RUMINANT NUTRITION

Effect of feeding barley or corn silage with dry-rolled barley, corn, or a blend of barley and corn grain on rumen fermentation, total tract digestibility, and nitrogen balance for finishing beef heifers

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Abstract

Five ruminally cannulated heifers were used in an incomplete 6 × 6 Latin square design to determine the effects of cereal silage (barley vs. corn), cereal grain (barley vs. corn vs. a 50:50 blend of barley and corn), and their interaction (S × G) on dry matter intake, ruminal fermentation, total tract digestibility, nitrogen balance, and in situ degradation. Corn silage (CS) or barley silage (BS) was included at 8% of dietary dry matter (DM). Within each silage source, diets contained (DM basis) either dry-rolled barley (BG; 86%), dry-rolled corn (CG; 85%), or an equal blend of barley and corn (BLEND; 85%). Periods were 25 d, with 5 d of dietary transition, 13 d of dietary adaptation, and 7 d of data and sample collection. Samples collected included feed and refusals, total urine and feces, and ruminal fluid. All data were analyzed using the Mixed model of SAS with the fixed effects of silage, grain, and the S × G. Dry matter intake ($P \geq 0.19$) and mean ruminal pH ($P \geq 0.096$) were not affected by the silage, grain, or S × G. Total short-chain fatty acid concentrations were greater for BLEND than BG or CG (grain, $P = 0.003$) and for CS (silage, $P = 0.009$) relative to BS. The molar proportion of acetate was greater for BS-BG and BS-CG (S × G, $P < 0.001$), while molar proportion of propionate was greater for CS-BG (S × G, $P < 0.001$) relative to other silage and grain source combinations. Rumen ammonia-N concentration was greater for CG than BG, or BLEND (grain, $P < 0.001$), and greater for CS compared to BS (silage, $P = 0.023$). Apparent total tract digestibility of DM, organic matter, neutral detergent fiber, starch, and gross energy were greatest for BG (grain, $P \leq 0.035$). Digestible energy content (Mcal/kg) was greater for BG (grain, $P = 0.029$) than CG and BLEND. Total nitrogen retention (g/d and % of intake) was greatest for CS-BG (S × G, $P \leq 0.033$) relative to all other treatments. In situ degradation rates of DM, crude protein, and starch were greater for BG than CG ($P \leq 0.004$). The potentially degradable fraction of DM, crude protein, and starch was greater for CG ($P \leq 0.031$), while the undegradable fraction was greater for BG ($P \leq 0.046$). For silage sources, CS had greater 24 h in situ DM digestibility ($P = 0.009$) and starch digestibility (24, 48, and 72 h incubations, $P \leq 0.034$) relative to BS. Results suggest that while feeding a combination of CS and BG promotes propionate production and greater N retention; few other additive effects were observed.

Key words: additive effects, cereal grain, short-season corn

Introduction

Development of short-season corn varieties has resulted in increased acreage of corn in western Canada (Statistics Canada, 2019). These newly developed varieties require less corn heat units (CHU) to reach maturity and are optimal for silage production in areas with as few as 2,100 CHU. Compared to barley, short-season corn has greater cost of production but also a greater yield that may justify the increased cost (Baron et al., 2014; Lardner et al., 2017). Barley and corn silage differ markedly as barley has less starch and greater protein (NASEM, 2016) and kernels are not processed at the time of ensiling. While the silage inclusion rate is low in finishing diets (Samuelson et al., 2016), it is possible that changes in the silage source may affect ruminal fermentation due to changes in starch and protein concentration and availability and thus total nutrient supply. Supporting the principle of the latter concept, a recent study reported that the use of corn silage increased carcass weight and rib-eye area relative to barley silage (Johnson et al., 2020). However, there is currently little data available on the use of short-season corn silage in finishing diets.

Several studies have directly compared corn and barley grain in diets for finishing cattle (Boss and Bowman, 1996; Beauchemin and Koenig, 2005). When dry-rolled, starch and protein supplied by barley is more rapidly fermented and digested to a greater extent in the rumen than for corn (Herrera-Saldana et al., 1990). The differing rates and extents of fermentation for barley and corn grain may provide an opportunity when fed in combination as in some cases, average daily gain (ADG) and feed efficiency were improved when cattle were fed a combination of grain sources (Stock et al., 1987a; Huck et al., 1998) differing in the rates of ruminal fermentation (Stock et al., 1987b; Bock et al., 1991). However, we are not aware of studies comparing dry-rolled corn and barley nor are we aware of studies that evaluated whether silage source affects the nature of the grain source response.

We hypothesized that diets containing a mixture of grains would optimize ruminal starch and protein degradation resulting in increased total short-chain fatty acid (SCFA) concentrations, greater total tract digestibility, and greater bacterial N production, and that silage source would affect the response. The objective of the current study was to evaluate the effects of combinations of silage type (corn vs. barley) and cereal grain type (corn vs. barley vs. blend) on dry matter intake (DMI), ruminal fermentation, total tract digestibility, fecal pH, and microbial protein supply for finishing beef cattle.

Materials and Methods

Use of heifers and the procedures used were preapproved by the University of Saskatchewan Animal Research Ethics Board (protocol 20100021) according to the guidelines of the Canadian Council on Animal Care (Ottawa, ON, Canada).

Silage Production and Cereal Grain Processing

Corn (P7213R, 2050 CHU, DuPont Pioneer, Mississauga, ON, Canada) was seeded for silage at a rate of 79,072 plants per ha on May 27, 2016 with 76.2-cm row spacing. Anhydrous ammonia was applied to deliver 72.1 kg of N/ha and 177 kg/ha of fertilizer was applied containing 36.3% nitrogen (N) and 12.1% phosphorus (P). Liquid Herbicide (R/T 540, Monsanto Canada, Winnipeg, MB, Canada) was applied June 6 at 0.82 L/ha and June 20 at 1.66 L/ha. Corn heat units were calculated for each day using historical weather data obtained from the Saskatoon RCS weather station according to the following calculation:

$$\text{Daily CHU} = \frac{[1.8 (T_{\min} - 4.4) + 3.3 (T_{\max} - 10) - 0.084 (T_{\max} - 10)^2]}{2}$$

Corn silage was harvested after 1,940 CHU using forage harvester with a kernel processor (2-mm roller gap) and chopped to a theoretical chop length of 0.95 cm on August 30 at 32% whole-plant dry matter (DM). Silage was treated with an inoculant (Biomax 5, Chr. Hansen Inc., Milwaukee, WI) at a rate of 1.0×10^8 lactic acid bacteria colony-forming units/kg during ensiling.

The barley variety used for silage production was CDC Copeland (SeCan, Kanata, ON, Canada). Barley was seeded at 108 kg/ha on May 19, 2016. Prior to seeding, seed was treated with a fungicide (Rancona Pinnacle, Arysta Lifescience Canada Inc., Guelph, ON, Canada) at a rate of 325 mL/100 kg of seed. Anhydrous ammonia was applied to deliver 64.6 kg of N/ha along with 22 kg/ha of 12-40-0-10-1 (MicroEssentials SZ, The Mosaic Company, Plymouth, MN). Curtail M Herbicide (Dow AgroSciences LLC, Indianapolis, IN) was selectively applied to the field on June 6 at a rate of 1.98 L/ha and a combination of 0.99 liter each of Buctril M Emulsifiable Selective Weedkiller (Bayer CropScience Inc., Calgary, AB, Canada) and Bison 400L (ADAMA Agricultural Solutions Canada Ltd, Winnipeg, MB, Canada) were applied on June 14, 2016. Barley silage harvest occurred between July 27 and 30 at the soft dough stage to target a DM of 35%. Silage was harvested with a theoretical chop length of 0.95 cm and was treated with Biomax 5 (Chr. Hansen Inc., Milwaukee, WI) inoculant at a rate of 1.0×10^8 lactic acid bacteria colony-forming units/kg during ensiling.

The severity of cereal grain processing was measured as the processing index (PI), expressed as the volume weight of the processed grain relative to the volume weight of unprocessed grain (Yang et al., 2000). Cereal grains were obtained from a commercial feed mill (Canadian Feed Research Centre, North Battleford, SK, Canada) and barley was dry-rolled to an average PI of 66%. Corn was processed to ensure that 5% of the sample (wt/wt basis) would pass through a 1-mm sieve. This processing resulted in a PI of 83.0%.

Animal Management, Experimental Design, and Dietary Treatments

Five Hereford-Angus cross yearling heifers with an initial body weight (BW) of 383 ± 29 kg were housed at the University of Saskatchewan Livestock Research Barn and were surgically fit with a 7.6-cm ruminal cannula (model 3C; Bar Diamond Inc., Parma, ID). Three weeks following surgery, the 7.6-cm cannula was replaced with a 9-cm ruminal cannula (model 9C; Bar Diamond Inc.). For the duration of the study, heifers were housed in individual pens (9 m²) with ad libitum access to water and rubber mats on the floor. Heifers were fed twice daily at 0930 and 1200 h with feed refusals collected at 0800 h each day. Pens were scraped and washed daily to remove manure. Heifers were allowed 2 h/d of exercise, except during total collections, in an outdoor dry lot pen at a frequency that conformed with animal care guidelines. During total collections, heifers were tethered to ensure complete urine and fecal output could be collected and measured.

This study was designed as an incomplete 6×6 Latin square design balanced for carryover effects. The incomplete design allowed for each diet to be tested for each heifer over the 6-period study while addressing a limitation in pen availability. Prior to the start of the study, heifers were gradually transitioned to a barley-based finishing diet over 24 d. The step-up transition period consisted of 6 steps, each step lasting 4 d. With each diet,

the amount of dry-rolled barley was increased and the amount of barley silage was decreased. The amount of feed offered during the step-up period was restricted to 2.5% of BW on a DM basis in order to control feed intake during adaptation.

Dietary treatments incorporated corn silage (CS) or barley silage (BS) at 8% of the diet (DM basis; Table 1), in combination with dry-rolled barley grain (BG; 86% of DM), dry-rolled corn grain (CG; 85% of DM), or an equal blend of barley and corn grain (BLEND; 85% of DM). The remainder of the diets was comprised of limestone, a vitamin and mineral pellet, and urea to make the diets isonitrogenous. The mineral pellet contained monensin (Elanco Animal Health, Greenfield, IN) to target a final dietary concentration of 33 mg/kg. After completion of period 3, 1 heifer was replaced with a heifer of similar BW due to complications unrelated to dietary treatments.

Each period was 25 d in duration. The first 5 d of each period were used to transition heifers to their respective treatment by incorporating 33% of the new diet on day 1 and 2, 66% on day 3 and 4, and 100% in the afternoon feeding on day 5. After completing the transition, heifers were provided 13 d of dietary adaptation. On day 18 of each period, indwelling urinary catheters (Foley, size 26 French, 75 cc balloon, Bard Urological Division, Covington, GA) were inserted in each heifer. Urine collected was diverted to a 25-liter carboy that was acidified with 150 mL of 12 M HCl to prevent N loss. A 4-d total collection period occurred from day 19 to day 23 and included measurement of daily fecal excretion, fecal pH, and daily urine excretion. During the total collection period heifers were tethered to facilitate urine and fecal collection. Urinary catheters were removed after the final collection on day 23 and heifers were allowed 2 d of rest prior to ruminal fluid collection on day 25. Ruminal fluid sampling was

initiated at 0800 h on day 25 and every 3 h thereafter until 0800 h on day 1 of the following period. Body weight was measured prior to feeding on 2 consecutive days at the start and end of each period (day 1 and day 25, respectively). The amount of feed allocated daily was recorded and provided to target ad libitum intake with 5% to 10% residual feed daily. In addition, silage DM was measured twice weekly and the DM of all other ingredients was measured once weekly. Dietary feed ingredient inclusion was updated to reflect most recent DM of ingredients to ensure that the as-fed inclusion of ingredients accurately represented the DM formulation.

Ruminal Fermentation

During the sampling period, indwelling ruminal pH measurement systems (Penner et al., 2009) were placed in the ventral sac of the rumen before feeding on day 19 and removed on day 24 to ensure 96 h of data collection. The pH systems were standardized in buffers 7 and 4 at 39 °C prior to insertion and after removal from the rumen and were programmed to record every 5 min. Data obtained were transformed from mV recordings to pH using beginning and ending linear regressions and assuming linear drift. A ruminal pH threshold of 5.5 was used as an indicator for ruminal acidosis and the duration and area below this threshold was calculated (Penner et al., 2006).

Ruminal digesta samples were manually collected every 3 h from 0800 h on day 25 until 0800 h on day 1 of the following period. This resulted in a total of 8 samples representing 3-h intervals over a 24-h cycle. Digesta was collected from 3 regions of the rumen (250 mL from each of the cranial central, central, and caudal central regions) and was strained through 2 layers of cheese cloth. After straining the digesta, samples of the

Table 1. Ingredient inclusion and chemical composition of dietary treatments (expressed as mean $\pm$ standard deviation between periods, $n = 6$) fed to ruminally cannulated beef heifers ($n = 5$)

	Barley silage			Corn silage		
	Barley	Corn	Blend	Barley	Corn	Blend
Ingredient, % DM						
Barley silage	8.00	8.00	8.00	–	–	–
Corn silage	–	–	–	8.00	8.00	8.00
Dry-rolled barley	85.94	–	42.72	85.86	–	42.69
Dry-rolled corn	–	84.96	42.72	–	84.89	42.69
Urea	–	0.98	0.50	0.08	1.06	0.57
Mineral pellet ¹	5.56	5.56	5.56	5.56	5.56	5.56
Limestone	0.50	0.50	0.50	0.50	0.50	0.50
Chemical composition, % DM ²						
DM, %	80.1 $\pm$ 0.56	80.1 $\pm$ 0.78	80.1 $\pm$ 0.66	82.3 $\pm$ 0.76	82.3 $\pm$ 0.83	82.3 $\pm$ 0.77
OM	94.9 $\pm$ 0.20	96.0 $\pm$ 0.29	95.5 $\pm$ 0.17	95.1 $\pm$ 0.19	96.1 $\pm$ 0.27	95.6 $\pm$ 0.07
CP	11.4 $\pm$ 0.35	11.7 $\pm$ 0.23	11.5 $\pm$ 0.08	11.5 $\pm$ 0.38	11.8 $\pm$ 0.19	11.7 $\pm$ 0.11
Starch	53.1 $\pm$ 1.17	62.0 $\pm$ 2.19	57.7 $\pm$ 1.29	53.5 $\pm$ 1.14	62.5 $\pm$ 2.07	58.0 $\pm$ 1.25
ADF	8.6 $\pm$ 0.53	6.8 $\pm$ 0.68	7.6 $\pm$ 0.50	8.4 $\pm$ 0.54	6.6 $\pm$ 0.69	7.5 $\pm$ 0.51
aNDFom	20.6 $\pm$ 1.74	13.2 $\pm$ 0.48	16.5 $\pm$ 1.31	20.4 $\pm$ 1.87	13.0 $\pm$ 0.45	16.7 $\pm$ 0.97
Ether extract	2.3 $\pm$ 0.21	4.3 $\pm$ 0.62	3.3 $\pm$ 0.29	2.2 $\pm$ 0.21	4.3 $\pm$ 0.60	3.3 $\pm$ 0.30
Ca	0.81 $\pm$ 0.01	0.78 $\pm$ 0.01	0.79 $\pm$ 0.02	0.80 $\pm$ 0.01	0.78 $\pm$ 0.01	0.79 $\pm$ 0.01
P	0.37 $\pm$ 0.02	0.36 $\pm$ 0.05	0.36 $\pm$ 0.03	0.37 $\pm$ 0.02	0.36 $\pm$ 0.05	0.37 $\pm$ 0.02
NE _m , Mcal/kg ³	1.85	2.01	1.94	1.85	2.01	1.94
NE _g , Mcal/kg ³	1.21	1.37	1.30	1.21	1.37	1.28

¹The mineral pellet supplement was mixed with barley grain for pelleting on a DM basis ratio of 78:21, respectively. On DM basis, the mineral supplement (excluding the barley grain) contained 9.2% of calcium, 0.32% of phosphorus, 1.64% sodium, 0.28% of magnesium, 0.60% of potassium, 0.12% of sulfur, 4.9 mg/kg of cobalt, 185 mg/kg of copper, 16.6 mg/kg of iodine, 84 mg/kg of iron, 500 mg/kg of manganese, 2 mg/kg of selenium, 558 mg/kg of zinc, 40,000 IU/kg of vitamin A, 5,000 IU/kg of vitamin D3, and 600 IU/kg of vitamin E. The final supplement contained 510 mg/kg of monensin (Elanco Animal Health, Greenfield, IN) on a DM basis.

²Chemical composition is expressed as means with standard deviation of the means ($n = 6$).

³Net energy values were calculated from feed samples using the NRC (2001) equations.

resulting ruminal fluid (10 mL) were preserved in either 2 mL of metaphosphoric acid (25% wt/v) or 2 mL of 1% sulfuric acid for SCFA and ammonia-N analysis, respectively. All ruminal fluid samples were sealed and stored at -20°C until further analysis. Analysis of ammonia-N was conducted using the colorimetric phenol hypochlorite method as described by Fawcett and Scott (1960). Short-chain fatty acid concentration was determined by gas chromatography (Agilent 6890 series, Agilent Technologies, Santa Clara, CA) as described by Khorasani et al. (1996).

Apparent Total Tract Digestibility

Every 6 h beginning at 0800 h on day 19 until 0800 h on day 23 total fecal output was collected from the floor of each pen, weighed, and the weight was recorded. At each time point, feces from each heifer were thoroughly mixed and a representative sample equating to 10% of the fecal weight was collected to form a period composite that was stored at -20°C . A subsample of feces was retained to determine the proportion of each type of cereal grain kernel (whole and partial kernels) in feces and the remaining composite sample of feces was then dried in forced air oven at 55°C to a constant weight. Samples were ground through a 1-mm screen using a Retch ZM 200 grinder (Haan, Germany). At each fecal collection time, an additional 100 g fecal sample was mixed with an equal weight of double-distilled water and pH was recorded in duplicate.

Over the 4-d sampling period, representative samples of all feed ingredients were collected daily and composited for DM and chemical analysis. Samples of refusal from the 4-d total collection were composited by heifer and also used for DM and chemical analysis. Feed and refusal samples were dried in a forced air oven at 55°C to a constant weight. A subsample of the grain and silage sources collected in periods 1, 3, and 5 were retained for nylon bag incubation, while the remaining concentrate samples (corn grain, barley grain, mineral pellet) were ground to pass through a 1-mm screen using a Retsch ZM 200 grinder (Haan, Germany). Barley silage and corn silage samples were ground to pass through a 1-mm screen using a hammer mill (Christie-Norris Laboratory Mill, Christie-Norris Ltd, Chelmsford, United Kingdom). All dried and ground feed, refusal, and fecal samples were analyzed for DM, organic matter (OM), crude protein (CP), acid detergent fiber (ADF), starch, ether extract, calcium, and phosphorus at Cumberland Valley Analytical Services (Waynesboro, PA) as described by Johnson et al. (2020) with the exception of aNDFom (NDF determined with α -amylase and sodium sulfite and corrected for ash content) which was estimated by combusting the final glass fiber filter and sample at 535°C for 2 h to correct for ash. Gross energy (GE) of all feed, refusal, and fecal samples was determined using a Parr 1281 bomb calorimeter (Parr Instrument Company, Moline, IL) at the University of Saskatchewan (Saskatoon, SK, Canada). Digestible energy (DE) was calculated as $\text{DE (Mcal/kg)} = [\text{GE intake (Mcal/d)} - \text{fecal energy (Mcal/d)}] / \text{DMI (kg/d)}$.

Fecal Composition

Composited fecal samples collected during the total collection period were thawed and thoroughly mixed. Prior to drying, a 250-mL subsample was weighed and subsequently screened using a sieve with 1.18-mm apertures while being rinsed with tap water until only solid material remained and the water passing through the screen was clear. The material retained on the 1.18-mm screen was dried at 55°C and weighed. After drying, the retained material was manually sorted according to grain type (corn or barley) or fine material and the grain kernels were further sorted into whole or partial grain kernels. The

weight of the sorted fractions was determined and recorded in order to estimate the source and amount of grain present in the feces. The whole and partial kernels of corn and barley grain and the fine material were calculated as a percentage of the total screened material weight after being dried.

Microbial Protein Supply

Total urine collection occurred from day 19 to day 23. Each day, a 30-mL representative sample was collected from each heifer and stored at -20°C . Collected samples were composited on an equal-volume basis and purine derivative (PD) concentrations were determined. Uric acid concentration was estimated using a fluorometric assay (Cayman Chemical, Ann Arbor, MI) and allantoin concentration was determined using a colorimetric method (Chen and Gomes, 1992). Measured PD concentrations were used to estimate microbial protein supply as described by Chen and Gomes (1992). Microbial PD absorbed (mmol/d) was calculated according to the formula:

$$\text{Microbial PD absorbed} = (\text{Total PD excreted} - 0.385 \times \text{BW}^{0.75}) / 0.85$$

where total PD excreted was the sum of allantoin (mmol/d) and uric acid (mmol/d) measured in the urine and 0.85 was the assumed efficiency of PD absorption. Using microbial PD absorbed, microbial N flow (g N/d) was calculated according to the formula:

$$\text{Microbial N flow} = (\text{PD absorbed} \times 70) / (0.116 \times 0.83 \times 1,000)$$

where PD absorbed was expressed as mmol/d, the N content of purines was estimated at 70 mg N/mmol, 0.116 was the ratio of purine N:total N for mixed rumen microbes, and 0.83 was the assumed digestibility of microbial purines (Chen and Gomes, 1992).

In Situ Nylon Bag Technique

Silage and grain samples retained from periods 1, 3, and 5 were used to measure ruminal degradation. All samples were previously dried in a forced air oven at 55°C prior to processing. Silage samples were ground using a hammer mill to pass through a 2-mm screen (Christy and Norris Ltd, Chelmsford, United Kingdom) and grain samples were left as dry-rolled grain. Seven grams of each sample were placed into 5×10 -cm bags (model #R510, Ankom Technology, Macedon, NY) with a pore size of 50 μm . Bags were heat-sealed and incubated in the ventral sac of the rumen for 0, 2, 4, 8, 16, 24, 48, and 72 h with 3, 3, 3, 4, 4, 5, 5, and 6 bags as technical replicates for each sample at each time point. Samples collected from each period of study during were considered as the experimental unit ($n = 3$).

To facilitate incubations, 3 heifers (the same heifers as described above) were used in 2 separate incubation runs to ensure that no more than 60 bags were incubated in each heifer per run. To avoid bias arising from diet, heifers were fed a common finishing diet containing (DM basis): 4.00% barley silage; 4.00% corn silage; 42.64% barley grain; 42.64% corn grain; 5.56% mineral pellet; 0.67% urea; and 0.50% limestone for at least 7 d prior to incubations. Bags were inserted into the rumen using a sequential-in, all-out approach (NRC, 2001) as detailed by Rosser et al. (2013). Upon removal, bags were washed 5 times in cold water and then placed in a forced air oven at 55°C for 48 h after confirming samples attained a constant weight (Rosser et al., 2013). Dried bags were subsequently weighed and all samples remaining in bags were composited by ingredient replication, period, and incubation time. Composited time point samples were then analyzed for DM, CP, aNDFom, and starch

content at Cumberland Valley Analytical Services (Waynesboro, PA) as described above.

Statistical Analysis

Data were analyzed as an incomplete Latin square using the Mixed model of SAS (SAS version 9.4; SAS Institute, Inc., Cary, NC) with fixed effects of silage type, cereal grain type, and the silage $\times$ cereal grain interaction ($S \times G$) and the random effects of heifer and period. The replacement of the heifer in this study was not considered in the statistical analysis. All data and their residuals were tested for normality, and data that were not normally distributed were corrected. Mean, minimum, and maximum pH, area that pH was <5.5 , ammonia-N, and isovalerate data were normalized using log transformation, propionate was reflected, and the inverse of valerate was used. Means and SEM were reverse transformed for presentation in tables. Short-chain fatty acid and ammonia-N concentrations were analyzed with time as a repeated measure using a compound symmetry covariance structure as that structure yielded the lowest Akaike's and Bayesian Information Criterion values.

For fecal kernel variables, data were analyzed using the Mixed model of SAS (SAS version 9.4; SAS Institute, Inc., Cary, NC) with the fixed effect of silage, grain, and the 2-way interaction. Heifer and period were included as random effects. For variables where all observations within a treatment were equal to 0, the treatment was excluded from analysis for that specific variable and kernel appearance was marked as not present (NP) instead. The latter occurred when it was not possible to have either corn or barley in the feces (e.g., diets based on CS with CG could not have BG in the feces). Data were analyzed using the GLIMMIX procedure of SAS (SAS version 9.4; SAS Institute, Inc., Cary, NC) with binominal error structure and logit data transformation.

In situ rumen degradation kinetics were used to calculate the soluble fraction (S , %), potentially degradable fraction (D , %), undegradable fraction (U , %), and rate of degradation (K_d , %/h) of DM, CP, aNDFom (for silages), and starch of feed samples. Data were analyzed using the nonlinear (NLIN) procedure of SAS (SAS version 9.4; SAS Institute, Inc., 2002) based on a modified first-order kinetics and iterative least squares regression (Ørskov and McDonald, 1979). Feed fractions and rate data were then analyzed using the Mixed Model (SAS version 9.4; SAS) to obtain least squared means. Due to low digestibility of DM, CP, and aNDFom for the silage sources, the data did not fit the kinetic model. As a result, 24, 48, and 72-h digestibility values were reported. The effective degradability (ED) of DM, CP, and starch was calculated for grain sources assuming a passage rate of 6%/h (Ørskov and McDonald, 1979).

For all analysis, significance was declared when the P value < 0.05 . When the effect of grain or $S \times G$ was significant, means were separated using the pdiff option in SAS.

Results

Dietary Treatments

As intended with the formulation strategy, starch and ether extract concentrations numerically increased and aNDFom numerically decreased with increasing corn grain inclusion (Table 1). As a result of numerically greater starch and ether extract, the net energy contents calculated using chemical composition were numerically greatest for CG diets, intermediate for BLEND, and least for BG.

Dry Matter Intake and Ruminal Fermentation

There were no effects of silage, grain, or their interaction on DMI ($P \geq 0.19$, Table 2). Starting and ending BW were also not affected by dietary treatment. For mean ruminal pH, there was no effect of silage or grain source ($P \geq 0.096$). A $S \times G$ interaction was detected for minimum pH ($P = 0.032$) with BS-BG and CS-BLEND having the greatest minimum pH values while BS-BLEND had the least, while BS-CG, CS-BG, and CS-CG were intermediate but not different. Maximum pH was the greatest for BG, least for CG, and intermediate but not different from BG or CG for BLEND (grain, $P = 0.025$). Maximum pH was greater for BS than CS (silage, $P = 0.015$). The duration that pH was <5.5 was not affected by grain, silage, or their interaction ($P \geq 0.21$). But, the area that pH < 5.5 was affected by a $S \times G$ interaction ($P = 0.027$) where area was greatest for CS-CG, BS-BLEND, and CS-BG, intermediate but not different for BS-CG and CS-BLEND, and least for BS-BG.

Total SCFA concentration was greater for CS than BS (silage, $P = 0.009$) and greater for BLEND relative to BG and CG (grain, $P = 0.003$). The molar proportion of acetate (mol/100 mol) was greatest ($S \times G$, $P < 0.001$) for BS-CG and BS-BG, intermediate for CS-BLEND, and least for CS-BG, CS-CG, and BS-BLEND. The molar proportion of propionate (mol/100 mol) was greatest for CS-BG, intermediate for CS-BLEND, and least for BS-BG, BS-CG, BS-BLEND, and CS-CG ($S \times G$, $P < 0.001$). The molar proportion of butyrate was greater for CS when fed with CG than when fed with BG; while the other treatment combinations were generally intermediate but not different ($S \times G$, $P = 0.003$). The molar proportion of isobutyrate was greater for BS-BG than for CS-BG, BS-CG, BS-BLEND, CS-CG, and CS-BLEND ($S \times G$, $P = 0.049$) while the molar proportion of isovalerate was greater for BS than CS (silage, $P \leq 0.001$). The molar proportion of valerate was greatest in rumen fluid from heifers fed BS-BLEND and CS-BG, and least when fed BS-BG and CS-BLEND ($S \times G$, $P \leq 0.001$). While the concentrations of ammonia-N were generally quite low, the concentration of ammonia-N was greater for CS relative to BS (silage, $P = 0.023$), and was greater for CG compared to BG or BLEND treatments (grain, $P \leq 0.001$). For ammonia-N, there was a time $\times$ grain interaction ($P < 0.001$; data not shown) in which concentrations were greatest for BLEND at 0800 h, least for BG at 1400 h, and generally intermediate and not different for other time points.

Apparent Total Tract Digestibility

There was no effect of silage or $S \times G$ interactions for apparent total tract digestibility, GE digestibility, or DE concentration ($P \geq 0.16$; Table 3). DM, OM, and aNDFom digestibility were greater for BG than CG and BLEND (grain, $P \leq 0.035$). Digestibility of ADF was greater for CG than BG and BLEND (grain, $P < 0.001$). Starch digestibility was greatest for BG, intermediate for BLEND, and least for CG (grain, $P < 0.001$). Ether extract digestibility did not differ among treatments ($P \geq 0.18$). Gross energy digestibility (grain, $P = 0.011$) and DE concentration (grain, $P = 0.029$) were greater for BG than for CG and BLEND treatments.

Nitrogen Balance

As diets were similar in CP content and DMI did not differ, N intake did not differ among silage or grain sources ($P \geq 0.09$; Table 4). Fecal pH was greater for BG than CG and BLEND (grain, $P \leq 0.001$), but did not differ by silage source ($P = 0.79$). Additionally, there were no effects of silage ($P \geq 0.43$), grain ($P \geq 0.77$), or $S \times G$ interaction ($P \geq 0.18$) on urine output or predicted bacterial N supply.

Both fecal N excretion (g/d) and total N excretion (g/d) were greater for CS than BS (silage, $P \leq 0.041$), and were greatest

Table 2. Effect of feeding barley or corn silage with dry-rolled barley, corn, or an equal blend of barley and corn grain on dry matter intake (DMI), body weight, and ruminal fermentation of ruminally cannulated beef heifers ($n = 5$)

	Barley silage			Corn silage			P-values			
	Barley	Corn	Blend	Barley	Corn	Blend	SEM ¹	Silage	Grain	S × G ²
DMI, kg/d	8.55	8.69	9.53	9.51	9.48	9.32	0.57	0.19	0.65	0.40
Start weight, kg	475	479	482	456	459	472	29.9	0.08	0.54	0.89
End weight, kg	508	508	518	493	496	510	28.6	0.20	0.43	0.94
Ruminal pH										
Mean pH	6.35	6.14	6.00	6.06	5.94	6.16	0.15	0.16	0.32	0.096
Minimum pH	5.68 ^y	5.55 ^{yz}	5.32 ^z	5.39 ^{yz}	5.33 ^{yz}	5.63 ^y	0.16	0.66	0.81	0.032
Maximum pH	7.04 ^a	6.78 ^b	6.76 ^{ab}	6.77 ^a	6.52 ^b	6.71 ^{ab}	0.12	0.015	0.025	0.31
Duration < 5.5, min/d	77.8	132.8	189.5	125.3	231.5	85.0	74.62	0.77	0.40	0.21
Area < 5.5, (pH × min)/d	10.6 ^z	14.4 ^{yz}	39.2 ^y	15.7 ^y	54.3 ^y	13.0 ^{yz}	16.04	0.28	0.43	0.027
Rumen fermentation										
Total SCFA, mM ^{3,4}	123.5 ^b	122.5 ^b	130.9 ^a	129.4 ^b	128.3 ^b	139.5 ^a	5.86	0.009	0.003	0.88
SCFA proportions, mol/100 mol ^{3,4}										
Acetate	46.83 ^x	47.14 ^x	44.79 ^z	44.11 ^z	44.49 ^z	45.78 ^y	0.91	<0.001	0.33	<0.001
Propionate	40.88 ^z	41.02 ^z	43.56 ^z	46.51 ^x	42.17 ^z	44.81 ^y	1.58	<0.001	<0.001	<0.001
Butyrate	8.63 ^{wx}	8.31 ^{wx}	7.57 ^{xy}	5.49 ^z	9.10 ^w	6.12 ^{yz}	0.95	0.004	0.002	0.003
Isobutyrate	0.70 ^y	0.55 ^z	0.55 ^z	0.59 ^z	0.58 ^z	0.53 ^z	0.06	0.13	<0.001	0.049
Isovalerate	1.39	1.42	1.18	0.97	1.07	0.91	0.14	<0.001	0.29	0.66
Valerate	1.15 ^z	1.14 ^{yz}	1.74 ^x	1.43 ^x	1.53 ^{xy}	1.19 ^z	0.18	0.11	0.71	<0.001
NH ₃ -N, mg/dL ³	2.20 ^b	2.97 ^a	1.93 ^b	2.39 ^b	3.50 ^a	3.11 ^b	0.48	0.023	<0.001	0.23

¹Greatest SEM was reported.²S × G, silage by grain interaction.³SCFA, short-chain fatty acids.⁴ $n = 240$ for total SCFA. Outliers were removed for acetate, propionate, butyrate, and isobutyrate, $n = 227$, for isovalerate $n = 225$, for valerate $n = 221$, and for NH₃-N $n = 235$.^{a,b}Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).^{w-z}Values within a row with uncommon letters differ significantly according to the silage × grain interaction ($P < 0.05$).**Table 3.** Effect of feeding barley or corn silage with dry-rolled barley, corn, or an equal blend of barley and corn grain on apparent total tract nutrient digestibility, gross energy digestibility, and dietary digestible energy content when fed to ruminally cannulated beef heifers ($n = 5$)

	Barley silage			Corn silage			P-values			
	Barley	Corn	Blend	Barley	Corn	Blend	SEM	Silage	Grain	S × G ¹
Apparent total tract digestibility, % DM basis ²										
DM	77.4 ^a	75.1 ^b	76.1 ^b	78.7 ^a	75.2 ^b	74.1 ^b	1.90	0.87	0.035	0.37
OM	78.9 ^a	76.1 ^b	77.4 ^b	80.0 ^a	76.2 ^b	75.2 ^b	1.86	0.74	0.016	0.37
ADF	27.1 ^b	49.6 ^a	33.6 ^b	31.6 ^b	54.2 ^a	37.0 ^b	4.26	0.16	<0.001	0.98
aNDFom	47.0 ^a	42.1 ^b	39.5 ^b	49.8 ^a	42.8 ^b	42.5 ^b	3.35	0.32	0.026	0.89
Starch	97.7 ^a	90.2 ^c	93.4 ^b	97.5 ^a	90.2 ^c	92.0 ^b	1.45	0.46	<0.001	0.69
Ether extract	77.5	80.5	78.3	76.7	77.3	74.5	3.71	0.18	0.53	0.78
GE	77.1 ^a	74.0 ^b	75.2 ^b	78.3 ^a	73.9 ^b	73.2 ^b	1.93	0.78	0.011	0.39
DE, Mcal/kg DM	3.42 ^a	3.32 ^b	3.34 ^b	3.47 ^a	3.32 ^b	3.26 ^b	0.09	0.79	0.029	0.46

¹S × G, silage by grain interaction.²DM, dry matter; OM, organic matter; ADF, acid detergent fiber; aNDFom, neutral detergent fiber measured using alpha amylase and sodium sulfite corrected for ash content; GE, gross energy; DE, digestible energy.^{a-c}Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

for BLEND, intermediate but not different for CG, and least for BG (grain, $P \leq 0.020$). Though urinary N excretion (g/d) was not affected by grain ($P = 0.19$), silage ($P = 0.057$), or the S × G interaction ($P = 0.065$), urine excretion as a % of N intake was greatest for CS-BLEND and least for CS-BG (S × G, $P = 0.011$). Fecal N excretion as a % of N intake was not affected by dietary treatment ($P \geq 0.17$). Total N excretion (% of N intake) was greatest for CS-BLEND and BS-BG, intermediate but not different for CS-CG, CS-CG, and BS-BLEND, and least for CS-BG (S × G, $P = 0.030$).

Apparent N digestion in g/d and as a % of N intake was not affected by dietary treatment ($P \geq 0.17$). N retention in g/d and as a % of intake was greatest for CS-BG, intermediate but not different for BS-CG, BS-BLEND, and CS-CG, and least for BS-BG and CS-BLEND (S × G, $P \leq 0.033$).

Fecal Composition

Fecal output did not differ between silage sources (silage, $P = 0.20$) but was greater for BLEND and CG compared to BG (grain, $P = 0.016$). Fecal DM and starch content were greatest for CG,

Table 4. Effect of feeding barley or corn silage with dry-rolled barley, corn, or an equal blend of barley and corn grain on nitrogen balance and estimated microbial protein supply in ruminally cannulated beef heifers ($n = 5$)

	Barley silage			Corn silage			P-values			
	Barley	Corn	Blend	Barley	Corn	Blend	SEM ¹	Silage	Grain	S × G ²
N intake, g/d	156.7	160.5	176.9	177.9	180.4	174.0	10.76	0.09	0.64	0.31
Fecal pH	6.76 ^a	6.16 ^b	6.40 ^b	6.90 ^a	6.08 ^b	6.27 ^b	0.15	0.79	<0.001	0.37
Urine output, kg/d	9.81	7.46	8.53	8.62	9.69	9.23	1.17	0.43	0.77	0.18
Bacterial N production, g/d	75.2	63.2	73.8	63.3	77.6	79.3	12.66	0.78	0.79	0.51
N excretion, g/d										
Fecal	44.1 ^b	48.1 ^{ab}	54.9 ^a	49.8 ^b	54.7 ^{ab}	55.5 ^a	4.05	0.041	0.011	0.41
Urine	85.0	79.4	84.3	79.4	94.4	96.8	6.37	0.057	0.19	0.065
Total	129.0 ^b	127.6 ^{ab}	139.7 ^a	129.0 ^b	149.2 ^{ab}	151.9 ^a	8.28	0.019	0.020	0.16
N excretion, % of N intake										
Fecal	29.0	30.1	30.9	28.1	30.2	32.1	2.17	0.93	0.17	0.77
Urine	54.6 ^{xy}	50.9 ^{xyz}	47.6 ^{yz}	44.5 ^z	51.9 ^{xyz}	56.4 ^x	3.40	0.98	0.67	0.011
Total	83.5 ^y	81.1 ^{yz}	78.6 ^{yz}	72.5 ^z	82.1 ^{yz}	88.4 ^y	4.17	0.99	0.33	0.030
Apparent N digestion										
g/d	112.8	112.0	122.1	128.2	125.9	118.4	9.07	0.17	0.97	0.37
% of N intake	71.0	69.9	69.1	71.9	69.8	67.9	2.70	0.93	0.17	0.77
N retained										
g/d	28.6 ^z	31.6 ^{yz}	38.1 ^{yz}	49.0 ^y	31.8 ^{yz}	21.1 ^z	7.65	0.82	0.36	0.033
% of N intake	16.5 ^z	18.9 ^{yz}	21.4 ^{yz}	27.5 ^y	17.9 ^{yz}	11.6 ^z	4.17	0.99	0.33	0.030

¹Greatest SEM was reported.²S × G, silage by grain interaction.^{a,b}Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).^{x-z}Values within a row with uncommon letters were identified as having a silage × grain interaction ($P < 0.05$).

intermediate for BLEND, and least for BG (grain, $P \leq 0.001$). Wet weight of the 250 mL fecal samples was greatest for BS-CG, intermediate for CS-BLEND, and least for BS-BLEND and CS-BG ($S \times G$, $P = 0.020$). The weight of material retained on the 1.18-mm sieve after screening was greatest for CG, intermediate for BLEND, and least for BG treatments (grain, $P \leq 0.001$). Appearance of whole barley kernels in the feces was greatest for CS-BG and least for BS-CG ($S \times G$, $P \leq 0.001$; Table 5). Partial barley kernels and whole corn kernels in feces were not affected by silage ($P \geq 0.26$), grain ($P \geq 0.061$), or their interaction ($P \geq 0.26$). Partial corn kernel appearance was greatest for CG diets, intermediate for BLEND diets, and least for BG diets (grain, $P \leq 0.001$). The proportion of fiber remaining was greatest for BG diets, intermediate for BLEND diets, and least for CG diets (grain, $P \leq 0.001$).

In Situ Nylon Bag Kinetics and Digestibility

The degradation rate of DM, CP, and starch was greater for BG than CG ($P \leq 0.004$; Table 6). There were no differences in the soluble fractions for DM, CP, or starch among grain sources ($P \geq 0.40$). But, CG had greater degradable fractions and less undegradable fractions of DM, CP, and starch than BG ($P \leq 0.031$). Effective degradability of DM, CP, and starch was greater for BG than CG ($P \leq 0.004$).

After 24 h of ruminal incubation, DM digestibility was greater for CS than BS ($P = 0.009$; Table 7), but there were no differences in DM digestibility at 48 or 72 h ($P \geq 0.17$). There were no differences in digestibility of CP or aNDFom between silages at any of the 3 time points measured ($P \geq 0.22$). However, starch digestibility after 24, 48, and 72 h was greater for CS than BS ($P \leq 0.034$).

Discussion

The objective of the current study was to evaluate the effects and possible interactions of silage type (corn vs. barley) and cereal grain type (corn vs. barley vs. blend) on DMI, ruminal

fermentation, total tract digestibility, fecal pH, and microbial protein supply in finishing beef heifers. While it is generally argued that the contribution of silage toward the metabolizable energy and metabolizable protein supply is low in finishing diets (Joy et al., 2016), a recent study reported that use of corn silage rather than barley silage increased hot carcass weight and rib-eye area (Johnson et al., 2020) suggesting that the silage source may affect nutrient supply. Given the greater starch concentration in corn silage than barley silage (Johnson et al., 2020), it is possible that there may be interactions among the silage and grain sources in finishing diets. Although a part of our hypothesis was that diets containing a blend of BG and CG would improve starch and protein degradation and ultimately result in increased total SCFA concentrations, greater total tract digestibility, and improved microbial protein production, our results do not support the hypothesis. Positive associative effects have been observed in a number of studies when feeding a combination of grain sources to finishing cattle (Kreikemeier et al., 1987; Stock et al., 1987b; Huck et al., 1998). However, the combination of dry-rolled CG and dry-rolled BG, to our knowledge, has not been previously examined. For studies evaluating dry-rolled grains, Kreikemeier et al. (1987) reported that including dry-rolled wheat within dry-rolled corn-based diets improved ADG and feed efficiency compared to feeding either grain source independently. In this instance, wheat had a 35% greater rate of starch digestion when measured in vivo than dry-rolled corn (Kreikemeier et al., 1987). Though, there are a limited number of studies that have evaluated the effect of combining grain sources on ruminal fermentation, nitrogen balance, or total tract digestibility, it has been suggested that the magnitude of the positive additive effect is dependent upon the grain sources being fed, where blends of grains that vary greatly in rate and extent of ruminal degradation produce the greatest benefits. Based on in situ measurements in the present study, we observed that the K_d for starch in barley was more

Table 5. Effects of feeding barley or corn silage with dry-rolled barley, corn, or an equal blend of barley and corn grain on fecal characteristics and composition of solids retained on a 1.18-mm sieve of a fecal composite collected from ruminally cannulated beef heifers ($n = 5$)

	Barley silage			Corn silage			P-values			
	Barley	Corn	Blend	Barley	Corn	Blend	SEM ¹	Silage	Grain	S × G ²
Fecal output, kg DM/d	1.90 ^b	2.18 ^a	2.29 ^a	2.03 ^b	2.36 ^a	2.38 ^a	0.21	0.20	0.016	0.94
Fecal DM, %	22.12 ^c	28.01 ^a	26.78 ^b	23.19 ^c	28.32 ^a	25.80 ^b	1.26	0.80	<0.001	0.48
Fecal starch, % DM	4.8 ^c	23.3 ^a	16.1 ^b	6.1 ^c	23.1 ^a	17.6 ^b	2.22	0.39	<0.001	0.76
Wet fecal weight, g/250 mL	248.3 ^{yz}	265.2 ^x	247.5 ^z	239.9 ^z	252.9 ^{xyz}	261.4 ^y	6.73	0.54	0.011	0.020
Total retained, g	18.3 ^c	42.9 ^a	32.3 ^b	23.3 ^c	42.3 ^a	32.9 ^b	4.89	0.50	<0.001	0.61
Whole barley, % retained	16.50 ^b	1.80 ^d	14.39 ^b	24.16 ^a	NP	8.45 ^c	1.91	0.64	<0.001	<0.001
Partial barley, % retained	3.22	NP ³	0.61	1.30	NP	0.60	0.82	0.26	0.061	0.26
Whole corn, % retained	NP	0.33	0.55	NP	1.06	0.55	0.46	0.36	0.90	0.36
Partial corn, % retained	NP	58.71 ^a	28.72 ^b	0.69 ^c	58.50 ^a	36.96 ^b	4.21	0.38	<0.001	0.35
Fiber, % retained	80.28 ^a	39.16 ^c	55.72 ^b	73.85 ^a	40.44 ^c	53.88 ^b	6.14	0.64	<0.001	0.82

¹Greatest SEM was reported.²S × G, silage by grain interaction.³NP, not present.^{a-d}Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).^{x-z}Values within a row with uncommon letters were identified as having a silage × grain interaction ($P < 0.05$).**Table 6.** Rate of in situ degradation, soluble, degradable, and undegradable fractions as determined by ruminal nylon bag incubation of grain sources collected during periods 1, 3, and 5 of the study

Parameter ¹	Barley grain	Corn grain	SEM ²	P-values
DM				
Kd, %/h	15.62 ^a	2.92 ^b	1.34	0.003
S, %	3.38	4.05	0.80	0.59
D, %	72.28 ^b	83.78 ^a	1.48	0.005
U, %	24.34 ^a	12.17 ^b	2.21	0.018
ED, %	55.38 ^a	31.45 ^b	2.82	0.004
CP				
Kd, %/h	9.29 ^a	1.53 ^b	0.52	<0.001
S, %	5.00	6.53	1.80	0.58
D, %	75.89 ^b	93.47 ^a	1.58	0.001
U, %	19.11 ^a	0.00 ^b	1.94	0.002
ED, %	51.02 ^a	25.48 ^b	2.82	0.003
Starch				
Kd, %/h	16.23 ^a	2.99 ^b	1.55	0.004
S, %	3.23	1.54	1.28	0.40
D, %	85.51 ^b	95.41 ^a	2.14	0.031
U, %	11.26 ^a	3.05 ^b	2.03	0.046
ED, %	65.30 ^a	33.22 ^b	2.87	0.001

¹DM, dry matter; Kd, rate of degradation for the degradable fraction; S, soluble fraction; D, degradable fraction; U, undegradable fraction; ED, effective degradability; CP, crude protein.²Greatest SEM was reported.^{a,b}Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

than 5 times greater and the ED was nearly 2 times greater than for corn. The observed differences in the rate of starch digestion and ED suggest that the magnitude of difference in fermentability between the 2 grain sources should have been adequate to detect additive effects with regards to improved digestibility or ruminal fermentation, yet none were observed.

Another theory to explain additive effects observed in growth performance studies as a result of feeding mixtures of grain has been through a reduced risk of ruminal acidosis. In fact, [Huck et al. \(1998\)](#) suggested that performance improvements observed

Table 7. In situ digestibility of DM, CP, aNDFom, and starch for corn silage and barley silage samples collected during periods 1, 3, and 5 of the study

Parameter ¹	Barley silage	Corn silage	SEM	P-values
Digestibility, %				
DM				
24 h	1.42 ^b	14.13 ^a	0.84	0.009
48 h	14.67	18.67	1.76	0.18
72 h	18.75	22.44	1.56	0.17
CP				
24 h	0.00	2.57	1.70	0.34
48 h	2.31	3.89	2.27	0.65
72 h	4.70	12.82	3.99	0.22
aNDFom				
24 h	3.55	2.70	1.64	0.73
48 h	8.70	6.93	3.31	0.72
72 h	11.48	10.04	2.13	0.66
Starch				
24 h	81.57 ^b	91.80 ^a	0.98	0.002
48 h	91.19 ^b	95.82 ^a	1.04	0.034
72 h	94.47 ^b	96.47 ^a	0.42	0.029

¹DM, dry matter; CP, crude protein; aNDFom, neutral detergent fiber measured using α -amylase, sodium sulfite, and corrected for ash content.^{a,b}Values within a row with uncommon letters differ significantly among grain sources ($P < 0.05$).

when combining differing sources of grain in finishing diets may be a result of replacing a portion of rapidly fermentable grain with a more slowly fermentable source thereby reducing the risk of ruminal acidosis ([Axe et al., 1987](#); [Kreikemeier et al., 1987](#)) and avoiding a decrease in DMI due to digestive upsets. These findings are supported by [Bock et al. \(1991\)](#) who, in contrast, fed diets composed of 2 rapidly fermented grain sources, high-moisture corn with either 25% dry-rolled wheat or 33% steam-rolled wheat, and observed that the addition of wheat in high-moisture corn-based diets slowed rate of ruminal starch digestion, potentially reducing risk of ruminal acidosis. However, in the current study, we did not observe differences in DMI and minimum pH was the lowest for BS-BLEND and highest

for BS-BG and CS-BLEND treatments. The general trend for pH being greater for BG diets despite the greater in situ ruminal degradation rate and ED of DM, CP, and starch for BG compared to CG suggests that greater supply of dietary starch content of CG and greater degradable fractions may have sustained ruminal fermentation over a longer duration. This hypothesis is supported by the reduction in ruminal pH in diets with CG relative to BG, indicating greater cumulative fermentation. In contrast, the rapid degradability of BG may have initially led to an increase in SCFA production, but with a high ED and rapid rates of fermentation, there may have been adequate time to facilitate recovery of ruminal pH, as demonstrated by reduced area below pH 5.5, and greater maximum and minimum pH values observed for BG treatments. These results and proposed mechanisms contrast the theory posed by [Huck et al. \(1998\)](#) in that we observed that the more rapidly degradable source of starch, in this case BG, actually resulted in greater maximum pH: a finding that is counterintuitive ([Herrera-Saldana et al., 1990](#)).

Given that the lowest minimum pH was observed with the BS-BLEND treatment, and that lower pH is generally associated with greater concentration of SCFA ([Aschenbach et al., 2011](#)), it is not surprising that total SCFA concentrations were greatest for BLEND. Concentrations of SCFA were also greater for CS than BS. It should be recognized that greater SCFA concentrations can result from greater production, reduced absorption, or altered ruminal volume: factors we could not measure with the current experimental design. When reported as a molar proportion, propionate was greatest for CS-BG. Since propionate is the major glucogenic precursor in ruminants ([Allen et al., 2009](#)), increased concentration of propionate is favorable as it is associated with increased energetic efficiency and improved performance. Additionally, the increased concentrations of ammonia-N for CG and CS treatments are likely a reflection of greater urea addition to balance CP for these treatments.

For silage sources, in situ digestibility of nutrients was low. It has been well documented that the rumen microbiome is altered based on diet composition ([Petri et al., 2012, 2013](#); [Khafipour et al., 2016](#)) and it has been speculated that the shift in the microbiome may reduce ruminal NDF digestibility ([Russell and Wilson, 1996](#)). These data support the concept that NDF contributes little to the dietary energy supply in finishing diets ([Joy et al., 2016](#)). In addition to the greater in situ ruminal starch digestion observed for CS relative to BS, a companion study observed greater DMI and ADG for steers finished with CS than BS ([Johnson et al., 2020](#)). These results suggest that greater concentrations of starch in CS may have stimulated the effects on ruminal fermentation observed in the current study despite an overall lack of other silage effects. The greater digestibility of starch in CS relative likely reflects the use of a kernel processor at harvest as compared to no kernel processing with BS, and may have been influenced by greater starch content for CS relative to BS (26.7% vs. 19.6%, respectively), though variation in starch content of dietary treatments was minimal between silage sources.

Results of the current study support those of previous studies that reported greater digestibility for dry-rolled BG than CG ([Boss and Bowman, 1996](#); [Johnson et al., 2020](#)). That said, we also observed that BG had a larger fraction of undegradable DM, CP, and starch when measured in situ. However, fecal starch for BG treatments was lower than expected given the relatively large amount of whole barley kernels in the feces of heifers fed BG. Given the greater PI of CG and less starch digestibility, a large amount of fractured CG kernels were present in the feces

of heifers fed CG. Likewise, the greater PI and use of dry-rolling for CG may not have promoted sufficient digestibility of CG as it is known that dry-rolling does very little to disrupt the structure of the starch and protein matrix in CG and is not an optimal processing method to maximize starch digestibility ([Owens et al., 1997](#); [Zinn et al., 2011](#)).

It is possible that combining sources of starch that are rapidly digested (BG) with sources that are slowly digested (CG) may shift the site of starch digestion from the rumen to the small and large intestine. [Owens et al. \(1986\)](#) estimated that starch digested in the small intestine may provide up to 42% more energy than when fermented in the rumen. However, data in the present study suggest that with dry-rolling, corn grain utilization was lower than for BG using similar processing methods. For example, CG had lower ED than barley, had lesser total tract starch digestion, greater fecal starch, and greater excretion of partial kernels in the feces. While the lower fecal pH observed for CG and BLEND diets in the current study suggests an increase in postruminal starch digestion, a companion study did not observe any growth or carcass-related improvements to suggest a benefit to altering the site of starch digestion ([Johnson et al., 2020](#)). Using values from the current study for the CS-CG treatment for fecal DM output and fecal starch, it can be calculated that over 545 g of starch was excreted daily. The potential ruminal and postruminal starch flows, at least based on in situ derived data, for the CS-CG treatment indicate that starch intake equated to 5.93 kg/d. Assuming 1.54% of that CG starch is soluble and 95.4% is degradable with a predicted ED of 33.22% for CG resulting in ruminal digestion of approximately 1.97 kg of starch and 3.96 kg of starch potentially flowing out of the rumen for digestion in the small and large intestine. While the intestinal flows are likely overestimated based on the use of in situ data and an assumed passage rate of 6%, it is possible that the large amount of starch reaching the small intestine may have exceeded the capabilities for intestinal starch digestion ([Huntington et al., 2006](#)). Thus, benefits of postruminal starch digestion were likely not observed and could not compensate for the excess undigested starch leaving the rumen. This is further supported by the high fecal starch values observed.

Altering the rate and extent of starch digestion in the rumen may also influence N use efficiency and microbial protein synthesis ([Axe et al., 1987](#); [Streeter et al., 1989](#)). In fact, [Huck et al. \(1998\)](#) suggested that altered N use efficiency may partially explain the positive associative effects observed when cereal grains with markedly different rumen fermentation are combined in a diet. Although, rates of ruminal starch digestion differed between the CG and BG, we did not observe any differences in microbial protein production. However, N retention, in g/d and as a % of intake, was greatest for the CS-BG treatment; the only evidence of an associative effect observed in the present study. [Kohn et al. \(2005\)](#) reported that 26 g of N retained was required per kg of ADG when holding the composition of tissue accretion constant. Based on the estimate of [Kohn et al. \(2005\)](#), estimates of ADG required to achieve the N retention values observed in the present study were 1.89, 1.39, 1.27, 1.21, 1.04, and 0.90 kg/d for CS-BG, BS-BLEND, BS-CG, CS-CG, BS-BG, and CS-BLEND, respectively. On average, these values were 9% lower than the gains observed during the study. Since actual gains include skeletal weight, adipose tissue, and muscle, it is possible that difference between actual gain and that predicted with N can be explained by accretion of components that do not contain N. While BW gains in Latin squares are often criticized due to the high variability in BW measurements and

the relatively short periods, we observed similar rates of gain in a companion study that evaluated growth performance (Johnson et al., 2020).

Previous studies have demonstrated that combining grain sources with varying rates of ruminal degradability may improve performance through various mechanisms including reducing ruminal acidosis, shifting site of starch digestion, altering N digestion, as well as improving efficiency of microbial protein production. Though it was hypothesized that feeding a combination of corn and barley grains would act through such mechanisms to result in improved total tract nutrient utilization and improved microbial protein production, there were few associate effects observed. Results of the present study confirm that when comparing dry-rolled corn and barley, barley has a greater rate of digestion, increased total tract digestibility, and may not reduce ruminal pH.

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