The effect of hybrid type and dietary proportions of corn silage on the lactation performance of high-producing dairy cows

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ABSTRACT

We evaluated the effects of corn silage hybrids [control vs. brown midrib (BMR)] and the proportion of corn silage in rations on the performance of high-producing dairy cows. The chemical composition of the corn silages was similar except for lignin, which was higher in the control hybrid [3.09%, dry matter (DM) basis] compared with the BMR hybrid (2.19%). The 30-h *in vitro* neutral detergent fiber (NDF) digestibility was also higher (62.8% of NDF) in the BMR hybrid than in the control hybrid (52.2%). Twenty-seven Holstein cows were fed 1 of 3 diets comprising 62% forage and 38% concentrate (DM basis) containing 35% (DM basis) corn silage from the control hybrid (NLO), 35% of the BMR hybrid (BLO), or 50% of the BMR (BHI). Cows were fed the diets in a replicated 3 × 3 Latin square design with 28-d periods. Intake of DM was similar among treatments but milk production was greater for cows fed BLO (50.1 kg/d) and BHI (51.1 kg/d) than for NLO (47.9 kg/d). Milk fat percentage was lower for cows fed BHI (3.37%) than for those fed BLO (3.55%) and NLO (3.56%) but yield of milk fat was similar among treatments. Yield and percentage of milk protein was higher for cows in BHI compared with NLO. The concentration of milk urea N was lower in cows fed BHI (14.0 mg/dL) than in those fed NLO (14.7 mg/dL) and intermediate for BLO (14.5 mg/dL). The yield of 3.5% fat-corrected milk was higher in cows fed BLO (50.2 kg/d) than in NLO (48.2 kg/d) and was intermediate for BHI (49.8 kg/d). The total-tract digestibility of dietary DM, organic matter, starch, and crude protein was lower for cows in NLO compared with the other treatments. The total-tract digestibility of NDF was highest for BHI (54.4%), intermediate for BLO (50.9%), and lowest for NLO (43.2%). We conclude that BMR corn silage can be included in rations at moderate and high proportions of a total ration, resulting in high levels of milk production.

Key words: corn silage, dairy cow, brown midrib corn

INTRODUCTION

Brown midrib (BMR) forages are low in lignin and, when fed to cows, result in increased milk production compared with non-BMR hybrids (Eastridge, 1999; Oliver et al., 2004; Dann et al., 2008). In a meta-analysis of corn silage hybrids fed to lactating dairy cows, Ferraretto and Shaver (2013) reported that DMI, milk production, and protein yield were 1.6, 1.3, and 0.05 kg/cow per day, respectively, greater for BMR than for control silages. Utilizing high-quality forages such as BMR corn silage is becoming more important, especially because higher proportions of forages are being fed to high-producing lactating dairy cows (Chase and Grant, 2013). This practice has the potential to improve feed efficiency from forage sources, reduce the use of high-cost concentrates, and improve animal health. However, most past studies evaluating BMR corn silage incorporated it at only moderate levels in the TMR (commonly at 35–40% of the TMR DM; Castro et al., 2010; Holt et al., 2010). Although several studies have evaluated the feeding value of BMR corn silage when incorporating it at varying levels to the diet, DMI and milk production were only moderately high in those studies.

Besides the increased proportion of forages being fed to lactating dairy cows, a current trend has been to include higher proportions of corn silage in those diets. Reasons for this practice include higher DM yields from corn and easier ensiling of corn silage, because of its lower buffering capacity compared with alfalfa. For example, Cherney et al. (2004) reported that cows fed a diet containing 60% of the DM from BMR corn silage tended to produce more milk than cows fed similar diets but with conventional hybrids. Thus, the objective of our study was to evaluate the performance of high-producing lactating dairy cows fed BMR corn silage that was included at moderate and high levels in the diet and compare performance to that of cows fed a control corn silage included at a moderate level in the diet. Our hypothesis was that cows fed BMR corn silage would be more productive than cows fed control corn silage and that BMR corn silage could provide a significant proportion of the total ration DM in a high-forage diet fed to relatively high producing cows.

Received August 8, 2014.

Accepted October 29, 2014.

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MATERIALS AND METHODS

A control (normal, **NML**) corn silage hybrid (Mycogen TMF2H699, Mycogen Seeds, Dow AgroScience, Indianapolis, IN) and a BMR hybrid (Mycogen F2F66, Mycogen Seeds) were used in this study. Seeds were planted in silt loam soil in separate test plots in the spring of 2012 at the University of Delaware dairy farm (Newark). Corn hybrids were seeded at a theoretical planting density of 74,100 seeds/ha and spaced with 0.76 m between rows. Agronomic management for both hybrids was similar throughout the growing season. Corn was harvested in September 2012 when the whole-plant DM was approximately 38% for both corn hybrids, using a pull-type harvester (John Deere 3975, Moline, IL) equipped with a mechanical processor (roller gap setting of 1.40 mm). Corn plants were chopped at a theoretical length of cut of 19 mm and stored in bag silos (AgBag Systems Inc., St. Nazianz, WI) for 7 mo before the start of feeding.

A lactation trial was conducted from March to June 2013 at the University of Delaware dairy farm. The Agricultural Animal Care and Use Committee, College of Agriculture and Natural Resources, University of Delaware approved care and handling of cows (Anonymous, 1989). Twenty-seven Holstein cows (3 primiparous and 24 multiparous) averaged 742 ± 97 kg of BW, 94 ± 39 DIM, 29 ± 4 kg/d of DMI, and 53 ± 9 kg of milk/d at the start of the study. Cows were housed in a sand-bedded, freestall barn equipped with Calan gates (American Calan, Northwood, NH) for individual feeding and monitoring of daily intake. During a 2-wk pretrial period, cows were acclimated to the gates and fed a pretrial diet consisting of 25% of hybrid TMF2H699, 25% of BMR hybrid F2F66, 12% alfalfa haylage, and 38% concentrate (DM basis). Cows were blocked by pretreatment milk production, DIM, BW, DMI, and lactation number and randomly assigned to 1 of 3 treatments in a simultaneously replicated 3×3 Latin square design with 28-d periods. The first 21 d of each period were used as an adaptation period, and

data collected during the last 7 d were used for statistical analysis. The rations (Table 1) contained (1) 35% of the total ration DM from hybrid TMF2H699 (**NLO**), (2) 35% from BMR hybrid F2F66 (**BLO**), or (3) 50% from BMR hybrid F2F66 (**BHI**). The remaining proportions of the rations comprised cottonseed, concentrates (Table 2), and other forages (Table 3). The TMR were formulated using the CPM-Dairy Nutrition Model (version 3.0; Cornell University, Ithaca, NY; University of Pennsylvania, Philadelphia, PA; William H. Miner Agricultural Research Institute, Chazy, NY) to be iso-nitrogenous and isocaloric and were balanced to satisfy or exceed the nutrient requirements of the test animals (NRC, 2001) at the start of the trial. Rations were offered once daily at 0800 h and provided about 110% of the previous day's consumption to ensure ad libitum intake. Refusals were measured daily before feeding. Cows had access to fresh clean water at all times.

Samples of all individual feeds and TMR were collected 3 times per week and composited weekly for chemical analyses. Feed samples were dried in a forced-draft oven (Isotemp Oven model 750F, Fisher Scientific, Dubuque, IA) set at 60°C for 48 h, and DM content of feed ingredients was used for weekly adjustments of the TMR mixture. Feed samples were sent to Cumberland Valley Analytical Services (Hagerstown, MD) for nutrient analyses through standard wet chemistry methods. Dried forages, concentrates, and TMR were ground to pass a 1-mm sieve using a Wiley mill (Arthur H. Thomas, Philadelphia, PA). The NDF content of samples was analyzed using sulfite and amylase according to the procedures of Van Soest et al. (1991), and ADF was analyzed as described by Robertson and Van Soest (1981). Acid detergent lignin was determined using the procedure outlined by Goering and Van Soest (1970). Ash content was determined according to AOAC International (2000) methods with the modification of using 1.5-g sample weights and a furnace temperature of 535°C for 4 h. Total N were determined by total combustion of samples in a Leco CNS 528 Analyzer (Leco Corp., St. Joseph, MI) and was multiplied by

Table 1. Ingredient proportions of the TMR fed during the treatment period (% DM basis)

Ingredient	Treatment ¹		
	NLO	BLO	BHI
Corn silage, Mycogen TMF2H699 ²	35		
Brown midrib corn silage, Mycogen F2F66 ²		35	50
Alfalfa haylage	20	20	5
Grass hay	4	4	4
Cottonseed	3	3	3
Concentrate	38	38	38

¹NLO = diet containing 35% (DM basis) normal corn silage; BLO = diet containing 35% (DM basis) brown midrib (BMR) corn silage; BHI = diet containing 50% (DM basis) BMR corn silage.

²Mycogen Seeds, Dow AgroSciences (Indianapolis, IN).

Table 2. Ingredient composition (% of DM) of concentrates used to formulate the experimental diets

Ingredient	Treatment ¹		
	NLO	BLO	BHI
Ground corn grain, medium	49.58	45.80	28.02
Turbo meal ²	12.16	12.10	11.91
Citrus pulp, dry	8.46	13.06	21.73
Canola meal, solvent	6.67	6.63	6.53
Soybean meal, 47.5%	4.46	4.43	16.15
Molasses	4.37	3.03	0.00
Blood meal	4.16	4.13	4.07
Sodium bicarbonate	1.56	1.55	1.54
Calcium carbonate	1.37	1.36	0.87
Palm fat	1.24	1.23	1.21
Megalac ³	1.03	1.03	1.01
NaCl	1.01	1.00	0.99
MM3 Mintrex ⁴	0.87	0.87	0.85
Rumensin ⁵	0.78	0.79	0.77
DCAD Plus ⁶	0.68	0.81	1.76
Calcium sulfate	0.61	0.61	0.60
Optigen ⁷	0.44	0.44	0.43
Biofos ⁸	0.15	0.25	0.29
Smartamine M ⁹	0.14	0.14	0.14
Urea	0.12	0.60	0.99
Magnesium oxide	0.12	0.12	0.12
Biotin	0.01	0.01	0.01
Levucell SC ¹⁰	0.01	0.01	0.01

¹NLO = diet containing 35% (DM basis) normal corn silage; BLO = diet containing 35% (DM basis) brown midrib (BMR) corn silage; BHI = diet containing 50% (DM basis) BMR corn silage.

²Extruded and expelled soybean meal; Renaissance Nutrition Inc. (Roaring Spring, PA).

³Calcium salts of free fatty acids; Arm and Hammer Animal Nutrition (Princeton, NJ).

⁴Vitamins and trace minerals premix containing 30% Mg, 7.9% S, 4.5% K, 187 mg/kg of Se, 1,408 kIU of vitamin A, 352 kIU of vitamin D, and 7.04 kIU of vitamin E; Renaissance Nutrition Inc.

⁵Monensin sodium; Elanco Animal Health (Greenfield, IN).

⁶Potassium carbonate; Arm and Hammer Animal Nutrition.

⁷Nonprotein nitrogen source for ruminants; Alltech (Thomasville, GA).

⁸Feed-grade monocalcium phosphate; Renaissance Nutrition Inc.

⁹Encapsulated methionine for ruminants; Bluestar Adisseo Nutrition Group (Alpharetta, GA).

¹⁰*Saccharomyces cerevisiae* CNCM I-1077; Lallemand Animal Nutrition (Milwaukee, WI).

Table 3. The average chemical composition of alfalfa haylage, grass hay, and cottonseed fed throughout the study¹

Item	Alfalfa haylage		Grass hay		Cottonseed	
	Mean	SD	Mean	SD	Mean	SD
DM, %	34.27	1.33	89.37	1.85	89.60	0.69
CP, %	20.47	1.89	9.20	0.26	22.03	0.38
SP, ² % of CP	57.87	8.42	26.20	5.56	31.30	2.03
NE _L , ³ Mcal/kg	1.39	0.03	1.01	0.08	NA ⁴	NA
ADF, %	33.37	0.91	42.30	2.82	36.00	1.13
NDF, %	39.67	3.38	66.40	3.67	43.63	1.80
Ash, %	10.52	0.66	6.23	1.47	4.55	0.48
Ca, %	1.04	0.01	0.42	0.09	0.21	0.04
P, %	0.38	0.01	0.18	0.07	0.67	0.02
Mg, %	0.37	0.11	0.21	0.05	0.42	0.01
K, %	2.84	0.69	2.11	0.58	1.22	0.01

¹Nutrient mean is an average of 12 weekly composite samples.

²Soluble protein.

³Calculated using NRC (2001).

⁴Not analyzed.

6.25 to estimate CP. Soluble protein, expressed as percent of CP, was determined following the procedure of Krishnamoorthy et al. (1982). Analysis of starch content was performed as described by Holm et al. (1986) but only in corn silage and TMR samples. The *in vitro* digestibility of NDF (**NDF-D**, 30-h incubation, 1-mm sample grind size) was determined on only corn silages and the TMR using the procedures outlined by Goering and Van Soest (1970).

Once a week, particle size distribution of corn silages and TMR was determined using a Penn State Particle Separator (Nasco Inc., Fort Atkinson, WI) as described by Kononoff et al. (2003). In addition, physically effective fiber (**peNDF**) of TMR and silages was calculated using measurements from the Z-box (W. H. Miner Agricultural Research Institute, Chazy, NY) following the procedures of Grant and Cotanch (2005). The BW of cows was measured (Allweigh Scale System Inc., Red Deer, AB, Canada) at the start of the study and on d 27 and 28 of each treatment period. Dry matter intake was determined by recording feed offered and refused and adjusting for DM content on d 22 to 28 for each cow during each period. Samples of diets and orts were collected daily from d 22 to 28 and a portion of each sample was dried in a forced-air oven at 60°C for 48 h for determination of DM. Cows were milked 3 times daily at 0600, 1400, and 2200 h in a double-8 parallel milking parlor (Xpressway Parallel Stall System, Bou-Matic, Madison, WI) and production was recorded automatically through a computer (SmartDairy, Bou-Matic). Milk samples were collected for 6 consecutive milkings (d 27 and 28) during the last week of each period. Milk samples were preserved using Bronopol tablets (D&F Control System, San Ramon, CA) and stored at 4°C until analysis of content of fat, true protein, MUN, lactose, and SCS. Milk samples were analyzed for composition by a commercial laboratory (Dairy One Laboratories, University Park, PA) using mid-infrared methods (Foss 4000; Foss Technology, Eden Prairie, MN; AOAC International, 2000; method 972.160). After analysis, samples were mathematically composited by day in proportion to milk yield at each sampling. Results of the analyses of milk fat percentage were used to convert milk yield to 3.5% FCM. Milk fat and protein percentages were used to convert milk yield to ECM. Feed efficiency of cows was calculated and expressed as 3.5% FCM/DMI for the last 7 d of each test period.

A random subset of 6 Latin square replicates (3 primiparous and 15 multiparous cows) was used for the determination of apparent total-tract nutrient digestibility. Fecal grab samples were collected from cows by rectal palpation during the last 3 d of the last period. Samples were collected at 4 time points each day and

advanced by 2 h on the succeeding day to give a total of 12 samples with 2-h collection intervals for each cow. Samples were stored at -20°C until composited into 1 sample per cow. Total mixed rations and orts were sampled daily during fecal sample collection. Samples of TMR, orts, and feces were dried for 48 h in a 60°C forced-air oven. Dry matter of ort samples was used for DMI calculations. Fecal and TMR samples were ground through a 1-mm screen using a Wiley mill and analyzed for NDF, CP, starch, ash, and indigestible NDF. Indigestible NDF was determined as the NDF residue of samples after 120 h of incubation *in vitro* following the procedures of Goering and Van Soest (1970). Indigestible NDF was used as an internal marker to calculate fecal output and the apparent total-tract digestibility of nutrients (Cochran et al., 1986).

Lactation data were analyzed as simultaneous 3 × 3 Latin squares using the generalized linear mixed model procedure (PROC GLIMMIX) of SAS (SAS Institute, 2008). The statistical model tested the effects of period, cow, and treatment. Cow was included as a random effect in the model. Data for the digestibility trial were analyzed as a completely randomized design. Significance was declared when $P \leq 0.05$ and differences among means was determined using the Tukey test (Snedecor and Cochran, 1980).

RESULTS

The chemical and physical compositions of corn silages fed throughout the study are presented in Table 4. In general, the chemical compositions of both types of silage hybrids were similar, with the main exception being a lower concentration of ADL in BMR compared with NML corn silage. The 30-h *in vitro* NDF-D of BMR was about 11 percentage units higher than that of the NML corn silage. The peNDF content and particle size distribution were also similar between the hybrids. The chemical and physical composition of the dietary treatments fed throughout the study is shown in Table 5. Diets ranged from 16.1 to 16.7% CP and from 1.69 to 1.71 Mcal of NE_L/kg of DM. The contents of ADF and NDF were slightly lower in the NLO diet than in the BMR diets. In contrast, the starch content was slightly higher in NLO than in the other treatments. The NDF-D of the BHI (60.3% of NDF) dietary treatment was higher than that of NLO (49.0%) and intermediate for BLO (53.6%). Concentrations of macro minerals were similar among treatments.

Table 6 shows the production responses of animals to the varying dietary treatments. Dry matter intake was not different among treatments and was high (almost 4% of BW). In contrast, cows fed BLO (50.1 kg/d) and BHI (51.1 kg/d) produced more milk than those fed

Table 4. The average chemical and physical composition of corn silages fed throughout the study^{1,2}

Item	NML		BMR	
	Mean	SD	Mean	SD
DM, %	40.57	0.84	38.33	0.47
CP, %	7.53	0.06	6.57	0.29
SP, ³ % CP	49.70	1.77	43.67	2.22
NE _L , ⁴ Mcal/kg	1.64	0.01	1.61	0.04
ADF, %	24.73	0.55	26.00	1.40
ADL, %	3.09	0.16	2.19	0.27
NDF, %	40.27	0.38	40.57	2.84
NDF-D, ⁵ % of NDF	52.17	0.70	62.83	1.44
Ash, %	3.71	0.17	3.08	0.40
Starch, %	30.00	1.56	33.00	2.01
Ca, %	0.19	0.01	0.22	0.02
P, %	0.26	0.01	0.23	0.01
Mg, %	0.18	0.02	0.19	0.01
K, %	0.94	0.11	0.81	0.05
peNDF, ⁶ % as fed	33.48	2.26	33.89	2.40
Particle size distribution, ⁷ % as fed				
>1.91 cm	2.68	0.96	1.98	0.78
0.79 to 1.91 cm	47.95	0.96	47.93	0.85
0.18 to 0.79 cm	44.84	1.34	46.92	1.28
<0.18 cm	4.53	1.45	3.17	1.22

¹Nutrient mean is an average of 12 weekly composite samples ($\pm$ SD).

²NML = normal corn; BMR = brown midrib corn.

³Soluble protein.

⁴Calculated using NRC (2001).

⁵30-h in vitro NDF digestibility.

⁶Physically effective NDF calculated by using a Z-Box (Grant and Cotanch, 2005).

⁷Particle size distribution measured using a Penn State Particle Separator (The Pennsylvania State University, University Park).

NLO (47.9 kg/d). However, milk fat percentage was lower in cows fed BHI (3.37%) than in those fed BLO (3.55%) and NLO (3.56%) but yield of milk fat was not different among treatments. Milk protein percentage was highest for cows fed BHI (2.98%), intermediate for BLO (2.93%), and lowest for NLO (2.90%). Similarly, the yield of milk protein was highest in cows fed BHI (1.51 kg/d), lowest in NLO (1.38 kg/d), and intermediate in BLO (1.46 kg/d). Milk lactose and SCC were similar among treatments. The concentration of MUN was highest in cows fed NLO (14.7 mg/dL), lowest for BHI (14.0 mg/dL), and intermediate for BLO (14.5 mg/dL). The yield of 3.5% FCM was higher in cows fed BLO (50.3 kg/d) than NLO (48.2 kg/d) but similar to that in BHI (49.8 kg/d). When milk yield was corrected for energy content, cows fed the NLO (47.1 kg/d) had lower yield of ECM than cows in BHI (49.2 kg/d) and BLO (49.2 kg/d). Feed efficiency was not different among treatments.

The apparent total-tract digestibility of nutrients as influenced by dietary treatments is shown in Table 7. Cows fed BLO and BHI had higher total-tract digestibility of dietary DM, OM, and CP than cows fed NLO. Apparent total-tract digestibility of starch was higher in cows fed BHI (98.6%) than in those fed NLO (97.9%)

but similar to that in BLO (98.2%). The apparent total-tract digestibility of NDF was highest for cows fed BHI (54.4%), lowest for NLO (43.2%), and intermediate for BLO (50.9%).

DISCUSSION

We conducted this study to assess the effect of incorporating a moderate or high proportion of BMR corn silage into diets for high-producing (>50 kg/d) dairy cows. Several studies have evaluated the effect of different proportions of BMR corn silage in the rations for dairy cows. For example, Min et al. (2007) and Qiu et al. (2003) fed 32 and 39 to 43%, respectively, of the ration DM as BMR corn silage. Oba and Allen (2000a) varied BMR corn silage in the diet from about 36 to 56% of total ration DM. However, in those studies, intake (about 21 to 25 kg/d) and milk production (about 30 to 36 kg/d) were moderately low relative to the values reported in the current study (approaching 30 kg of DMI/d and 50 kg of milk/d).

As expected, we found that the BMR corn silage used in the current study was lower in ADL and higher in NDF-D but similar in most other nutritional attributes compared with the control hybrid. These findings are

Table 5. The DM (%), average chemical (% DM basis unless stated otherwise) and particle size distribution (% as fed) of the various TMR fed throughout study¹

Item	Treatment ²					
	NLO		BLO		BHI	
	Mean	SD	Mean	SD	Mean	SD
DM, %	49.60	1.06	50.13	1.12	49.60	0.79
CP, %	16.40	0.66	16.67	0.50	16.10	0.46
SP, ³ % of CP	37.73	6.27	42.13	5.23	39.10	2.75
RDP, % of CP	58.5		58.8		57.4	
MP-protein, ⁴ g/d	2,990		3,014		3,196	
MP-methionine, ⁴ g/d	67.3		68.4		72.5	
MP-lysine, ⁴ g/d	207.3		211.0		225.8	
NE _L , ⁵ Mcal/kg	1.71	0.03	1.69	0.05	1.69	0.03
ADF, %	21.93	2.08	24.13	2.66	24.20	0.46
ADL, %	3.76	0.39	4.00	0.35	3.42	0.62
NDF, %	30.80	1.39	33.73	2.12	36.03	0.40
fNDF, ⁶ %	23.67		24.36		25.04	
NDF-D, ⁷ % of NDF	49.03	3.44	53.60	3.20	60.30	1.51
Ash, %	7.51	0.36	7.49	0.14	7.13	0.38
Starch, %	24.20	2.40	22.67	2.79	22.70	0.87
Ca, %	0.90	0.06	0.84	0.03	0.86	0.06
P, %	0.39	0.01	0.39	0.01	0.37	0.02
Mg, %	0.41	0.03	0.44	0.05	0.40	0.02
K, %	1.55	0.16	1.61	0.16	1.59	0.14
peNDF, ⁸ % as fed	23.42	4.73	25.42	2.38	26.63	3.85
Particle size distribution, ⁹ % as fed						
>1.91 cm	8.52	1.78	7.85	1.82	7.04	1.82
0.79 to 1.91 cm	35.73	2.40	37.82	2.37	37.68	2.39
0.18 to 0.79 cm	41.62	1.30	40.66	1.61	40.51	1.33
<0.18 cm	14.13	3.30	13.67	3.24	14.77	3.23

¹Mean values are the average of 12 weekly composite samples ($\pm$ SD).²NLO = diet containing 35% (DM basis) normal corn silage; BLO = diet containing 35% (DM basis) brown midrib (BMR) corn silage; BHI = diet containing 50% (DM basis) BMR corn silage.³Soluble protein.⁴Calculated using CPM Dairy (version 3.0.8; Cornell University, Ithaca, NY; University of Pennsylvania, Kennett Square, PA; and Miner Agricultural Research Institute, Chazy, NY).⁵Calculated using NRC (2001).⁶Percent of NDF from forage.⁷30-h in vitro NDF digestibility.⁸Physically effective NDF calculated using measurements obtained using a Z-Box (Grant and Cotanch, 2005).⁹Particle size distribution measured using a Penn State Particle Separator (The Pennsylvania State University, University Park).

similar to those reported by Weller et al. (1984) and Eastridge (1999) and support the fact that the mutation in BMR does not alter the chemical composition of the silage.

We found that DMI was not affected by type of corn silage or proportion of BMR silage in the ration. Calculated intake of NDF as a percentage of BW was 1.20, 1.36, and 1.41%, respectively, for NLO, BLO, and BHI diets (data not shown). Dry matter intake has been reported to be higher when cows were fed BMR corn silage compared with a control hybrid in some studies (Oba and Allen, 2000a; Qiu et al., 2003; Ebling and Kung, 2004; Castro et al., 2010) but not in others (Taylor and Allen, 2005; Weiss and Wyatt, 2006; Kung et al., 2008). Higher DMI in cows fed BMR has been associated with enhanced NDF digestion of this hybrid,

resulting in a higher ruminal passage rate and increased capacity for intake (Oba and Allen, 2000a). The reason for the differences among studies is unclear but might be related to factors such as stage of lactation (Holt et al., 2013), energetic requirements of cows (Oba and Allen, 2000a), rumen fill, quality of other fibrous components and/or study design. Relative to study design, Kung et al. (2008) questioned whether short experimental periods (3 to 4 wk, as in Latin square type studies) allowed sufficient time to elicit differences in intake when feeding BMR silages.

Although DMI was not affected by type of hybrid in our study, we found that cows fed BLO and BHI produced more milk than those cows fed NLO. This finding agrees with previous studies comparing BMR corn silage to control silages from our laboratory

Table 6. Effects of hybrid type and dietary proportions of corn silage on production performance of cows

Item	Treatment ¹			SEM
	NLO	BLO	BHI	
DMI, kg/d	29.8	30.6	29.8	0.3
DMI, % BW	3.92	4.06	3.95	0.05
Milk, kg/d	47.9 ^b	50.1 ^a	51.1 ^a	0.4
Milk fat				
%	3.56 ^a	3.55 ^a	3.37 ^b	0.05
kg/d	1.70	1.76	1.71	0.03
Milk protein				
%	2.90 ^b	2.93 ^{ab}	2.98 ^a	0.02
kg/d	1.38 ^c	1.46 ^b	1.51 ^a	0.01
SCC, log ₁₀ /mL	4.76	4.81	4.87	0.13
MUN, mg/dL	14.7 ^a	14.5 ^{ab}	14.0 ^b	0.2
Lactose, %	4.73	4.73	4.74	0.02
FCM, kg/d	48.2 ^b	50.2 ^a	49.8 ^{ab}	0.5
ECM, kg/d	47.1 ^b	49.2 ^a	49.2 ^a	0.5
Feed efficiency (FCM/DMI)	1.62	1.64	1.67	0.02
BW, kg	765	760	760	5

^{a-c}Means in rows with unlike superscripts differ ($P < 0.05$).

¹NLO = diet containing 35% (DM basis) normal corn silage; BLO = diet containing 35% (DM basis) brown midrib (BMR) corn silage; BHI = diet containing 50% (DM basis) BMR corn silage.

(Ebling and Kung, 2004; Kung et al., 2008), the summary of milk production data by Eastridge (1999), and the recent meta-analysis on feeding corn silage hybrids to dairy cows of Ferraretto and Shaver (2013). In the current study, the percentage of milk fat was lower in cows fed BHI than in the other treatments but yield of milk fat was similar among treatments. In the past, some studies have reported that the percentage and yield of milk fat were not different between cows fed BMR and control corn silage (Ebling and Kung, 2004; Kung et al., 2008). However, other studies found that milk fat percentage was slightly lower in cows fed BMR corn silage (Block et al., 1981; Qiu et al., 2003; Weiss and Wyatt, 2006). Oba and Allen (2000a) theorized that lower milk fat percentage in cows fed BMR corn silage might be due to a dilution effect from higher milk synthesis relative to milk fat synthesis. Lower milk fat percentage in cows fed BMR corn silage has also been attributed to lower ruminal pH and acetate:propionate ratio compared with cows fed control corn silage (Block et al., 1981). We hypothesize that the lower fat in cows fed the high level of BMR silage in our study could be due to the phenomena described by Block et al. (1981) because the BHI diet contained relatively high proportions of ruminal fermentable NDF and starch (about 73% of total starch from corn silage in BHI vs. about 50% of total starch from corn silage in BLO). It is well documented that potential rumen fermentable starch increases with time of ensiling (Der Bedrosian et al., 2012) because of proteolytic activities (Hoffman et al., 2011) in the silo; thus, adjustments must be made when formulating diets high in corn silage that has been stored for long periods. In fact, apparent total-tract

digestion of both NDF and starch were greater in cows fed BHI than in those fed NLO in our study. Similarly, Akins and Shaver (2012) reported that cows fed a diet containing 65% of the ration DM from corn silage (85% of dietary starch from corn silage) produced less milk than those fed the same hybrid at 40% of the diet (52% of starch from corn silage) and hypothesized that lower milk production was a consequence of a diet with a large proportion of its starch from highly fermentable corn silage. Cherney et al. (2004) fed cows TMR containing 54 to 60% of the TMR DM from various types of corn silage and reported relatively low milk fat tests (about 3.2 to 3.3%) and rumen pH (about 5.3 to 5.4), which may also have been a result of highly fermentable starch from corn silage.

Yield and percentage of milk protein were higher in cows fed BHI than NLO and intermediate in BLO. One possible explanation for this finding was the higher pro-

Table 7. The effect of hybrid type and dietary proportions of corn silage on the apparent total-tract digestibility of nutrients

Item	Treatment ¹			SEM
	NLO	BLO	BHI	
DM, %	70.6 ^b	73.8 ^a	74.9 ^a	0.4
OM, %	72.0 ^b	75.4 ^a	75.8 ^a	0.4
NDF, %	43.2 ^c	50.9 ^b	54.4 ^a	0.9
Starch, %	97.9 ^b	98.2 ^{ab}	98.6 ^a	0.1
CP, %	71.6 ^b	75.6 ^a	76.3 ^a	0.4

^{a-c}Means within a row with unlike superscripts differ ($P < 0.05$).

¹NLO = diet containing 35% (DM basis) normal corn silage; BLO = diet containing 35% (DM basis) brown midrib (BMR) corn silage; BHI = diet containing 50% (DM basis) BMR corn silage.

jected metabolizable protein, methionine, and lysine for BHI than NLO. This finding also agrees with the meta-analysis by Ferraretto and Shaver (2013), who reported that, on average, cows fed BMR silage produced 0.05 kg/d more milk protein per day than cows fed normal silage. However, percentage and yield of milk protein have not always been affected by feeding BMR compared with control corn silage (Taylor and Allen, 2005; Gehman et al., 2008). The concentration of MUN was also lower in cows fed BHI than NLO but similar to that in BLO in the current study. This finding was in agreement with results of some studies (Taylor and Allen, 2005; Kung et al., 2008). A higher percentage and yield of milk protein coupled with lower MUN suggested that cows fed the BHI were more efficient in utilizing dietary N than cows fed NLO. Cows fed the BLO treatment also had a moderate level of alfalfa silage in their diets, which may have slightly reduced the efficiency of N use in cows fed this diet compared with those fed BHI, suggesting that performance of rations with BMR corn hybrid may be sensitive to protein supplementation strategies. Nutrient digestibility of diets containing BMR have been reported to be the same or slightly higher than diets containing control corn silage in several studies (Oba and Allen, 2000b; Greenfield et al., 2001; Tine et al., 2001; Ebling and Kung, 2004). In those trials, cows fed a diet with BMR had higher DMI than those fed control corn silage. Tyrrell and Moe (1975) reported that nutrient digestibility is negatively related with DMI level. This may partially explain the minimal difference in nutrient digestibility between BMR and control corn silage-based diets in those studies. Tine et al. (2001) reported that apparent digestibility of DM, OM, ADF, and NDF was greater in BMR than in control corn silage when diets were fed to cows at maintenance or restricted intake levels. However, nutrient digestibility was almost comparable between BMR and control corn silage diets when fed to cows at ad libitum intake. Oba and Allen (2000b) reported that higher in vitro NDF-D in BMR corn silage did not necessarily translate to higher NDF-D in vivo. They proposed that higher DMI and passage rate could have reduced retention time and digestibility of BMR fiber in the rumen, which explains the discrepancy between in vitro and in vivo NDF digestibility. In the current study, DMI was not affected by treatments, which may explain the substantial difference in digestibility of nutrients that we observed between BMR and the control hybrid.

Providing highly digestible forages is critical to produce large quantities of milk. This is especially true when the proportion of forage in the diet is high to maintain high levels of DMI. In the current study, intake of NDF was 1.20, 1.36, and 1.41% of BW, re-

spectively, for NLO, BLO, and BHI diets, showing that intake of highly digestible NDF can support high levels of milk production.

CONCLUSIONS

We conclude that BMR corn silage can be incorporated into high-forage diets for high-producing cows at moderate or high levels of inclusion while supporting relatively high levels of milk production. If corn silage inventories are limiting, feeding a moderate level of BMR to high-producing cows would be sufficient to elicit a positive production response compared with cows fed a normal corn silage hybrid. We also conclude that some caution should be taken when formulating high-forage diets that have high proportions of corn silage as the "forage" source because of the contribution of starch from corn grain that may be extremely fermentable in the rumen if silage has been stored for moderately long periods.

ACKNOWLEDGMENTS

This research was partially funded by Dow AgroSciences (Indianapolis, IN). The authors thank Ian Shivas of Renaissance Nutrition Inc. (Roaring Spring, PA) for assistance with ration balancing. We also thank the staff of the University of Delaware Dairy for care and feeding of cows and students from the Dairy Nutrition and Silage Fermentation Laboratory for assistance throughout the study.

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