IT'S THE COMBINATION: SCIENTIFIC DATA REVIEW OF THE FIRST CORN SILAGE TO BRING TOGETHER FIBER AND STARCH DIGESTIBILITY

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INTRODUCTION

Lactating dairy cows require highly digestible forages with the correct mix of fermentable fiber and non-fiber carbohydrates to ensure efficient rumen fermentation, optimal feed intake, and high output of milk solids. With lower fiber digestibility, rumen fill constraints may limit dry matter intake (DMI) and productive capabilities of dairy cattle fed higher forage diets (Allen, 2000). Brown midrib (*bm3*) corn silage contains lower lignin content than conventional corn silage, resulting in improved NDF digestibility and greater DMI before rumen fill limitations are encountered (Ebling and Kung, 2004). But, starch digestibility is often lower for diets containing *bm3* rather than conventional corn silage. For example, Ferraretto and Shaver (2015) measured a 6%-unit reduction in rumen starch digestibility and a 1.4%-unit reduction in total tract starch digestibility for cows fed *bm3* versus conventional corn silage. The lower dietary starch digestibility with *bm3* corn silage may be related to: 1) greater passage rate of digesta driven by higher DMI (Moharrery et al., 2014), and(or) 2) greater kernel vitreousness of *bm3* corn hybrids compared with other commercially available corn hybrids (Ferraretto and Shaver, 2015).

Corn hybrids with floury kernel mutations, such as the *FL2* allele, contain less zein protein in the kernel and have greater rumen and total tract starch digestibility (Lopes et al., 2009). Zein protein cross-links and surrounds starch granules in the endosperm, preventing rumen microbial degradation of starch (Hoffman et al., 2011; Giuberti et al., 2014). Taylor and Allen (2005b) reported a 63% improvement in rumen starch digestion when diets contained floury versus vitreous corn grain. To-date, similar responses have not been observed for corn harvested at silage, rather than grain, moisture content, although Longuski et al. (2002) did observe a trend toward greater efficiency of fat-corrected milk production with floury endosperm corn silage.

The objective of this study was to compare diets containing a novel *bm3* corn silage hybrid with softer endosperm to diets containing commercially available conventional and *bm3* corn silage hybrids for their short-term effects on: 1) DMI, 2) lactational performance, 3) feeding behavior, and 4) total tract nutrient digestibility when fed to lactating Holstein cows. We hypothesized that the experimental *bm3* corn silage hybrid with softer endosperm would supply more fermentable carbohydrates (i.e., NDF and starch) than the conventional or *bm3* hybrids, resulting in greater milk component yields and gross feed efficiency.

SILAGE TREATMENTS AND EXPERIMENTAL APPROACH

Corn Silage Production

Three corn hybrids (Mycogen TMF2R447, 98-d relative maturity; Mycogen F2F498, 99-d relative maturity; and Mycogen FBDAS3, 96-d relative maturity, Mycogen Seeds, Dow AgroSciences LLC, Indianapolis, IN) were planted in a 6.07-ha field at the William H. Miner Agricultural Research Institute (Chazy, NY) on May 31, 2014 with 76-cm row spacing and 84,000 seeds/ha. Plots were separated by a buffer strip of a commercially available corn silage hybrid (Mycogen 2H079, 79-d relative maturity). All 3 plots were managed under the same tillage, fertilizer, and weed control procedures. Areas harvested were 1.32, 1.38, and 2.10 ha for TMF2R447, F2F498, and FBDAS3, respectively. Field plots were harvested using a self-propelled forage harvester with a kernel-processing unit (model 7300, John Deere, Moline, IL) with a 20.3-cm cut height, a 19-mm theoretical length of cut, and 3-mm roller gap spacing. Plots were harvested when kernel maturity reached ¼-milk line on October 7, 2014. Each corn silage hybrid was inoculated with Biotal Buchneri 500 (Lallemand Animal Nutrition, Milwaukee, WI) and stored in separate 2.7- × 30.5-m silage bags (AG-BAG plastic, Cottage Grove, MN). Average yields were 13.0, 13.8, and 11.7 tons of DM/ha for the TMF2R447, F2F498, and FBDAS3 corn silage hybrids, respectively.

Experimental Design, Diets, Management of Cows, and Measurements

Fifteen multiparous Holstein cows were blocked by 3.5% fat-corrected milk and assigned randomly to 1 of 3 squares using a replicated 3 × 3 Latin square design with 28-d periods. Cows averaged (mean ± standard deviation) 682 ± 59 kg of BW, 112 ± 13 days in milk, and 2.4 ± 0.7 lactations at the start of the experiment. Cows were fed a diet containing 49.1% corn silage with the three diets formulated with a 1:1 replacement of corn silage: 1) conventional TMF2R447 (CCS); 2) F2F498 *bm3* (*BM3*); and 3) experimental FBDAS3 *bm3* hybrid with softer endosperm kernel genetics (BMR-EXP). Ingredient composition of the three dietary treatments is shown in Table 1. Diets were formulated with the Nutritional Dynamic System model (RUM&N Sas; Via Sant'Ambrogio, Italy) utilizing the Cornell Net Carbohydrate and Protein System (version 6.5). Diets were formulated using the description for a 3rd lactation cow, 119 days in milk with a BCS of 3.0, mature BW of 726 kg, and milk yield of 45 kg/d containing 3.8% fat and 3.2% true protein.

Cows were housed in a tie-stall barn on mattresses bedded with sawdust with individual feed boxes and water bowls. Cows were fed for ad libitum intake (targeted refusal rate of 10%) once daily at 1300 h; feed was pushed up at 0730 h. The diets were mixed in a Calan Data Ranger (American Calan, Inc., Northwood, NH). Cows were milked 3 times daily (0430, 1230, and 2030 h) in a double-12 parallel milking parlor (Xpressway Parallel Stall System; BouMatic, Madison, WI).

Table 1. Ingredient composition (% of DM) of the diets.

	Diets[1]

Item	CCS	*BM3*	BMR-EXP
TMF2R447 corn silage	48.99	–	–
F2F498 corn silage	–	48.99	–
FBDAS3 corn silage	–	–	48.99
Hay crop silage	6.32	6.32	6.32
Grain mix			
Ground corn grain	13.91	13.91	13.91
Beet pulp pellets	7.26	7.26	7.26
Canola meal	6.41	6.41	6.41
Soybean meal, solvent extracted	5.69	5.69	5.69
Soybean meal, heat-treated [2]	4.17	4.17	4.17
Rumen inert fat[3]	2.13	2.13	2.13
Molasses	1.15	1.15	1.15
Blood meal	1.07	1.07	1.07
Calcium carbonate	0.99	0.99	0.99
Sodium sesquicarbonate[4]	0.79	0.79	0.79
Salt	0.39	0.39	0.39
Magnesium oxide	0.28	0.28	0.28
Urea	0.19	0.19	0.19
Methionine[5]	0.11	0.11	0.11
Yeast and organic selenium[6]	0.09	0.09	0.09
Vitamins A, D, and E[7]	0.03	0.03	0.03
Organic minerals[8]	0.01	0.01	0.01
Vitamin E[9]	0.01	0.01	0.01
Monensin[10]	0.01	0.01	0.01

[1]CCS = diet containing TMF2R447, a conventional corn silage; *BM3* = diet containing F2F498, a *bm3* corn silage; BMR-EXP = diet containing FBDAS3, a *bm3* corn silage with softer endosperm.
[2]Amino Plus; Ag. Processing, Inc.; Omaha, NE.
[3]BergaFat; Berg + Schmidt America, LLC; Libertyville, IL.
[4]S-Carb; FCM Industrial Chemical Group; Philadelphia, PA.
[5]Meta Smart; Adisseo USA, Inc.; Alpharetta, GA.
[6]Diamune; Diamond V Mills, Inc; Cedar Rapids, IA.
[7]Contained 24,093 kIU vitamin A/kg, 5,552 kIU vitamin D/kg, 92,676 IU vitamin E/kg.
[8]Availa 4; Zinpro Co.; Eden Prairie, MN.
[9]Contained 89,985 IU vitamin E/kg.
[10]Elanco Animal Health; Greenfield, IN.

Individual feed ingredients were collected weekly and dried in a forced-air oven at 105°C for 16 to 24 h for DM determination. Diets were adjusted for changes in the DM content of the feed ingredients when the DM of an ingredient varied by 1.2 standard deviations from the mean DM. Feed ingredients, diets, and orts were collected daily on d 22 to 28 of each period and dried in a forced-air oven at 105°C for 16 to 24 h for DM determination. Composites of feed ingredients, diets, and orts were analyzed for chemical composition by a commercial laboratory (Cumberland Valley Analytical Services, Inc., Hagerstown, MD). Analyses included DM, ash (method 942.05; AOAC, 2012), OM (method 942.05; AOAC, 2012), CP (method 990.03; AOAC, 2012), soluble protein according to Krishnamoorthy et al. (1982), fat (method 2003.05; AOAC, 2012), ADF (method 973.18; AOAC, 2012), NDF using α-amylase but excluding sodium sulfite (Van Soest et al., 1991), ADL (Goering and Van Soest, 1970), starch according to Hall (2009), sugar as ethanol soluble carbohydrates according to Dubois et al. (1956), and minerals (method 985.01; AOAC, 2012). Fermentation analysis was performed on the ensiled forage composite samples (Cumberland Valley Analytical Services, Inc.). Forage and diet composite samples were used to determine particle size distribution on an as-fed basis using the Penn State Particle Separator (Lammers et al., 1996) with 19-, 8-, and 4-mm screens . Particle size distribution was also determined on forages, the grain mix, and diets on a DM basis (55°C) by dry vertical sieving (Ro-Tap testing sieve shaker model B; W. S. Tyler Combustion Engineering, Inc., Mentor, OH) with 19.0-, 13.2-, 9.5-, 6.7-, 4.75-, 3.35-, 2.36-, 1.18-, 0.60-, and 0.30-mm sieves for 10 min. The physical effectiveness factor (pef) was determined by the standard dry vertical sieving method for feed ingredients and diets (Mertens, 2002).

In vitro NDF digestibility (30, 120, and 240 h) for forage composite samples (1-mm grind; Wiley mill, Arthur H. Thomas, Philadelphia, PA) were determined using an in vitro fermentation (Daisy^{II} Incubator, Ankom Technology Corp., Fairpoint, NY) in buffered medium containing rumen fluid (Goering and Van Soest, 1970). Rumen in vitro digestibility of starch (7-h incubation) of grain mixes, diets, and (2- and 7-h incubation) corn silage ground to pass a 4-mm screen using a Wiley mill was determined (Cumberland Valley Analytical Services Inc.) according to Richards et al. (1995). Additionally, all 3 corn silage hybrids were analyzed for the fast pool rate (kd per h) of nutrient digestion, slow pool rate (kd per h) of nutrient digestion, the carbohydrate B_1 and B_3 rates (%/h) specific to the Cornell Net Carbohydrate and Protein System, and microbial biomass production (mg/g; Fermentrics; RFS Technologies, Ottawa, ON) according to Fermentrics Interpretation and Guidelines (2013).

Body weight was measured (Allweigh computerized scale; Allweigh Scale System Inc., Red Deer, AB) and BCS was assigned in 0.25-unit increments on a 1 to 5 scale (Ferguson et al., 1994) for each cow after the 1230 h milking at the beginning of the experiment and on d 28 of each period. Dry matter intake was determined by recording feed offered and refused daily on d 22 to 28 for each cow during each period. Dry matter content was determined for diets and orts on d 22 to 28 and used to calculate DMI. Milk yields were recorded (ProVantage Information Management System; Bou-Matic, Madison, WI) at every milking from d 22 to 28 of each period and used to calculate average daily yield. Milk samples from 3 consecutive milkings per d for each cow were collected on d 25 and 26 of each test period, preserved (Bronolab-W II Liquid Preservative; D & F Control Systems, Inc., Dublin, CA), and stored at 4°C. Milk samples were sent to a commercial laboratory (Dairy One, Ithaca, NY), and analyzed for fat, true protein, lactose, SNF, MUN (method 972.16; AOAC, 2012), and SCC by infrared procedures (Foss 4000; Foss Technology, Eden Prairie, MN). Feed efficiency (kg/kg) was calculated and expressed as actual milk/DMI, 3.5% FCM/DMI, and SCM/DMI for d 25 through 26 of each period. Milk N efficiency was calculated as (kg of milk N/kg of N intake) × 100.

Cows were monitored for eating, rumination, and chewing (eating + rumination) behavior every 5 min for 2 consecutive 24-h blocks (d 25- 26) each period. Apparent total tract nutrient digestibility was determined from fecal grab samples collected on d 25 to 28 of each period so that every 3 h in a 24-h time period were represented. Composite samples of feces (by cow and period) were analyzed for DM, NDF, starch, and OM as described above. Undigested ash-free NDF (uNDFom) determined after a 240-h rumen in vitro incubation was used as an internal marker in the diets, orts, and feces and total tract digestibility was determined according to (Maynard et al., 1979).

Statistical analysis was performed using SAS (Version 9.2, SAS Institute Inc., Cary, NC). Data from the analysis of feed ingredients and diets were analyzed using the MEANS procedure of SAS (n = 3 per feed ingredient and diet). The data were reported as descriptive statistics (mean ± standard error). The experiment was conducted and analyzed as a Latin square design. Data collected over time (i.e., DMI, milk yield and composition, and behavior) were reduced to a period mean per cow. Data were subjected to ANOVA using the MIXED procedure of SAS. Fixed effects were treatment, period, square, and the treatment × square interaction. Cow nested within square was considered a random effect. Least squares means from the ANOVA results were separated using the Tukey procedure when the resulting *F*-test was $P \leq 0.05$. Significance was declared at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Dietary and Ingredient Nutrient Composition

The NDF content averaged 42.9, 40.6, and 39.7% for CCS, *BM3*, and BMR-EXP, respectively (Table 2). The particle size distributions of all three corn silages were similar when assessed by the Penn State Particle Separator (as-fed basis) and Ro-Tap shaker method (DM-basis; data not shown).

Starch content averaged 30.2, 30.2, and 32.2% for CCS, *BM3*, and BMR-EXP, respectively. As expected, uNDFom was greater for CCS compared with *BM3* and BMR-EXP resulting in higher NDF digestibility for *BM3* and BMR-EXP compared with CCS. Digestibility of starch determined after a 2- and 7-h rumen in vitro incubation was similar among corn silage hybrids, averaging 28.5% and 80.1%, respectively. With Fermentrics analysis, the fast pool of nutrient digestion was 25.1, 37.7, and 36.7 %/h for the CCS, *BM3*, and BMR-EXP corn silage hybrids, respectively. With this system, the fast pool digestion rate is derived from the maximal Kd per hour of silage acids, sugars, rapidly degraded starch, soluble fiber, and very rapidly digesting NDF (Fermentrics, 2013). Although there was little difference among the corn silage hybrids in starch digestion rate (B1 fraction), the rates increased slightly from CCS to *BM3* to BMR-EXP.

Table 2. Chemical composition, in vitro digestibility, and fermentation analysis (mean ± standard error) of ingredients used in the diets[1].

Item	CCS	*BM3*	BMR-EXP	Haycrop silage

DM, %	31.7±0.3	28.7±0.2	30.9±0.2	34.1±1.4
CP, % of DM	8.0±0.0	7.9±0.1	7.6±0.1	15.1±0.4
NDF[2], % of DM	42.9±1.0	40.6±0.4	39.7±1.6	55.7±1.0
ADL, % of DM	3.2±0.3	2.0±0.2	2.0±0.2	5.4±0.0
Starch, % of DM	30.2±0.5	30.2±0.3	32.2±1.3	1.9±0.1
ESC[3], % of DM	1.2±0.0	1.4±0.0	1.5±0.1	3.3±0.4
Fat, % of DM	3.0±0.0	3.2±0.0	3.2±0.0	4.2±0.4
Ash, % of DM	4.5±0.3	4.3±0.2	4.03±0.3	9.5±0.5
Lactic acid, % of DM	4.0±0.2	4.4±0.2	3.8±0.4	4.5±0.4
Acetic acid, % of DM	1.5±0.2	1.8±0.1	2.3±0.2	2.6±0.2
Total VFA, % of DM	5.5±0.3	6.2±0.2	6.1±0.2	7.9±0.0
Ammonia, % of CP	0.7±0.0	0.6±0.0	1.1±0.5	1.9±0.6
pH	3.9±0.1	3.8±0.0	3.8±0.0	4.5±0.1
30-h uNDFom, % of DM[4]	23.6±0.3	17.3±0.5	16.3±0.7	32.1±1.7
120-h uNDFom, % of DM	13.9±0.2	8.7±0.3	7.7±0.3	22.6±1.3
240-h uNDFom, % of DM	12.6±0.2	6.8±0.2	6.6±0.3	19.5±2.5
2-h starch digestibility, % of starch	28.1±4.05	27.9±3.8	29.4±2.5	–
7-h starch digestibility, % of starch	81.0±3.2	79.7±4.7	79.6±3.9	–
Fast pool Kd, %/h[5]	25.1±4.1	37.7±8.0	36.7±4.1	–
Slow pool Kd, %/h	3.0±0.6	3.8±1.0	3.0±0.3	–
Carbohydrate B_1, %/h	20.3±0.6	21.8±1.9	22.9±0.7	–
Carbohydrate B_3, %/h	3.0±0.6	3.8±1.0	3.0±0.3	–
Microbial biomass, mg/g	125.2±3.7	138.3±3.8	147.0±5.6	–

[1]CCS = TMF2R447, a conventional corn silage; *BM3* = F2F498, a *bm3* corn silage; BMR-EXP = FBDAS3, a *bm3* corn silage with softer endosperm.
[2]NDF with residual ash using α-amylase without sodium sulfite.
[3]ESC = Ethanol soluble carbohydrate.
[4]uNDFom = undigested NDF on organic matter basis (i.e., ash-free).
[5]Fast pool, slow pool, carbohydrate B_1 and B_3 rate, and microbial biomass were analyzed by Fermentrics (RFS Technologies, Ottawa, ON).

Microbial biomass production, which is considered to be the “gold standard” parameter in this system and found to be associated with higher milk yield, was greater for the BMR-EXP corn silage hybrid (147.0 mg/g) compared to CCS (125.2 mg/g) and *BM3* (138.3 mg/g). These differences reflect the potential for greater rumen carbohydrate digestibility and increased microbial protein synthesis for BMR-EXP. The daily microbial biomass production (MBP) can be calculated using the formula: Rumen microbial protein production (g/d) = MBP x 0.41 x 1.30 x DMI (kg/d). With this formula, we predict microbial protein production of 1788, 2063, and 2163 g/d for CCS, *BM3*, and BMR-EXP, respectively. From a protein perspective, these differences translate into approximately 2 kg/d more milk for BMR-EXP versus *BM3*, and 6 kg/d more milk for BMR-EXP versus CCS. These predicted differences in milk yield, driven by microbial biomass, agree reasonably well with the measured milk production shown in Table 5.

Chemical composition and in vitro NDF and starch digestibility of the diets are presented in Table 3. The content of CP, NDF, starch, and sugars were similar across the diets. Particle distribution (as-fed basis) based on the Penn State Particle Separator and particle size (DM basis) were consistent across all diets with an average physical effectiveness factor and peNDF value of 0.69 and 22.2%, respectively.

Table 3. Chemical composition (mean ± standard error) of the diets.

	Diets[1]		
Item	CCS	*BM3*	BMR-EXP
DM, %	45.4±0.4	41.3±0.4	44.2±0.2
CP, % of DM	15.1±0.2	14.8±0.1	14.6±1.0
aNDF[2], % DM	33.0±1.1	32.6±0.4	32.4±1.3
Starch, % DM	26.1±0.9	25.7±0.6	27.1±1.3
ESC[3], % DM	4.4±0.6	4.8±0.7	5.1±0.8
Fat, % DM	4.6±0.0	4.5±0.3	4.3±0.2
Ash, % DM	7.1±0.2	7.6±0.7	6.9±0.3

[1]CCS = diet containing TMF2R447, a conventional corn silage; *BM3* = diet containing F2F498, a *bm3* corn silage; BMR-EXP = diet containing FBDAS3, a *bm3* corn silage with softer endosperm.

[2] NDF with residual ash using α-amylase without sodium sulfite.

[3] ESC = Ethanol soluble carbohydrate.

Dry Matter and Nutrient Intake

Dry matter and nutrient intake, BW, and BCS are summarized in Table 4. Dry matter intake, expressed as kg/d and % of BW, was greater for cows consuming *BM3* (28.0 kg/d and 4.03%) compared with CCS (26.8 kg/d and 3.87%; P = 0.013 and P = 0.005). Dry matter intake for cows consuming BMR-EXP was intermediate (27.6 kg/d and 3.94%). Holt et al. (2013a) found that, for cows between 60 and 180 days in milk, those fed a *bm3* corn silage diet consumed approximately 1 kg/d more than cows fed a conventional corn silage diet, likely due to reduced gut fill for cows consuming *bm3*. Similarly, Ferraretto and Shaver (2015) reported a 0.9 kg/d increase in DMI for cows consuming brown midrib corn silages, most likely related to increased NDF digestibility and rumen passage rate. In contrast to fiber, Taylor and Allen (2005a) reported no effect of grain endosperm type on DMI in diets containing floury or vitreous endosperm corn.

Neutral detergent fiber intake was increased for cows consuming both *BM3* (9.2 kg/d; P = 0.009) and BMR-EXP (9.2 kg/d; P = 0.003) compared with CCS (8.7 kg/d). Taylor and Allen (2005b) observed no differences in NDF intake between cows fed diets containing conventional and *bm3* corn silage. Because undigested NDF intake was 0.7 kg/d greater (P = 0.001) and potentially digestible NDF intake was 1.2 kg/d less (P = 0.001) for cows consuming CCS compared with both brown midrib hybrids, the differences in NDF intake may be due to interactions between gut fill, passage rate, and NDF digestibility. Starch intake was increased for BMR-EXP (7.5 kg/d) compared with CCS (7.0 kg/d; P = 0.005) while *BM3* was intermediate (7.2 kg/d).

Table 4. Least squares means of DMI, BW, and BCS of multiparous Holstein cows fed diets containing different sources of corn silage.

Item	Diets[1]			SEM	*P*-value
	CCS	*BM3*	BMR-EXP		
DMI, kg/d	26.8[b]	28.0[a]	27.6[ab]	0.5	0.016
DMI, % of BW	3.87[b]	4.03[a]	3.94[ab]	0.08	0.006
NDF intake, kg/d	8.7[b]	9.2[a]	9.2[a]	0.16	0.002
uNDFom intake[2], kg/d	2.3[a]	1.6[b]	1.6[b]	0.03	0.001
pdNDF intake[3], kg/d	6.4[b]	7.6[a]	7.6[a]	0.14	0.001
Starch intake, kg/d	7.0[b]	7.2[ab]	7.5[a]	0.17	0.007
BW, kg	696	698	705	16	0.21
BW change, kg/28-d period	8	5	20	4	0.08
BCS	2.86	2.78	2.84	0.08	0.18
BCS change, kg/28-d period	–0.04	0.05	–0.01	0.04	0.41

[ab]Least squares means within a row without a common superscript differ ($P \leq 0.05$).
[1]CCS = diet containing TMF2R447, a conventional corn silage; *BM3* = diet containing F2F498, a *bm3* corn silage; BMR-EXP = diet containing FBDAS3, a *bm3* corn silage with softer endosperm.
[2] Undigested NDF, determined after a 240 h rumen in vitro incubation.
[3] Potentially digestible NDF = (NDF – uNDFom).

Body weight and BCS were unaffected by dietary treatment. Change in body weight (kg/28-d period) tended ($P = 0.08$) to be greater for cows consuming the BMR-EXP diet (20 kg) compared with *BM3* (5 kg) or CCS (8 kg).

Lactational Performance

Milk yield, FCM, SCM, and ECM were greater for cows consuming *BM3* and BMR-EXP compared to cows that were fed CCS ($P = 0.001$: Table 5). Increased milk yields have been reported when cows were fed 30 to 40% *bm3* corn silage-based diets in comparison to diets containing conventional corn silage (Lim et al., 2014; Ferraretto and Shaver, 2015). Milk fat content was greater for cows consuming CCS (4.0%) compared to *BM3* (3.85%; $P = 0.02$) and BMR-EXP (3.87%; $P = 0.04$), but milk fat yield was greatest for cows fed BMR-EXP (1.87 kg/d) compared to CCS (1.74 kg/d; $P = 0.001$) and *BM3* (1.80 kg/d; $P = 0.05$).

Table 5. Least squares means of lactational performance and feed efficiency for multiparous Holstein cows fed diets containing different sources of corn silage

	Diets[1]	

Item	CCS	*BM3*	BMR-EXP	SEM	*P*-value
Milk yield					
Milk, kg/d	43.8[b]	47.3[a]	48.0[a]	1.3	0.001
3.5% FCM, kg/d	47.1[b]	49.7[a]	51.2[a]	1.4	0.001
SCM, kg/d	43.1[b]	46.2[a]	47.8[a]	1.4	0.001
ECM, kg/d	47.2[b]	50.3[a]	51.8[a]	1.5	0.001
Milk composition					
Fat, %	4.00[a]	3.85[b]	3.87[b]	0.07	0.013
Fat, kg/d	1.74[b]	1.80[b]	1.87[a]	0.06	0.001
True protein, %	3.13[b]	3.19[a]	3.19[a]	0.07	0.012
True protein, kg/d	1.36[b]	1.49[a]	1.54[a]	0.06	0.001
Lactose, %	4.80[b]	4.85[a]	4.84[ab]	0.03	0.012
Lactose, kg/d	2.08[b]	2.28[a]	2.34[a]	0.07	0.001
SNF, %	8.80[b]	8.93[a]	8.93[a]	0.06	0.001
SNF, kg/d	3.82[b]	4.19[a]	4.32[a]	0.13	0.001
MUN, mg/dL	13.60[a]	11.61[b]	11.16[b]	0.30	0.001
SCS	1.93	1.58	1.17	0.40	0.349
Feed efficiency					
Milk/DMI	1.63[b]	1.69[ab]	1.74[a]	0.04	0.001
3.5% FCM/DMI	1.75[b]	1.77[b]	1.85[a]	0.04	0.004
SCM/DMI	1.60[b]	1.65[b]	1.73[a]	0.04	0.001
ECM/DMI	1.76[b]	1.79[b]	1.87[a]	0.04	0.001
Milk N efficiency, %	35.3[c]	38.1[b]	40.4[a]	1.2	0.001

[abc] Least squares means within a row without a common superscript differ ($P \leq 0.05$).

[1]CCS = diet containing TMF2R447, a conventional corn silage; *BM3* = diet containing F2F498, a *bm3* corn silage; BMR-EXP = diet containing FBDAS3, a *bm3* corn silage with softer endosperm.

Milk true protein content and yield were greater for cows fed *BM3* and BMR-EXP compared to cows fed CCS (P < 0.03 and P = 0.001, respectively). Lim et al. (2014) also reported increased protein content and yield for cows fed *bm3* corn silage diets compared to conventional corn silage diets. Differences in protein content and yield may be related to greater microbial protein synthesis due to increased rumen OM digestibility for cows fed *bm3* corn silage diets. When Ramirez et al. (2012) estimated microbial CP by measuring purine derivatives in diets containing 40% *bm3* or dual purpose corn silage, *bm3* corn silage diets resulted in greater calculated microbial CP flows. These results agree well with our study where the Fermentrics data showed greater microbial biomass production for the *BM3* and particularly for the BMR-EXP corn silages.

Solids non-fat content and yield were greater for cows fed *BM3* and BMR-EXP compared to cows fed CCS (P = 0.001). Milk urea N concentration was greater for cows consuming CCS (13.60 mg/dL) compared to *BM3* (11.61 mg/dL; P = 0.001) and BMR-EXP (11.16 mg/dL; P = 0.001). Others have also reported a reduction in MUN concentration when feeding brown midrib silages (Taylor and Allen, 2005b; Holt et al., 2013b).

Feed efficiency (milk/DMI) was greatest for cows consuming BMR-EXP (1.74 kg milk/kg DMI) compared to cows consuming CCS (1.63 kg milk/kg DMI; *P* = 0.001), and intermediate for cows consuming *BM3* (1.69 kg milk/kg DMI). Cows consuming BMR-EXP had greater efficiency of production of 3.5% FCM, SCM and ECM when compared to either the *BM3* or CCS-fed cows (*P* < 0.005). Several studies have reported that feed efficiency is similar for cows fed *bm3* and conventional corn silage diets (Stone et al., 2012; Holt et al., 2013a; Ferraretto and Shaver, 2015). However, Taylor and Allen (2005a) reported that floury grain not originating in silage tended to increase 3.5% FCM, indicating that a source of more digestible floury grain in diets may improve feed efficiency.

Milk N efficiency was greatest for cows consuming BMR-EXP (40.4%), compared to cows consuming *BM3* (38.1%; *P* = 0.03) and CCS (35.3%; *P* = 0.001). Milk N efficiency was also greater for cows consuming *BM3* compared to CCS (*P* = 0.006). Holt et al. (2013b) demonstrated that feeding forages greater in rumen degradability such as *bm3* corn silage resulted in improved N utilization. Our study indicates that the combined effects of greater rumen fiber degradability and greater total carbohydrate fermentability provided by feeding the BMR-EXP corn silage enhanced N utilization of dairy cows. The observed responses of greater N efficiency, greater ECM/DMI, lower MUN, and higher microbial biomass production all fit together.

Feeding Behavior

Chewing, eating, and rumination behavior expressed as minutes per day were similar across all diets (Table 6). Interestingly, even though DMI was the least, chewing and ruminating time expressed as minutes per kilogram of DM was greater for cows fed the CCS diet compared with the *BM3* diet (*P* = 0.006) but did not differ when compared to cows fed the BMR-EXP diet. Feeding behavior differences based on NDF and peNDF intake may better reflect biological differences among treatments. Chewing time per kilogram of NDF was increased for cows consuming CCS (96.5 min/kg NDF) compared with *BM3* and BMR-EXP (91 min/kg NDF; *P* = 0.002). Forage fragility, while not incorporated into pef values, plays a role in chewing activity (Mertens, 1997). Differences in forage fragility of *BM3* and BMR-EXP may help account for decreased chewing time per kilogram of NDF which subsequently allowed for 0.5 kg/d greater NDF intake for cows consuming *bm3* hybrids because fiber containing lower lignin or uNDFom content requires less fracture force for exposure to microbial degradation. Eating time on an NDF basis was greater for cows consuming CCS (33.9 min/kg NDF) compared to cows consuming BMR-EXP (30.9 min/kg NDF; *P* = 0.03) and intermediate for cows consuming *BM3* (32.3 min/kg NDF). Cows consuming CCS ruminated longer per kilogram of NDF than either group of cows fed *bm3* (*P* = 0.002).

Table 6. Least squares means of eating and ruminanting behavior for multiparous Holstein cows fed diets containing different sources of corn silage.

	Diets[1]				
Item	CCS	*BM3*	BMR-EXP	SEM	*P*-value

Chewing					
min/d	838	826	832	16	0.645
min/kg DM	31.4[a]	29.7[b]	30.3[ab]	0.8	0.006
min/kg NDF	96.5[a]	90.8[b]	90.6[b]	2.3	0.001
Eating					
min/d	294	294	284	11	0.41
min/kg DM	11.0	10.5	10.4	0.4	0.126
min/kg NDF	33.9[a]	32.3[ab]	30.9[b]	1.3	0.027
Ruminating					
min/d	543	532	547	13	0.303
min/kg DM	20.4[a]	19.1[b]	19.9[ab]	0.6	0.006
min/kg NDF	62.6[a]	58.5[b]	59.6[b]	1.9	0.002

[ab]Least squares means within a row without a common superscript differ ($P \leq 0.05$).
[1]CCS = diet containing TMF2R447, a conventional corn silage; *BM3* = diet containing F2F498, a *bm3* corn silage; BMR-EXP = diet containing FBDAS3, a *bm3* corn silage with softer endosperm.

Total Tract Digestibility

Apparent total tract digestibility for all nutrients was unaffected by dietary treatment (Table 7). Total tract digestibility of OM, NDF, and potentially digestible NDF averaged 74.4, 58.1, and 73.0%, respectively. Ferraretto and Shaver (2015) reported that treatments containing *bm3* corn silage had greater total tract NDF digestibility (44.8%) compared to conventional corn silage (42.3%). In contrast, similar NDF digestibility was observed by Ferraretto et al. (2015) and thought to be related to greater passage rate of digesta due to higher DMI. Total tract starch digestibility was similar among treatments, averaging 99.3%.

Table 7. Least squares means of apparent total tract nutrient digestibility (%) of the diets for multiparous Holstein cows fed diets containing different corn silages.

Item	Diets[1]			SEM	*P*-value
	CCS	*BM3*	BMR-EXP		
OM	74.2	74.6	74.3	0.3	0.31
NDF	58.2	58.4	57.8	0.5	0.62
Potentially digestible NDF	73.0	73.0	72.9	0.5	0.98
Starch	99.3	99.4	99.3	0.1	0.42

[1] CCS = diet containing TMF2R447, a conventional corn silage; *BM3* = diet containing F2F498, a *bm3* corn silage; BMR-EXP = diet containing FBDAS3, a *bm3* corn silage with softer endosperm.

CONCLUSIONS

The results of this experiment show that an experimental *bm3* corn silage hybrid containing softer endosperm improves NDF intake similar to traditional *bm3* hybrids, while also increasing starch intake compared to conventional corn silage. Greater feed efficiency (FCM, SCM and ECM) indicates that the *bm3* corn silage hybrid containing softer endosperm improves energy utilization compared to *bm3* and conventional corn silage. Additionally, improved milk N efficiency suggests that greater rumen degradability and greater carbohydrate fermentability can be achieved when feeding a BMR-EXP diet. Availability of a *bm3* corn silage hybrid with softer endosperm will allow dairy producers to feed a high quality forage that will efficiently satisfy both fiber and energy requirements of high producing dairy cows.

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