Effect of amount of milk replacer fed and the processing of corn in starter on growth performance, nutrient digestibility, and rumen and fecal fibrolytic bacteria of dairy calves

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ABSTRACT

The aim of this study was to evaluate effects of milk replacer (MR) feeding rate and processing of corn in calf starter (CS) on growth performance, nutrient digestibility, and rumen and fecal fibrolytic bacteria in dairy calves. Holstein male calves ($n = 48$, 2–3 d of age) were randomly assigned to 1 of 4 treatments with a 2×2 factorial arrangement of MR level of 0.749 kg of MR/d (LO) or up to 1.498 kg of MR/d (HI); and whole corn or flaked corn in textured CS. Calves were weaned by reducing MR offered by 50% during wk 6. Intakes of MR and CS were recorded daily, whereas body weight (BW) was measured weekly. Rumen fluid and fecal matter were collected at wk 5 and 8 to quantify fibrolytic bacteria and nutrient digestibility. Data were analyzed as a completely randomized design using mixed model ANOVA. Repeated measures were used as appropriate. Calves fed HI had greater average daily gain than calves fed LO at wk 2, 3, 4, and 5, yet at wk 7 calves fed HI had lower average daily gain compared with calves fed LO. Starter intake was greater for calves fed LO compared with HI at wk 4, 5, 6, and 7. During wk 5 and 8, calves fed LO had increased ADF and NDF digestibility compared with calves fed HI. During wk 5, dry matter and organic matter digestibility were lower for LO-fed calves compared with HI-fed calves, but during wk 8 the opposite was observed, with HI-fed calves having lower dry matter and organic matter digestibility than LO-fed calves. At wk 5, *Clostridium* cluster IV and *Butyrivibrio fibrisolvens* proportions in rumen fluid tended to be higher and *Clostridium* cluster IV, *Fecalibacterium* sp., and *Prevotella* sp. proportions in fecal matter were higher in calves fed LO compared

with HI. From wk 8 to 16, dry matter intake was unaffected by treatment; however, energy efficiency was greater in calves fed LO, causing LO calves to have higher BW gain during this period. Greater starter digestibility was observed for calves fed LO versus HI in concert with increased fibrolytic bacteria proportions (wk 5) in fecal and rumen samples, which resulted in greater postweaning BW gain and similar BW and frame measurements by 16 wk of age. Overall the results show that rate of MR feeding has a larger effect than the processing of corn in CS on performance, fiber digestibility, and rumen and fecal fibrolytic bacterial communities.

Key words: calf, milk replacer feeding, digestion, fibrolytic bacteria

INTRODUCTION

Recently, there has been interest in feeding dairy calves a higher volume of whole milk or milk replacer (MR) preweaning than the conventional rate of 10% of birth BW due to observed advantages during the preweaning phase, including improved weight gain (Jasper and Weary, 2002; Khan et al., 2011; Rosenberger et al., 2017) and improved feed efficiency (Khan et al., 2007a; Moallem et al., 2010; Davis Rincker et al., 2011). In addition, there is potential for heifer calves with increased preweaning ADG to have increased milk production later in life (Soberon et al., 2012; Soberon and Van Amburgh, 2013; Gelsinger et al., 2016). However, negative results of such feeding regimens have also been reported, such as poor performance (Cowles et al., 2006) and reduced feed efficiency during the weaning transition (liquid to solid feed) and thereafter (Hill et al., 2006). This is likely because preweaning starter intake is negatively influenced by a high MR feeding rate (Jasper and Weary, 2002; Jensen, 2006; Kristensen et al., 2007; Hill et al., 2009), resulting in diminished intake of calf starter (CS; Hill et al., 2006), leading to a delay in rumen development (Khan et al., 2016)

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that causes a reduction in nutrient digestibility, especially fiber, postweaning (Terré et al., 2007; Hill et al., 2010, 2016b). Inadequate rumen microbial fermentation caused by decreased CS intake when calves are fed higher volumes of milk or MR may result in a reduction in fiber digestion; however, the exact cause by which fiber digestion is decreased when calves are fed higher volumes of milk or MR is unknown. Therefore, further investigation regarding fibrolytic bacterial communities present in the rumen and feces is warranted.

The importance of supplying readily fermentable carbohydrates in CS is well established for its role in butyrate and propionate production in the rumen (Flatt et al., 1958; Sander et al., 1959). Corn is one of the ingredients most commonly used in CS and substituting corn with barley, oats, or wheat in CS resulted in reduced solid feed intake and weight gain in dairy calves up to 12 wk old (Khan et al., 2007b). Alteration (processing) of grains (e.g., grinding, steam- or dry-rolling, and steam-flaking) enhances surface area for degradation, which leads to improved ruminal fermentation rate, passage rate, and total-tract starch digestibility in mature animals (Huntington, 1997). However, CS intake was increased when whole grains (corn and barley) were fed to calves compared with steam-rolled grains (Bateman et al., 2009; Terré et al., 2016). To date, most studies (Owens, et al., 1997; Firkins et al., 2001) have investigated effects of processing corn on mature animals (mainly dairy cows and feedlot animals) and research regarding the effect of feeding processed corn to dairy calves in CS is limited.

The objective of this study was to determine how the amount of MR and the processing of corn in CS can affect performance, nutrient digestibility, and the fibrolytic bacterial community in dairy calves. We hypothesized that feeding an elevated amount of MR with CS with whole corn would reduce nutrient digestion, resulting in poor performance.

MATERIALS AND METHODS

Animals, Housing, and Environment

A total of 48 Holstein bull calves (± 3 d of age) were obtained from a single farm. Calves received 2 L of fresh colostrum within 1 h of birth followed by 2 additional feedings at 6 and 12 h. Thereafter, calves were fed 2 L of pasteurized whole milk twice daily until being transported (3.5 h) to the Nurture Research Center (New Paris, OH). In this study, calves were cared for and handled in accordance with the Canadian Council on Animal Care (CCAC, 1993) regulations, *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 1999), and the institu-

tional Animal Care and Use Committee (University of Alberta, AB; AUP00002303).

This study consisted of 2 phases. In the first phase (nursery; wk 1 to 8), calves were housed in a barn with side curtains and natural ventilation in individual pens (1.2 m $\times$ 2.4 m) bedded with wheat straw and given access to the experimental textured CS and fresh water ad libitum. Individual animal was the experimental unit. This phase consisted of 2 periods, pre- and postweaning at wk 1 to 6 and wk 7 to 8, respectively. In phase 2 (grower; wk 9–16), calves were randomly assigned within nursery treatment to group pens ($n = 4$ calves/pen) that provided 6.5 m² per calf outside with inside shelter (1.35 m² space per calf) bedded with wheat straw. Pen ($n = 3$ /treatment) was the experimental unit during the grower phase. During this phase, calves had access to a TMR consisting of CS and chopped grass hay (Table 1) in a 95:5 on an as-fed ratio. Calves were dehorned and castrated at d 36. Average temperature was 24°C (range 12–38°C) and 19°C (range 2–33°C) for the nursery and grower phases, respectively. Average relative humidity was 79% (range 24–100%) and 81% (range 24–100%) for the nursery and grower phases, respectively.

Experimental Design and Dietary Treatments

The experiment was a completely randomized design with a 2 $\times$ 2 factorial arrangement of 0.749 kg of MR powder/d (**LO**) or up to 1.498 kg of MR powder/d (**HI**), and whole (**WC**) or flaked (**FC**) corn in a textured CS (37% corn, 35% supplement pellet, 25% whole oats, and 3% molasses; Table 1). Milk replacer (Table 1) contained 25.2% CP, 17.9% fat on a DM basis and was reconstituted to 14% solids. Corn for WC and FC treatments was obtained from the same batch of corn to ensure similar composition between starch sources.

Table 1. Chemical composition of milk replacer (MR), starter, and hay (mean $\pm$ SD) fed to dairy calves

Item	MR	Starter ¹	Hay
DM, % as fed	93.1 $\pm$ 1.13	87.8 $\pm$ 0.66	86.2 $\pm$ 2.1
DM basis, %			
Ash	5.9 $\pm$ 0.33	6.1 $\pm$ 0.67	8.3 $\pm$ 1.14
CP	25.2 $\pm$ 0.57	20.3 $\pm$ 0.45	6.6 $\pm$ 0.91
Fat	17.9 $\pm$ 0.01	3.6 $\pm$ 0.22	1.9 $\pm$ 0.45
ADF	—	7.2 $\pm$ 0.50	40.9 $\pm$ 0.65
NDF	—	15.4 $\pm$ 1.14	63.3 $\pm$ 0.85
Starch	—	41.5 $\pm$ 0.86	1.4 $\pm$ 0.43
Sugar	—	7.3 $\pm$ 1.62	8.8 $\pm$ 1.49
ME, ² Mcal/kg	4.75	3.26	2.05

¹37% corn (either whole or steam flaked), 35% protein/mineral pellet, 25% whole oats, and 3% liquid molasses.

²Calculated using NRC (2001).

Calves fed LO ($n = 24$) received 0.749 kg/d (DM basis) of MR for 6 wk, followed by 0.375 kg/d of MR for the last week. Calves fed HI received 0.749 kg/d of MR during wk 1, 0.851 kg/d during wk 2, 1.135 kg/d during wk 3, 1.498 kg/d during wk 4 and 5, and 0.749 kg/d of MR for the last week. Amounts of MR fed to calves were divided into 2 equal feedings (AM and PM) until wk 6, when MR was only fed once (AM). All calves were weaned at the end of wk 6.

Data and Sample Collection

Intake and Growth Performance. During the pre- and postweaning period, individual MR and CS intakes were recorded daily and during the grower phase group pen intakes were recorded daily. Samples of MR and CS were taken from every second bag, whereas samples of hay were taken from every bale. Samples were composited by type and stored (4°C) before chemical analysis. Individual BW was measured weekly (wk 1 to 8) pre- and postweaning and at wk 10, 12, and 16 during the grower phase. Body condition score, adapted from Wildman et al. (1982), and hip width were measured every 2 wk. Hip height, heart girth, and paunch girth were measured at wk 0, 8, and 16. Efficiency was estimated by calculating total ME intake divided by BW gain.

Apparent Total-Tract Nutrient Digestibility. Fecal samples were collected over 5 d, as described previously (Hill et al., 2016a), to estimate apparent total-tract digestibility. During wk 5 and 8, 6 calves from each treatment (total $n = 24$) were randomly selected for fecal sample collection. Samples were pooled by calf (5 d) by time point. During wk 11 to 12, fecal samples were collected from the pen and were pooled (5 d) by pen. All fecal samples were stored at -20°C before chemical analysis.

Fibrolitic Bacteria in Rumen and Feces. Ruminal fluid was sampled 4 h after AM feeding from the subset ($n = 24$) of calves at wk 5 and 8 using a Geishauser probe (adapted for calves; Geishauser, 1993) fitted to a 60-mL syringe. Ruminal contents were squeezed through 4 layers of cheesecloth and 8 mL of ruminal fluid was snap frozen (dry ice and ethanol mixture). Spot fecal samples were collected 3 h after the AM feeding from the same subset ($n = 24$) of calves at wk 5 and 8 and snap frozen. Both samples (rumen and fecal) were stored at -20°C before the quantification of the fibrolitic bacterial community.

Sample Analyses

Feed and Fecal Composition. Milk replacer, CS, hay, and fecal samples were analyzed (AOAC Inter-

national, 2000) for DM (oven method 930.15), ash (oven method 942.05), CP (Kjeldahl method 988.05), fat (MR only; alkaline treatment with Roese-Gottlieb method 932.06), and acid-insoluble ash (Van Keulen and Young, 1977). Calf starter, hay, and fecal samples were analyzed for ADF (Robertson and Van Soest, 1981), NDF (Van Soest et al., 1991) without sodium sulfite or α -amylase, ether extract (method 2003.05), sugar (colormetric method; DuBois et al., 1956), and starch (α -amylase method; Hall, 2009). Acid-insoluble ash measured in MR, CS, hay, and fecal samples was used as an internal digestibility marker (Van Keulen and Young, 1977). The ratio of acid-insoluble ash and nutrients in the feed and fecal matter was used to estimate apparent total-tract nutrient digestibility.

Quantification of Fibrolitic Bacteria in Rumen and Feces. The DNA was extracted from rumen fluid and fecal samples using the repeated bead beating plus column method (Yu and Morrison, 2004). Briefly, samples were treated with cell lysing buffer (containing 4% SDS) followed by physical disruption ($2,160 \times g$ for 3 min at room temperature using Biospec Mini Beads Beater 16, BioSpec, Bartlesville, OK). Then, DNA was isolated using 10 M ammonium acetate and precipitated using isopropanol followed by further purification using a QIAmp fast DNA stool mini kit (Qiagen Inc., Germantown, MD). Quantity and purity of the DNA were evaluated using NanoDrop 1000 spectrophotometer (Nanodrop Technologies, Wilmington, DE) and DNA was stored at -20°C until further analysis.

Real-time PCR was used to estimate 16S rRNA gene copy numbers of total bacteria; cellulose digesters *Ruminococcus albus* (Zhou et al., 2015), *Fecalibacterium prausnitzii* (Kopečný et al., 2004), and *Fibrobacter succinogenes* S85 (Zhou et al., 2015); hemicellulose digesters *Butyrivibrio fibrisolvens* (Zhou et al., 2015), *Ruminococcus flavefaciens* (Zhou et al., 2015), and *Prevotella* sp. (Zhou et al., 2015); and the fiber digester *Clostridium* cluster IV (Zeng et al., 2015). Primers (Table 2) specific to each bacteria and SYBR Green chemistry (Fast SYBR Green Master Mix, Applied Biosystems, Foster City, CA) were used for PCR. Bacterial populations were estimated using high-throughput Viia 7 Real-Time PCR System (Thermo Fisher Scientific, Waltham, MA). Purified 16S rRNA genes of *Butyrivibrio hungatei*, *R. albus* 7, *Clostridium* cluster IV, *B. fibrisolvens*, *F. prausnitzii* A2-165, *R. flavefaciens* (ATCC 49949), *Prevotella ruminicola* (ATCC 19189), and *F. succinogenes* (ATCC 19189) were used as standards for each bacterial community, respectively.

The copy number of 16S rRNA genes per unit of sample for total bacteria and other communities was calculated using the equation as described by Li et al. (2009):

Table 2. Bacterial primers used to determine the copy number of 16S rRNA genes in rumen fluid and fecal matter of dairy calves

Bacteria	Primer	Sequence (5' to 3')	Product size, bp	Annealing temperature, °C	Reference
Total bacteria	Forward	ACTCCTACGGGAGGCAG	467	60	Stevenson and Weiner, 2007
	Reverse	GACTACGAGGTATCTAATCC			
<i>Ruminococcus albus</i>	Forward	TGTTAACAGAGGGAAGCAAGCA	75	60	Stevenson and Weiner, 2007
	Reverse	TGCAGCCTACATCCGAATAA			
<i>Fecalibacterium prausnitzii</i>	Forward	GGAGGAAGAAGTCTTCGG	248	60	Vital et al., 2013
	Reverse	AATTCGGCCTACCTCTGCACT			
<i>Butyrivibrio fibrisolvens</i>	Forward	GGTGAGTAACGGTGGGTAA	189	60	Present study
	Reverse	CAGGTGGCTACTGATCGTC			
<i>Clostridium</i> cluster IV	Forward	TTAACACAATAAGTWTCCACCTGG	314	60	Ramirez-Farias et al., 2009
	Reverse	ACCTTCCTCCGTTTGTCAAC			
<i>Ruminococcus flavefaciens</i>	Forward	TGGCGGACGGGTGAGTAA	71	60	Stevenson and Weiner, 2007
	Reverse	TTACCAATCCGTTTCCAGAAGCT			
<i>Prevotella</i> sp.	Forward	GGTCTGAGAGGAAGTCCCC	121	60	Stevenson and Weiner, 2007
	Reverse	TCCTGCACGCTACTTGGCTG			
<i>Fibrobacter succinogenes</i> S85	Forward	GCGGGTAGCAACACAGGATTAGA	77	60	Stevenson and Weiner, 2007
	Reverse	CCCCGGACACCCAGTAT			

copy number =

$$\frac{\left(\frac{\text{copy number obtained} \times \text{total DNA amount per unit of sample (ng)}}{20 \text{ ng (amount of template used for real-time reaction)}} \right)}{\text{amount of sample used (g)}}$$

Proportion (% of total bacteria) of each community was also calculated:

proportion =

$$\frac{\text{copy number of a community}}{\text{total bacterial copy number per unit of sample}} \times 100.$$

Statistical Analyses

Data were analyzed as a completely randomized 2×2 factorial design using the mixed model procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC). The statistical model used was $Y = \mu + MR + CS + (MR \times CS) + e$, where Y is the dependent variable, μ is the mean, MR is the effect of MR feeding rate, CS is the effect of corn processing, $MR \times CS$ is the interaction of MR and corn processing in CS, and e is the error term. Data collected over time were summarized by week and repeated measures were used. Tukey test was used to separate the least squares means. At least 3 variance-covariance structures (auto-regressive type 1, Toeplitz, and compound symmetry) were tested and the covariance structure that minimized the Schwarz's Bayesian information criterion was chosen. Significance was declared at $P < 0.05$ and tendencies at $0.05 \leq P < 0.10$.

RESULTS

Intake, Growth Performance, and Efficiency

Milk replacer intake was affected by week $\times$ treatment interaction (Figure 1A; $P < 0.0001$) due to the step-up protocol followed by calves on the HI diet. Calf starter intake, BW, and ADG were influenced by week (Figure 1B, C and D; $P < 0.0001$). Calves fed HI had greater (Figure 1A; $P < 0.001$) MR intake at wk 2 to 6 compared with calves fed LO, which led to a 48.6% increase in total MR intake (Table 3; $P < 0.0001$) for calves fed HI compared with calves fed LO. Calves fed HI had 3.6 kg greater MR refusals than calves fed LO. Calf starter intake was greater at wk 4 to 7 (Figure 1B; $P \leq 0.0005$) and had a tendency ($P \leq 0.10$) to be greater at wk 8 in calves fed LO versus HI. Total CS intake was higher (Table 3; $P \leq 0.0083$) during the pre-

Figure 1. Mean weekly (A) milk replacer (MR) intake, (B) calf starter (CS) intake, (C) BW, and (D) ADG for calves fed a low (LO) or high (HI) MR feeding rate and CS containing whole (WC) or flaked (FC) corn (wk 1 to 8). Milk replacer was fed at LO = 0.749 kg/d of MR for 35 d, then 0.375 kg/d for the last 7 d; HI = 0.749 kg/d of MR for 6 d, 0.851 kg/d for 7 d, 1.135 kg/d for 7 d, 1.498 kg/d for 15 d, then 0.749 kg/d for the last 7 d. Error bars represent SEM for each treatment $\times$ week interaction.

and postweaning period for calves fed LO versus HI, which resulted in total CS intake for the overall period being 33% greater ($P = 0.001$) for calves fed LO versus HI. Calves fed HI were heavier from wk 3 to 8 compared with calves fed LO (Figure 1C; $P \leq 0.022$). Calves fed HI had greater ADG at wk 2, 3, 4, and 5 (Figure 1D; $P = 0.01$), but lower ADG at wk 7 (the week after weaning) compared with calves fed LO. Body weight gain during the preweaning period was higher (Table 3; $P < 0.0001$) and lower ($P = 0.0008$) during the postweaning period for calves fed HI compared with LO. Overall BW gain for the pre- and postweaning period were higher ($P = 0.01$) in calves fed HI compared with LO. Other initial and wk 8 measurements (BW, hip height and width, and heart and paunch girth) were similar among dietary treatments. Pre- and postweaning and overall (pre- and postweaning period) energy efficiency did not differ among dietary treatments. Milk replacer and CS intake, BW and ADG were unaffected

by corn processing in CS (Figure 1). This resulted in no change in total MR and CS intake and performance measurements during the pre- and postweaning and overall (pre- and postweaning) period (Table 3). Also, no effect was observed of the combination of MR feeding rate and corn processing on intake, performance, and efficiency during the pre- and postweaning and overall (pre- and postweaning period) period (Figure 1 and Table 3).

Total DMI was unaffected by dietary treatment during the grower phase (Table 4). Final BW and other body measurements were unaffected by dietary treatment. Calves fed LO had greater ($P < 0.0001$) energy efficiency during the grower phase than calves fed HI, which resulted in LO calves having higher ($P = 0.018$) BW gain during this period. Hip width tended ($P = 0.06$) to be higher for calves fed LO compared with HI. No effect was observed of processing of corn or the combination of MR feeding rate and corn processing

Table 3. Effect of treatment¹ on intake, growth performance, and efficiency in dairy calves (0 to 8 wk)

Item	Treatment				SEM	Contrast, <i>P</i> -value		
	LO-WC	LO-FC	HI-WC	HI-FC		LO vs. HI	FC vs. WC	Interaction
Preweaning (wk 1–6)								
Milk replacer offered, kg	28.84	28.84	46.11	46.11	—	—	—	—
Milk replacer intake, kg	28.30	28.09	41.27	42.54	0.796	<0.0001	0.51	0.36
Starter intake, kg	7.89	5.85	3.00	3.51	0.796	<0.0001	0.34	0.12
ME intake, Mcal	160.14	152.47	205.84	213.47	4.774	<0.0001	0.99	0.12
BW gain, kg	21.41	19.85	26.17	29.63	1.172	<0.0001	0.42	0.038
Energy efficiency, Mcal/kg	7.68	7.95	7.96	7.27	0.333	0.55	0.53	0.16
Postweaning (wk 7–8)								
Starter intake, kg	25.10	21.87	20.01	19.12	1.416	0.0083	0.15	0.41
ME intake, Mcal	81.83	71.29	65.24	62.34	4.62	0.0083	0.15	0.41
BW gain, kg	10.46	9.64	8.10	5.70	0.87	0.0008	0.07	0.37
Energy efficiency, Mcal/kg	7.91	7.58	9.15	12.40	2.674	0.26	0.59	0.51
Overall (wk 1–8)								
Starter intake, kg	33.00	27.71	23.01	22.63	2.064	0.001	0.18	0.24
ME intake, Mcal	241.97	223.75	271.08	275.81	8.042	<0.0001	0.41	0.16
BW gain, kg	31.87	29.49	34.28	35.33	1.533	0.01	0.67	0.27
Energy efficiency, Mcal/kg	7.66	7.78	7.95	7.88	0.237	0.41	0.90	0.69
Initial								
BW, kg	40.4	39.7	40.7	40.6	1.06	0.58	0.71	0.76
Hip height, cm	70.1	70.6	69.6	71.8	0.88	0.71	0.14	0.33
Heart girth, cm	80.4	78.4	78.9	78.7	0.98	0.53	0.26	0.38
Paunch girth, cm	83.1	81.6	82.4	81.4	0.99	0.68	0.21	0.80
Hip width, cm	17.1	17.1	16.8	17.0	0.23	0.45	0.82	0.62
BCS	2.1	2.0	2.1	2.1	0.03	0.07	0.54	0.22
Wk 6								
BW, kg	61.8	59.6	66.9	70.2	1.60	<0.0001	0.73	0.08
Hip width, cm	19.5	19.6	20.0	20.2	0.21	0.013	0.47	0.59
BCS	2.3	2.3	2.4	2.5	0.04	0.001	0.32	0.14
Wk 8								
BW, kg	72.3	69.2	75.0	76.0	1.99	0.022	0.6	0.31
Hip height, cm	81.3	81.0	81.6	81.7	1.09	0.62	0.91	0.85
Heart girth, cm	97.3	95.8	97.2	97.9	1.09	0.35	0.73	0.31
Paunch girth, cm	111.6	110.7	113.0	110.8	1.42	0.60	0.27	0.64
Hip width, cm	20.7	20.7	20.9	21.0	0.23	0.22	0.22	0.82
BCS	2.4	2.3	2.4	2.4	0.04	0.08	1.00	0.08

¹Treatment: LO = 0.749 kg/d of milk replacer (MR) for 35 d, then 0.375 kg/d for the last 7 d; HI = 0.749 kg/d of MR for 6 d, 0.851 kg/d for 7 d, 1.135 kg/d for 7 d, 1.498 kg/d for 15 d, then 0.749 kg/d for the last 7 d; WC = whole corn and FC = steam-flaked corn in textured calf starter.

Table 4. Effect of treatment¹ on intake, growth performance, and efficiency from wk 9 to 16 in dairy calves

Item	Treatment				SEM	Contrast, <i>P</i> -value		
	LO-WC	LO-FC	HI-WC	HI-FC		LO vs. HI	FC vs. WC	Interaction
Wk 9–16								
DMI, kg	173.71	159.64	163.39	162.71	8.340	0.68	0.40	0.45
ME intake, Mcal	555.87	510.86	522.85	520.66	26.689	0.68	0.40	0.45
BW gain, kg	61.37	60.18	52.21	52.69	1.067	<0.0001	0.75	0.46
Energy efficiency, Mcal/kg	9.01	8.48	10.02	9.87	0.401	0.018	0.39	0.61
Wk 16								
BW, kg	133.9	129.6	127.4	128.9	2.86	0.24	0.64	0.34
Hip height, cm	92.7	91.9	92.3	91.9	1.04	0.84	0.55	0.87
Heart girth, cm	116.6	113.8	114.5	115.5	1.43	0.91	0.53	0.19
Paunch girth, cm	145.9	142.0	144.0	143.3	1.72	0.87	0.19	0.35
Hip width, cm	25.9	25.4	25.1	25.3	0.24	0.06	0.73	0.15
BCS	2.7	2.6	2.6	2.7	0.08	1.00	1.00	0.59

¹Treatment: LO = 0.749 kg/d of milk replacer (MR) for 35 d, then 0.375 kg/d for the last 7 d; HI = 0.749 kg/d of MR for 6 d, 0.851 kg/d for 7 d, 1.135 kg/d for 7 d, 1.498 kg/d for 15 d, then 0.749 kg/d for the last 7 d; WC = whole corn and FC = steam-flaked corn in textured calf starter.

Table 5. Effect of treatment¹ on apparent total-tract digestibility during 3 different time points (wk 5, 8, and 12) in dairy calves

Digestion, %	n	Treatment				SEM	Contrast, <i>P</i> -value		
		LO-WC	LO-FC	HI-WC	HI-FC		LO vs. HI	FC vs. WC	Interaction
DM									
Wk 5	6	94.6	95.1	96.4	96.0	0.46	0.010	0.87	0.30
Wk 8	6	75.5	76.6	74.1	73.1	0.94	0.018	0.29	0.95
Wk 12	3	78.8	79.7	75.7	76.6	0.30	<0.0001	0.016	0.92
OM									
Wk 5	6	94.9	95.5	96.5	96.2	0.46	0.021	0.75	0.31
Wk 8	6	77.1	77.1	74.4	75.6	0.98	0.017	0.30	0.90
Wk 12	3	80.8	82.2	77.3	79.2	0.71	0.002	0.05	0.77
CP									
Wk 5	6	92.0	93.1	93.1	91.9	0.72	0.93	0.94	0.14
Wk 8	6	72.6	74.7	73.7	70.8	1.86	0.45	0.84	0.20
Wk 12	3	80.1	82.0	77.7	79.7	0.96	0.039	0.07	0.95
NDF									
Wk 5	6	43.4	35.8	7.3	6.7	4.32	<0.0001	0.35	0.43
Wk 8	6	42.4	35.7	30.2	28.2	2.60	0.001	0.11	0.37
Wk 12	3	53.5	49.1	41.5	40.2	1.41	<0.0001	0.08	0.29
ADF									
Wk 5	6	22.4	21.2	1.8	3.7	3.65	<0.0001	0.92	0.67
Wk 8	6	29.1	29.4	14.5	18.0	2.29	<0.0001	0.42	0.49
Wk 12	3	44.0	41.1	33.1	30.3	2.66	0.004	0.31	0.98
Starch									
Wk 5	6	99.3	99.3	94.1	98.9	1.67	0.11	0.17	0.17
Wk 8	6	95.9	96.3	94.1	95.4	1.19	0.25	0.49	0.72
Wk 12	3	99.5	99.4	99.3	99.4	0.06	0.20	0.62	0.23
Sugar									
Wk 5	6	87.8	81.2	26.2	52.0	6.83	<0.0001	0.17	0.028
Wk 8	6	88.5	89.1	86.6	87.9	0.91	0.10	0.29	0.69
Wk 12	3	78.5	71.6	68.7	72.1	3.97	0.28	0.67	0.23
Fat									
Wk 5	6	98.4	98.1	98.3	98.2	0.21	0.89	0.41	0.76
Wk 8	6	75.5	78.4	76.0	74.6	1.97	0.42	0.68	0.29
Wk 12	3	77.6	81.9	71.3	78.6	1.99	0.042	0.020	0.48

¹Treatment: LO = 0.749 kg/d of milk replacer (MR) for 35 d, then 0.375 kg/d for the last 7 d; HI = 0.749 kg/d of MR for 6 d, 0.851 kg/d for 7 d, 1.135 kg/d for 7 d, 1.498 kg/d for 15 d, then 0.749 kg/d for the last 7 d; WC = whole corn and FC = steam-flaked corn in textured calf starter.

on intake, performance, or efficiency during the grower phase.

Apparent Total-Tract Nutrient Digestibility

Digestibility of DM and OM was lower ($P \leq 0.02$) in calves fed LO compared with HI during wk 5, but during wk 8 and 12 calves fed LO had higher ($P \leq 0.02$) DM and OM digestibility compared with calves fed HI (Table 5). Calves fed FC had higher ($P \leq 0.05$) DM, OM, and fat digestibility and tended to have higher ($P = 0.07$) CP digestibility and lower ($P = 0.08$) NDF digestibility during wk 12 compared with calves fed WC. Calves fed LO had higher ($P = 0.039$) CP digestibility during wk 12 compared with calves fed HI. During wk 5, 8, and 12, calves fed LO had 5.6-, 1.3-, and 1.3-fold higher ($P \leq 0.001$) NDF digestibility, respectively, compared with calves fed HI. Digestibility of ADF had a similar pattern to NDF, where calves fed LO had 7.9-, 1.8-, and 1.3-fold higher ($P \leq 0.004$) digestibility for wk 5, 8, and 12, respectively, compared with calves fed

HI. An interaction was observed between MR level and processing of corn in CS for sugar digestibility during wk 5. Calves fed HI-WC had the lowest ($P = 0.028$) digestibility. Calves fed LO tended to have higher ($P = 0.10$) sugar digestibility during wk 5 and higher ($P = 0.042$) fat digestibility during wk 12 compared with calves fed HI.

Fibrolytic Bacteria Quantification

Density of total bacteria and fibrolytic bacterial community in rumen fluid were unaffected by dietary treatment at wk 5 and 8 (Table 6). No effect was observed for ruminal total bacteria at wk 5 and 8. At wk 5, *B. fibrisolvens* density tended to be higher ($P = 0.05$) in calves fed LO compared with HI. Proportion (% of total bacteria) of *Clostridium* cluster IV and *B. fibrisolvens* tended ($P \leq 0.07$) to be 2-fold higher in rumen fluid when calves were fed LO compared with HI at wk 5. At wk 8, proportion of *Ruminococcus albus* was higher ($P = 0.045$) in rumen fluid of calves fed

LO-WC compared with calves fed LO-FC and HI-WC. In fecal matter, total bacteria was unaffected by diet at wk 5 and 8 (Table 7). *Clostridium* cluster IV, *Fecalibacterium* sp., and *Prevotella* sp. densities were higher ($P \leq 0.003$) and *B. fibrisolvens* density tended to be higher ($P = 0.09$) in calves fed LO compared with HI at wk 5. *Fecalibacterium* sp. density also tended to be higher ($P = 0.07$) at wk 8 in calves fed LO compared with HI. In contrast, *R. flavefaciens* density was higher ($P < 0.0001$) in calves fed HI compared with LO during wk 5. At wk 5, proportions of *Clostridium* cluster IV, *Fecalibacterium* sp., and *Prevotella* sp. were higher ($P \leq 0.043$) and *R. flavefaciens* tended to be lower ($P = 0.05$) in calves fed LO compared with HI. No dietary treatment effects were observed on proportion of any bacterial community at wk 8.

DISCUSSION

The goal of this study was to determine the effect of amount of MR fed and the processing method of corn in CS on calf performance, digestibility, and rumen and fecal bacterial communities. Based on our findings, MR treatment had a greater effect on performance, fiber digestibility, and rumen and fecal fibrolytic bacterial communities in dairy calves than corn processing in CS treatment.

Effect of MR Feeding Rate

Similar findings to the present study regarding MR feeding rate (LO vs. HI) and its effect on preweaning CS intake (Hill et al., 2016a; Dennis et al., 2018, 2019), BW (Jasper and Weary, 2002; Khan et al., 2011; Rosenberger et al., 2017) and fiber apparent total-tract digestibility (Hill et al., 2016a; Dennis et al., 2018) have been reported. Feeding high rates of MR to calves should provide enough nutrients to sustain satiety largely on MR alone, thus decreasing CS intake compared with calves fed MR at a low rate, as was shown in the present study and previous reports (Hill et al., 2016a; Dennis et al., 2018, 2019). The higher rate of MR feeding also resulted in higher BW until wk 7 from the greater ME intake compared with calves fed MR at a lower rate (Rosenberger et al., 2017). In addition, MR has a higher digestibility compared with CS, therefore contributing more energy toward growth compared with CS. Studies reporting NDF and ADF digestibility have consistently noted that calves fed higher rates of MR have lower NDF and ADF digestibility at various weeks of life (Chapman et al., 2016; Dennis et al., 2018, 2019). In our study, poor fiber apparent total-tract digestibility was carried over into the grower period (6 wk after

weaning) by calves fed HI, as reported previously (Hill et al., 2016a). This was thought to be indicative of inadequate rumen microbial fermentation due to reduced CS intake when calves are fed a high MR feeding rate preweaning (Hill et al., 2016a). Calves fed LO tended to have increased *B. fibrisolvens* density and *B. fibrisolvens* and *Clostridium* cluster IV proportions during wk 5 in the rumen, possibly from the increase in CS intake, which may support greater fiber digestion observed in LO versus HI calves. The proportion of *Clostridium* cluster IV and *Fecalibacterium* sp. increased in the fecal matter of LO calves at wk 5, which suggests that more fiber digestion may occur in the hindgut of calves fed LO versus HI. The extent and biological significance of fiber digestion postruminally in calves is largely unknown; however, Gressley et al. (2011) summarized a variety of studies from mature ruminants and reported that NDF digestion can range from 3.7 to 23.2% and ADF digestion from 3.3 to 6.5% in the large intestine. In the present study, only a select number of fibrolytic bacteria were identified using quantitative PCR and their activity was not evaluated. Few differences were observed regarding the effect of MR treatment on the proportion of bacteria. We postulate that this may be due to the high variation (CV range: 10.0 to 240.7% in rumen fluid, 40.3 to 214.1% in fecal matter) between calves within the same dietary treatment for the proportion of fibrolytic bacterial communities.

Different dietary sources (MR vs. CS) have different digestibilities and the ratio of MR to CS intake in calves differed at wk 5, which resulted in calves fed HI having higher DM and OM digestibility compared with calves fed LO. Digestibility of DM and OM may influence intake and calves fed LO had higher DM and OM digestibility when only consuming solid feed, as well as higher CS intake postweaning. However, during the grower phase, intakes were unaffected by dietary treatment.

Calves fed LO tended to have a higher proportion of ruminal fibrolytic bacteria (*B. fibrisolvens* and *Clostridium* cluster IV) and a higher proportion of fecal fibrolytic bacteria (*Fecalibacterium* sp., *Clostridium* cluster IV, and *Prevotella* sp.) than calves fed HI during wk 5. Additionally, calves fed LO had greater digestion of OM and fiber than calves fed HI. Greater growth rates in both BW and structure during wk 9 to 16 for calves fed LO versus HI was likely attributed to better development of the digestive system and transition to a dry feed diet. These digestibility and performance measures are consistent with several other studies (Hill et al., 2016a; Dennis et al., 2018). The CS in the present study contained a high amount of starch (41.5%), with ADF and NDF being low at 7.2 and 15.4%, re-

Table 6. Effect of treatment¹ on density and proportion (% of total bacteria) of fibrolytic bacteria in rumen fluid of dairy calves

Item	Treatment					Contrast, <i>P</i> -value		
	LO-WC	LO-FC	HI-WC	HI-FC	SEM	LO vs. HI	FC vs. WC	Interaction
Wk 5, copy number, log 10/mL								
Total bacteria	11.47	11.50	11.51	11.59	0.083	0.48	0.50	0.78
<i>Ruminococcus albus</i>	5.13	5.72	5.61	5.62	0.248	0.44	0.24	0.26
<i>Clostridium</i> cluster IV	7.77	7.80	7.41	7.77	0.226	0.41	0.40	0.47
<i>Butyrivibrio fibrisolvens</i>	9.44	9.27	9.04	9.21	0.100	0.05	0.74	0.18
<i>Ruminococcus flavefaciens</i>	7.40	7.30	7.17	7.19	0.152	0.28	0.78	0.69
<i>Prevotella</i> sp.	8.39	8.40	8.57	8.69	0.161	0.17	0.68	0.76
<i>Fibrobacter succinogenes</i> S85	7.77	7.51	7.50	7.56	0.153	0.47	0.54	0.33
Wk 5, % of total bacteria								
<i>R. albus</i>	5.35E-05	4.00E-04	2.46E-04	2.45E-04	0.000173	0.92	0.33	0.33
<i>Clostridium</i> cluster IV	0.032	0.028	0.014	0.017	0.0076	0.07	1.00	0.65
<i>B. fibrisolvens</i>	1.01	0.65	0.43	0.57	0.160	0.05	0.49	0.13
<i>R. flavefaciens</i>	0.0117	0.0081	0.0059	0.0049	0.00273	0.13	0.42	0.64
<i>Prevotella</i> sp.	0.106	0.102	0.119	0.127	0.0184	0.33	0.90	0.74
<i>F. succinogenes</i> S85	0.025	0.015	0.014	0.012	0.0054	0.21	0.29	0.47
Wk 8, copy number, log 10/mL								
Total bacteria	11.19	11.25	11.40	11.26	0.11	0.35	0.72	0.39
<i>R. albus</i>	5.44	4.73	5.07	5.10	0.28	0.99	0.25	0.20
<i>Clostridium</i> cluster IV	7.11	7.03	7.14	7.18	0.17	0.60	0.91	0.74
<i>B. fibrisolvens</i>	9.32	9.42	9.34	9.60	0.13	0.45	0.19	0.52
<i>R. flavefaciens</i>	6.84	6.79	6.72	7.09	0.15	0.57	0.28	0.16
<i>Prevotella</i> sp.	7.84	8.01	8.19	7.57	0.25	0.85	0.37	0.13
<i>F. succinogenes</i> S85	7.44	7.67	7.43	7.70	0.391	0.99	0.53	0.96
Wk 8, % of total bacteria								
<i>R. albus</i>	3.24E-04	4.33E-05	7.18E-05	2.03E-04	9.60E-05	0.64	0.45	0.045
<i>Clostridium</i> cluster IV	0.0113	0.0067	0.0057	0.0125	0.00352	0.98	0.77	0.12
<i>B. fibrisolvens</i>	1.55	1.57	1.36	2.34	0.339	0.40	0.16	0.17
<i>R. flavefaciens</i>	0.0063	0.0040	0.0043	0.0076	0.00178	0.66	0.78	0.13
<i>Prevotella</i> sp.	0.060	0.102	0.113	0.028	0.0354	0.76	0.55	0.08
<i>F. succinogenes</i> S85	0.043	0.283	0.019	0.046	0.1456	0.38	0.37	0.47

¹Treatment: LO = 0.749 kg/d of milk replacer (MR) for 35 d, then 0.375 kg/d for the last 7 d; HI = 0.749 kg/d of MR for 6 d, 0.851 kg/d for 7 d, 1.135 kg/d for 7 d, 1.498 kg/d for 15 d, then 0.749 kg/d for the last 7 d; WC = whole corn and FC = steam-flaked corn in textured calf starter.

Table 7. Effect of treatment¹ on density and proportion (% of total bacteria) of fibrolytic bacteria in fecal matter of dairy calves

Item	Treatment				Contrast, <i>P</i> -value			
	LO-WC	LO-FC	HI-WC	HI-FC	SEM	LO vs. HI	FC vs. WC	Interaction
Wk 5, copy number, log 10/mL								
Total bacteria	11.14	11.23	11.13	11.14	0.134	0.67	0.72	0.76
<i>Ruminococcus albus</i>	4.38	4.24	4.37	3.98	0.250	0.59	0.31	0.61
<i>Clostridium</i> cluster IV	8.30	8.38	7.64	7.61	0.187	0.001	0.91	0.78
<i>Fecalibacterium</i> sp.	7.95	8.16	7.44	7.55	0.186	0.007	0.41	0.78
<i>Butyrivibrio fibrisolvens</i>	9.28	9.25	9.06	9.00	0.134	0.09	0.75	0.90
<i>Ruminococcus flavefaciens</i>	7.04	6.64	7.56	7.79	0.199	0.0006	0.68	0.14
<i>Prevotella</i> sp.	8.72	8.65	7.94	7.98	0.217	0.0031	0.93	0.81
<i>Fibrobacter succinogenes</i> S85	7.87	8.13	7.74	7.79	0.184	0.22	0.41	0.60
Wk 5, % of total bacteria								
<i>R. albus</i>	2.48E-05	1.54E-05	8.45E-05	1.01E-05	3.70E-05	0.48	0.28	0.40
<i>Clostridium</i> cluster IV	0.164	0.204	0.038	0.035	0.0478	0.006	0.70	0.66
<i>Fecalibacterium</i> sp.	0.083	0.143	0.023	0.028	0.0405	0.043	0.44	0.51
<i>B. fibrisolvens</i>	1.49	1.48	0.95	0.82	0.382	0.13	0.85	0.88
<i>R. flavefaciens</i>	0.011	0.004	0.038	0.084	0.0251	0.05	0.46	0.32
<i>Prevotella</i> sp.	0.530	0.314	0.103	0.088	0.0888	0.0015	0.21	0.27
<i>F. succinogenes</i> S85	0.079	0.111	0.056	0.063	0.0300	0.25	0.53	0.69
Wk 8, copy number, log 10/mL								
Total bacteria	11.76	11.77	11.49	11.86	0.160	0.61	0.25	0.28
<i>R. albus</i>	6.22	6.71	6.28	6.66	0.306	0.98	0.17	0.87
<i>Clostridium</i> cluster IV	8.33	8.25	7.90	8.22	0.165	0.18	0.46	0.24
<i>Fecalibacterium</i> sp.	6.99	6.87	6.61	6.61	0.164	0.07	0.73	0.71
<i>B. fibrisolvens</i>	9.35	9.17	9.21	9.19	0.123	0.64	0.43	0.51
<i>R. flavefaciens</i>	7.59	7.56	7.54	7.98	0.169	0.28	0.25	0.18
<i>Prevotella</i> sp.	8.74	8.57	8.08	8.32	0.280	0.12	0.90	0.47
<i>F. succinogenes</i> S85	8.11	8.06	8.17	7.99	0.161	0.95	0.50	0.70
Wk 8, % of total bacteria								
<i>R. albus</i>	7.21E-04	1.07E-03	1.11E-03	1.61E-03	6.05E-04	0.45	0.49	0.91
<i>Clostridium</i> cluster IV	0.049	0.044	0.041	0.028	0.0142	0.39	0.53	0.78
<i>Fecalibacterium</i> sp.	0.049	0.044	0.041	0.028	0.0020	0.58	0.16	0.30
<i>B. fibrisolvens</i>	0.53	0.39	1.19	0.29	0.408	0.50	0.22	0.36
<i>R. flavefaciens</i>	0.008	0.010	0.022	0.016	0.0060	0.14	0.52	0.71
<i>Prevotella</i> sp.	0.141	0.093	0.110	0.058	0.0397	0.41	0.22	0.96
<i>F. succinogenes</i> S85	0.061	0.022	0.085	0.019	0.0289	0.73	0.09	0.65

¹Treatment: LO = 0.749 kg/d of milk replacer (MR) for 35 d, then 0.375 kg/d for the last 7 d; HI = 0.749 kg/d of MR for 6 d, 0.851 kg/d for 7 d, 1.135 kg/d for 7 d, 1.498 kg/d for 15 d, then 0.749 kg/d for the last 7 d; WC = whole corn and FC = steam-flaked corn in textured calf starter.

spectively; therefore, additional factors contributing to fiber digestion may play a role and resulted in a growth depression. It is possible that HI calves, when weaned at wk 6 with a 1-wk step-down, experience greater gut health challenges during the weeks postweaning, causing more energy to be partitioned to the gut to adapt and recover from the more dramatic weaning transition (Steele et al., 2016).

Overall, the poor DM, OM, and fiber digestibility observed in our study during the postweaning stage for calves fed the HI diet resulted in fewer nutrients available for utilization toward growth. During the grower phase, calves fed the LO diet were more efficient at utilizing feed, resulting in calves fed the HI diet to lose their preweaning growth advantage by wk 16. However, it is important to note that these calves were bedded with long wheat straw and consumption was not accounted for. Yet, Hill et al. (2019) reported that digestion estimates were not affected when calves were bedded on long straw compared with no straw. Thus, we speculate that bedding consumption would have had minimal effect in the current study.

Effect of Corn Processing

Processing grain can maximize starch digestibility, yet processing can also change the site of digestion (Owens, 2005). Processing corn may be beneficial to young calves because starch digestion in the rumen stimulates rumen papillae development (Flatt et al., 1958; Sander et al., 1959). Based on unpublished data, dietary treatment had no influence ($P \geq 0.12$) on total ruminal short-chain fatty acid (SCFA) concentration during wk 5 or 8, which may indicate that corn was fermented to the same extent in the rumen in both treatments. The SCFA concentration did increase from wk 5 to 8, which is reflective of increased starter intake. The total SCFA averages were as follows: 47.3 ± 8.3 , 36.9 ± 5.7 , 31.4 ± 1.1 , and 36.8 ± 6.4 $\mu\text{mol/mL}$ for LO-WC, HI-FC, HI-WC, and HI-FC, respectively, during wk 5, and 62.6 ± 6.0 , 62.5 ± 6.3 , 61.5 ± 4.2 , and 72.5 ± 8.3 $\mu\text{mol/mL}$ for LO-WC, HI-FC, HI-WC, and HI-FC, respectively, during wk 8. It has been demonstrated that total-tract digestibility of steam-rolled (or flaked) corn was 97% compared with 84% for whole corn in mature ruminants (Owens, 2005). Thus, starch digestibility in the current study was expected to be different among CS treatments based on mature ruminant data; however, no differences were observed ($>95\%$ for both treatments wk 5, 8, and 12). Owens (2005) reported that site and extent of digestion and passage rate of corn (whole or processed) can be altered by dietary fiber levels in the diet. We speculate that the low levels

of fiber in our diet compared with feedlot or lactating cow diets may have resulted in equal digestion between CS treatments. It is possible that passage rate of corn is different in calves than that of adult animals because of different particle distribution in the rumen and calves may also have the ability to use whole corn kernels more efficiently than cows by chewing their feed more thoroughly (Owens, 2005), which would affect starch digestion. Thus, further investigation into corn processing and digestion when forage is included in the diet preweaning is warranted. Specifically, future research should investigate rumination times in young calves fed differentially processed corn to provide further insight into the mechanisms responsible for the comparable digestion of whole corn and steam-flaked corn evidenced in the present study.

Calves fed WC had decreased DM and OM digestibility during wk 12 compared with calves fed FC, but this result is most likely due to the observed lower CP and fat digestion in WC calves. Consistent with previous studies (preweaning: Lesmeister and Heinrichs, 2004; pre- and postweaning: Bateman et al., 2009), the processing of corn in CS did not influence intake and, thus, calf performance. In contrast, previous studies have shown that CS intake increased when whole corn was fed to calves compared with steam-flaked (postweaning: Lesmeister and Heinrichs, 2004) and steam-rolled (during weaning: Terré et al., 2016) corn. Although digestibility was not measured in these studies, the increase in CS intake did not result in increased BW, suggesting that calves were unable to use the additional nutrients toward growth. Lesmeister and Heinrichs (2004) reported that total SCFA concentrations were lower in the whole corn-fed calves compared with the steam-flaked-corn-fed calves, indicating that whole corn was not digested in the rumen to the same extent as steam-flaked, and that a certain amount must have bypassed the rumen. Starch digestion in the rumen is beneficial for ruminal development and thus further investigation on site of digestion of whole corn in calves is warranted, especially given the high cost of corn processing. All of the above-mentioned studies (Lesmeister and Heinrichs, 2004; Bateman et al., 2009; Terré et al., 2016) only investigated the effects of grain processing when calves were fed a low MR feeding rate (<6 L), and therefore the interaction with higher MR feeding rate is unknown.

Interaction of MR Feeding Rate with Processing of Corn in CS

The effect of milk/MR feeding rate on intake, growth performance, and total-tract nutrient digestibility has

been investigated in numerous studies (Terré et al., 2007; Hill et al., 2010, 2016a; Chapman et al., 2016) in relation to weaning method/age (Dennis et al., 2018), amount of starch in CS (Quigley et al., 2018), and additives (Hill et al., 2016b; Dennis et al., 2018), but not in relation to the processing of corn in CS. To our knowledge, this is the first study to evaluate the combination of MR feeding rate with processing of corn in CS (whole vs. steam-flaked corn) in calves. We thought that feeding a higher rate of MR would delay rumen development and WC-fed calves would have reduced nutrient digestibility. When digestibility is reduced, and CS intake remains the same between the WC and FC, calf performance would be reduced. However, we found that the combination of MR feeding rate and corn processing in CS did not have an effect on digestibility, as hypothesized, although CS intakes were similar between the WC and FC. However, during wk 5, sugar digestibility was lower for calves fed the HI-WC diet compared with the other dietary treatments, which could have resulted in numerically lower starch digestion for this treatment. As expected, BW, ADG, body measurements, and feed efficiency throughout the study were not affected by dietary treatment, since no change was observed in CS intake or digestibility. As described above, fiber content in the diet could influence corn digestibility, yet minimal amounts of fiber were included in these diets. Therefore, the addition of fiber or low starch diets on the digestibility of corn in calves fed high rates of MR needs to be explored further.

CONCLUSIONS

Our results show that a high MR feeding rate reduced fiber digestibility, both pre- and postweaning and during the grower phase (wk 5, 8, and 12). Preweaning ADG and hip width measurements were higher in HI versus LO MR feeding rate, but reduced postweaning, resulting in similar BW and hip width measurements by 16 wk of age. Calves fed LO had a higher proportion of fibrolytic bacteria in both the rumen and feces than calves fed HI. When considering the combination of MR feeding rate and the processing of corn feeding, low and high MR feeding rate can be combined with either flaked corn or whole corn in the CS because corn processing had little to no effect on digestibility, intake, and growth of calves.

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