Use of barley or corn silage when fed with barley, corn, or a blend of barley and corn on growth performance, nutrient utilization, and carcass characteristics of finishing beef cattle

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ABSTRACT: The objective of this study was to evaluate the effects of the source of silage, cereal grain, and their interaction on growth performance, digestibility, and carcass characteristics of finishing beef cattle. Using a completely randomized design within an 89-d finishing study, 288 steers were randomly assigned to 1 of 24 pens (12 steers/pen) with average steer body weight (BW) within a pen of 464 kg ± 1.7 kg (mean ± SD). Diets were arranged in a 2 × 3 factorial with corn silage (CS) or barley silage (BS) included at 8% (dry matter [DM] basis). Within each silage source, diets contained dry-rolled barley grain (BG; 86% of DM), dry-rolled corn grain (CG; 85% of DM), or an equal blend of BG and CG (BCG; 85% of DM). Total tract digestibility of nutrients was estimated from fecal samples using near-infrared spectroscopy. Data were analyzed with pen as the experimental unit using the Mixed Model of SAS with the fixed effects of silage, grain, and the two-way interaction. Carcass and fecal kernel data were analyzed using GLIMMIX utilizing the same model. There were no interactions detected between silage and grain source. Feeding CG increased ($P < 0.01$) DM intake by 0.8 and 0.6 kg/d relative to BG and BCG, respectively. Gain-to-feed ratio was greater ($P = 0.04$) for BG (0.172 kg/kg) than CG (0.162 kg/kg) but did not differ from BCG (0.165 kg/kg). Furthermore, average daily gain (2.07 kg/d) and final body weight did not differ among treatments ($P \geq 0.25$). Hot carcass weight (HCW) was 6.2 kg greater (372.2 vs. 366.0 kg; $P < 0.01$) and dressing percentage was 0.57 percentage units greater (59.53 vs. 58.96 %; $P = 0.04$) for steers fed CS than BS, respectively. There was no effect of dietary treatment on the severity of liver abscesses ($P \geq 0.20$) with 72.0% of carcasses having clear livers, 24.4% with minor liver abscesses, and 3.6% with severe liver abscesses. Digestibility of DM, organic matter, crude protein, neutral detergent fiber, and starch were greater for BG ($P < 0.01$) than CG or BCG. As expected, grain source affected the appearance of grain kernels in the feces ($P \leq 0.04$). Feeding CS silage increased the appearance of fractured corn kernels ($P = 0.04$), while feeding BS increased fiber appearance in the feces ($P = 0.02$). Current results indicate that when dry rolled, feeding BG resulted in improved performance and digestibility compared with CG and BCG. Even at low inclusion levels (8% of DM), CS resulted in improved carcass characteristics relative to BS.

Key words: barley, carcass quality, corn, finishing, grain, silage

INTRODUCTION

Western Canadian feedlots have predominantly relied on the use of barley silage (BS) and barley grain (BG) as feed ingredients for finishing diets. However, the recent development of short-season corn hybrids offers a yield advantage for producers relative to BS (Baron et al., 2014; Lardner et al., 2017). Although corn silage (CS) typically has greater starch and lesser protein content than BS, the amount of dietary energy contributed by silage is relatively small in finishing diets. At such low levels of inclusion (<10% dry matter [DM] basis), forage in finishing diets is more likely to provide value as a source of effective fiber rather than as a source of energy.

When processed similarly, starch and protein from barley is degraded more rapidly and to a greater extent in the rumen than corn grain (CG; Herrera-Saldana et al., 1990). Due to the rapid fermentation of dry-rolled BG, the risk of ruminal acidosis is perceived to be greater than with dry-rolled CG, a response that can have a negative impact on average daily gain (ADG) and gain-to-feed ratio (G:F; Castillo-Lopez et al., 2014). Several studies have demonstrated that combining grain sources with differing rates of degradable carbohydrate fractions may improve the efficiency and growth performance of finishing cattle (Kreikemeier et al., 1987; Stock et al., 1987b). That being said, there are currently no studies that compare barley and corn and limited studies that have evaluated short-season CS. Additionally, while previous studies have evaluated the use of either barley- or corn-based diets for finishing cattle (Beauchemin et al., 1997), they have not examined the interactions between cereal silage and cereal grain sources.

We hypothesized that due to the differing concentrations of starch and the expected differences for starch and protein degradability in CG and BG, diets containing blended grains will result in improved digestibility, growth performance, and feed efficiency compared with single grain diets, with little effect of silage source.

MATERIALS AND METHODS

The use of steers 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) was seeded for silage at a rate of 79,072 plants/ha on May 27, 2016 with 76.2-cm row spacing. Anhydrous ammonia was applied to deliver 72.1 kg of N/ha and 4.03 MT of fertilizer was applied containing 36.3% N and 12.1% P. Liquid Herbicide (R/T 540, Monsanto Canada, Winnipeg, MB) was applied June 6 at 0.82 L/ha and June 20 at 1.66 L/ha. Corn heat units (CHU) were calculated for each day using historical weather data obtained from the Saskatoon RCS weather station according to the following calculation:

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

Corn silage was harvested after 1,940 CHU using a kernel processor (2-mm roller gap) and at a theoretical chop length of 0.95 cm on August 30 at 32% whole-plant DM. Silage was treated with an inoculant (Biomax 5, Chr. Hansen Inc., Milwaukee, WI) at a rate of 1.0×10^{11} lactic acid bacteria colony-forming units (CFU) per tonne during ensiling.

The barley variety used for silage production was CDC Copeland (SeCan, Kanata, ON). Barley was seeded at 108 kg/ha on May 19, 2016. Prior to seeding, the seed was treated with a fungicide (Rancona Pinnacle, Arysta Lifescience Canada Inc., Guelph, ON) at a rate of 325 mL/100 kg of seed. Anhydrous ammonia was applied to deliver 64.56 kg of N/ha along with 1.36 MT of 12-40-0 10 S 1 Zn (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 L each of Buctril M Emulsifiable Selective Weedkiller (Bayer CropScience Inc., Calgary, AB) and Bison 400L (ADAMA Agricultural Solutions Canada Ltd., Winnipeg, MB) 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 an inoculant (Biomax 5, Chr. Hansen Inc., Milwaukee, WI) at a rate of 1.0×10^{11} lactic acid bacteria CFU/tonne during ensiling.

Cereal grains were obtained from a commercial feed mill (Canadian Feed Research Centre, North Battleford, SK) and barley was dry rolled to an average processing index (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%. Chemical compositions of the silage and grain sources used for the duration of the finishing study are presented in Table 1.

Steer Management, Experimental Design, and Dietary Treatments

A total of 288 commercial crossbred steers were purchased from a local auction market and used in a previous study until reaching a mean body weight (BW) of 465 ± 28 kg. One day before the start of the study, steers were implanted with 120 mg of trenbolone acetate and 24 mg of estradiol (Revalor-S, Merck Animal Health, Madison, NJ). Steers were stratified by BW into 1 of 24 pens (12 steers/pen) with the average BW of each pen being 464 kg ± 1.7 kg (mean ± SD). Pens were then randomly assigned to one of six treatments (described below) in a completely randomized design. Steers were housed in pens measuring 12 × 24 m with a 3.3-m high windbreak (20 cm/m porosity) fence along the back of each pen.

Dietary treatments were arranged in a 2 × 3 factorial with silage source: CS or BS included at 8% (DM basis; Table 2) and cereal grain source: dry-rolled BG (86% of DM); dry-rolled CG (85% of DM); or an equal blend of BG and CG (BCG; 85% of DM). Steers were gradually transitioned to their respective finishing diet over 24 d (Table 3). All diets were formulated to be similar in crude protein (CP)

and to have the same forage inclusion and mineral and vitamin concentrations. The mineral supplement contained monensin (Elanco Animal Health, Greenfield, IN) to target a final dietary concentration of 33 mg/kg. Steers were fed once daily between 0830 and 1100 hours with the amount of feed delivered targeted to achieve ad libitum intake while also minimizing residual feed.

Growth Performance and DM Intake

Measurements obtained during the dietary transition period were included when calculating overall performance. The BW of individual steers was measured on two consecutive days at the start and end of the study and the average BW was calculated to determine initial and final BW. Throughout the study, steers were weighed every 2 weeks with BW data used to calculate ADG by regressing BW with the day of study. On weigh days, cattle BW measurements were initiated at 0830 hours and feeding was delayed to reduce the effect of gut fill on BW. Feed bunks were also cleaned and the residual feed was weighed and sampled to determine DM concentration. The difference in weight between the amount of DM offered and the quantity of DM refused was used to determine the biweekly pen DM intake (DMI). These values were then used to determine the average DMI per steer represented as kilograms per day by dividing the biweekly pen DMI by the number of steers per pen and by the number of days between consecutive measurements.

On the same days as BW measurement, representative samples of BS, BG, CS, CG, urea, limestone, mineral and vitamin pellet, and canola meal were collected. All samples of feed ingredients, as well as samples of refusals, were dried in a forced-air oven at 55 °C for 72 h for DM determination. The DM content of each ingredient was used to ensure that the as fed ingredient inclusion achieved dietary formulation specifications. Dried feed ingredient samples were then composited by month ($n = 3$) on an equal weight basis. Concentrate samples (CG, BG, mineral pellet, and canola meal) were ground using a Retch ZM 200 grinder (Haan, Germany) to pass through a 1-mm screen, while silage samples were ground through a 1-mm screen using a hammer mill (Christie-Norris Laboratory Mill, Christie-Norris Ltd, Chelmsford, UK). All dried and ground feed samples were submitted for chemical analysis to Cumberland Valley Analytical Services (Waynesboro, PA) for determination of DM, organic matter (OM), CP, neutral detergent

Table 1. Chemical composition of silage and grain sources used for the duration of the study

	Ingredient			
	Barley silage	Barley grain	Corn silage	Corn grain
Chemical composition, % DM*				
DM, %	40.54 ± 3.40	90.15 ± 0.36	35.38 ± 2.33	89.44 ± 1.27
OM	93.92 ± 0.53	97.88 ± 0.16	95.13 ± 0.11	98.38 ± 0.13
CP	10.90 ± 0.56	11.77 ± 0.25	9.57 ± 0.15	8.57 ± 0.21
Starch	22.47 ± 1.55	58.80 ± 1.66	30.17 ± 0.81	71.36 ± 1.33
ADF	27.57 ± 1.55	6.80 ± 0.40	26.00 ± 0.35	3.93 ± 0.25
NDF	44.90 ± 2.36	19.63 ± 2.08	42.70 ± 0.72	10.27 ± 0.38
Ether extract	2.91 ± 0.13	2.18 ± 0.10	2.93 ± 0.02	4.22 ± 0.42
Ca	0.31 ± 0.06	0.06 ± 0.01	0.25 ± 0.01	0.02 ± 0.01
P	0.26 ± 0.02	0.35 ± 0.02	0.26 ± 0.01	0.32 ± 0.02
NE_m, Mcal/kg[†]	1.52 ± 0.07	1.94 ± 0.02	1.61 ± 0.02	2.14 ± 0.02
NE_g, Mcal/kg[†]	0.93 ± 0.07	1.30 ± 0.02	1.01 ± 0.02	1.46 ± 0.02

*Chemical composition is expressed as means ± SD ($n = 3$).

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

Table 2. Ingredients and chemical composition of diets used during the finishing period

	Barley silage			Corn silage		
	Barley grain	Corn grain	Blend	Barley grain	Corn grain	Blend
Ingredient, % DM						
Barley silage	8.00	8.00	8.00	—	—	—
Corn silage	—	—	—	8.00	8.00	8.00
Barley grain	85.94	—	42.72	85.86	—	42.69
Corn grain	—	84.96	42.72	—	84.89	42.69
Urea	—	0.98	0.50	0.08	1.06	0.57
Mineral pellet*	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[†]						
DM, %	82.2 ± 1.07	81.7 ± 0.83	82.0 ± 0.81	80.0 ± 0.95	79.9 ± 1.65	80.1 ± 1.28
OM	95.6 ± 0.10	96.0 ± 0.16	95.8 ± 0.03	95.7 ± 0.14	96.1 ± 0.11	95.9 ± 0.02
CP	11.5 ± 0.17	11.3 ± 0.18	11.5 ± 0.14	11.6 ± 0.21	11.4 ± 0.20	11.5 ± 0.17
NDF	21.6 ± 1.57	13.5 ± 0.50	17.5 ± 0.53	21.4 ± 1.82	13.3 ± 0.26	17.3 ± 0.78
ADF	8.4 ± 0.44	5.9 ± 0.34	7.1 ± 0.31	8.3 ± 0.33	5.8 ± 0.24	7.0 ± 0.16
Starch	54.2 ± 1.43	64.5 ± 1.17	59.3 ± 0.27	54.7 ± 1.35	65.1 ± 1.23	59.9 ± 0.15
Ether extract	2.3 ± 0.08	4.0 ± 0.35	3.2 ± 0.22	2.3 ± 0.09	4.0 ± 0.36	3.2 ± 0.23
Ca	0.86 ± 0.03	0.83 ± 0.03	0.84 ± 0.03	0.86 ± 0.03	0.82 ± 0.02	0.84 ± 0.03
P	0.35 ± 0.02	0.32 ± 0.02	0.34 ± 0.01	0.35 ± 0.02	0.32 ± 0.02	0.34 ± 0.01
NE_m, Mcal/kg[‡]	1.85	2.00	1.93	1.86	2.00	1.93
NE_g, Mcal/kg[‡]	1.23	1.35	1.29	1.23	1.36	1.30

*The mineral pellet supplement was mixed with ground barley grain for pelleting at a ratio of 78:21 (DM basis), 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.

[†]Chemical composition is expressed as means ± SD (n = 3).

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

fiber (NDF), acid detergent fiber (ADF), starch, ether extract, calcium, and phosphorus concentrations. For silage, DM was determined using a modified procedure that combined a partial DM adapted from Goering and Van Soest (1970), followed by heating samples to 105 ℃ for 3 h according to method 2.1.4 (Shreve et al., 2006). For all other feeds, DM was determined by drying samples at 135 ℃ using AOAC (2000) method 930.15. Ash was determined using AOAC (2000) method 942.05 with the modification of using 1.5-g sample weight with a 4-h ashing time, followed by hot weighing. Ash content was used to determine the OM concentration by subtracting ash from 100%. Crude protein was determined using AOAC (2000) method 990.03 using a LECO FP-528 Nitrogen Combustion Analyzer (LECO, St. Joseph, MI). Neutral detergent fiber was determined using the method of Van Soest et al. (1991) including α-amylase and sodium sulfite, and ADF was determined using AOAC (2000) method 973.18, both with the modification that Whatman 934-AH (GE Healthcare Life Sciences, Chicago, IL) glass 1.5-um microfiber filters were used in place of a fritted glass crucible. Starch concentration was determined with correction for free glucose as described by Hall (2009). Ether extract was determined according to AOAC (2000) method 2003.05 using the Tecator Soxtec System HT 1043 Extraction unit (Tectator, Foss, Eden Prairie, MN). Calcium and phosphorus content were determined according to AOAC (2000) method 985.01 with the modification that a 0.35-g sample was ashed for 1 h at 535 ℃, digested in open crucibles for 25 min in 15% nitric acid on a hotplate, diluted to 50 mL, and analyzed on axial view using a Perkin Elmer 5300 DV ICP (Perkin Elmer, Shelton, CT). Finally, the net energy values (NE) of feed were calculated using National Research Council (NRC, 2001) equations.

At the end of the study (89 d on feed), steers were transported to a federally inspected abattoir (Cargill Meat Solutions, High River, AB). Hot carcass weight, back-fat thickness, and rib eye area were measured between the 12th and 13th ribs. The Canadian Beef Grading Agency yield and quality grades, as well as marbling score, were determined using the Computer Vision Grading System (VBG 2000 e+v

Table 3. Ingredient composition of transition diets used to transition steers to their respective finishing diets over 24 d, each step was 4 d in duration with the final diet being fed on day 25

Ingredient, % DM	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Final
BS–BG							
Barley silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Barley grain	31.44	44.44	55.44	65.94	73.94	80.94	85.94
Canola meal	8.00	5.00	4.00	3.00	2.00	1.00	0.00
Limestone	0.00	0.00	0.00	0.50	0.50	0.50	0.50
Mineral pellet*	5.56	5.56	5.56	5.56	5.56	5.56	5.56
BS–CG							
Barley silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Corn grain	30.97	42.94	54.74	65.74	73.94	80.96	84.96
Canola meal	8.00	6.00	4.00	3.00	2.00	0.00	0.00
Urea	0.47	0.50	0.70	0.70	0.80	0.98	0.98
Limestone	0.00	0.00	0.00	0.00	0.50	0.50	0.50
Mineral pellet*	5.56	5.56	5.56	5.56	5.56	5.56	5.56
BS–BCG							
Barley silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Barley grain	15.61	22.07	27.57	33.22	37.22	40.72	42.72
Corn grain	15.61	22.07	27.57	33.22	37.22	40.72	42.72
Canola meal	8.00	5.00	4.00	2.00	1.00	0.00	0.00
Urea	0.22	0.30	0.30	0.50	0.50	0.50	0.50
Limestone	0.00	0.00	0.00	0.50	0.50	0.50	0.50
Mineral pellet*	5.56	5.56	5.56	5.56	5.56	5.56	5.56
CS–BG							
Corn silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Barley grain	31.17	44.24	55.29	65.84	73.86	80.86	85.86
Canola meal	8.00	5.00	4.00	3.00	2.00	1.00	0.00
Urea	0.27	0.20	0.15	0.10	0.08	0.08	0.08
Limestone	0.00	0.00	0.00	0.50	0.50	0.50	0.50
Mineral pellet*	5.56	5.56	5.56	5.56	5.56	5.56	5.56
CS–CG							
Corn silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Corn grain	30.72	42.72	54.64	65.54	72.94	79.94	84.89
Canola meal	8.00	6.00	4.00	3.00	2.00	1.00	0.00
Urea	0.72	0.72	0.08	0.90	1.00	1.00	1.05
Limestone	0.00	0.00	0.00	0.00	0.50	0.50	0.50
Mineral pellet*	5.56	5.56	5.56	5.56	5.56	5.56	5.56
CS–BCG							
Corn silage	55.00	45.00	35.00	25.00	18.00	12.00	8.00
Barley grain	15.47	21.97	27.47	32.72	36.72	40.22	42.69
Corn grain	15.47	21.97	27.47	32.72	36.72	40.22	42.68
Canola meal	8.00	5.00	4.00	3.00	2.00	1.00	0.00
Urea	0.50	0.50	0.50	0.50	0.50	0.50	0.57
Limestone	0.00	0.00	0.00	0.50	0.50	0.50	0.50
Mineral pellet*	5.56	5.56	5.56	5.56	5.56	5.56	5.56

*The mineral pellet supplement was mixed with barley grain for pelleting at 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.

Technology GmbH, Oranienburg, Germany). Liver scores were determined using the Elanco Liver Check System (Elanco Animal Health, Greenfield, IN).

Carcass-adjusted final BW was calculated for each pen as the average hot carcass weight divided by the corresponding average pen dressing percentage. ADG and G:F were then adjusted on a carcass

basis. Net energy values for maintenance (NE_m) and gain (NE_g) were calculated based on animal performance as described by Zinn et al. (2002). The retained energy (RE) for large framed yearling calves was used (RE = [0.0437BW$^{0.75}$] × ADG$^{1.097}$; NRC, 1984) where BW was the shrunk (4% shrink) midtest weight. Net energy of gain was determined from NE_m according to Zinn and Shen (1998) using the equation: $NE_g = NE_m × 0.877 – 0.41$.

Near-Infrared Estimated Digestibility and Fecal Composition

On day 51 of the study, fecal samples were collected from each pen. Approximately 1 L of fresh feces were collected from pats produced by at least four steers in each pen while avoiding contamination with bedding or soil from the pen floor (Jancewicz et al., 2016a). The total number of fecal pats collected per pen was recorded. Composited fecal samples were thoroughly mixed and a 250-mL subsample was weighed, diluted in 250 mL of tap water, and screened using a 1.18-mm screen. The sample was continuously rinsed with tap water until only solid material remained. The residue was then dried for 24 h at 55 °C and sorted according to grain type (corn or barley) and fibrous portions. Material retained on the screen was further sorted into whole, fractured grain kernels, and fiber. The weight of the sorted fractions was then used to estimate the source and amount of grain kernels in the feces. The remaining composite sample of feces was dried in a forced-air oven at 55 °C to a constant weight and then ground to pass through a 1-mm screen using a Retsch ZM 200 grinder (Haan, Germany).

Ground fecal samples were analyzed using near-infrared (NIR) spectroscopy to estimate apparent total tract digestibility using previously developed calibration equations as described by Jancewicz et al. (2016b). For each pen, quartz ring cups were evenly filled and packed with the dried and ground fecal samples and scanned in duplicate using two repacks with the second scan utilizing a separate subsample from the original sample. Samples were scanned using a SpectraStar Near-Infrared analyzer 2400 RTW (Unity Scientific, Brookfield, CT). Spectral information was collected at wavelengths between 1,200 and 2,400 nm in 1-nm increments.

Statistical Analysis

Data were analyzed with pen as the experimental unit in a completely randomized design using the mixed model of SAS (SAS version 9.4; SAS Institute, Inc. Cary, NC) with the fixed effect of silage source, grain source, and the two-way interaction. Yield grades, quality grades, liver scores, and marbling scores were analyzed using the GLIMMIX procedure of SAS (SAS version 9.4, SAS Institute, Inc. 2002) with a binominal error structure and logit data transformation. Following analysis, means and SEM were reverse transformed for presentation.

For grain kernels isolated from feces, data were analyzed using the mixed model of SAS (SAS version 9.4; SAS Institute, Inc. Cary, NC) with the fixed effect of silage source, grain source, and the two-way interaction. When data were not normally distributed, the GLIMMIX procedure of SAS (SAS version 9.4; SAS Institute, Inc. Cary, NC) was used with a logit link function and binominal distribution. For variables where all observations within a treatment were not possible (e.g., the appearance of corn in feces from steers fed diets only containing barley), the individual treatment was excluded from analysis for that specific variable and kernel appearance was denoted as not present (NP). For all analyses, when the P value for grain type or the interaction was <0.05, means were separated using the Tukey's test.

RESULTS

Growth Performance and Carcass Characteristics

No interactions between silage source and cereal grain source were observed and as such, the main effects of grain and silage source are presented and discussed. Unshrunk initial BW and final BW and carcass-adjusted final BW were not affected by cereal silage or cereal grain source (P ≥ 0.20; Table 4). Feeding CG increased ($P < 0.01$) DMI by 0.8 and 0.6 kg/d relative to BG and BCG, respectively, but ADG, whether reported on a live weight basis or carcass-adjusted basis did not differ among grain source. As a result, G:F was greater ($P = 0.04$) for BG (0.172 kg/kg) than CG (0.162 kg/kg) but did not differ from BCG (0.165 kg/kg). Adjusted G:F was also greatest for BG, intermediate but not different for BCG, and least for CG ($P = 0.02$). Silage source did not affect DMI, ADG, carcass-adjusted ADG, or G:F. Hot carcass weight was 6.2 kg greater ($P < 0.01$) and dressing percentage was 0.57 percentage units greater ($P = 0.04$) for steers fed CS than BS, respectively. Grain source did not affect hot carcass weight or dressing percentage.

Table 4. Effect of cereal silage source (8% of DM) and cereal grain source (86% of DM) on DMI, BW, ADG, G:F, and carcass characteristics for finishing steers (12 steers/pen with 4 pens/treatment)

	Barley silage			Corn silage			SEM*	P value		
	Barley	Corn	Blend	Barley	Corn	Blend		Silage	Grain	S × G[†]
Initial BW, kg	464	464	464	464	466	464	0.80	0.30	0.20	0.30
Final BW, kg	648	647	645	654	651	649	4.93	0.25	0.71	0.99
Adjusted final BW, kg[‡]	622	621	619	628	625	623	4.78	0.27	0.71	0.99
DMI, kg/d	12.1[b]	12.8[a]	12.3[b]	12.3[b]	13.2[a]	12.4[b]	0.22	0.23	<0.01	0.79
ADG, kg/d	2.05	2.05	2.04	2.13	2.10	2.05	0.05	0.25	0.60	0.70
Carcass-adjusted ADG, kg/d[‡]	1.99	1.97	1.95	2.05	2.00	1.99	0.06	0.37	0.69	0.94
G:F, kg/kg	0.170[a]	0.163[b]	0.165[ab]	0.173[a]	0.160[b]	0.165[ab]	0.004	1.00	0.04	0.79
Carcass-adjusted G:F, kg/kg[‡]	0.164[a]	0.154[b]	0.158[ab]	0.167[a]	0.152[b]	0.161[ab]	0.004	0.82	0.02	0.77
Hot carcass, kg	365	368	365	372	375	370	2.05	<0.01	0.17	0.85
Dressing, %	58.7	59.2	59.0	59.2	60.0	59.4	0.31	0.04	0.14	0.80
Back fat, cm	1.09	1.12	1.19	1.14	1.19	1.12	0.06	0.57	0.76	0.37
Rib eye area, cm²	88.98	87.80	88.68	91.55	89.93	91.53	0.57	0.05	0.56	0.94
Yield grade, %**										
CBGA 1	47.9	47.9	37.5	50.0	34.0	40.8	7.2	0.63	0.36	0.42
CBGA 2	47.9	37.5	45.8	29.2	53.2	40.8	7.3	0.62	0.61	0.08
CBGA 3	4.2	12.5	16.7	18.8	12.8	18.4	5.6	0.13	0.30	0.24
Quality grade, %**										
CBGA AAA	79.2	83.3	75.0	75.0	78.7	67.4	6.7	0.30	0.30	0.98
CBGA AA	20.8	14.6	25.0	22.9	21.3	32.7	6.7	0.28	0.22	0.89
CBGA A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.00	1.00	1.00
CBGA B	0.0	2.1	0.0	2.1	0.0	0.0	2.1	1.00	1.00	1.00
Marbling score, %[††]										
Moderate	2.1	0.0	0.0	0.0	4.3	2.0	2.9	0.99	1.00	1.00
Modest	6.2	4.2	14.6	6.3	12.8	14.3	5.1	0.38	0.15	0.46
Small	54.2	72.9	56.2	45.8	48.9	38.8	7.3	0.01	0.16	0.52
Slight	37.5	22.9	29.2	47.9	34.0	44.9	7.2	0.04	0.15	0.91
Trace	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.00	1.00	1.00
Liver score[‡‡]										
Clear	68.0	73.3	76.6	79.2	71.7	63.0	7.1	0.85	0.85	0.20
Minor	32.0	22.2	19.1	20.8	28.3	23.9	6.6	0.98	0.74	0.34
Severe	0.0	4.4	4.3	0.0	0.0	13.0	5.0	0.99	1.00	1.00
NE_m, Mcal/kg***	1.98[a]	1.89[b]	1.92[ab]	2.00[a]	1.86[b]	1.96[ab]	0.03	0.87	<0.01	0.68
NE_g, Mcal/kg***	1.33[a]	1.24[b]	1.28[ab]	1.34[a]	1.22[b]	1.30[ab]	0.03	0.89	<0.01	0.73

[a,b,c]Values within a row with uncommon letters differ among grain sources ($P < 0.05$).

*Greatest SEM was reported.

[†]S × G = silage by grain interaction.

[‡]Adjusted final BW was calculated for each pen as hot carcass weight divided by the corresponding average pen dressing percent. Carcass-adjusted ADG was calculated the adjusted BW and was used to determine G:F.

**Percent of total according to Canadian Beef Grading Agency (CBGA).

[††]Percent of total according to U.S. Department of Agriculture (USDA) where 600–699 = moderate; 500–599 = modest; 400–499 = small; 300–399 = slight; and 200–299 = trace.

[‡‡]According to Elanco Liver Check System (Elanco Animal Health, Greenfield, IN).

***Net energy values calculated based on animal performance for the finishing period as described by Zinn et al. (2002) and Zinn and Shen (1998)

There was no effect of silage or cereal grain source on back-fat thickness, ribeye area, yield grades, or quality grades. For marbling scores, the percentage of carcasses grading small was greater for BS relative to CS (61.6 vs. 44.5%; $P = 0.01$), while CS had a greater percentage of carcasses grading slight relative to BS (42.3 vs. 29.9%; $P = 0.04$).

There were no differences in the severity of liver abscesses among steers fed differing silage or cereal grain sources ($P \geq 0.20$) with 72.0% of carcasses having no evidence of abscesses, 24.4% with minor liver abscesses, and 3.6% with severe liver abscesses. The NE_m and NE_g, calculated based on steer performance, were greater for BG compared with CG

Table 5. Effect of cereal silage (8% of DM) and cereal grain source (86% of DM) on apparent total tract digestibility in steers during the finishing period using NIR calibrations (Jancewicz et al., 2016b) on feces collected on day 51 of the study.

	Barley silage			Corn silage				P values		
	Barley	Corn	Blend	Barley	Corn	Blend	SEM	Silage	Grain	S × G*
Digestibility, % DM basis										
DM	84.4[a]	77.2[b]	78.0[b]	83.0[a]	78.0[b]	79.5[b]	0.75	0.63	<0.01	0.17
OM	85.7[a]	74.0[c]	76.1[b]	83.3[a]	74.2[c]	77.3[b]	0.77	0.60	<0.01	0.08
CP	73.2[a]	67.6[b]	67.1[b]	72.7[a]	66.4[b]	67.5[b]	0.87	0.57	<0.01	0.68
NDF	61.5[a]	52.0[c]	56.4[b]	59.8[a]	52.0[c]	56.3[b]	0.61	0.24	<0.01	0.31
ADF	30.3[a]	28.1[b]	26.3[ab]	29.9[a]	26.1[b]	29.3[ab]	1.08	0.84	0.03	0.10
Starch	92.5[a]	83.0[c]	85.9[b]	90.1[a]	82.3[c]	85.0[b]	0.63	0.02	<0.01	0.33
Fecal starch, % DM	14.5[c]	32.4[a]	26.0[b]	15.8[c]	32.3[a]	28.0[b]	1.35	0.33	<0.01	0.72
GE digestibility, %	88.4[a]	81.6[b]	83.2[b]	89.0[a]	84.1[b]	84.8[b]	1.16	0.12	<0.01	0.71

[a,b,c] Values within a row with uncommon letters differ significantly among grain sources (P < 0.05).

*S × G = silage by grain interaction.

Table 6. Effects of cereal silage (8% of DM) and cereal grain source (86% of DM) on the composition of solids retained on a 1.18-mm sieve after wet screening a 250-mL subsampled fecal composite collected from pen floors on day 51 of the study

	Barley silage			Corn silage				P values		
	Barley	Corn	Blend	Barley	Corn	Blend	SEM*	Silage	Grain	S × G†
Wet fecal weight, g/250mL	240.2[b]	259.6[a]	245.1[b]	243.9[b]	259.1[a]	246.7[b]	4.33	0.65	<0.01	0.89
Total solids retained, g‡‡	17.4[c]	43.1[a]	35.2[b]	20.6[c]	44.5[a]	35.8[b]	1.95	0.29	<0.01	0.81
Whole barley, % retained	21.11[a]	1.30[c]	9.61[b]	21.30[a]	NP	7.33[b]	0.71	0.13	<0.01	0.07
Fractured barley, % retained	1.69[a]	0.19[b]	1.57[b]	6.20[a]	NP	1.48[b]	0.48	0.10	0.04	0.08
Whole corn, % retained	NP	0.71	0.72	0.48	1.37	1.42	0.40	0.08	0.14	0.96
Fractured corn, % retained	NP	66.65[a]	42.36[b]	2.69[c]	70.43[a]	51.02[b]	2.78	0.04	<0.01	0.40
Fiber, % retained	77.20[a]	31.17[c]	44.73[b]	68.48[a]	28.20[c]	38.75[b]	2.70	0.02	<0.01	0.58

NP = Not present. Data were not included in statistical analysis as there was no supply of the specific grain source and fecal analysis confirmed that none were present.

[a,b,c] Values within a row with uncommon letters differ significantly among grain sources (P < 0.05).

*Greatest SEM was reported.

†S × G = silage by grain interaction.

‡Total weight of dry solid material that was retained on a 1.18-mm sieve after rinsing a 250-mL fecal sample under tap water.

but not different from BCG (P < 0.01) and did not differ among silage sources.

Estimated Total Tract Digestibility and Fecal Composition

There was no effect of silage source on predicted total tract digestibility of DM, OM, CP, NDF, or ADF digestibility (P ≥ 0.24; Table 5). However, predicted starch digestibility was greater (87.1 vs. 85.8%; P = 0.02) for BS than CS. Digestibility of DM and CP was greater for BG relative to CG or BCG (P < 0.01). Organic matter, NDF, and starch, digestibility were greatest for BG, intermediate for BCG, and the least for CG (P < 0.01). In general, fecal starch concentrations were high, but fecal starch content was greatest

for CG, least for BG, and intermediate for BCG (P < 0.01). Predicted gross energy (GE) digestibility was greatest (P < 0.01) for BG relative to other grain sources and not affected by silage source.

More (P < 0.01) whole barley kernels appeared in the feces of cattle fed BG, intermediate for BCG, and the least for CG (Table 6). More fractured barley kernels were present in the feces of cattle fed BG (P = 0.04). Whole corn kernels in feces were not affected by diet, but more fractured kernels were observed for CS than BS (P = 0.04). Likewise, fractured corn kernels were most common in feces from cattle fed CG, intermediate for BCG, and least for BG (P < 0.01), and greater for CS than BS (P = 0.04). Fibrous (nonkernel) content in feces was greater for BG, intermediate for BCG, and least for

CG diets ($P < 0.01$), and greater for BS than CS ($P = 0.02$).

DISCUSSION

We hypothesized that diets containing a blend of CG and BG would have greater digestibility, growth performance, and feed efficiency compared to single grain diets. The dietary treatments in the current study were formulated to deliver similar CP concentrations while comparing the effects of differing grain and silage sources fed at similar levels of dietary DM. To achieve this, silage and grain inclusion were held constant, with the exception that urea was used as a substitute for the cereal grain to maintain isonitrogenous diets. As a result of differences in starch content between CG and BG, the diet starch content was numerically greatest for CG diets, intermediate for BCG diets, and least for BG diets. Starch content was allowed to change with grain source as ingredient substitution approaches are common in industry and that cereal grain inclusion rates rather than dietary starch were reported to be considerations of feedlot nutritional consultants in the United States (Samuelson et al., 2016). That said, it should be acknowledged that in addition to starch source, starch concentration may affect the responses observed.

Though not examined when feeding a combination of dry-rolled CG and dry-rolled BG, several studies have demonstrated synergistic effects on growth performance and feed efficiency for finishing cattle fed a combination of grain sources that differ in their ruminal fermentability. Stock et al. (1987a, 1987b) demonstrated, in multiple studies, a positive associative effect of combining high moisture corn with diets comprised of whole CG or dry-rolled sorghum grain, noting an improvement in feed efficiency and ADG for blended grain diets. Additionally, Stock et al. (1987b) found that feeding a combination of grain sources improved ruminal and total tract starch digestion, an observation that may partially explain the positive impact of this practice on feed efficiency. In another study, Huck et al. (1998) observed positive associative effects of feeding steam flaked sorghum in combination with high moisture or dry-rolled corn noting improvements in ADG and G:F. A similar study conducted by Kreikemeier et al. (1987) indicated that with wheat, which had 35% more digestible starch than dry-rolled corn, ADG and G:F were improved when wheat was included with corn in finishing diets as compared with either grain source was fed alone. For dairy cattle,

Khorasani et al. (2001) demonstrated an increase in milk and milk component yield in primiparous cows fed an equal blend of coarse ground CG and BG relative to individual grain-based diets. Those authors suggested that improvements were due in part to the synchronization of dietary energy and protein with the blended grain diet. As such, there is a large body of support suggesting that there may be potential additive benefits when combining grain sources that have varying rates and extents of starch degradation. However, no additive effects of feeding a blend of cereal grain sources were detected in this study. It is possible that the cereal grain processing method imposed in the current study were inadequate to improve fermentability sufficiently enough to observed additive effects or that differences in the fermentability of the grain sources were small.

Effects of Cereal Silage Source

Although inclusion rates of silage were low (8% of DM), we observed that CS improved hot carcass weight, and dressing percentage relative to diets with BS. Given the relatively low inclusion rate, these observations are difficult to explain. However, it is possible that numerically greater starch concentration in CS may have contributed to greater quantity of digestible starch supply to the rumen and potentially the intestine relative to BS (Table 1). 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. While this suggestion may provide a potential explanation, given the high fecal starch content in general, and particularly that of CG-fed steers (>30% DM), it could be expected that limits to intestinal starch digestion may have been exceeded (Huntington et al., 2006). Second, fat provided by corn-based diets is generally greater in content and of different composition than that provided by barley which, given its higher energy value relative to carbohydrates, would increase energy intake and could relate to carcass quality improvement (Table 1). However, the contribution of silage towards energy supply, at such low levels of inclusion is unlikely to stimulate carcass gain, particularly considering that there were no differences in predicted NDF or ADF digestibility among silage sources. The most reasonable explanation is that although only numerically greater, that the increase in estimated GE digestibility of CS treatments, as well as the numerically greater starch and NE for CS (Table 1) when compounded over

the 89-d finishing study may have increased total energy intake and subsequently resulted in improvements for carcass quality. Although not significant, the additional energy intake may have been sufficient to result in the improvements in carcass gain observed. Interestingly, when energy density was predicted based on growth performance, no differences were detected and silage source did not affect DMI. However, the equations of Zinn et al. (2002) and Zinn and Shen (1998) use shrunk live BW rather than carcass weight, a potential flaw when using this method in cases where there are differences in HCW.

Interestingly, feeding BS increased the appearance of whole barley kernels in the feces. When feeding CS, the appearance of whole and fractured corn kernels in the feces was also increased. With finishing diets, it is generally assumed that the appearance of grain in the feces may be an indication of inadequately processed cereal grain. However, despite the fact that CS was harvested using a kernel processor (2-mm gap width) there was still an influence of silage source on kernel appearance in the feces. Previous studies have suggested that kernel processing through a 2-mm gap should be sufficient to optimize starch digestibility in CS (Ferraretto and Shaver (2012). However, such processing conditions may not be adequate with finishing diets or with short-season corn varieties. For barley kernel appearance in the feces, it is evident that the majority of whole kernels arise from the grain source as opposed to the silage source, suggesting that not all kernels were adequately damaged during the dry-rolling process despite achieving an adequate processing index.

Effects of Cereal Grain Source

In the current study, there were no observed benefits in feeding a combination of dry-rolled BG and CG. In fact, feeding BG improved G:F and had greater predicted digestibility compared with CG or BCG. Several studies have been conducted directly comparing dry-rolled BG and CG, although results have been inconsistent with regards to feed intake and growth performance given the reported differences in energy value between these grain sources. Consistent with results in the current study, studies by Boss and Bowman (1996) and Milner et al. (1995) both demonstrated an increase in DMI for steers fed dry-rolled corn compared with barley. Boss and Bowman (1996) also reported that feed efficiency was greater for barley-fed steers compared with those fed dry-rolled corn. In contrast, studies

by Mathison and Engstrom (1995) reported that when dry rolled, no effect of grain source (corn vs. barley) was observed on intake or growth performance. Nelson et al. (2000) reported that steers fed dry-rolled corn were more efficient than those fed dry-rolled barley. The greater DMI and G:F with barley are most likely influenced by the less severe processing of CG and consequently reduced digestibility relative to BG. Supporting this, fecal starch for all treatments was high in this study. Jancewicz et al. (2017) reported a mean fecal starch of 7% when evaluating 282 fecal samples from six feedlots in southern Alberta. Although the study only evaluated diets containing BG or a combination of barley and wheat, they observed a quadratic relationship between fecal starch and G:F and a high PI was also correlated with higher fecal starch. Given the high fecal starch and low digestibility for CG in the present study, these results support that dry-rolling corn is not a processing method sufficient to disrupt the complex starch and protein matrix of CG and subsequently improve digestibility (Owens et al., 1997; Zinn et al., 2011). For barley, even with a mean PI of 66.6% in the current study, fecal starch for the BS–BG treatment was still 14.5%, substantially greater than observed by Jancewicz et al. (2017). Although PI was more severe for BG, it is possible that large variability in kernel size may have resulted in a non-uniform processing and that a portion of smaller kernels may have remained unprocessed as further evidenced by whole kernel appearance in feces. Such processing conditions would explain the lower than expected starch digestibility for BG, as well as the higher fecal starch content, given that whole barely has poor digestibility. However, it should be noted that despite high fecal starch, ADG still exceeded 2 kg/d for all treatments.

In feedlot diets, DMI is predominantly influenced by metabolic factors (Allen et al., 2009). Net energy values published by National Academies of Sciences, Engineering, and Medicine NASEM (2016) suggest that dry-rolled corn should have a greater energy content than dry-rolled barley (2.17 vs. 2.06 Mcal/kg NE_m, respectively). However, when calculated based on growth performance, NE values were greater for BG than CG. The relationship between NE and DMI has been well established such that dietary NE_m content can be used to predict DMI (NASEM, 2016). Predictions developed by both NASEM (2016) and Anele et al. (2014) demonstrate that DMI decreases with increasing NE_m. As such, it is likely that the lower growth performance, as calculated NE_m, as well as the lower digestibility of CG were driving factors behind the greater DMI for CG-fed steers,

despite there being no increase in growth performance. Additionally, the low processing index of CG may explain the low energy utilization. Likewise, greater digestibility of BG diets may have reduced feed intake, the extent to which likely limited a corresponding improvement in ADG or G:F.

Not surprisingly, the appearance of whole barley kernels in the feces was greater for BG diets, while whole and fractured corn kernel appearance were greatest on CG diets. Results suggest that at least for CG, a PI of 83% resulted in a large amount of bypass starch. These results reinforce the importance of adequate grain processing in finishing diets to maximize feed utilization, while also minimizing the risk of digestive upsets such as acidosis that can occur when feeding over processed grains.

Contrary to our hypothesis, feeding a blend of dry-rolled CG and BG showed no benefit with respect to growth performance or carcass characteristics for finishing beef cattle. Current results indicate that when dry rolled, feeding BG resulted in improved growth performance and digestibility compared to either CG or BCG. Despite low inclusions levels (8% of DM), feeding CS improved carcass characteristics relative to BS and no interactions were detected between silage and grain sources, indicating there were no observed additive benefits of concurrently feeding BG with CS.

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