than do normal sorghums, but similar ferulic acid concentrations (4, 9) (Table 2). Alfalfa, being a legume, has only very small quantities of alkali-labile phenolic monomers. Corn has by far the highest concentrations of extractable phenolic acids. No previous direct comparisons of corn and sorghum silages are evident in the literature, but our data indicate that the ratio of *p*-coumaric to ferulic acid for normal sorghum silage is approximately twice that for corn silage (Table 2). In contrast, the ratio for BMR sorghum is similar to that for corn silage.

All silages contained minimal concentrations of propionic and butyric acids, but substantial amounts of acetic and lactic acids (Table 3). The pH of fresh silage samples indicated a well-fermented, high quality silage from all forages. Data in Table 3 indicate no differences in silage quality among the forages, except for chemical composition given in Table 2.

All diets contained 65% silage (DM basis) to emphasize forage effects on cow performance (Table 1). As formulated and fed, all four TMR were nearly equal in CP, and the calculated RUP concentrations met the recommendations for midlactation dairy cows (20); therefore, the primary differences among the four diets were 1) the concentration of lignin and phenolic monomers supplied by the forage, 2) the concentration of dietary ADF and NDF as influenced by forage source, 3) the dietary content of physically effective fiber (NDF level × particle size), and 4) the source of dietary starch.

Nutrient Intake and Performance

Cows consumed significantly more DM from the BMR sorghum than the normal sor-

TABLE 2. Nutrient, monosaccharide, and phenolic acid composition of experimental silages.

Item	Silage				
	Normal sorghum	BMR[1] Sorghum	Alfalfa	Corn	SE
DM, %	30.0	30.0	41.0	35.0	1.3
	(% of DM)				
CP	7.3	7.9	21.0	8.1	1.6
ADF	36.6	39.8	33.0	28.7	1.1
NDF	59.0	60.4	40.0	55.4	2.3
Lignin	10.3	7.5	8.0	6.3	.4
Particle size,[2] mm	2.42	2.57	3.06	4.04	.20
NE_L,[3] Mcal/kg	1.41	1.35	1.43	1.55	.02
	(% of total monosaccharides in NDF)				
Monosaccharide					
Rhamnose	. . .[4]	. . .	.9	. . .	
Arabinose	3.8	4.2	3.9	6.1	.3
Xylose	33.7	33.8	23.4	36.9	1.5
Mannose	.3	.4	3.8	.7	.4
Galactose	10.5	6.0	3.5	8.1	.7
Glucose	51.7	55.5	64.8	48.3	1.8
	(g/kg of NDF)				
Phenolic monomer					
Vanillin	.12	.08	.02	.31	.08
p-Coumaric acid	13.6	7.8	.09	14.9	.9
Ferulic acid	4.3	4.6	.3	8.4	.4
PCA:FA[5]	3.2	1.7	.5	1.8	.2

[1]Brown midrib.

[2]Mean particle size measured according to Grant et al. (12).

[3]Calculated from ADF concentration according to NRC (20).

[4]Not detectable.

[5]*p*-Coumaric acid:ferulic acid.

TABLE 3. Fermentation acids and pH of experimental silages.

Item	Silage				SE
	Normal sorghum	BMR[1] Sorghum	Alfalfa	Corn	
Acid, mmol/g wet silage					
Acetic	32.86	36.02	34.80	36.52	.41
Propionic	.11	.17	.19	.16	.01
Butyric	.13	.06	.18	.18	.01
Lactic	30.79	41.69	35.62	45.23	1.60
pH	3.89	3.89	4.99	3.96	.13

[1]Brown midrib.

ghum silage diets and more of the corn than the alfalfa silage diets (Table 4). In contrast to the results of our study, in which cows consumed equivalent amounts of corn and BMR sorghum silage diets, the only other lactation trial (16) conducted found that cows consumed more DM from high quality corn silage than from BMR sorghum silage. However, dairy heifers consumed more BMR sorghum silage than either normal sorghum or corn silages (16), although normal and BMR sorghum-sundangrass silages were consumed in equal amounts by Holstein steers (28). Broderick (2) observed no difference in DMI between alfalfa and corn silages when fed at 60% of dietary DM to lactating dairy cows.

Despite the differences in DMI observed in our study, intake of CP did not differ among diets when adjusted for BW. Intake of ADF was greater for the normal and BMR sorghum diets than for the corn or alfalfa silages. Cows fed the alfalfa diet consumed the least NDF daily, reflecting both a lower DMI and lower dietary NDF content of the alfalfa diet. The daily NDF intake for all diets averaged 1.3% of BW, which is close to reported values for cows in midlactation (17). The range in daily NDF intake was substantial (1.0 to 1.6% of BW); the BMR sorghum and corn silage diets promoted higher DMI (4% of BW) than was commonly observed for cows in midlactation.

Lignification of the cell wall is a primary factor limiting ruminal digestion of forage fiber. Cows fed the normal sorghum silage consumed approximately 15% more lignin daily than cows fed the BMR sorghum diet, 35% more than the alfalfa diet, and 43% more than the corn silage diet. Cows fed the BMR sor-

TABLE 4. Nutrient intake by midlactation cows as influenced by forage source.

Intake	Diet				SE
	Normal sorghum	BMR[1] Sorghum	Alfalfa	Corn	
DM					
kg/d	20.4[b]	25.3[a]	19.6[b]	23.1[ab]	.6
% of BW	3.4[b]	4.1[a]	3.3[b]	3.9[a]	.1
CP					
kg/d	3.4[b]	4.2[a]	3.4[b]	4.0[a]	.1
% of BW	.6	.7	.6	.7	<.1
ADF					
kg/d	6.3[a]	7.6[a]	4.3[b]	4.8[b]	.4
% of BW	1.0[a]	1.2[a]	.7[b]	.8[b]	<.1
NDF					
kg/d	8.5[a]	10.1[a]	5.9[b]	9.3[a]	.5
% of BW	1.4[a]	1.6[a]	1.0[b]	1.5[a]	<.1

[a,b]Means within a row with no common superscripts differ ($P < .10$).

[1]Brown midrib.

TABLE 5. Performance of midlactation cows as influenced by forage source.

	Diet				
Item	Normal sorghum	BMR[1] Sorghum	Alfalfa	Corn	SE
Milk, kg/d	20.3[b]	26.0[a]	30.1[a]	26.4[a]	1.6
Fat					
%	3.47[c]	4.01[ab]	3.75[b]	4.29[a]	.15
kg/d	.71[b]	1.05[a]	1.11[a]	1.12[a]	.05
Protein					
%	3.13[b]	3.24[ab]	3.22[ab]	3.31[a]	.05
kg/d	.63[c]	.82[b]	1.00[a]	.87[b]	.04
Lactose					
%	4.72[b]	4.86[a]	4.92[a]	4.79[ab]	.03
kg/d	.96[b]	1.30[a]	1.47[a]	1.26[a]	.05
4% FCM, kg/d	17.9[b]	26.2[a]	24.6[a]	26.6[a]	1.2
4% FCM/DMI, kg/kg	.87[c]	1.04[b]	1.24[a]	1.16[a]	.04
BW, kg	604	612	595	601	5

[a,b,c]Means within a row with no common superscripts differ ($P < .10$).

[1]Brown midrib.

ghum diet consumed 17 and 25% more lignin than did cows fed the alfalfa or corn silage diets, respectively.

Milk production was similar for cows fed the BMR sorghum, alfalfa, and corn silage diets, but cows fed the normal sorghum silage diet produced approximately 23% less milk daily (Table 5). Milk fat and protein percentages were greatest for the corn silage and lowest for the normal sorghum silage diet. Production of milk fat (kilograms per day) was similar for cows consuming the BMR sorghum, alfalfa, and corn silage diets, but cows fed the normal sorghum silage produced approximately 35% less milk fat daily. Milk protein production was greatest for cows fed the alfalfa silage diet, intermediate for the BMR sorghum and corn silage diets, and lowest for the normal sorghum silage diet. Lactose production was least for the normal sorghum silage diet. Production of 4% FCM was similar for cows consuming the BMR sorghum, alfalfa, and corn silage diets and was lowest for the normal sorghum silage diet. Because of differences in DMI among diets, the efficiency of FCM production was greatest for the alfalfa and corn silage diets, intermediate for the BMR sorghum, and lowest for the normal sorghum silage diet.

Although no previous lactation trial has compared normal and BMR sorghum silages to corn silage, Lusk et al. (16) found no differences in milk production and composition between BMR sorghum and corn silages. In our study, the normal sorghum silage was clearly inferior for milk production, DMI, and efficiency of milk production relative to corn silage, which agrees with some earlier research (14), but disagrees with others (22).

Broderick (2) compared alfalfa and corn silages fed at 60% of dietary DM and observed no differences in milk or protein production, although milk fat production was 65% greater for the alfalfa silage diet. In our study, the significantly higher milk protein production for alfalfa than for corn silage reflected the numerically greater milk production. No previous study has compared sorghum to alfalfa silage, but, in our study, the BMR sorghum was equivalent to alfalfa silage in supporting milk and fat production, although efficiency of milk production was lower than for either the alfalfa or corn silage diets, reflecting a greater DMI of the BMR sorghum diet (Table 4).

Chewing Activity and Ruminal Environment

Source of silage had no effect on eating activity (Table 6). Corn silage promoted the greatest rumination activity (495 min/d), which reflected its comparatively large particle size (Table 2) relative to that for the other silages. Physically effective fiber is defined commonly as a function of fiber concentration and particle size. In our study, the ranking of silages by physically effective fiber and by rumination

TABLE 6. Chewing activity as influenced by forage source.

Item	Diet				SE
	Normal sorghum	BMR[1] Sorghum	Alfalfa	Corn	
Eating					
min/d	175	170	145	145	16
min/kg of NDF intake	20.6	16.8	24.6	15.6	1.0
Ruminating					
min/d	420[ab]	400[ab]	350[b]	495[a]	60
min/kg of NDF intake	49.3[ab]	39.5[b]	59.3[a]	53.1[a]	2.1
Total chewing					
min/d	595[ab]	570[ab]	495[b]	640[a]	15
min/kg of NDF intake	70.0[b]	56.3[c]	83.9[a]	68.8[b]	2.8

[a,b]Means within a row with no common superscripts differ ($P < .10$).

[1]Brown midrib.

activity (minutes per day), from greatest to least, was corn silage, BMR sorghum and normal sorghum, and then alfalfa. When rumination activity was expressed per kilogram of NDF intake, the activity increased for alfalfa silage, which reflected the low DMI (Table 4) for this diet.

Total chewing activity (minutes per kilogram of NDF intake) was greatest for the alfalfa silage diet, lowest for the BMR sorghum silage diet, and intermediate for the normal sorghum and corn silage diets. When expressed in minutes per day, total chewing activity was greatest for cows fed the corn silage and least for those fed the alfalfa diet. Total chewing activity had little direct relationship with dietary NDF concentration, an observation also reported by DeBoever et al. (6) for diets containing ≥50% forage (DM basis).

Ruminal pH and ammonia concentrations, averaged over 24 h, were not influenced by source of silage (Table 7). The mean pH was ≥6.2 for all diets, and all diets resulted in relatively high acetate to propionate ratios. The total concentration of VFA was greater for the BMR sorghum and corn silage diets than for the alfalfa and normal sorghum silage diets. In agreement with the results of our study, Wedig

TABLE 7. Ruminal pH, VFA, and ammonia as influenced by forage source.[1]

Item	Diet				SE
	Normal sorghum	BMR[2] Sorghum	Alfalfa	Corn	
pH	6.58	6.44	6.49	6.29	.03
Total VFA, mM	104.7[b]	116.6[a]	108.0[b]	120.5[a]	1.8
VFA, mol/100 mol					
Acetate (A)	61.6[b]	63.3[b]	68.2[a]	62.8[b]	.7
Propionate (P)	21.9[a]	20.9[a]	17.4[b]	20.9[a]	.5
n-Butyrate	12.3	11.5	10.6	11.9	.2
Isobutyrate	1.1	.9	1.0	1.0	.1
n-Valerate	1.4	1.5	1.5	1.5	.1
Isovalerate	1.7	1.8	1.4	1.9	.2
A:P	2.83[b]	3.03[ab]	3.93[a]	3.01[ab]	.1
Ammonia, mg/dl	12.1	12.2	8.9	13.7	.5

[a,b]Means within a row with no common superscripts differ ($P < .10$).

[1]All values are means of 6 measurements taken every 4 h for 24 h.

[2]Brown midrib.

TABLE 8. Kinetics of ruminal forage fiber digestion and passage measured in situ.

Item	Diet				SE
	Normal sorghum	BMR[1] Sorghum	Alfalfa	Corn	
Digestion					
Lag, h	–.35[b]	–.04[b]	7.34[a]	5.20[a]	3.7
Fractional rate, /h	.044[b]	.041[b]	.053[ab]	.086[a]	.014
PED,[2] %	60.8[b]	65.3[a]	52.2[b]	57.1[b]	2.9
R^2	.97	.99	.98	.96	
Forage passage					
Fractional rate, /h	.041[b]	.055[a]	.043[b]	.052[a]	.001
AED,[3] %	31.4[a]	27.9[a]	21.0[b]	27.2[a]	1.1
Total tract digestibility, %					
ADF	38.4[b]	40.2[a]	37.1[b]	43.5[a]	.8
NDF	44.8[b]	46.7[a]	41.0[b]	50.0[a]	1.1

[a,b,c]Means within a row with no common superscript differ ($P < .10$).

[1]Brown midrib.

[2]Potential extent of ruminal fiber digestion calculated using equations by Grant (11).

[3]Apparent extent of ruminal fiber digestion calculated using equations by Grant (11).

et al. (27) noted no differences in acetate to propionate ratio in ruminal fluid from Holstein steers fed BMR or normal sorghum-sudangrass silage.

The acetate to propionate ratio and milk fat production data from our study agree with the results of Broderick (2), who observed no consistent relationships among ruminal pH, acetate to propionate ratio, and milk fat production for cows fed diets containing 60% alfalfa or corn silage (DM basis). In our study, milk fat percentage was greater for the corn silage diet, even though it had a lower acetate to propionate ratio than did the alfalfa diet. Similarly, in one trial, Broderick (2) observed that the milk fat percentage was equal for alfalfa and corn silage diets, despite lower acetate to propionate ratios for the corn silage diet, but, in a second trial, milk fat was depressed in the absence of any change in the acetate to propionate ratio for the corn silage diet. Broderick (2) attributed his observations to short experimental periods (3 wk), which were insufficient to document milk fat depression. Our study employed 4-wk periods, which have been used successfully to study milk fat depression (12). A more probable explanation for the acetate to propionate ratios and milk fat data from our study might involve the high dietary forage content (65% of DM) and the observed lack of consistent relationships among acetate to propionate ratios, ruminal pH, and milk fat at higher forage intakes (6).

Forage Fiber Digestion and Passage

Normal and BMR sorghum silages had similar lag times and fractional rates of NDF digestion, but the potential extent of NDF digestion was 7.4% greater for the BMR sorghum (Tables 8 and 9), which agrees with previous research results (8, 9, 27). In vitro and in situ techniques resulted in similar conclusions about digestion kinetics of NDF, but absolute values differed for lag and potential extent of digestion. Our measured fractional rate of NDF digestion (.040/h) for the BMR and normal sorghum silages agrees with values reported by Fritz et al. (9).

Fractional passage rate of forage from the rumen of these lactating cows was greater for the BMR than for the normal sorghum silage (Table 8). In contrast, Fritz et al. (8) observed no effect of BMR mutation on the fractional passage rate of sorghum-sudangrass hay fed to nonlactating Holstein cows. Because of the increased ruminal passage rate for the BMR sorghum, apparent extent of ruminal NDF disappearance that incorporates fractional digestion and passage rates did not differ between the two sorghum hybrids (Table 8). The appar-

TABLE 9. Kinetics of forage fiber digestion measured in vitro.

	Diet				
Item	Normal sorghum	BMR[1] Sorghum	Alfalfa	Corn	SE
Lag, h	9.57[a]	1.67[b]	1.80[b]	3.50[b]	.93
Fractional rate, /h	.048[b]	.044[b]	.059[a]	.062[a]	.002
PED,[2] %	43.4[b]	52.8[ab]	56.5[a]	60.6[a]	1.8
R^2	.96	.92	.95	.95	

[a,b]Means within a row with no common superscript differ ($P < .05$).

[1]Brown midrib.

[2]Potential extent of ruminal fiber digestion calculated according to equations by Grant (11).

ent extent of ruminal NDF disappearance for corn silage was similar to that for the sorghum silages but was 37% less for the alfalfa silage.

Total tract ADF digestibility was greatest for the BMR sorghum and corn silage diets, but the NDF digestibility was greatest for the BMR sorghum silage diet (Table 8). Broderick (2) found that DM digestibility was greater for corn than for alfalfa silage, but no differences in fiber digestibility were significant. Lusk et al. (16) reported DM digestibility in dairy heifers to be equal for corn and BMR sorghum silages but 12.9% lower for normal sorghum silage. That value compares favorably with the reductions in ADF digestibility observed in our study.

The ratio of indigestible residue to lignin was 55% greater for the BMR than for the normal sorghum silage, which agrees with the 37% increase observed by Thorstensson et al. (24). Thus, BMR lignin may inhibit digestion more per unit of lignin than normal lignin (24).

Apparent extent of ruminal NDF disappearance was similar for BMR and normal sorghum silage diets, but total tract NDF digestibility was greater for the BMR sorghum silage diet. Furthermore, the BMR sorghum silage promoted significantly greater performance than the normal sorghum silage. These observations imply that hindgut fermentation may be important for dairy cows fed BMR sorghum silage. Jung and Deetz (13) proposed a model of BMR cell wall in which BMR lignin is richer in guaiacyl units and more branched in structure, resulting in less penetration of lignin into the secondary cell wall in contrast to normal cell-wall lignin. If this model is correct, BMR sorghum could be relatively more degradable postruminally than either normal sorghum, alfalfa, or corn silage. Hindgut fermentation may play a role in effective utilization of BMR sorghum silage by lactating dairy cows by compensating for the more rapid fractional passage rate relative to that of normal sorghum silage.

CONCLUSIONS

Close physical association of lignin with polysaccharide within the cell-wall matrix and the covalent bonding between lignin and the cell wall limits cell-wall accessibility to microbial enzymatic degradation. The BMR mutants of sorghum contain lower lignin concentrations than do normal sorghums and, consequently, have greater potential as sources of digestible fiber for lactating dairy cows. The potential extent of ruminal NDF disappearance and the fractional passage rate were greater for the BMR than for the normal sorghum silage diets. The BMR sorghum silage supported milk production similar to corn and alfalfa silages in midlactation dairy cows. The BMR sorghum is agronomically suited to the midwestern and plains region of the US and has considerable potential as a silage crop for use in lactation diets. Further research with dairy cows in early lactation appears to be warranted.

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