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Effects of increased dietary roughage during the late finishing period on beef cattle performance, carcass traits, and blood, ruminal, and faecal characteristics

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SUMMARY

Finishing cattle are fed diets high in concentrates to promote efficient deposition of both muscle and adipose tissue while decreasing cost of gain during finishing. The continued incidence of liver abscesses and increases in morbidity and mortality in the late finishing period have led to interest in increasing dietary roughage inclusion during late finishing. The objective of the current experiment was to evaluate the effects of increased roughage inclusion late in the finishing period on growth performance, carcass traits, blood metabolites, inflammation markers, and ruminal and faecal characteristics of feedlot steers. Crossbred beef steers (*n* = 60; initial body weight; BW = 289 ± 35,6 kg) were blocked by BW and assigned to experimental dietary treatments in a randomized complete block design during the final 58 d on feed. Experimental treatments included control (CON; 6% roughage dry matter; DM), intermediate (INT; 12% roughage DM), and high (HGH; 18% roughage DM) roughage diets (CON = 5 pens and INT and HGH = 4 pens; 4 steers per pen). All experimental diets contained dry-rolled corn, prairie hay, Sweet Bran (Cargill, Inc., Blair, NE), dry supplement, urea, and a corn-steep- and molasses-based liquid supplement. The inclusion rates of roughage and dry-rolled corn were adjusted for each experimental treatment, in which the increased roughage replaced dry-rolled corn. Overall dry

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matter intake (DMI) tended to increase linearly ($P = 0,02$) with increasing roughage inclusion. No differences in BW, overall average daily gain (ADG), or gain to feed ratio (G:F) were observed ($P \geq 0,72$). Rib eye area increased linearly with increasing roughage inclusion ($P = 0,02$). Fat thickness, hot carcass weight (HCW), marbling, liver score, and kidney, pelvic, and heart fat (KPH) did not differ ($P \geq 0,29$) among treatments. Steers consuming the HGH diet had a lower faecal pH at the end of the finishing period ($P = 0,05$) compared to CON and INT steers. Ruminal lactate was increased on d 14 for CON steers compared to other treatments ($P < 0,001$). No differences were observed for ruminal pH ($P \geq 0,11$) among treatments at any collection. Results from the experiment suggest that increasing roughage late in the finishing period may not negatively impact growth performance or carcass characteristics but does alter feed intake and may alter fermentation and digestion.

KEY WORDS: **concentrate, feedlot, finishing diet, hay, ruminant nutrition**

INTRODUCTION

Within the North American beef production system, feedlot cattle are typically fed high-concentrate, low-roughage diets during the finishing period to improve the economics of production. Feedlots transition cattle from high-roughage diets to high-concentrate diets in order to increase deposition of muscle and adipose tissue as well as to decrease the cost of gain. However, consumption of high-concentrate diets for extended periods of time can have detrimental effects, such as liver abscesses, acidosis, and reduced feed intake (Brown et al., 2006; NASEM, 2016). Although high-concentrate diets generally cost less on an energy basis and are easier to mix and deliver than diets with higher roughage inclusions, there is a greater risk of acidosis and other digestive issues (Faleiro et al., 2010). In feedlot diets, roughage is included to reduce the incidence of digestive disorders and liver abscesses, while stimulating intake and increasing average daily gain (ADG; Reinhardt and Hubbert, 2015). Typical roughage levels in feedlot finishing diets range from 0 to 13% on a dry matter (DM) basis, and average between 8% and 10% of DM in commercial feedlot diets (Brown et al., 2006; Galyean and Hubbert, 2014; Samuelson et al., 2016).

There are reports that increasing the forage level in feedlot diets can improve DM intake (DMI), animal performance, and feeding behaviours (Calderon-Cortes and Zinn, 1996; Fimbres et al., 2002; Gentry et al., 2016). More specifically, diets with increased roughage inclusion during the final days or months in the feedlot may help prevent late term acidosis and also stimulate ADG and DMI. Loerch and Fluharty (1998) reported that increasing forage inclusion during the last 102 d of finishing increased DMI and decreased liver abscesses.

While some effects of increased forage inclusion during the finishing period on performance have been reported, there is little information regarding the effects of increasing forage inclusion during the late finishing period on the rumen environment and blood metabolites. The objective of the current experiment was to evaluate the effects of increased roughage levels late in the finishing period on the performance, carcass characteristics, blood metabolites, inflammation markers, and ruminal and faecal

characteristics of feedlot steers. We hypothesized that increasing roughage inclusion late in the finishing period would result in decreases in performance (i.e. increased feed intake and decreased feed efficiency) but improvements in ruminal and faecal characteristics and decreases in markers of inflammation in feedlot steers.

MATERIALS AND METHODS

All procedures were approved by the Oklahoma State University Institutional Animal Care and Use Committee (ACUP # AG-19-07).

Animal Management

Sixty-two *Bos taurus taurus* crossbred beef steers from a single ranch and of similar genetics (initial body weight; BW = 289 ± 35,6 kg) were transported approximately 589 km from the University of Arkansas Livestock and Forestry Research Station in Batesville, AR, USA to the Willard Sparks Beef Research Center in Stillwater, OK, USA. Upon arrival, steers were held overnight in a dry lot pen with *ad libitum* access to fresh water and prairie hay. The following morning, steers were individually weighed, vaccinated against clostridial and viral pathogens (Covexin; Merck Animal Health, Madison, NJ, and Titanium 5 PHM; Elanco Animal Health, Greenfield, IN), administered a fenbendazole drench (Safeguard; Merck Animal Health), implanted with 80 mg trenbolone acetate, 16 mg estradiol, and 29 mg tylosin tartrate (Component TE-IS with Tylan; Elanco Animal Health), and had their tail switches clipped. Steers were reimplanted 104 d later with 120 mg trenbolone acetate, 24 mg estradiol, and 29 mg tylosin tartrate (Component TE-S with Tylan; Elanco Animal Health).

Steers were maintained at the Willard Sparks Beef Research Center on the same ration for 104 d prior to initiation of experimental treatments, which consisted of a control diet (CON) with 6% roughage, an intermediate-roughage treatment (INT, 12% roughage), and a high-roughage treatment (HGH, 18% roughage). On d 0 of the experiment, steers were blocked by d −6 BW into five weight blocks and allocated randomly to pens within each block (4 steers/pen; 3 pens/block). Pens were then assigned randomly to experimental dietary treatments. In this way five pens were initially allocated to each experimental treatment. Due to an unfortunate error, animals in two pens (one INT pen and one HGH pen) were incorrectly penned after the d 28 weigh day. Therefore the animals in these pens received the wrong experimental treatment diet, and the data from animals in these two pens were excluded from the final (d 58) and carcass analyses. This resulted in 13 total pens (5 pens for CON, 4 pens for INT, and 4 pens for HGH) for the final data collection and all carcass data. Steers were housed in fifteen 4,57 × 13,24 m partially covered soil-surfaced feedlot pens with a shared 76 L concrete water tank between adjacent pens (model J 360-F; Johnson Concrete, Hastings, NE). Based on block, steers were separated into two groups by harvest date, where group 1 contained the three heaviest blocks (9 pens; 183 total days on feed) and group 2 contained the two lightest blocks (6 pens; 218 total days on feed). Thus, in order for the experimental treatments to be applied during the final 58 d of finishing, they were begun on different days on feed for group 1 and group 2.

Diets and Feed Management

All steers were fed a common receiving diet for 7 d before a 21-d transition onto the pre-experiment finishing diet using a two-ration blending system, where the receiving ration was decreased 5% each day and the pre-experiment diet was increased 5% each day until the ration was 100% pre-experiment diet (Table 1). All steers consumed the pre-experiment diet (124 d for group 1 and 159 d for group 2) until the experimental treatments were implemented for the last 58 d prior to shipping. The dietary treatments (Table 2) were balanced to target 13,4% crude protein (CP), based on historical data on all diet ingredients; urea was used to balance for CP and to meet degradable intake protein requirements. All values are presented on a DM basis. All diets were formulated to meet or exceed NASEM (2016) recommendations for the nutrient and energy requirements of growing and finishing cattle. The CON (Table 2) diet consisted of 6,00% prairie hay; 63,84% dry-rolled corn; 20,00% Sweet Bran (Cargill, Dalhart, TX); 5% liquid supplement (Westway Feed Products; Tomball, TX); 5% dry supplement, and 0,16% urea. The INT diet consisted of 12,00% prairie hay; 57,77% dry-rolled corn; 20,00% Sweet Bran (Cargill); 5% dry supplement; 5% liquid supplement (Westway Feed Products); and 0,23% urea. The HGH diet consisted of 18,00% prairie hay; 51,70% dry-rolled corn; 20,00% Sweet Bran (Cargill); 5% liquid supplement (Westway Feed Products); 5% dry supplement; and 0,30% urea. All prairie hay was ground through a commercial hay grinder using a 17,8 cm screen to target a maximum roughage particle length of 17,8 cm. The dry supplement contained monensin sodium (Rumensin 90; Elanco Animal Health, Greenfield, IN) and tylosin (Tylan-40; Elanco Animal Health) and was formulated to provide 30 g of monesin and 9 g of tylosin per 907 kg of feed. Ractopamine hydrochloride (Optaflexx 45; Elanco Animal Health) was included in the supplement for the last 30 d before harvest (actual calculated ractopamine hydrochloride intake was 292 $mg \cdot steer^{-1} \cdot d^{-1}$).

Table 1

Pre-experiment diet composition

Ingredients, % of dry matter (DM)	Diet[1]	
	Receiving	Pre-experiment finishing
Prairie hay	28,44	6,00
Dry-rolled corn	15,00	63,84
Sweet Bran[2]	51,26	20,00
Urea	-	0,16
Dry supplement[3]	5,20	5,00
Liquid supplement[4]	-	5,00
Nutrient composition[5]		
DM, %	68,44	77,15
Crude protein, % DM	13,46	13,29
Neutral detergent fibre, % DM	56,15	22,59
Acid detergent fibre, % DM	26,21	8,07
Acid detergent lignin, % DM	5,44	3,36
Fat, % DM	1,91	3,36
Net energy for maintenance, Mcal/kg DM	1,32	1,72
Net energy for gain, Mcal/kg DM	0,75	1,10
Ca, %	0,64	0,48
P, %	0,75	0,48
K, %	1,19	0,84
Mg, %	0,35	0,23

[1]Receiving diet and pre-experiment finishing diets were fed to all cattle before the treatment period during the last 58-days pre-shipping.
[2]Wet corn gluten feed product (Cargill, Inc., Dalhart, TX)
[3]Dry supplement: (% DM basis) 40,00% ground corn; 29,60% limestone; 20,00% wheat middlings; 7,00% urea; 1,00% salt; 0,53% magnesium oxide; 0,51% zinc sulfate; 0,17% manganese oxide; 0,13% copper sulfate; 0,08% selenium premix (0,6%); 0,0037% cobalt carbonate; 0,32% vitamin A (30,000 IU/g); 0,10% vitamin E (500 IU/g); 0,009% vitamin D (30,000 IU/g); 0,20% tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0,33% monensin (Rumensin 90; Elanco Animal Health)
[4]Liquid supplement (Westway Feed Products, Tomball, TX): (% DM basis) 45,86% corn steep; 36,17% cane molasses; 6% hydrolysed vegetable oil; 5,46% 80VOP/20 oil; 5,2 % water; 1,23% urea (55% solution); and 0,10% xanthan gum
[5]Diet analysed by Servi-Tech Laboratories, Dodge City, KS

Table 2
Composition of experimental diets fed during the 58-day pre-harvest experimental period

Ingredients, % dry matter (DM)	Diet[1]		
	CON	INT	HGH
Prairie hay	6,00	12,00	18,00
Dry-rolled corn	63,84	57,77	51,70
Sweet Bran[2]	20,00	20,00	20,00
Urea	0,16	0,23	0,30
Dry supplement[3]	5,00	5,00	5,00
Liquid supplement[4]	5,00	5,00	5,00
Nutrient composition[5], DM basis			
DM, %	77,79	77,29	77,27
Crude protein, % DM	13,10	14,10	14,20
Acid detergent fibre, % DM	5,66	9,63	13,18
Acid detergent lignin, % DM	0,99	2,64	3,68
Fat, % DM	3,61	4,82	2,36
Net energy for maintenance, Mcal/kg DM	1,81	1,69	1,49
Net energy for gain, Mcal/kg DM	1,18	1,08	0,90
Ca, %	0,59	0,64	0,43
P, %	0,49	0,49	0,49
K, %	0,86	0,93	0,90
Mg, %	0,22	0,24	0,23

[1]Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn
[2]Wet corn gluten feed product (Cargill, Inc., Dalhart, TX)
[3]Dry supplement: (% DM basis) 40,00% ground corn; 29,60% limestone; 20,00% wheat middlings; 7,00% urea, 1,00% salt; 0,53% magnesium oxide; 0,51% zinc sulfate; 0,17% manganese oxide; 0,13% copper sulfate; 0,08% selenium premix (0,6%); 0,0037% cobalt carbonate; 0,32% vitamin A (30,000 IU/g); 0,10% vitamin E (500 IU/g); 0,009% vitamin D (30,000 IU/g); 0,20% tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0,33% monensin (Rumensin 90; Elanco Animal Health)
[4]Liquid supplement (Westway Feed Products, Tomball, TX): (% DM basis) 45,86% corn steep; 36,17% cane molasses; 6% hydrolysed vegetable oil; 5,46% 80VOP/20 oil; 5,2 % water; 1,23% urea (55% solution); and 0,10% xanthan gum
[5] Diet analysed by Servi-Tech Laboratories, Dodge City, KS

At 0500 h each morning, feed bunks were visually appraised to determine the quantity of feed remaining from the previous day. Feed refusals were weighed back prior to feeding on all days cattle

were weighed or if excessive orts remained in the bunk. The feed to be delivered was adjusted daily so that cattle left no more than 0,45 kg of feed in the bunk. Rations were delivered once daily at 0900 h, using a trailer-mounted feed mixer to mix and deliver the experimental rations (274-12B feed mixer; Roto-mix, Dodge City, KS). For all rations, a 400 g sample was collected from the middle of the feed batch in the mixer twice weekly, and diet DM was measured by drying samples for 48 h in a forced air oven (55°C; Model 1327F, VWR Scientific Products, Cornelius, OR). After drying, weekly samples were composited by month, and a monthly composite sample was collected and frozen for future nutrient analysis. Following completion of the experiment, monthly composite samples were composited to generate a composite of the diet over the duration of the experiment. Refusal samples were dried to determine DM content and subtracted from DM delivered to calculate DMI.

Cattle Health

Animals were observed for health status daily as described by Wilson et al. (2015) and treated according to university facility protocols as needed. One steer on the INT diet was injured by another animal in the pen and treated with flunixin meglumine (Prevail; VetOne, Boise, ID) and oxytetracycline (Noromycin 300 LA; Norbrook, Newry, Ireland). One steer on the CON diet died during the experiment 9 d after the initiation of experimental dietary treatments, but the death was determined to be unrelated to the dietary treatments. All data from the dead animal were excluded from the analyses.

Data Collection

As mentioned previously, groups 1 and 2 started their dietary treatments at different times based on shipping dates for harvest. However, within the 58-d feeding period, each group followed the same schedule for data collection. For that reason, the initiation of experimental dietary treatments will be referred to throughout the remainder of the manuscript as d 0.

Body weights were collected on d 0, 14, 28, and 58 for each group. Body weights were collected prior to feeding, and steers were not withheld from feed or water prior to weighing. All BW were adjusted using a calculated 4% pencil shrink (BW × 0,96) to account for fill. Individual ADG was calculated by dividing individual shrunk BW gain by days on feed for each period. Pen ADG was calculated as the average of the individual ADG for each steer in the pen for that period. Dry matter intake was calculated by dividing total DMI for the pen for that period by the days on feed in that period. Gain to feed ratio was calculated by dividing the ADG for the pen by the DMI for the pen for each respective period.

Data from the dead animal were excluded from all statistical analyses. As all animals were individually weighed, this animal's BW was easily excluded from any BW or ADG calculations. As animals were fed together within a pen, pen DMI needed to be adjusted for the DM consumed by this animal prior to death for all DMI and G:F calculations. As this animal was clinically healthy prior to death, the DMI associated with the animal was removed at the average DMI of the pen for those 9 d.

A faecal grab sample was collected via rectal palpation on d 0, 14, 28 and 58. The pH of the faecal sample was recorded using a portable pH meter (pH 6+ Meter; Oakton Instruments, Vernon Hills, IL). Faecal samples were also visually scored for consistency based on the scale used in Woolsoncroft et al. (2018). This system utilizes a 1 to 5 scale: 1 = firm, hard, and dry, 2 = slightly less firm and hard, 3 =

relatively soft and moist, but not runny, 4 = loose, very moist and runny; consistency of pancake batter, 5 = very thin and watery, cannot be caught in hand. Samples were handled and visually appraised by the same evaluator at each collection. The changes in faecal pH were calculated by subtracting the earlier date value from the subsequent date value for each steer, and then the average change for the pen was determined.

On d 0, 14, and 28, ruminal fluid samples were collected using an oral lavage technique similar to processes described by Lodge-Ivey et al. (2009). The same individual conducted the oral lavage sample collection at each collection day. The first 50 mL of rumen fluid collected was discarded to reduce saliva contamination before collecting the sample. In cases where blood appeared in the oral lavage tube, the tubing and collection flask were exchanged for clean samples. If the second attempt produced blood in the oral lavage tube, the tube was immediately removed, and the animal was recorded as a no sample. Immediately following ruminal fluid collection, the fluid was strained through two layers of cheesecloth into a pre-labelled 50 mL container. Rumen fluid pH was recorded immediately following straining, using a benchtop pH meter (Fisherbrand Accumet AE150 Benchtop pH Meter; Fisher Scientific, Pittsburgh, PA), then stored on ice for subsequent preparation of the samples (Wiese et al., 2017). Samples were handled by the same individuals at each collection.

Two microcentrifuge tubes, each containing 1 mL of rumen fluid, were stored for each animal from each collection day. One microcentrifuge tube was prepped for volatile fatty acid (VFA) analysis by adding 100 μL of meta-phosphoric acid (m-Phosphoric acid; Fisher Scientific) and 100 μL of a 2-ethyl butyrate internal standard (2-Ethylbutyric acid; Fisher Sigma-Aldrich, St. Louis, MO). The remaining microcentrifuge tube contained 1 mL of rumen fluid for lactate analysis. Following preparation, samples were stored at −20°C until analysis. The lactate samples were centrifuged at 21,100 × g for 30 min at 8°C (Sorvall Legend Micro 21R Microcentrifuge; Thermo Scientific, Waltham, MA). After centrifuging, 200 μL of rumen fluid was analysed for L-Lactate using an immobilized enzyme system (YSI Model 2950 D; YSI Inc., Yellow Springs, OH). Concentrations of VFA were measured using gas chromatography with a flame ionization detector at the University of Kentucky Ruminant Nutrition Laboratory (Foote et al., 2013).

On d 0, 14, 28, and 58, two 10-mL blood samples were collected via jugular venipuncture into Red Top Vacutainer tubes (Becton Dickinson, Franklin Lakes, NJ). Whole blood was allowed to clot for an average of 1.5 h prior to centrifuging. Blood tubes were centrifuged at 3,000 × g for 20 min at 4°C (Sorvall RC6; Thermo Scientific). Following centrifuging, serum was collected and stored at −20°C until subsequent analysis.

On d 58, the three heaviest blocks (9 pens) were shipped approximately 522 km to Tyson Fresh Meats (Amarillo, TX) for harvest, while the two lightest blocks (6 pens) were shipped approximately 600 km to Caviness Beef Packers (Hereford, TX). Due to complications associated with COVID-19, the two lightest blocks could not be harvested at Tyson Fresh Meats. Carcass data were collected by trained personnel from the West Texas A&M University Beef Carcass Research Center (Canyon, TX) for both groups at harvest.

Laboratory Analysis

The composited diet samples were sent to a commercial laboratory for mineral analysis (Table 1 and 2; Servi-Tech, Dodge City, KS). Composite diet samples were analysed at the OSU Ruminant Nutrition Laboratory for DM, CP, neutral detergent fibre (NDF), acid detergent fibre (ADF), crude fibre (CF), ether extract (EE), and physically effective NDF (peNDF). Samples were dried in a 55°C oven for 48 h and then ground through a 1 mm screen (Pulversiette 19; Fritsch Milling and Sizing, Inc.). Laboratory DM was calculated by weight difference when samples were dried at 105°C for 48 h. Acid detergent fibre and NDF were analysed using an ANKOM 2000 automated fibre analyser (ANKOM Technology, Macedon, NY) according to manufacturer's instructions. Acid detergent lignin (ADL) was conducted using the ANKOM ADL protocol (ANKOM Technology). Petroleum ether was used to analyse the fat content of the diet using an automated ether extractor (XT 15 Extractor; ANKOM Technology) according to manufacturer's instructions. Nitrogen was determined by dry combustion analysis utilizing a Carbon Nitrogen analyser (TruSpec Carbon Nitrogen analyser; LECO, St. Joseph, MI). Crude protein was calculated by multiplying % nitrogen × 6,25.

Physically effective NDF was determined using the Penn State Particle Separator 3 sieve model. The peNDF for whole diets was estimated by calculating the percentage of the sample remaining in the top three sieves (all ≥ 4 mm) and multiplying by the NDF (DM basis) content of the diet (Table 3; NASEM, 2016). Composite grab samples were taken from the top three sieves (all ≥ 4 mm) for each dietary treatment to determine the NDF content of the peNDF portion of the diet.

Table 3

Particle separation and estimated physically effective fibre of diets

Item	Diet[1]		
	CON	INT	HGH
NDF[2], % DM	18,1	20,6	27,3
Sieve screen size, mm	Retained/screen %		
19,0	4,3	13,4	40,7
8,0	13,6	11,6	5,4
4,0	72,2	66,4	46,7
Particles less than 4 mm	9,9	8,6	7,2
Particles greater than 4 mm	90,1	91,4	92,8
Estimated peNDF[3], % DM	16,3	18,8	25,3

[1]Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn

[2] Neutral detergent fibre (NDF) values calculated from analyses in the Oklahoma State University Nutrition Laboratory

[3] Percentage of physically effective NDF (peNDF) was estimated by multiplying the percentage of sample larger than 4 mm in particle size by the percent NDF (as a decimal) of the diet after separation

Serum samples were thawed at room temperature immediately before analysis. Blood urea nitrogen was analysed according to the methods described by Marsh et al. (1965) adapted for a 96-well plate, and absorbance was read at 520 nm (SpectraMax M3; Molecular Devices, San Jose, CA). Blood glucose and lactate concentrations were analysed using an immobilized enzyme system with undiluted serum samples pipetted into a 96-well plate (YSI Model 2950 D; YSI Inc., Yellow Springs, OH).

Statistical Analysis

The experiment was organized as a randomized complete block design. For all data measurements, pen served as the experimental unit (n = 15 total pens). All data were analysed using the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Covariance structures within the model were compared. All performance data, faecal characteristics, and carcass traits were analysed with the fixed effect of treatment and the random effect of block within the model. Linear and quadratic contrasts were used to evaluate the relationships between treatments. The data from two pens were removed from the d 58 and carcass analyses because the animals had been incorrectly penned after the d 28 weigh day, resulting in 13 pens (5 pens for CON, 4 pens for INT, and 4 pens for HGH) for d 58 (final) data collection. Ruminal characteristics, blood metabolites and ruminal fluid were analysed with the fixed effects of treatment, day, and interaction (treatment by day), with block as a random effect. Day was included as a repeated measure using an autoregressive covariance structure with pen as the subject. If

no treatment by day interaction was present, either the linear and quadratic contrasts for the treatments or the main effects of treatment and day were presented. Significance was declared when $P \leq 0.05$, and tendencies when $P > 0,05$ and $P \leq 0,10$.

Table 4

Effect of roughage inclusion late in the finishing period on the growth performance and feed efficiency of crossbred steers

Item	Diet[1]			SEM[2]	Linear *P*-value	Quadratic *P*-value
	CON	INT	HGH			
Bodyweight, kg						
d -27	374	374	374	4,2	0,99	0,98
d 0	497	504	500	14,6	0,82	0,63
d 14	512	516	511	14,4	0,94	0,66
d 28	521	522	520	14,3	0,95	0,91
d 58	551	551	548	8,9	0,66	0,86
Average daily gain, kg/d						
d -27 to 0	1,75	1,90	1,81	0,091	0,66	0,30
d 0 to 14	1,15	0,99	0,89	0,290	0,49	0,87
d 15 to 28	0,74	0,51	0,76	0,229	0,95	0,19
d 29 to 58	1,36	1,57	1,44	0,324	0,68	0,37
d 0 to 58	1,10	1,09	1,11	0,129	0,88	0,86
Dry matter intake, kg/d						
d -27 to 0	10,02	10,26	10,13	0,302	0,68	0,45
d 0 to 14	9,88	9,87	9,83	0,393	0,89	0,96
d 15 to 28	9,23	9,31	9,60	0,261	0,13	0,62
d 29 to 58	9,67	10,31	11,20	0,320	< 0,01	0,62
d 0 to 58	9,58	10,00	10,34	0,315	0,02	0,87
Gain:Feed						
d -27 to 0	0,183	0,195	0,188	0,0126	0,77	0,53
d 0 to 14	0,114	0,101	0,092	0,0107	0,16	0,85
d 15 to 28	0,097	0,075	0,092	0,0189	0,74	0,18
d 29 to 58	0,131	0,140	0,121	0,0126	0,58	0,38
d 0 to 58	0,117	0,113	0,108	0,0147	0,42	0,96

[1]Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn.

[2]Standard error of the mean ($n = 5$ for all days except d 58; on d 58, CON $n = 5$, INT and HGH $n = 4$).

RESULTS AND DISCUSSION

Experimental Diets and Steer Performance

Diet nutrient information and particle size separation data are presented in Tables 2 and 3, respectively. Experimental diets were formulated for similar CP levels utilizing historical ingredient analysis records, with the only adjustments between experimental diets being corn, hay, and urea percentages. While nearly all ingredient analyses conducted following the completion of the experiment were similar to historical values, there were some differences in analysed versus expected CP content. The protein content of the prairie hay was almost 2 times historical values and resulted in the differences in CP of the experimental diets, with the HGH diet having 14,20% CP; the INT diet 14,10% CP; and the CON diet 13,10% CP. All diets met NASEM (2016) requirements for CP, so these differences may be negligible in impact.

The results of the particle separation (Table 3) were not surprising, as the CON diet contained a larger proportion of smaller particles, and adding forage increased the number of larger particles in the diet. Literature has reported that peNDF is an important factor in maintaining a healthy ruminal environment, because it is related to the ability of the roughage to stimulate rumination activity (Gentry et al., 2016). Previous reports recommend that peNDF inclusion for feedlot cattle diets should range from 7% to 15% DM (Fox and Tedeschi, 2002; Mertens, 2002). Inclusion rates of peNDF in the current experiment were higher than the most liberal recommendations, but this was expected, as the goal of the experiment was to evaluate increased inclusion rates to reduce any incidence of ruminal dysfunction while maintaining performance. Differences in peNDF suggest that the HGH steers should have increased rumination stimulation, which could improve the rumen environment.

Body weight, ADG, and G:F were not affected by the roughage inclusion level (Table 4; $P \geq 0,16$). Swanson et al. (2017) evaluated 5%, 10%, 15%, and 20% forage inclusion in feedlot finishing diets and observed a negative linear relationship with ADG and G:F. Final BW and ADG results reported by Farran et al. (2006) were similar to those of the current experiment, in which finishing steers were fed diets containing 3,75% or 7,5% alfalfa hay. Similarly, Benton et al. (2015) reported no difference in final BW or G:F when including 3% or 6% corn stalks in a dry-rolled corn-based diet, and Gentry et al. (2016) reported no difference in final BW or ADG with 5% or 10% corn stalk inclusion when feeding a steam-flaked corn-based diet with wet corn gluten feed. May et al. (2011) also reported no difference in BW or ADG between steers consuming 7,5%; 10%; or 12,5% alfalfa hay in a steam-flaked corn-based diet, but did report a tendency for a linear increase in DMI and a linear decrease in G:F as alfalfa hay in the diet increased.

No differences were detected for animal performance (BW, ADG, or G:F) in the current experiment, but the experiment was not designed with enough statistical power to detect small differences in animal performance. In addition, the experimental power was unfortunately further reduced by the loss of two pens part-way through the experiment. Additional research with more replications should be conducted to verify the animal performance results reported here.

In the current experiment, DMI increased linearly with forage inclusion rate during the last 30 d of finishing ($P \leq 0,01$) and the last 58 d of finishing ($P \leq 0,05$). These results are in agreement with

previous reports of linearly increasing DMI with increasing roughage inclusion (Farran et al., 2006; Parsons et al., 2007; Hales et al., 2013; Galyean and Hubbert, 2014). Gentry et al. (2016) reported increased DMI with diets containing longer-stemmed forage, even compared to diets with a greater inclusion rate of shorter, ground forage. The impact of forage inclusion on DMI may depend both on the inclusion rate of the forage and its type or quality. While increased DMI typically drives increases in ADG, the diets in the current experiment were not equivalent in NE_g and therefore were potentially less likely to alter ADG strictly based on intake. Thus, as the roughage inclusion rate increased, it is possible that cattle had to consume more feed to obtain the same energy provided by the CON diet.

In an analysis of 48 experiment means from 11 experiments, Arelovich et al. (2008) reported that DMI and NE_g intake (kcal/kg metabolic BW) increased linearly as NDF increased from 7,5% to 35,3% but did not affect NE_g intake per unit of DMI. The analysis by Arelovich et al. (2008) indicates that at very low dietary NDF concentrations, physiological mechanisms appear to be preventing cattle from maximizing energy intake. In the current experiment, based on diet energy content (Table 2) and average DMI for each treatment (Table 4), NE_g intake was calculated to be 11,3 mcal/day for CON; 10,8 mcal/day for INT; and 9,3 mcal/day for HGH. Based on NASEM (2016) equations, the calculated NE_g content of the experimental diets was 1,21; 1,15; and 1,12 Mcal/kg for CON, INT, and HGH, respectively.

There was no effect of roughage inclusion concentration on HCW, fat thickness, KPH, marbling score, or liver scores (Table 5; $P \geq 0,12$), similar to results reported by Swanson et al. (2017). Previous studies have described an increase in HCW with increasing forage in the diet (Farran et al., 2006; Parsons et al., 2007; Swanson et al., 2017). In contrast, Gentry et al. (2016) reported increased HCW for lower inclusion of longer roughage compared to greater inclusion of shorter roughage, which again indicates a difference in response to increased forage based on forage type or quality. Rib eye area increased linearly with increasing roughage inclusion rate (P = 0,02), and calculated yield grade decreased linearly with increasing roughage inclusion (P = 0,04). Dressing percentage tended to decrease linearly with increasing roughage inclusion (P = 0,10). This trend is in agreement with Gentry et al. (2016), who reported that steers consuming a diet with less forage have a higher dressing percentage than those consuming high forage diets, which is likely the result of increased gut fill. Other studies have reported no differences in dressing percentage between cattle consuming varying amounts of forage (May et al., 2011; Quinn et al., 2011; Benton et al., 2015).

Table 5

Effect of roughage inclusion in the late finishing period on carcass characteristics of crossbred feedlot steers

Item	Diet[1]			SEM[2]	Linear *P*-value	Quadratic *P*-value
	CON	INT	HGH			
Hot carcass weight, kg	389,00	389,00	384,00	7,30	0,16	0,92
Rib eye area, cm^2	82,60	85,50	88,20	2,45	0,02	0,97
Fat thickness, cm	1,30	1,17	1,03	0,161	0,23	0,98
Kidney, pelvic, heart fat, %	2,56	2,57	2,51	0,174	0,72	0,77
Dressing percentage	63,20	62,60	62,10	1,09	0,10	0,95
Calculated USDA Yield Grade	2,70	2,36	1,99	0,586	0,04	0,95
Marbling score[3]	506,00	479,00	500,00	18,00	0,81	0,29
Liver score[4], % of pen						
O	100,00	93,80	100,00	7,03	0,94	0,12
Contaminated	-	6,20	-	-	-	-

[1]Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn

[2]Standard error of the mean (CON $n = 5$, INT and HGH $n = 4$)

[3]$Small^{00} = 400$; $Modest^{00} = 500$; $Moderate^{00} = 600$

[4]Liver scores at harvest: O = normal, healthy liver, free of abscesses. A− = livers that displayed less than 2 abscesses which are generally less than 2,54 cm in diameter. Contaminated = contaminated with faecal material during harvest

Differences in liver abscesses were expected, as increased forage inclusion should result in less liver disease. However, the inability to detect differences may be due to the small sample size. Weise et al. (2017) reported an increased rate of liver pathology when steer rumen pH was below 5,8 for a considerable length of time. While in the current experiment rumen pH was only measured at set time points, values were never lower than 5,8; which would indicate that these animals were at very low risk of subacute ruminal acidosis. The diets used in the experiment were primarily composed of dry-rolled corn and Sweet Bran, which reduces the ruminally available starch load compared with diets primarily composed of steam-flaked corn, commonly fed in commercial feedlots in the High Plains. The risk for acidosis is lower late in the finishing period compared to the beginning of the feeding period (Leedle et al., 1995; Nagaraja and Titgemeyer, 2007); thus, because measures were collected at the end of the finishing period, the risk of true acidosis may have been lower.

Faecal Characteristics

No differences were observed in faecal score between roughage inclusion groups (Table 6; $P \geq 0,12$). Woolsoncroft et al. (2018) reported the optimal faecal score to be 3 on the 5-point scale that was used in the current experiment. Faecal scores can directly relate to passage rate and degree of digestibility, especially within the hindgut. Since there were no differences in faecal score in the current experiment and all scores were considered biologically normal, it does not appear that forage inclusion within the last 58 d of finishing affected faecal quality.

Table 6

Effect of roughage inclusion in the late finishing period on faecal score and faecal pH of crossbred feedlot steers

Item	Diet[1]			SEM[2]	Linear *P*-value	Quadratic *P*-value
	CON	INT	HGH			
Faecal score[3]						
d 0[4]	3,54	3,67	3,39	0,204	0,36	0,14
d 14	3,19	3,32	3,30	0,181	0,67	0,75
d 28	3,03	3,13	2,80	0,193	0,17	0,13
d 58	2,97	2,78	2,96	0,299	0,96	0,32
Faecal pH						
d 0	6,43	6,16	5,97	0,277	0,06	0,85
d 14	7,04	6,60	6,67	0,128	0,07	0,13
d 28	6,68	6,64	6,80	0,056	0,15	0,16
d 58	6,88	6,77	6,54	0,088	0,02	0,54
Faecal pH change[4]						
d 0 to 14	0,708	0,566	0,804	0,2977	0,70	0,38
d 15 to 28	-0,360	0,138	0,094	0,1286	0,03	0,11
d 29 to 58	0,224	0,253	-0,228	0,0826	0,002	0,03
d 0 to 58	0,426	0,668	0,415	0,2934	0,96	0,24

[1]Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn

[2]Standard error of the mean ($n = 5$ for all days except d 58; on d 58, CON $n = 5$, INT and HGH $n = 4$)

[3]Faecal score adapted from Woolsoncroft et al. (2018), with a 1-5 scale, where a low score represents a solid stool and a higher score represents a loose stool

[4]Difference between collection periods; the later date was subtracted from the earlier date

While faecal pH (Table 6) tended to be greater in the CON steers on d 0 and 14 ($P < 0,10$), a negative linear relationship was observed on d 58 ($P \leq 0,05$), when faecal pH decreased with increasing forage inclusion. The reason for the increased faecal pH in the CON steers on d 0 is unknown. The change in faecal pH from d 0 to 14 or d 0 to 58 ($P \geq 0,24$) did not differ among treatments, but it increased linearly with increasing roughage inclusion from d 15 to 28 ($P = 0,03$). Conversely, from d 29 to 58 there was a quadratic ($P = 0,03$) effect of roughage inclusion on faecal pH change, with faecal pH reduced by HGH and increased by CON and INT.

Faecal pH can serve as an indicator of digestion and fermentation in the large intestine. Previous literature suggests that increased starch digestion in the rumen may be correlated with a higher faecal pH, whereas a decrease in faecal pH may be attributed to increased hindgut fermentation (Wheeler and Noller, 1977; Yang and Beauchemin, 2006). The increased roughage in the INT and HGH diets may have contributed to the reduced faecal pH observed, which could indicate decreased ruminal starch fermentation compared to the CON diet. However, the faecal pH observed in the experiment was within normal limits for finishing beef steers. The faecal pH data combined with the faecal scores indicate that there was likely no major disruption at the site of digestion that could have negatively affected animal health and performance.

Table 7
Effect of roughage inclusion in the late finishing period on ruminal characteristics of crossbred feedlot steers

Item	Diet[1]			SEM[2]	Linear[3] *P*-value	Quadratic *P*-value
	CON	INT	HGH			
Rumen lactate, mg/dL						
d 0[3]	1,61	2,02	2,02	0,894	0,75	0,85
d 14	2,55	0,945	0,865	0,2377	< 0,01	0,02
d 28	1,78	0,307	0,357	1,107	0,06	0,23
Rumen pH						
d 0	6,98	6,97	6,92	0,175	0,58	0,85
d 14	7,17	7,17	7,33	0,104	0,07	0,26
d 28	6,81	6,88	6,90	0,133	0,39	0,79
Rumen pH change[3]						
d 0 to 14	0,125	0,123	0,341	0,1428	0,09	0,29
d 15 to 28	-0,316	-0,240	-0,378	0,1454	0,55	0,24
d 0 to 28	-0,227	-0,161	-0,069	0,1854	0,32	0,92

[1]Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay, 51,70% dry-rolled corn
[2]Standard error of the mean (n = 5)
[3]There were no treatment × time interactions ($P \geq 0,30$), so only linear and quadratic contrasts for the experimental treatments are presented
[4]Difference between collection periods; the later date was subtracted from the earlier date

Rumen Fluid Characteristics

Ruminal L-lactate concentrations decreased quadratically (P = 0,02) on d 14, when CON steers had concentrations more than 2,5 times greater than in the other treatments. Ruminal L-lactate concentrations tended (P = 0,06) to decrease linearly with increasing roughage inclusion, with much higher lactate levels again in the CON steers compared with INT and HGH. The decrease in ruminal lactate on d 14 and 28 with increasing dietary roughage inclusion is an indicator of the reduction in readily digestible carbohydrates as the roughage replaced corn in the diets. The rate of lactate production in the rumen increases with increasing levels of concentrate in the diet (Nagaraja and Titgemeyer, 2007). Additionally, Dunlop and Hammond (1965) reported that lactate-utilizing microbial species are unable to maintain their rumen population when the concentrate content of the diet increases, leading to depressed rumen pH. Hence, the results of the current experiment were expected because of the greater concentrate inclusion in the CON diet.

Ruminal pH (Table 7) was not affected by the roughage inclusion rate ($P \geq 0,26$), except for a tendency observed on d 14 for increased pH in HGH steers ($P = 0,07$). Similarly, rumen pH change was not affected by the roughage inclusion rate ($P \geq 0,24$), except for a tendency ($P = 0,09$) for a linear increase in pH change from d 0 to 14 with increasing dietary roughage. Rumen pH values ranged from 6,55 to 7,94, which is above the normal range reported for feedlot cattle by Schwartzkopf-Genswein (2003; 5,6 to 6,2). Other authors have reported that the oral–stomach tube technique utilized in the current experiment for rumen fluid collection can cause variations in pH range due to intra-ruminal localization and potential for saliva contamination (Enemark et al., 2002). To account for saliva contamination, which can raise rumen pH, the first 50 mL of rumen fluid collected was discarded prior to collecting the sample for analysis. All animals were also sampled prior to feeding in order to limit the effect of time and recent intake on ruminal pH, as feeding greatly affects rumen pH (Goulart et al., 2020). Previous experiments have reported decreased rumen pH in cattle consuming low-forage diets (5-8%) compared to high forage diets (10-16%; Calderon-Cortes and Zinn, 1996; Salinas-Chavira et al., 2013; Goulart et al., 2020). The same results were reported for concentrate-fed sheep, with rumen pH increasing linearly with increasing forage inclusion rate, up to 30% inclusion (Fimbres et al., 2002).

There was a treatment by time interaction ($P = 0,04$; Fig. 1A and Table 8) on total VFA concentration. While there were no major changes in total VFA concentrations between the treatments on the days tested, the HGH steers displayed a decrease in VFA concentration from d 0 to d 14. There was a shift in acetate and propionate proportions and the acetate:propionate ratio between the diets in the experiment. For the HGH diet, the acetate proportion increased ($P < 0,01$) from d 0 to d 14 while propionate decreased ($P < 0,01$), which resulted in an increase in the acetate:propionate ratio in the HGH-fed steers ($P = 0,03$). The proportions of acetate and propionate did not change over time in the CON steers, and the INT-fed steers displayed intermediate proportions compared to CON and HGH. Additionally, there was a treatment by time interaction for butyrate ($P = 0,04$), isovalerate ($P < 0,01$), and valerate ($P = 0,02$) proportions (Fig. 2). Butyrate proportions increased in the HGH treatment on d 14 compared to CON, with INT not differing from either treatment. There was no difference on d 0 or 28. A similar trend was observed for isovalerate proportions, where CON was lower than the other treatments on d 14 but did not differ on d 0 or 28. Valerate proportions decreased in INT and HGH compared to CON on d 14 and remained lower on d 28.

Table 8
Effect of roughage inclusion in the late finishing period on ruminal characteristics of crossbred feedlot steers

Item	Diet[1]			SEM[2]	*P*-value		
	CON	INT	HGH		Treatment	Time	Treatment × Time
Volatile fatty acid							
Total, mM	71,5	68,4	68,8	4,99	0,57	< 0,01	0,04
Proportion, mol/100 mol							
Acetate	49,2	52,2	54,8	0,54	< 0,01	< 0,01	< 0,01
Propionate	37,5[a]	33,8[b]	30,9[c]	0,63	< 0,01	< 0,01	< 0,01
Isobutyrate	0,83	0,91	0,98	0,037	0,02	< 0,01	0,13
Butyrate	7,72	8,69	9,22	0,387	0,05	0,02	0,04
Isovalerate	1,81	2,44	2,50	0,090	< 0,01	< 0,01	< 0,01
Valerate	2,92	1,98	1,54	0,021	< 0,01	< 0,01	0,02
Acetate:Propionate	1,33	1,56	1,88	0,078	< 0,01	< 0,01	0,03

[1]Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn
[2]Standard error of the mean (n = 5 for all days except d 58; on d 58, CON n = 5, INT and HGH n = 4)
[abc]Within a row, least squares means lacking a common superscript differ (P < 0,05)

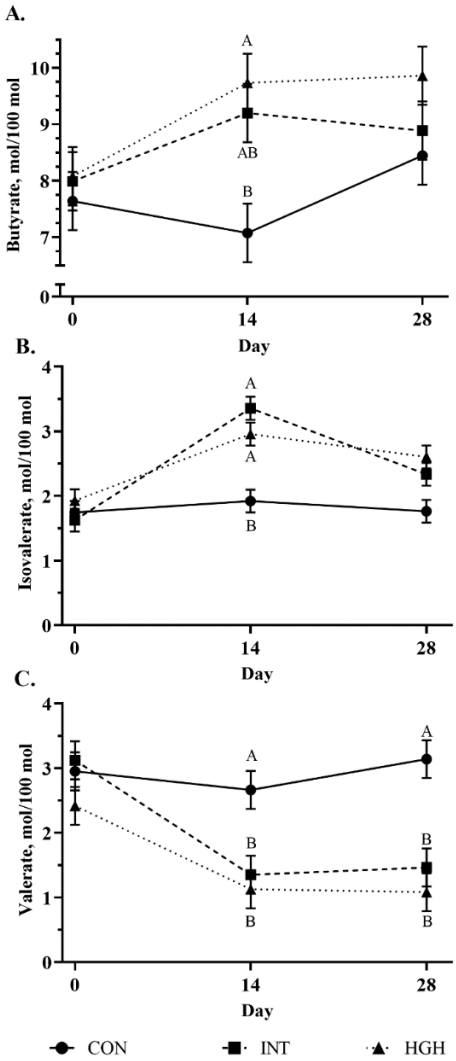

Fig. 1. Interaction of time and dietary treatments on the final 58 d on feed on (A) total VFA concentrations, (B) acetate:propionate ratio, (C) acetate proportion, and (D) propionate proportion. Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn. [abc]Within a day, least squares means lacking a common superscript differ ($P \leq 0{,}05$).

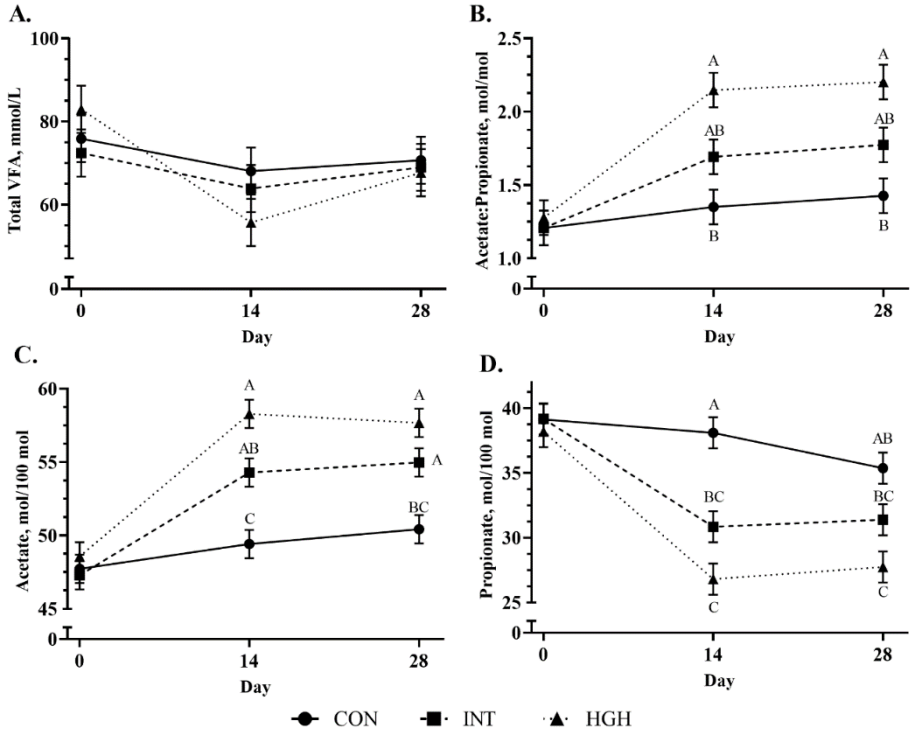

Fig. 2. Interaction of time and dietary treatments the final 58 d on feed on (A) butyrate proportions, (B) isovalerate proportion, and (C) valerate proportions. Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn. [abc]Within a day, least squares means lacking a common superscript differ ($P \leq 0,05$).

Rumen VFA concentration typically varies depending on the proportion of roughage and grain in the diet, and the results of the current experiment reflect alterations that would be expected with changes in the roughage content of the diet. Approximately 75,85% of energy from feed is converted to VFA during rumen fermentation (Sutton, 1979). Zinn et al. (1994) and Wang et al. (2020) both reported that the amount of carbohydrates and roughage fed can determine the ratios of VFA within the rumen. Specifically for beef cattle, normal VFA concentrations can fluctuate between 30 to 200 mM, depending on rumen environment and diet composition (Sutton, 1979; France and Siddons, 1993). Goulart et al. (2020) reported similar results for total VFA concentration and acetate:propionate ratio, stating that diets that promote chewing time and saliva production typically result in decreased VFA concentration

and increased A:P due to dilution by increased salivary production. While chewing behaviour and saliva production were not directly measured in the current experiment, increasing particle size of the diet typically increases chewing behaviour (Goulart et al., 2020; Fimbres et al., 2002).

The shift in acetate, propionate, and acetate:propionate ratio in the current experiment were expected based on the roughage inclusion in the diets. Previous reports have documented that increasing roughage inclusion resulted in increased molar proportions of acetate while decreasing the proportions of propionate (Zinn et al., 1994; Penner et al., 2009; Salinas-Chavira et al., 2013), matching the results reported in the current experiment. Similar experiments conducted with sheep have reported increased propionate and decreased acetate concentrations in sheep consuming a low-roughage diet compared to a high-roughage diet, with levels ranging from 0–30% forage inclusion (Evans et al., 1975; Fimbres et al., 2002). In contrast, Calderon-Cortes and Zinn (1996) and Alvarez et al., (2004) observed no difference in acetate or propionate concentrations after increasing forage inclusion. Calderon-Cortes and Zinn (1996) did report a decrease in butyrate when increasing forage inclusion, which is opposite to the results of the current experiment. This could be linked to differences in the type of forage utilized in the experiments, as both aforementioned experiments used sudangrass hay.

Blood Metabolites

No treatment by day interactions were observed for blood metabolites ($P \geq 0{,}29$; data not shown). Serum glucose was affected by both treatment (Table 9; $P \leq 0{,}01$) and day ($P \leq 0{,}01$). Serum glucose was slightly lower in the INT steers compared to CON and HGH. Glucose concentrations were consistent throughout the study, but decreased from d 28 to d 58. It is worth noting that all glucose values presented are within normal ranges for beef cattle (Evans et al., 1975; Hancock et al., 1988). Cattle consuming high-roughage diets typically have reduced quantities of alpha-linked glucose polysaccharides that would pass from the rumen into the small intestine (Bird et al., 1996). The starch that escapes ruminal digestion is mostly digested in the small intestine and absorbed into the bloodstream, potentially leading to increased blood glucose concentrations (Huntington et al., 1980; Church, 1988). Calderon-Cortes and Zinn (1996) did not observe differences in ruminal digestion or total tract digestibility of starch when increasing dietary forage from 8% to 16%. Additionally, because all measures are within normal limits, the decrease in INT steers may not be biologically important.

Table 9
Effect of roughage inclusion in the late finishing period on serum metabolite concentrations of crossbred feedlot steers

Variable[3]	Diet[1]			SEM[2]	*P*-value	Day				SEM[2]	*P*-value
	CON	INT	HGH			0	14	28	58		
Glucose, mg/dL	93,3[a]	82,2[b]	90,1[a]	3,92	< 0,01	9,5[a]	94,4[a]	91,4[a]	76,8[b]	4,107	<0,01
Lactate, g/L	0,486	0,454	0,450	0,047	0,55	0,540[a]	0,507[a]	0,521[a]	0,287[b]	0,050	<0,01
BUN, mg/dL	2,49	2,41	2,48	0,084	0,72	2,30[b]	2,40[b]	2,66[a]	2,47[ab]	0,093	0,04
SAA, µg/mL	97,1	101,6	69,1	15,13	0,29	80,9[ab]	68,6[b]	104,1[a]	103,4[a]	14,70	0,02

[1]Treatments: The control (CON) diet consisted of 6% prairie hay; 63,84% dry-rolled corn; the intermediate (INT) diet consisted of 12% prairie hay; 57,77% dry-rolled corn; the high (HGH) diet consisted of 18% prairie hay; 51,70% dry-rolled corn
[2]Standard error of the mean (n = 5 for all days except d 58; on d 58, CON n = 5, INT and HGH n = 4)
[3]There were no treatment × time interactions ($P \geq 0,49$), so only the main effects for treatment and time are presented
[4]BUN, blood urea nitrogen; SAA, serum amyloid A
[abc]Within a row, least squares means lacking a common superscript differ ($P < 0,05$)

While serum lactate was not affected by treatment (P = 0,55), there was an effect of day ($P \leq$ 0,001), with concentrations decreasing on d 58. Lactate is primarily derived from anaerobic metabolism of glucose within the body and could indicate rumen lactate production or muscle breakdown for glucose. Because the differences in lactate and glucose were observed on d 58, it is possible that the differences were driven by beta-agonist inclusion during the final 28 d at the facility. Previous reports have identified differences in glucose and creatine kinase when a beta-agonist was included in the diet (Antonelo et al., 2017), while other studies did not report differences (Van Bibber-Krueger et al., 2015). Differences in these results may be due to differences in the products, as Antonelo et al. (2017) explained that different beta-agonist products will cause different results in blood metabolites.

Blood urea nitrogen (BUN) was not affected by treatment (P = 0,72) but was affected by day (P = 0,04), with concentrations of BUN increasing from d 14 to d 28. Blood urea nitrogen is used in ruminants and other production species as a marker of nitrogen intake and utilization (Kohn et al., 2005). Additionally, like the lactate measures, the inclusion of a beta-agonist during the last 30 days may have contributed to decreased BUN measures, as previous experiments have also reported decreased BUN with beta-agonist inclusion (Van Bibber-Krueger et al., 2015; Hales et al., 2017). Hales et al. (2016) stated that differences in plasma urea nitrogen during this time are likely driven by decreased catabolism of amino acids and increased nitrogen retention.

There were no differences in serum amyloid A (SAA) between cattle fed the different experimental diets (P = 0,29). Serum amyloid A is an acute phase protein which can indicate the innate immune response and is considered the most diagnostically important indicator of inflammation (Gruys et al., 1993; Alsemgeest et al., 1994; Eckersall, 2000). Levels of SAA in the current experiment were above the reported normal ranges. Cows with chronic inflammatory diseases have had reported SAA levels between 17.1 and 298.2 $\mu g \cdot ml^{-1}$ (Tourlomoussis et al., 2004; Takahashi et al., 2007). Wiese et al. (2017) reported SAA values up to 80 $\mu g \cdot ml^{-1}$ in cattle with rumen or liver pathology. Serum amyloid A can also be elevated due to increased stress (Alsemgeest et al., 1995). The reason for the elevated SAA results reported in the current experiment is unknown but may have been due to increased inflammation or stress associated with handling or general discomfort at the end of the finishing phase.

APPLICATIONS

Results from the current experiment indicate that increasing dietary forage inclusion late in the finishing period did not impact final BW, overall animal performance, most carcass traits, or ruminal pH between dietary treatments. While there was a shift in VFA profile, the shift did not impact the animals' overall performance during finishing or at harvest. There were also no effects on metabolic parameters or liver condemnation scores, indicating that while cattle may still be able to be effectively finished when fed a higher forage diet, it may be too late in the finishing period to decrease the incidence of liver abscesses. Further evaluation of increased dietary roughage during the late finishing period may be warranted to validate the animal performance and carcass results observed in the current experiment.

DISCLOSURES

The authors declare no conflicts of interest.

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