

Effects of varying bulk densities of steam-flaked corn and dietary roughage concentration on in vitro fermentation, performance, carcass quality, and acid-base balance measurements in finishing steers¹

K. E. Hales,² J. P. McMeniman, J. Leibovich, J. T. Vasconcelos,³ M. J. Quinn, M. L. May, N. DiLorenzo, D. R. Smith, and M. L. Galyean⁴

Department of Animal and Food Sciences, Texas Tech University, Lubbock 79409

ABSTRACT: Effects of varying bulk densities of steam-flaked corn (SFC) and level of inclusion of roughage in feedlot diets were evaluated in 3 experiments. In Exp. 1, a total of 128 beef steers were used in a 2 × 2 factorial arrangement to evaluate the effects of bulk density of SFC (335 or 386 g/L) and roughage concentration (6 or 10% ground alfalfa hay, DM basis) on performance and carcass characteristics. No interactions were observed between bulk density and roughage concentration for performance data. From d 0 to the end, cattle fed the 335 g/L SFC had greater overall G:F ($P = 0.04$) than those fed the 386 g/L SFC, with tendencies ($P < 0.10$) for improved G:F with the lighter flake weight evident at all 35-d intervals throughout the feeding period. Dry matter intake was less for cattle fed 6 vs. 10% roughage from d 0 to 35 ($P = 0.03$) and d 0 to 70 ($P = 0.05$), but not for the overall feeding period. Feeding 6 vs. 10% ground alfalfa as the roughage source tended ($P = 0.09$) to improve overall G:F. Treatment effects on carcass measurements were generally not significant ($P > 0.20$). In Exp. 2, the effects of bulk density of SFC (283, 335, or 386 g/L) and 6 or 10% ground alfalfa hay on IVDMD and in vitro pH were evaluated at 6, 12, 18, and 24 h of incubation. With a

reduced-strength buffer in vitro fermentation system, pH increased ($P < 0.01$) with increasing bulk density at 6 and 12 h, and IVDMD decreased ($P < 0.03$) as bulk density increased. In contrast, in a normal-strength buffer system, there were no treatment differences ($P > 0.23$) for IVDMD. In Exp. 3, two diets that varied in bulk density of SFC and roughage concentration (335 g/L SFC with 6% alfalfa hay vs. 386 g/L SFC with 10% alfalfa hay) were compared for their effects on the pattern of feed intake and the acid-base balance in Holstein steers (12/treatment). No differences ($P > 0.10$) between treatments were noted for blood gases or urine pH; however, day effects ($P < 0.02$) were detected for blood pH, partial pressure of CO₂, and urine pH, which generally decreased ($P < 0.05$) with an increasing time on feed. The 2 treatments had little effect on the pattern of feed intake within the sampling days, with the exception that the 386 g/L SFC with 10% alfalfa hay diet increased ($P < 0.05$) the percentage of total DMI consumed at 1 and 6 h after feeding on d 14. Within the ranges of bulk density and roughage level studied, 335 g/L SFC with 6% alfalfa hay yielded the optimal animal performance, with limited effects on in vitro fermentation and the acid-base balance.

Key words: acid-base balance, bulk density, feedlot cattle, in vitro dry matter disappearance, roughage, steam-flaked corn

©2010 American Society of Animal Science. All rights reserved.

J. Anim. Sci. 2010. 88:1135–1147
doi:10.2527/jas.2009-2400

¹Supported in part by funding from the Texas Cattle Feeders Association (Amarillo, TX). The Jessie W. Thornton Chair in Animal Science Endowment at Texas Tech University also provided funding to support this research. We thank Cactus Feeders (Amarillo, TX) for supplying the cattle used in Exp. 1, and DSM Nutritional Products (Belvidere, NJ), Elanco Animal Health (Greenfield, IN), Fort Dodge Animal Health (Overland Park, KS), Intervet/Schering-Plough (Millsboro, DE), and Kemin Industries (Des Moines, IA) for supplying products used in this research. The efforts of K. Robinson

and R. Rocha in assisting with the conduct of this research are greatly appreciated.

²Present address: USDA-ARS Conservation and Production Research Laboratory, Bushland, TX 79012.

³Present address: Panhandle Research and Extension Center, Department of Animal Science, University of Nebraska, Scottsbluff 69361.

⁴Corresponding author: michael.galyean@ttu.edu

Received August 18, 2009.

Accepted November 7, 2009.

INTRODUCTION

Grain-processing methods have been studied extensively, and the use of processed grains is standard in the cattle-feeding industry. Grain processing increases starch availability (Owens et al., 1998), thereby improving cattle performance (Owens et al., 1997; Bengochea et al., 2005; Reed et al., 2005) and BW gain efficiency (Xiong et al., 1991). Including relatively small concentrations of roughage in processed grain diets can prevent digestive upsets such as acidosis and bloat (Owens et al., 1998) and maximize energy intake by feedlot cattle (Galylean and Defoor, 2003).

Dry matter intake can be markedly affected by roughage source and concentration (Galylean and Defoor, 2003), but the biological mechanisms for such changes in DMI are not fully understood. Furthermore, diet composition affects the acid-base balance of domestic animals (Patience, 1990; Riond et al., 2001), and feeding processed-grain, low-roughage diets to feedlot cattle increases the concentration of total acids in the rumen (Owens et al., 1998), affecting the ability of the animal to maintain the acid-base balance (Odongo et al., 2006). When acidosis occurs, DMI is typically decreased and often becomes more variable, thereby decreasing performance (Owens et al., 1998).

Thus, grain processing and dietary roughage concentration are major factors affecting the performance and acid-base balance of feedlot cattle, but little is known about how these 2 factors interact in practical feedlot diets. Our objective was to evaluate the interaction of bulk density of steam-flaked corn (SFC) and dietary roughage concentration on performance and carcass measurements in feedlot cattle, *in vitro* fermentation of the diet, and acid-base balance measurements in finishing steers.

MATERIALS AND METHODS

All procedures involving live animals were approved by the Texas Tech University Animal Care and Use Committee.

Exp. 1

Cattle Processing. On May 24, 2007, a total of 348 beef steers [British and British \times Continental breeding; BW 1 wk after arrival (mean \pm SD) of 377 ± 40.9 kg] were delivered to the Texas Tech University Burnett Center near New Deal, TX. After arrival, steers were weighed individually [squeeze chute (C & S, Garden City, KS) set on 4 electronic load cells (Rice Lake Weighing Systems, Rice Lake, WI; readability of ± 0.45 kg); scale calibrated with 454 kg of certified weights before use], tagged in the ear with an individual identification tag, vaccinated (Vision 7 with SPUR and Vista 5 SQ, Intervet/Schering-Plough Animal Health, Millsboro, DE), and treated for internal and external parasites using moxidectin (Cydectin, Fort Dodge Animal Health,

Overland Park, KS). After processing, steers were fed a 65% concentrate starter diet, which was changed to a 75% concentrate diet in approximately 7 to 10 d. All cattle were weighed on June 1, and 128 steers were selected for use in the experiment. Selected steers were blocked by BW and sorted into 32 concrete, partially slotted floor pens (4 steers/pen; 2.9 m wide \times 5.5 m deep with 2.4 m of bunk space), and adapted over the next 2 wk to ad libitum intake of an 88% concentrate diet with alfalfa hay as the roughage source. Treatments were assigned randomly to pens within blocks (1 pen/treatment within 8 weight blocks), resulting in a total of 8 pens (32 steers) per treatment. The cattle were weighed individually on June 20, 2007, implanted with Revalor-S (120 mg of trenbolone acetate and 24 mg of estradiol, Intervet/Schering-Plough Animal Health), and pens were fed the assigned treatment diets to begin the experiment.

Treatment and Experimental Design. A 2×2 factorial arrangement of treatments was used in a randomized complete block design. Factors consisted of bulk density of SFC [335 or 386 g/L (26 or 30 pounds/bushel)] and roughage concentration [6 or 10% coarsely ground alfalfa hay (approximately 2.54-cm chop length) on a DM basis]. Thus, the resulting 4 treatment combinations consisted of 1) 335 g/L bulk density with 6% roughage (**335-6**); 2) 335 g/L bulk density with 10% roughage (**335-10**); 3) 386 g/L bulk density with 6% roughage (**386-6**); and 4) 386 g/L bulk density with 10% roughage (**386-10**). Diets (Table 1) were formulated to contain approximately 13.5% CP and 3% supplemental fat (DM basis). Rumensin and Tylan (33 and 11 mg/kg of DM, respectively; Elanco Animal Health, Greenfield, IN), as well as vitamins and minerals to meet or exceed NRC (1996) requirements, were incorporated into a premix (Table 1).

Grain Processing, Feeding, Weighing, and Routine Management. Whole, shelled corn grain was conditioned in an auger by adding 189 mg/kg of surfactant that primarily contained organic acids and sarsaponin (Mycoflake, Kemira Food Technologies, Des Moines, IA) to the volume of water necessary to increase the moisture content of the grain to approximately 17%. The whole grain was then steamed for approximately 30 min at 93°C in a vertical steam chamber (capacity 2,268 kg), which increased the moisture content to approximately 20%. Steamed corn grain was passed through the roller mill (46 \times 61 cm), and the 2 bulk densities were produced by varying the roll tension. Bulk density was monitored each time fresh flaked corn was produced to ensure that the target values were achieved, and samples of each bulk density were collected beneath the rolls for DM analysis. The average moisture content throughout the experiment was 20.1 (SD = 1.12) and 20.3% (SD = 0.98) for the 335 and 386 g/L treatments, respectively. Additional samples of the 2 bulk densities were allowed to air-equilibrate for 15 min and frozen for later laboratory analyses of total starch and enzymatic starch availability.

Table 1. Composition and analyzed nutrient content (DM basis) of diets based on steam-flaked corn processed to different bulk densities and fed with different roughage concentrations¹

Item	335 g/L		386 g/L	
	6%	10%	6%	10%
Ingredient, %				
Steam-flaked corn	77.66	74.37	77.69	74.41
Ground alfalfa hay	6.14	10.23	6.14	10.22
Cottonseed meal	5.22	4.41	5.21	4.40
Urea	0.90	0.91	0.90	0.91
Fat	3.94	3.94	3.94	3.93
Molasses	3.05	3.05	3.04	3.05
Supplement ²	3.09	3.09	3.08	3.08
Analyzed composition, %				
CP	13.2	13.3	13.5	13.2
ADF	8.0	8.8	8.3	8.9
Ether extract	5.2	5.3	5.8	6.0
Ca	0.58	0.66	0.64	0.58
P	0.28	0.26	0.32	0.30
K	0.74	0.78	0.77	0.87

¹Steam-flaked corn was processed to bulk densities of 335 or 386 g/L (26 or 30 pounds/bushel); roughage concentration was 6 or 10% of dietary DM.

²Supplement contained (DM basis): 27.841% cottonseed meal; 0.500% antioxidant (Endox, Kemin Industries, Des Moines, IA); 35.088% limestone; 0.432% dicalcium phosphate; 6.667% potassium chloride; 14.493% Min-Ad (Min-Ad Corp., Amarillo, TX); 3.559% magnesium oxide; 2.778% ammonium sulfate; 10.000% salt; 0.001% cobalt carbonate; 0.131% copper sulfate; 0.056% iron sulfate; 0.002% ethylenediamine dihydroiodide; 0.222% manganese oxide; 0.083% selenium premix (0.2% Se); 0.657% zinc sulfate; 0.007% vitamin A (1,000,000 IU/g); 0.105% vitamin E (500 IU/g); 0.562% Rumensin (176.4 mg/kg; Elanco Animal Health, Indianapolis, IN); and 0.375% Tylan (88.2 mg/kg; Elanco Animal Health). Concentrations in parentheses by nutrient or feed additive sources are expressed on a 90% DM basis.

Feed bunks were evaluated visually each day of the experiment at approximately 0730 h to determine the quantity of feed to offer to each pen. The bunk management approach was designed to allow for 0 to 0.23 kg of feed remaining in the feed bunk at the time of evaluation. After the quantity of feed to be provided to each pen was determined, a batch of each diet sufficient to supply the feed for all the pens on a given treatment was mixed in the feed mill (1.3-m³-capacity Marion paddle mixer). After mixing, each diet was conveyed to a tractor-pulled, power take-off-driven mixer unit (Roto-Mix 84-8, Roto-Mix, Dodge City, KS) equipped with load cells and a digital indicator. The weight of feed delivered to each pen was measured using the load cells and indicator on the mixer unit (readability ± 0.45 kg). Cleanout of the mixer unit was monitored to ensure that cross-contamination of diets was minimized.

All steers were weighed individually using the squeeze chute-scale described previously at the beginning of the experiment and just before shipment to slaughter. Pen-based interim BW (scale readability ± 2.3 kg; scale calibrated with 454 kg of certified weights before use) were obtained every 35 d. On each weighing day, feed bunks were swept, and any feed remaining in the bunks was weighed and its DM content was determined (forced-air oven at 100°C for approximately 24 h). Orts were removed on weighing days and when rain or spoilage occurred and were subtracted from the feed delivery log.

Feed Sampling. Ingredient samples were collected every 2 wk to determine DM content, using the meth-

ods described previously for Orts. Samples of mixed feed from each pen were collected weekly throughout the experiment and composited by treatment within weighing periods. Composited samples of mixed feed were analyzed for DM, CP, ADF, ether extract (**EE**), Ca, P, and K by SDK Laboratories (Hutchinson, KS).

Carcass Evaluation. When approximately 60% of the steers in a BW block were deemed by visual appraisal to have sufficient finish to grade USDA Choice, they were sent to the Cargill Meat Solutions facility in Plainview, TX. Personnel from the Texas Tech University Meat Laboratory collected carcass data, which included HCW, LM area, 12th-rib fat, KPH, marbling score, and maturity data (USDA, 1997). Quality grade was determined from the marbling score and maturity data. Liver condemnations were classified for the presence of liver abscesses using the scale described by Brink et al. (1990).

Laboratory Analyses. The method for determining total starch was adapted from the method of Galyean (1997). Frozen SFC samples were thawed and air-dried for approximately 48 h by means of a fan blowing air across the surface of the samples. Air-dried samples were subsequently ground in a Wiley mill to pass a 1-mm screen, after which duplicates (approximately 0.20 g) were placed in 125-mL Erlenmeyer flasks. The flasks and contents were weighed on a top-loading balance (Mettler PC 8000, Mettler-Toledo Inc., Columbus, OH), 50 mL of deionized water was added, and flasks were covered with aluminum foil and placed in a boil-

ing water bath for 90 min to gelatinize the starch. The flasks were cooled to room temperature, and 50 mL of an acetate buffer solution (0.2 M; pH 4.5 ± 0.05) and 1 mL of glucoamylase enzyme (5 glucose activity units/mL; Glucoamylase Concentrate, Valley Research, South Bend, IN) were added. The flask and contents were reweighed to determine volume, covered with aluminum foil, and incubated in a water bath at 60°C for 24 h. After removal from the water bath, the contents of the flask were mixed and allowed to settle while the flasks cooled to room temperature. A glucose stock solution (100 mg of glucose/mL) was prepared, to which benzoic acid was added at 0.1% (wt/vol) as a preservative. A standard curve was prepared from the stock solution to provide concentrations of 0, 50, 100, 200, and 300 mg of glucose/100 mL. Glucose concentrations in standards and samples were determined by combining 0.1-mL aliquots with 4 mL of a glucose reagent (Webster et al., 1971) in a disposable glass test tube. The glucose reagent included 1.5 g of thiourea, 9.5 g of sodium borate, and 80 mL of *o*-toluidine diluted to 1 L with glacial acetic acid. After addition of the reagent, tubes were vortexed and placed in a boiling water bath for 15 min, and thereafter placed in tap water for 15 min. Tubes were vortexed, and the absorbance was determined (Beckman DU-50, Beckman Instruments Inc., Irvine, CA) at 630 nm vs. the reagent blank.

The method for determination of enzymatic starch availability was also adapted from the method of Galylean (1997). Approximately 0.2 g of air-dried duplicate samples were placed in 25-mL graduated glass test tubes, and 15 mL of the acetic acid buffer solution (pH 4.5 ± 0.05) was added, followed by 1 mL of an aqueous amyloglucosidase enzyme suspension (305 enzyme units/mL; No. A-7255, Sigma-Aldrich Inc., St. Louis, MO). Tubes were placed in a 40°C water bath for a 1-h incubation period and were shaken initially and every 15 min thereafter during incubation. After incubation, 2 mL of a 10% (wt/vol) zinc sulfate solution and 1 mL of sodium hydroxide (0.5 N) were added to each tube. The tube was then brought to a 25-mL volume with deionized water and vortexed. A gravitational flow funnel rack was used to filter the samples with qualitative student grade filters (No. 102, Hangzhou Whatman-Xinhua Filter Paper Co. Ltd., Singapore, China), and the filtrate was diluted to 25 mL with deionized water. Glucose concentration was determined as described previously for the total starch analysis.

Calculations and Statistical Analyses. Final BW for the carcass-adjusted data were calculated from the HCW divided by the overall average dressing percent. The ADG and G:F were calculated on a BW and carcass-adjusted basis. The G:F was computed as the quotient of ADG divided by daily DMI. All data were analyzed with pen as the experimental unit as a randomized complete block design using the MIXED procedure (SAS Inst. Inc., Cary, NC). The random effect of block was included in the model, and the fixed effects of SFC bulk density, roughage concentration, and the

bulk density \times roughage concentration interaction were evaluated by single degree of freedom *F*-tests. When significant ($P < 0.05$) bulk density \times roughage concentration interactions were detected, pairwise comparisons of the simple-effect means were conducted with the PDIF option of the MIXED procedure of SAS. The proportion of cattle grading USDA Choice or greater in each pen were analyzed as a binomial proportion using the GLIMMIX procedure of SAS, with block as a random effect. Effects were considered significant at a *P*-value of ≤ 0.05 , with tendencies declared at *P*-values between 0.05 and 0.10.

Exp. 2

Feed Samples. Six dietary treatments (the 4 diets in Exp. 1 and 2 additional diets; Table 5) were used in an in vitro fermentation experiment to evaluate IVDMD and in vitro pH at 6, 12, 18, and 24 h of incubation. The 2 additional diets were added to increase the range in bulk density of SFC at the same 2 roughage concentrations used in Exp. 1. The 6 treatment combinations, arranged in a 3×2 factorial design, consisted of 1) 283 g/L bulk density with 6% roughage (**283-6**); 2) 283 g/L bulk density with 10% roughage (**283-10**); 3) 335-6; 4) 335-10; 5) 386-6; and 6) 386-10. After mixing, the diets were placed on a flat surface for 48 h and dried with an electric fan blowing air across the surface of the samples. Samples were then ground in a Wiley mill to pass a 2-mm screen.

In Vitro Incubations. The in vitro fermentation system used in Exp. 2 was adapted from Defoor et al. (2000). Ruminal fluid was obtained approximately 4 h after feeding from 2 ruminally cannulated Jersey steers housed at the Burnett Center. The steers were fed a 75% concentrate diet based on SFC, cottonseed meal, ground alfalfa hay, cottonseed hulls, molasses, fat, and the same supplement used in Exp. 1 (Table 1). Whole ruminal contents were collected, strained through 4 layers of cheesecloth, and transported (approximately 30 min in transit) in a Thermos to the laboratory. Duplicate samples (approximately 0.5 g) were placed into 50-mL polyethylene centrifuge tubes. A total of 56 tubes [6 treatments \times 4 incubation times (6, 12, 18, and 24 h) \times 2 replicate tubes + 8 blank tubes (2 blanks/incubation time)] were used for each of 2 separate runs. Reduced-strength buffer was prepared by mixing 1 part of McDougall's buffer solution with 3 parts of physiological saline [0.9% (wt/vol) NaCl solution] in a volume of 6 L and adding 10 mL of a 4% (wt/vol) CaCl₂ solution. Carbon dioxide was bubbled through the diluted buffer until the pH was approximately 6.8 to 7.0. Each in vitro tube was charged with 28 mL of the buffer and 7 mL of strained ruminal fluid. The tubes were flushed with CO₂, capped with a stopper fitted with a 16-gauge needle for gas release, and shaken after 2, 4, and 6 h of incubation.

After 6 h of incubation at 39°C, the 6-h tubes were removed from the water bath and a combination elec-

trode (Accumet Basic, Fisher Scientific, Pittsburgh, PA) was inserted to determine the pH of the fluid in each tube. The electrode was then rinsed with deionized water to prevent removal of DM from the tube. Tubes were then centrifuged at $2,000 \times g$ for 15 min at 4°C, after which the supernatant fluid was aspirated by vacuum, and the tubes were stored frozen until pepsin digestion was initiated. The pH measurement procedures were repeated for the 12-, 18-, and 24-h incubation periods.

With the exception of pH measurements, the procedures described for the reduced-strength buffer system were repeated using a normal-strength buffer (not diluted with physiological saline). To provide statistical replication, the in vitro procedures for both buffer systems were conducted on 2 separate days (i. e., the 2 separate runs mentioned previously).

After completion of the reduced- and normal-strength buffer incubation periods, frozen tubes were thawed, charged with 35 mL of acidified pepsin solution (Galylean, 1997), and incubated for 48 h in a 39°C water bath. The tubes were shaken at 2, 4, and 6 h of incubation, after which they were removed, and the contents were filtered using a modified Büchner funnel system and filter paper (No. 541 ashless, Whatman International Ltd., Maidstone, UK). Filter papers were dried at 100°C for 24 h, desiccated for 15 min, and weighed. The average weight of the residue in the blank tubes was subtracted from the residue weight of each tube to account for DM introduced by the inoculum.

Calculations and Statistical Analyses. The IVDMD (%) was calculated as follows: $100 \times [(\text{initial sample dry weight} - \text{blank residue weight}) \div \text{initial sample dry weight}]$. Duplicate tubes were averaged within each incubation time. Data were analyzed within each in vitro incubation time using the MIXED procedure of SAS with a model that included the fixed effects of SFC bulk density, roughage level, and the bulk density \times roughage level interaction. Replicate runs were included as a random effect in the model. Main effects of roughage level and bulk density were evaluated by single degree of freedom *F*-tests. In the case of significant ($P < 0.05$) bulk density \times roughage level interactions, simple-effect means were separated using the PDIF option of SAS. Effects were considered significant at a *P*-value of ≤ 0.05 , with tendencies declared at *P*-values between 0.05 and 0.10.

Exp. 3

Cattle Processing. Twenty-four Holstein steers that had been housed at the Burnett Center were adapted for 3 wk to an 85% concentrate diet, weighed individually, tagged in the ear with an individual identification tag, vaccinated (Vision 7 with SPUR and Vista 3 SQ, Intervet/Schering-Plough Animal Health), and dewormed with moxidectin (Cydectin, Fort Dodge Animal Health).

Treatment Assignment. Steers were stratified by BW and allotted randomly to partially slotted floor pens [1 steer/pen, resulting in a total of 24 pens (12 steers) per treatment], and treatments were then assigned randomly to pens. Treatments consisted of 2 of the treatment diets from Exp. 1 (Table 1): 1) 335–6; and 2) 386–10. These 2 diets were chosen based on the results of Exp. 1 to provide the maximal range in bulk density and roughage concentration acceptable by industry standards, presumably providing the maximal range in potential acid load in cattle consuming these diets.

Feeding, Cattle Weighing, and Routine Management. Approximately 14 d before the beginning of the experiment, the steers were accustomed to the feeding procedures that were used during the trial. The bunk management approach was the same as described in Exp. 1. Diets (milled as described for Exp. 1) were weighed on a platform scale (90-kg capacity and 0.45-kg readability; Ohaus Corp., Pine Brook, NJ) into buckets (189.3 L), which were placed in front of each pen. Feed was then delivered with a 5-min interval between pens, which allowed for individual pen measurements to be taken at timed intervals. The baseline pattern of feed intake was measured on December 12, 2007, and baseline blood gas measurements were taken the next morning. After baseline measurements, cattle were switched to the treatment diets on December 14, 2007. Subsequent feed intake measurements were taken at various times after feeding 7, 14, 21, and 28 d later. For each sampling day, feed bunks were cleaned before the morning feeding, and fresh feed delivered to the bunk was weighed for each steer at the 5-min intervals noted previously. Percentage of total daily DMI consumed was measured at 0.5, 1, 1.5, 2, 3, 4, 6, and 8 h after feeding by weighing the feed remaining in the bunk and then returning unconsumed feed to the bunk. On the following day (24 h later), orts were weighed for each pen. In cases of rain, snow, or spoilage, DM analysis was conducted on the orts. Samples of the dietary ingredients were collected weekly during the experiment to determine DM content. Likewise, feed samples from the 12 pens/treatment were collected weekly and were subsequently analyzed for DM, CP, ADF, EE, Ca, P, and K (SDK Laboratories). Each time corn was steam flaked, samples were collected from below the rolls and allowed to air-equilibrate for 15 min, after which samples were frozen for later analyses of total starch and starch availability.

Blood gas and urine pH measurements were obtained on the day after feed intake measurements at approximately 24 h after fresh feed was offered on the previous day. Baseline blood gas and urine pH measurements were taken 1 d before the beginning of the experiment, with subsequent blood samples taken 8, 15, 22, and 29 d later. On each sampling day, arterial blood was collected from the auricularis caudalis artery, which is situated subcutaneously on the dorsal surface of the

Table 2. Analyzed total starch and enzymatic starch availability contents (DM basis) of steam-flaked corn samples collected weekly and composited over the duration of Exp. 1 and fed to Holstein steers in Exp. 3^{1,2}

Item	335 g/L	386 g/L
Exp. 1		
Total starch, %	72.9 ± 4.00	71.3 ± 3.44
Enzymatic starch availability, ³ %	67.3 ± 5.93	52.9 ± 5.07
Exp. 3		
Total starch, %	73.7 ± 4.60	69.8 ± 6.46
Enzymatic starch availability, %	63.4 ± 5.37	52.5 ± 6.86

¹Steam-flaked corn was processed to bulk densities of 335 or 386 g/L (26 or 30 pounds/bushel).

²Mean ± SD; n = 40 samples/mean for Exp. 1; n = 12 samples/mean for Exp. 3.

³Enzymatically available starch reflects the proportion of total starch that is gelatinized.

ear. To aid in detection of the artery, hair was removed from both ears using livestock clippers, and arterial blood was collected using a 3-mL heparinized arterial blood sampling syringe and needle set (4023L TRU, Vital Signs Inc., Englewood, CO). After collection, arterial blood was analyzed with an immediate-response mobile analysis system (IRMA Tru Point 443900, ITC Medical, Edison, NJ). The blood analysis system measured pH directly by potentiometric methods using an ion-specific electrode and partial pressures of CO₂ and O₂ by amperometric methods. Urine was collected for determination of urine pH by placing a 15-mL plastic tube underneath the sheath of each steer and massaging the sheath to stimulate urination. A combination pH electrode (Accumet Basic, Fisher Scientific) was used to measure the pH.

Statistical Analyses. All data were analyzed with steer as the experimental unit in a completely randomized design with repeated measures in time. Fixed effects were day, treatment, and the day × treatment interaction. The pattern of intake data (calculated as the percentage of total daily DMI consumed for each collection time), in addition to the blood gas and urine pH data were analyzed using repeated measures analysis. Animal within treatment was the subject of the repeated measure, and several covariance structures were tested. The covariance structure resulting in the smallest Akaike and Schwarz Bayesian criteria was considered the most appropriate for analysis. Baseline measurements were included as covariates for all analyses, and effects were considered significant at a *P*-value of ≤0.05.

RESULTS AND DISCUSSION

Exp. 1

Diet Analyses. Chemical composition of the dietary treatments is shown in Table 1. Results were similar to values expected from formulation. Fat content of the 386 g/L SFC diets was approximately 0.7% greater than that noted with the 335 g/L diets. To our knowledge, changes in fat content as a result of steam

flaking have not been reported previously, and we assume this difference reflects sampling errors and not a biological effect of steam flaking to a lesser bulk density. The total starch and enzymatic starch availability of SFC samples are shown in Table 2. The proportions of both total starch and enzymatically available starch were greater in more extensively processed (lesser bulk density) SFC. Our results are consistent with previous studies using corn (Zinn, 1990) and sorghum (Xiong et al., 1990, 1991). This effect of bulk density on starch availability has been noted across many laboratory methods, including enzymatic glucose release, degree of gelatinization, and 6-h gas production (Xiong et al., 1990, 1991), and in vitro enzymatic starch availability has been reported to increase linearly as bulk density decreases in both corn and sorghum (Zinn, 1990; Swingle et al., 1999). Defoor et al. (2000) reported that steam-flaked sorghum had a greater total starch content and starch availability as a proportion of total starch than did high-moisture sorghum.

Animal Performance. No interactions were observed between bulk density and roughage concentration for any of the performance variables measured. Therefore, the main effects of bulk density and roughage concentration are reported in Table 3. Initial BW did not differ between the 2 bulk density treatments (Table 3). Similarly, final BW (nonshrunk) and carcass-adjusted final BW did not differ between the 2 bulk densities. As a result, no differences were observed between the bulk density treatments for ADG, except for a tendency (*P* = 0.11) for greater ADG by cattle fed the 335 g/L bulk density from d 0 to 105 (Table 3). Similar to our results, Xiong et al. (1991) noted that feeding steam-flaked sorghum processed to bulk densities of 283, 360, or 437 g/L did not affect ADG; however, a tendency was noted by Zinn (1990) for reduced ADG when steers were fed corn steam flaked to 300 vs. 360 or 420 g/L. Decreased ADG was thought to result from lower ruminal pH and a subsequently decreased DMI that accompanied feeding the lighter bulk density flake (Zinn, 1990). Similarly, Swingle et al. (1999) indicated that decreasing the bulk density of steam-flaked sorghum resulted in a linear decrease in ADG for the feeding period.

Table 3. Effects of bulk density of steam-flaked corn and dietary roughage concentration on performance by finishing beef steers in Exp. 1¹

Item	335 g/L	386 g/L	<i>P</i> -value ²	6%	10%	<i>P</i> -value ²	SE ³
BW, kg							
Initial	393.7	394.2	0.78	392.8	395.2	0.21	11.52
Final	594.9	589.1	0.30	592.0	591.9	0.99	10.46
Adjusted final ⁴	594.1	590.2	0.51	588.6	595.7	0.23	11.30
ADG, kg							
d 0 to 35	1.85	1.82	0.63	1.77	1.90	0.09	0.056
d 0 to 70	1.82	1.79	0.52	1.78	1.82	0.44	0.039
d 0 to 105	1.74	1.68	0.11	1.71	1.71	0.88	0.030
d 0 to end ⁵	1.61	1.56	0.20	1.60	1.57	0.53	0.039
Adjusted, d 0 to end ⁴	1.61	1.57	0.35	1.57	1.61	0.36	0.044
Daily DMI, kg/steer							
d 0 to 35	7.60	7.85	0.07	7.58	7.88	0.03	0.143
d 0 to 70	8.36	8.47	0.37	8.28	8.55	0.05	0.148
d 0 to 105	8.66	8.75	0.46	8.61	8.80	0.16	0.154
d 0 to end ⁵	8.67	8.71	0.76	8.63	8.75	0.35	0.156
G:F							
d 0 to 35	0.244	0.231	0.09	0.233	0.242	0.24	0.0050
d 0 to 70	0.217	0.211	0.10	0.215	0.213	0.59	0.0027
d 0 to 105	0.201	0.192	<0.01	0.199	0.194	0.14	0.0022
d 0 to end ⁵	0.186	0.179	0.04	0.185	0.180	0.09	0.0021
Adjusted, d 0 to end ⁴	0.185	0.180	0.20	0.182	0.183	0.69	0.0026

¹Steam-flaked corn was processed to bulk densities of 335 or 386 g/L (26 or 30 pounds/bushel); roughage concentration was 6 or 10% of dietary DM. No bulk density × roughage concentration interactions were detected, $P \geq 0.33$.

²Observed significance level for bulk density or roughage concentration main-effect comparisons.

³Pooled SE of main-effect means, $n = 16$ pens/main-effect mean.

⁴Adjusted final BW equaled HCW divided by the average dressing percent (61.98%). Adjusted ADG (d 0 to end) was calculated from the adjusted final BW and the initial BW, and adjusted G:F (d 0 to end) was calculated as the ratio of adjusted ADG to d 0 to end DMI.

⁵Cattle in blocks 1 through 4 were on feed for 136 d, whereas cattle in blocks 4 through 8 were on feed for 115 d, resulting in an average of 125.5 d on feed.

Initial BW (Table 3), final nonshrunk BW, and carcass-adjusted final BW were not affected by roughage concentration. As a result, there was no effect of roughage concentration on ADG for the overall feeding period. There was, however, a tendency ($P = 0.09$) for a greater ADG by cattle fed 10 vs. 6% roughage during the first 35 d of the feeding period. Similarly, Xiong et al. (1991) reported a tendency for greater ADG by steers fed steam-flaked sorghum-based diets with 18% roughage than by those fed diets with 9% roughage. In contrast, using a substantially greater roughage content than in the present experiment, Bartle et al. (1994) demonstrated that ADG decreased linearly as roughage content increased in steam-flaked sorghum-based finishing diets. The effect on ADG was greater for cattle fed 20 vs. 30% roughage than for those fed 10 vs. 20% roughage. Moreover, White and Reynolds (1969) reported a decrease in ADG when alfalfa concentration was increased from 20 to 40% in steam-flaked sorghum-based diets. In cattle fed high-moisture or dry-rolled sorghum, Stock et al. (1990) observed a quadratic response in ADG when roughage was increased from 0 to 9% in 3% increments. Cattle fed 3 and 6% roughage had greater ADG than those fed 0 and 9% roughage (Stock et al., 1990). When feeding SFC, high-moisture corn, or a 50:50 mixture of SFC and high-moisture corn, with 5 graded levels of roughage, Gill et al. (1981) reported that ADG response to roughage depended on the grain-processing method. When SFC-based diets were fed,

8% roughage was optimal, whereas 12 and 16% roughage optimized ADG for the 50:50 mixture and high-moisture corn-based diets, respectively.

In the present study, bulk density affected DMI from d 0 to 35 ($P = 0.07$), with a decreased DMI by cattle fed 335 g/L flakes compared with those fed 386 g/L flakes (Table 3). No differences in DMI were observed between bulk density treatments during the remainder of the feeding period. The decreased DMI for d 0 to 35 with lighter bulk density is similar to results by Owens et al. (1997), who reported that more extensively processed SFC decreased DMI. Likewise, Swingle et al. (1999) reported that DMI by steers decreased linearly as bulk density decreased in steam-flaked sorghum-based diets. Conversely, DMI increased as the extent of grain processing increased when Theurer et al. (1999) fed steers SFC-based diets processed to 283 or 437 g/L. Nonetheless, most data available on DMI by cattle fed different bulk densities of steam-flaked sorghum or corn suggest that DMI decreases as bulk density decreases (Zinn, 1990; Xiong et al., 1991; Reinhardt et al., 1997). This result can be partially explained from the fact that total tract starch digestibility is a kappa curve function (Zinn, 1990; Zinn et al., 2002), and digestibility of total starch is maximized when bulk density is approximately 310 g/L (Zinn et al., 2002). Thus, when SFC is processed beyond this threshold, the extent of ruminal starch digestion increases rapidly, and the animal compensates by decreasing DMI. Furthermore, processing

grain beyond a bulk density of 310 g/L could predispose animals to acidosis and bloat (Zinn, 1990).

Dry matter intake (Table 3) was less by cattle fed 6 vs. 10% roughage from d 0 to 35 ($P = 0.03$) and from d 0 to 70 ($P = 0.05$), but did not differ between roughage concentrations from d 0 to 105. Likewise, for the overall feeding period, DMI did not differ between roughage concentrations. Present results were somewhat unexpected because increased dietary roughage concentration often increases DMI by feedlot cattle. Gill et al. (1981) noted that the addition of roughage to SFC or high-moisture corn increased DMI, and Bartle et al. (1994) showed that DMI increased linearly when roughage was increased from 10 to 30% in a steam-flaked sorghum-based diet. Moreover, DMI increased linearly when the roughage level was increased from 0 to 9% in diets based on high-moisture corn or dry-rolled sorghum (Stock et al., 1990).

Cattle fed the 335 g/L bulk density had greater G:F than those fed 386 g/L SFC from d 0 to 105 ($P < 0.01$) and from d 0 to the end ($P = 0.04$; Table 3). This pattern of greater G:F with the 335 g/L bulk density also was evident from d 0 to 35 ($P = 0.09$) and d 0 to 70 ($P = 0.10$). Our results agree with those of Xiong et al. (1991), in which G:F increased linearly when steam-flaked sorghum bulk density was decreased from 437 to 360 to 283 g/L. Furthermore, previous results suggest that the greatest effect of decreasing steam-flaked grain bulk density on feedlot cattle performance is on G:F (Xiong et al., 1991). In the present study, carcass-adjusted G:F (Table 3) did not differ between bulk density treatments, presumably reflecting a slightly smaller dressing percent for cattle fed the 335 g/L SFC. In contrast to the results of the present study, Zinn (1990) noted that G:F decreased with a SFC bulk density of 300 compared with 360 or 420 g/L.

No differences were observed between the 2 roughage concentrations for G:F, except for a tendency for decreased G:F from d 0 to the end ($P = 0.09$) with cattle fed 10% roughage. Likewise, no differences were observed between roughage concentrations for carcass-adjusted G:F (Table 3). Similar to the present results, Bartle et al. (1994) reported that efficiency of BW gain decreased as roughage concentration increased, which was attributed to the decreased energy content of diets with greater roughage concentrations. In addition, Stock et al. (1990) noted a linear decrease in efficiency of BW gain as roughage increased in high-moisture corn and dry-rolled sorghum diets. Likewise, Calderon-Cortes and Zinn (1996) reported greater efficiency of BW gain with 8 vs. 16% roughage in a SFC-based diet. In contrast, Gill et al. (1981) reported that when feeding SFC or high-moisture corn, efficiency of BW gain was improved with the addition of roughage. A relatively small fraction of ADF is digested ruminally when cattle are fed high-concentrate diets (Stock et al., 1990). Therefore, in the absence of acidosis, an increase in roughage concentration would likely have an adverse

effect on G:F through dilution of the DE concentration (Stock et al., 1987, 1990).

Carcass Characteristics. Interactions between bulk density and roughage concentration were not detected for carcass data, except for the percentage of cattle grading USDA Choice, as discussed in a subsequent section. Thus, main-effect means are reported in Table 4. Hot carcass weight, dressing percent, LM area, fat thickness, KPH, yield grade, marbling score, and liver abscesses did not differ between the 2 bulk density treatments. These results are similar to previous findings of no differences in carcass quality between steers fed varying bulk densities of SFC (Zinn, 1990). Cattle fed the 386 g/L treatments tended ($P = 0.07$) to have a larger percentage of carcasses grading USDA Choice or greater compared with those fed the 335 g/L treatment (Table 4), which conflicts with the results of Xiong et al. (1991), who reported that less extensively processed sorghum was associated with a greater percentage of USDA Choice carcasses than was more extensively processed sorghum. As noted previously, however, an interaction was detected for the percentage of USDA Choice carcasses, so main effects should be viewed with caution. No differences were observed between the 2 dietary roughage concentrations (Table 4) for HCW, LM area, 12th-rib fat thickness, yield grade, marbling score, percentage of carcasses grading USDA Choice or greater, and liver abscesses. Cattle fed the 10% roughage concentration treatment had a greater dressing percent ($P = 0.01$) and less KPH ($P < 0.01$) than those fed 6% roughage (Table 4), but the reasons for these differences are not clear.

Regarding the interaction ($P = 0.07$) between SFC bulk density and roughage concentration for percentage of carcasses grading USDA Choice or greater, evaluation of the simple-effect means indicated that the percentage of carcasses grading Choice (mean = 52.61%) did not differ between roughage concentrations for cattle fed the 335 g/L bulk density treatments. Conversely, cattle fed the 386 g/L SFC bulk density treatment with 10% roughage had a greater ($P < 0.05$; 81.25 vs. 56.25%, respectively) percentage of carcasses that graded USDA Choice than did cattle fed 6% roughage. As with the changes in dressing percent and KPH noted previously, reasons for the quality grade interaction are not readily evident.

Exp. 2

Diet Analyses. The chemical composition of the dietary substrates used in the in vitro experiments is presented in Table 5. Diets were formulated to have the same nutrient concentrations (with the exception of ADF), and ingredients were weighed with great precision on a laboratory balance. Thus, the variation in the analyzed composition among diets presumably reflects problems in obtaining representative samples from relatively small quantities of the ground substrates.

Table 4. Effects of bulk density of steam-flaked corn and dietary roughage concentration on carcass characteristics of finishing beef steers in Exp. 1¹

Item	335 g/L	386 g/L	<i>P</i> -value ²	6%	10%	<i>P</i> -value ²	SE ³
HCW, kg	368.2	365.7	0.51	364.7	369.1	0.23	7.03
Dressing percent	61.9	62.1	0.48	61.6	62.4	0.01	0.19
LM area, cm ²	82.46	82.61	0.94	82.26	82.80	0.78	1.895
12th-rib fat, cm	1.42	1.40	0.81	1.37	1.45	0.43	0.060
KPH, %	3.38	3.40	0.88	3.61	3.17	<0.01	0.170
Yield grade	3.77	3.73	0.77	3.76	3.74	0.86	0.123
Marbling score ⁴	431.5	444.1	0.48	438.3	437.2	0.95	13.27
USDA Choice, ⁵ %	52.60	68.75	0.07	56.25	65.10	0.22	—
USDA Select, ⁵ %	47.40	31.25	—	43.75	34.90	—	—
Abscessed livers, ⁶ %	9.38	10.94	0.77	9.38	10.94	0.68	—

¹Steam-flaked corn was processed to bulk densities of 335 or 386 g/L (26 or 30 pounds/bushel); roughage concentration was 6 or 10% of dietary DM. No bulk density × roughage concentration interactions were detected ($P \geq 0.17$), except for quality grade data, for which simple-effect means are provided in the text.

²Observed significance level for bulk density or roughage concentration main-effect comparisons.

³Pooled SE of main-effect means, $n = 16$ pens/main-effect mean.

⁴Marbling score: 300 = Slight⁰; 400 = Small⁰; 500 = Modest⁰.

⁵Bulk density × roughage concentration interaction, $P = 0.07$.

⁶Sum of A–, A, and A+ liver abscess scores.

IVDMD. The results for IVDMD using normal- and reduced-strength buffer systems are presented in Table 6. Main effects are presented because no bulk density × roughage level interactions were detected, except as noted below for IVDMD at 18 h of incubation in the reduced-strength buffer system. There were no bulk density or roughage concentration differences in IVDMD at 6, 12, 18, or 24 h using a normal-strength buffer. In contrast, with the reduced-buffer system, IVDMD was greater ($P = 0.03$) for the 2 smaller bulk

densities at 6 h, with a similar tendency ($P = 0.10$) at 12 h (Table 6). At 24 h, however, IVDMD was greater ($P < 0.01$) for the 2 less extensively processed SFC diets (335 and 386 g/L). This result was likely caused by more rapid fermentation at 6 and 12 h with SFC that was more extensively processed, coupled with a lower pH, thereby resulting in less IVDMD at 24 h compared with corn processed to 335 and 386 g/L. An interaction was observed between SFC bulk density and roughage concentration for IVDMD in the reduced-strength

Table 5. Composition and analyzed nutrient content (DM basis) of in vitro substrates based on steam-flaked corn processed to different bulk densities and mixed with different roughage concentrations in Exp. 2¹

Item	283 g/L		335 g/L		386 g/L	
	6%	10%	6%	10%	6%	10%
Ingredient, %						
Steam-flaked corn	77.66	74.37	77.66	74.37	77.69	74.41
Ground alfalfa hay	6.14	10.23	6.14	10.23	6.14	10.22
Cottonseed meal	5.22	4.41	5.22	4.41	5.21	4.40
Urea	0.90	0.91	0.90	0.91	0.90	0.91
Fat	3.94	3.94	3.94	3.94	3.94	3.93
Molasses	3.05	3.05	3.05	3.05	3.04	3.05
Supplement ²	3.09	3.09	3.09	3.09	3.08	3.08
Analyzed composition, %						
CP	11.7	13.3	12.4	14.1	12.6	12.8
ADF	4.1	5.9	4.0	6.5	4.6	5.4
Ca	0.49	0.52	0.39	0.70	0.52	0.50
P	0.20	0.28	0.20	0.31	0.22	0.23
K	0.70	0.90	0.68	0.97	0.68	0.79

¹Steam-flaked corn was processed to bulk densities of 283, 335, or 386 g/L (22, 26, or 30 pounds/bushel); roughage concentration was 6 or 10% of dietary DM.

²Supplement contained (DM basis): 27.841% cottonseed meal; 0.500% antioxidant (Endox, Kemins Industries, Des Moines, IA); 35.088% limestone; 0.432% dicalcium phosphate; 6.667% potassium chloride; 14.493% Min-Ad (Min-Ad Corp., Amarillo, TX); 3.559% magnesium oxide; 2.778% ammonium sulfate; 10.000% salt; 0.001% cobalt carbonate; 0.131% copper sulfate; 0.056% iron sulfate; 0.002% ethylenediamine dihydroiodide; 0.222% manganese oxide; 0.083% selenium premix (0.2% Se); 0.657% zinc sulfate; 0.007% vitamin A (1,000,000 IU/g); 0.105% vitamin E (500 IU/g); 0.562% Rumensin (176.4 mg/kg; Elanco Animal Health, Indianapolis, IN); and 0.375% Tylan (88.2 mg/kg; Elanco Animal Health). Concentrations in parentheses by nutrient or feed additive sources are expressed on a 90% DM basis.

Table 6. Effects of bulk density of steam-flaked corn and dietary roughage concentration on IVDMD (%) in normal- and reduced-strength buffer systems in Exp. 2¹

Incubation time, h	283 g/L	335 g/L	386 g/L	<i>P</i> -value ²	SE ³	6%	10%	<i>P</i> -value ²	SE ⁴
Normal-strength buffer									
6	41.5	41.6	40.8	0.92	1.45	41.6	41.1	0.78	1.18
12	58.8	58.4	54.9	0.75	3.81	57.3	57.5	0.97	3.11
18	72.4	70.5	66.3	0.23	2.27	70.3	69.2	0.71	1.85
24	78.7	80.1	76.7	0.70	2.74	78.2	78.8	0.86	2.23
Reduced-strength buffer									
6	38.9 ^a	36.9 ^a	33.6 ^b	0.03	0.94	35.9	36.9	0.38	0.76
12	52.7	50.9	47.6	0.10	1.37	49.7	51.1	0.42	1.12
18 ⁵	50.4	51.9	50.8	0.43	0.74	51.4	50.7	0.45	0.61
24	58.7 ^a	62.8 ^b	63.3 ^b	0.01	0.76	61.1	62.1	0.31	0.62

^{a,b}Row means with different superscripts differ, $P < 0.01$.

¹Steam-flaked corn was processed to bulk densities of 283, 335, or 386 g/L (22, 26, or 30 pounds/bushel); roughage concentration was 6 or 10% of dietary DM. No bulk density \times roughage concentration interactions were detected ($P \geq 0.51$), except as noted for 18 h of incubation.

²Observed significance level for bulk density or roughage concentration main-effect comparisons.

³Pooled SE of main-effect means, $n = 4$ replications/main-effect mean.

⁴Pooled SE of main-effect means, $n = 6$ replications/main-effect mean.

⁵Bulk density \times roughage concentration interaction, $P = 0.05$. See text for simple-effect means.

buffer system at 18 h. Evaluation of the simple-effect means indicated that IVDMD did not differ ($P \geq 0.25$; 50.4 and 51.1% \pm 1.05, respectively) at either roughage concentration for substrates with 283 and 335 g/L bulk density SFC; however, IVDMD was greater ($P \leq 0.05$; 52.9 vs. 48.7% \pm 1.05) for the 283 g/L SFC with 6 vs. 10% roughage. Reasons for these differences are not clear. Increased in vitro digestibility has been noted in the literature with processed grains. Ramirez et al. (1985) demonstrated that grain processing increased digestibility in the early hours of incubation (4 and 8 h) and that SFC-based diets had greater IVDMD than whole corn or steamed whole corn. Likewise, Leibovich et al. (2009) reported that SFC-based diets had greater IVDMD than dry-rolled corn-based diets, and Corona et al. (2006) reported that SFC processed to a bulk density of 370 g/L had greater total tract digestibility of starch (85.6 vs. 99.3%) and digestibility of OM (73.9 to 82%) than dry-rolled corn.

In Vitro pH Measurements. There were no bulk density \times roughage level interactions for pH at various incubation times in the reduced-strength buffer in vitro fermentation system; main-effect means are shown in

Table 7. At 6 h, pH was least ($P < 0.01$) for the most extensively processed SFC (283 g/L) compared with the 335 or 386 g/L bulk densities, and at 12 h, the least processed SFC (386 g/L) had the greatest pH. The pH at 18 and 24 h did not differ among the 3 bulk densities of SFC (Table 7). Roughage concentration did not affect pH changes over time, except at 6 ($P = 0.01$) and 12 h ($P = 0.07$), when there was a tendency for pH to be greater with the 10% roughage concentration. Measurements of in vitro pH in the present study are consistent with the results of previous in vivo studies (Johnson et al., 1968; Zinn, 1987) in which ruminal pH was greater for dry-rolled vs. SFC, illustrating the effects of the greater fermentability of SFC on ruminal fermentation and production of organic acids. Moreover, Zinn (1990) reported that decreasing the bulk density of SFC from 420 to 300 g/L resulted in a linear decrease in ruminal pH.

Exp. 3

Diet Analyses. The ingredient composition of diets used in Exp. 3 was the same as the 335–6 and 386–10

Table 7. Effects of bulk density of steam-flaked corn and dietary roughage concentration on pH changes over time in an in vitro fermentation system using a reduced-strength buffer in Exp. 2¹

Incubation time, h	283 g/L	335 g/L	386 g/L	<i>P</i> -value ²	SE ³	6%	10%	<i>P</i> -value ²	SE ⁴
0	5.79	5.79	5.77	0.42	0.013	5.78	5.78	0.99	0.010
6	5.34 ^a	5.47 ^b	5.49 ^b	0.01	0.018	5.41	5.46	0.10	0.015
12	4.85 ^a	4.89 ^a	4.97 ^b	0.01	0.013	4.88	4.92	0.07	0.011
18	4.65	4.65	4.69	0.08	0.010	4.65	4.67	0.32	0.008
24	4.61	4.63	4.65	0.17	0.014	4.63	4.64	0.56	0.011

^{a,b}Row means with different superscripts differ, $P < 0.01$.

¹Steam-flaked corn was processed to bulk densities of 283, 335, or 386 g/L (22, 26, or 30 pounds/bushel); roughage concentration was 6 or 10% of dietary DM. No bulk density \times roughage concentration interactions were detected, $P \geq 0.84$.

²Observed significance level for bulk density or roughage concentration main-effect comparisons.

³Pooled SE of main-effect means, $n = 4$ replications/main-effect mean.

⁴Pooled SE of main-effect means, $n = 6$ replications/main-effect mean.

Table 8. Effects of diets with different combinations of bulk density of steam-flaked corn and roughage concentrations on changes in arterial blood gas, blood pH, and urine pH measurements on various sampling days in Holstein steers in Exp. 3

Item and sampling day ¹	Treatment ²		SE ³
	335-6	386-10	
Blood pH			
d 7	7.45	7.46	—
d 14	7.44	7.47	—
d 21	7.41	7.41	—
d 28	7.44	7.46	0.01
pCO ₂ , ⁴ mmHg			
d 7	41.2	40.8	—
d 14	40.9	38.6	—
d 21	41.8	43.7	—
d 28	39.2	36.7	1.32
pO ₂ , mmHg			
d 7	66.9	62.1	—
d 14	75.8	78.7	—
d 21	72.6	78.6	—
d 28	87.4	89.9	7.43
Urine pH			
d 7	7.92	7.82	—
d 14	7.77	7.79	—
d 21	7.57	7.64	—
d 28	7.27	7.65	0.12

¹No day × treatment interactions were detected, $P \geq 0.14$. pCO₂ = partial pressure of CO₂; pO₂ = partial pressure of O₂.

²335-6 = diet with steam-flaked corn processed to a bulk density of 335 g/L with 6% alfalfa hay in the dietary DM; 386-10 = diet with steam-flaked corn processed to a bulk density of 386 g/L with 10% alfalfa hay in the dietary DM.

³Pooled SE of sampling day × treatment means, n = 12 steers/mean.

⁴Day effect, $P < 0.01$.

diets used in Exp. 1 (Table 1). The analyzed chemical composition (DM basis) of diets used in Exp. 3 agreed closely with expected values (average values: CP = 13.0%; ADF = 6.7%; EE = 6.0%; Ca = 0.49%; P = 0.29%; and K = 0.89%). The total and enzymatic starch contents of SFC fed to Holstein steers throughout Exp. 3 are presented in Table 2. The relationships between the concentrations of total and enzymatic starch and bulk density were similar to the results for Exp. 1 in that the proportions of total and enzymatic starch were greater when SFC was flaked to 335 vs. 386 g/L.

Blood Gas, Electrolyte, and Urine pH Measurements. There were no day × treatment interactions for blood and urine measurements ($P \geq 0.14$); therefore, only main-effect means are presented in Table 8. There were no differences between the 2 treatments for any of the measurements collected in the study ($P \geq 0.20$); however, there was a day effect ($P < 0.01$) for blood pH, partial pressure of CO₂, and urine pH. Furthermore, urine pH decreased ($P < 0.05$) as days on feed increased, as shown in Table 8. Because pH measurements were made on 1 urine sample from each steer, diurnal variation that potentially occurred in urine pH was not evaluated. Brown et al. (2000) simulated acute and subacute acidosis by feeding SFC or a combination

of dry-rolled wheat and dry-rolled corn at 3 and 1.5% of BW, respectively. When cattle were induced with acute and subacute acidosis, blood pH and partial pressure of CO₂ decreased linearly 7 d after the challenge, but not thereafter (Brown et al., 2000), reflecting the ability of the animal to cope with the challenge. Conversely, Bevans et al. (2005) found that blood pH did not differ on d 0, 4, and 19 and across treatments when the proportion of grain in the diet was increased from 40 to 90% by either rapid or gradual adaptation. Owens et al. (1998) reported that blood is buffered with bicarbonate during exposure to an acid disturbance, and differences in blood pH are rarely observed. A study similar to the current one was conducted in our laboratory by Abney et al. (2007), in which steers were fed a 90% concentrate diet supplemented with 0 or 200 mg/d of ractopamine, and the rate and variation of DMI and acid-base balance were measured. As in the present study, no differences were noted in urine pH, blood gas measurements, or variation of DMI, indicating that the acid-base balance was not affected by ractopamine. Additional research is needed to evaluate the biological mechanisms that allow animals to compensate metabolically during exposure to acidosis. In addition, evaluation of blood samples at multiple times after feeding might allow for a more precise evaluation of acid-base responses than could be achieved with a single evaluation 24 h after feeding, as used in the present study and in the study of Abney et al. (2007).

Pattern of Feed Intake. A treatment × day interaction ($P \leq 0.01$) was observed for the proportion of total DMI consumed at various sampling times after feeding; however, because there were no differences between treatments ($P \geq 0.14$) in the proportion of DMI consumed at any sampling time, except on d 14, day and treatment main-effect means are presented in Table 9. As days increased from 7 to 21, the proportion of total DMI consumed at each sampling time generally decreased, whereas from d 21 to 28, the proportion of total DMI at each sampling time increased. The decreasing proportion of total DMI consumed from d 7 to 21 was accompanied by an increase in total daily DMI (Table 9). With respect to treatment effects on d 14, cattle fed the 386-10 diet consumed a greater ($P < 0.05$) proportion of their total DMI at 1 (simple-effect means = 34.7 vs. 20.9 ± 3.98%) and 6 h (52.8 vs. 34.9 ± 3.77%) after feeding than those fed the 335-6 diet. Little research has been done to evaluate within-day feed intake patterns by feedlot cattle. Abney et al. (2007) measured the rate of and variation in DMI with finishing steers fed 0 or 200 mg/d of ractopamine and found that feeding ractopamine altered the within-day DMI pattern of steers, but it did not affect feedlot performance or metabolic measurements.

General Conclusions

Under the conditions in Exp. 1, no interactions were observed between bulk density and roughage concen-

Table 9. Effects of diets with different combinations of bulk density of steam-flaked corn and roughage concentrations on the proportion of total daily DMI consumed at various times after feeding, and total daily DMI by Holstein steers in Exp. 3 at various times after feeding on 4 sampling days

Item	Cumulative proportion of total DMI, %							
	Day				SE ¹	Treatment ²		
	7	14	21	28		335-6	386-10	SE ³
Time, ⁴ h								
0.5	44.0	25.3	18.2	21.1	2.91	29.9	26.6	2.14
1.0	49.6	29.1	22.1	24.3	3.08	34.4	30.3	2.12
1.5	50.9	31.0	23.8	26.1	3.04	36.7	31.8	2.26
2.0	51.7	32.7	25.2	27.8	3.05	37.9	33.1	2.30
3.0	57.3	33.9	27.9	31.1	3.25	41.2	37.2	2.49
4.0	63.8	38.7	33.7	38.0	3.31	46.7	43.9	2.77
6.0	75.0	43.9	44.3	50.0	3.14	57.4	53.5	2.15
8.0	84.7	57.3	62.5	61.2	2.71	70.8	66.1	2.57
Total DMI, kg/d	8.99	10.46	10.78	10.36	0.30	10.02	10.27	0.21

¹Pooled SE of day means, n = 24 steers/mean.

²335-6 = diet with steam-flaked corn processed to a bulk density of 335 g/L with 6% alfalfa hay in the dietary DM; 386-10 = diet with steam-flaked corn processed to a bulk density of 386 g/L with 10% alfalfa hay in the dietary DM.

³Pooled SE of treatment means, n = 48 steers/mean.

⁴Day × treatment interactions ($P \leq 0.01$) were detected for all sampling times; however, main-effect means are reported because no differences ($P \geq 0.14$) were detected for cumulative proportion of DMI between treatments on any day or measurement time, except as noted in the text for d 14. The baseline measurement of cumulative proportion of total DMI was a significant covariate ($P < 0.05$) for all analyses.

tration for the performance traits and most of the carcass traits measured. Our results suggest that cattle fed SFC at a bulk density of 335 g/L were more efficient than those fed SFC at a bulk density of 386 g/L. Vasconcelos and Galyean (2007) reported that feedlot consulting nutritionists recommend an average bulk density of SFC of 348 g/L; however, the most frequently used bulk density (mode) in their survey was 360 g/L. Thus, both the bulk densities evaluated in Exp. 1 are similar to those typically used in commercial feedlots. With respect to dietary roughage concentration, cattle fed 6% alfalfa hay as the dietary roughage tended to be more efficient than those fed 10% dietary roughage. Thus, within the ranges of bulk density and roughage concentration we evaluated, it should be possible to achieve increased G:F by simultaneously decreasing the bulk density of SFC and dietary roughage concentration.

Changes in pH and IVDMD in the reduced-buffer in vitro system among the different bulk density and roughage concentrations were minor, and the IVDMD in a normal-strength buffer in vitro fermentation system was generally not affected by treatments. It seems likely, based on the limited changes in urine pH and blood over time in Exp. 3, that cattle can adapt fairly readily to dietary factors that affect acid load. Because of this adaptive ability, the bulk densities of SFC and the roughage concentrations evaluated in Exp. 3 had little effect on the blood acid-base balance. The relative importance of the within-day pattern of DMI by feedlot cattle and how it might influence performance and acid-base status are not well documented, and more research is needed in this area. Overall, our results suggest that SFC with a bulk density of 335 g/L in combination

with 6% alfalfa hay would likely provide optimal animal performance with a limited risk of perturbed acid-base balance in feedlot cattle adapted to high-grain diets.

LITERATURE CITED

- Abney, C. S., J. T. Vasconcelos, J. P. McMeniman, S. A. Keyser, K. R. Wilson, G. J. Vogel, and M. L. Galyean. 2007. Effects of ractopamine hydrochloride on performance, rate and variation in feed intake, and acid-base balance in feedlot cattle. *J. Anim. Sci.* 85:3090-3098.
- Bartle, S. J., R. L. Preston, and M. F. Miller. 1994. Dietary energy source and density: Effects of roughage source, roughage equivalent, tallow level, and steer type on feedlot performance and carcass characteristics. *J. Anim. Sci.* 72:1943-1953.
- Bengochea, W. L., G. P. Lardy, M. L. Bauer, and S. A. Soto-Navarro. 2005. Effect of grain processing degree on intake, digestion, ruminal fermentation, and performance characteristics of steers fed medium-concentrate growing diets. *J. Anim. Sci.* 83:2815-2825.
- Bevans, D. W., K. A. Beauchemin, K. S. Schwartzkopf-Genswein, J. J. McKinnon, and T. A. McAllister. 2005. Effect of rapid or gradual grain adaptation on subacute acidosis and feed intake by feedlot cattle. *J. Anim. Sci.* 83:1116-1132.
- Brink, D. R., S. R. Lowry, R. A. Stock, and J. C. Parrott. 1990. Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. *J. Anim. Sci.* 68:1201-1207.
- Brown, M. S., C. R. Krehbiel, M. L. Galyean, M. D. Remmenga, J. P. Peters, B. Hibbard, J. Robinson, and W. M. Moseley. 2000. Evaluation of models of acute and subacute acidosis on dry matter intake, ruminal fermentation, blood chemistry, and endocrine profiles of beef steers. *J. Anim. Sci.* 78:3155-3168.
- Calderon-Cortes, J. F., and R. A. Zinn. 1996. Influence of dietary forage level and forage coarseness of grind on growth performance and digestive function in feedlot steers. *J. Anim. Sci.* 74:2310-2316.
- Corona, L., F. N. Owens, and R. A. Zinn. 2006. Impact of corn vitreousness and processing on site and extent of digestion by feedlot cattle. *J. Anim. Sci.* 84:3020-3031.

- Defoor, P. J., M. L. Galyean, N. A. Cole, and O. R. Jones. 2000. Effects of planting density and processing method on laboratory characteristics of grain sorghum for ruminants. *J. Anim. Sci.* 78:2032–2038.
- Galyean, M. L. 1997. *Laboratory Procedures in Animal Nutrition Research*. Texas Tech Univ. http://apps.depts.ttu.edu/afs/home/mgalyean/lab_man.pdf Accessed Aug. 11, 2009.
- Galyean, M. L., and P. J. Defoor. 2003. Effects of roughage source and level on intake by feedlot cattle. *J. Anim. Sci.* 81(E-Suppl. 2):E8–E16.
- Gill, D. R., F. N. Owens, J. J. Martin, D. E. Williams, R. A. Zinn, and R. J. Hillier. 1981. Roughage level in feedlot rations. *Res. Reprod.* MP-108:141–146.
- Johnson, D. E., J. K. Matsushima, and K. L. Knox. 1968. Utilization of flaked vs. cracked corn by steers with observations on starch modification. *J. Anim. Sci.* 27:1431–1437.
- Leibovich, J., J. T. Vasconcelos, and M. L. Galyean. 2009. Effects of corn processing method in diets containing sorghum wet distillers grain plus solubles on performance and carcass characteristics of finishing beef cattle and on in vitro fermentation of diets. *J. Anim. Sci.* 87:2124–2132.
- NRC. 1996. *Nutrient Requirements of Beef Cattle*. 7th ed. Natl. Acad. Press, Washington, DC.
- Odongo, N. E., O. AlZahal, M. I. Lindinger, T. F. Duffield, E. V. Valdes, S. P. Terrell, and B. W. McBride. 2006. Effects of mild heat stress and grain challenge on acid-base balance and rumen histology in lambs. *J. Anim. Sci.* 84:447–455.
- Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: A review. *J. Anim. Sci.* 75:868–879.
- Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: A review. *J. Anim. Sci.* 76:275–286.
- Patience, J. F. 1990. A review of the role of acid-base balance in amino acid nutrition. *J. Anim. Sci.* 68:398–408.
- Ramirez, R. G., H. E. Kiesling, M. L. Galyean, G. P. Lofgreen, and J. K. Elliott. 1985. Influence of steam-flaked, steam-whole or whole shelled corn on performance and digestion in beef steers. *J. Anim. Sci.* 61:1–8.
- Reed, J. J., M. L. Bauer, G. P. Lardy, E. R. Loe, and J. S. Caton. 2005. Effect of processing on feeding value of sprouted barley and sprouted durum in growing and finishing rations for beef cattle. *Prof. Anim. Sci.* 21:7–12.
- Reinhardt, C. D., R. T. Brandt Jr., K. C. Behnke, A. S. Freeman, and T. P. Eck. 1997. Effect of steam-flaked sorghum grain density on performance, mill production rate, and subacute acidosis in feedlot steers. *J. Anim. Sci.* 75:2852–2857.
- Riond, J. L., M. Wanner, H. Coste, and G. Parvu. 2001. Pathophysiological effects of low dietary phosphorus in pigs. *Vet. J.* 161:165–173.
- Stock, R. A., D. R. Brink, K. K. Kreikemeier, and K. K. Smith. 1987. Evaluation of early-harvested and reconstituted grain sorghum in finishing steers. *J. Anim. Sci.* 65:548–556.
- Stock, R. A., M. H. Sindt, J. C. Parrott, and F. K. Goedecken. 1990. Effects of grain type, roughage level and monensin level on finishing cattle performance. *J. Anim. Sci.* 68:3441–3455.
- Swingle, R. S., T. P. Eck, C. B. Theurer, M. De la Llata, M. H. Poore, and J. A. Moore. 1999. Flake density of steam-processed sorghum grain alters performance and sites of digestibility by growing-finishing steers. *J. Anim. Sci.* 77:1055–1065.
- Theurer, C. B., R. S. Swingle, R. C. Wanderley, R. M. Kattinig, A. Urias, and G. Ghenniwa. 1999. Sorghum grain flake density and source of roughage in feedlot cattle diets. *J. Anim. Sci.* 77:1066–1073.
- USDA. 1997. *United States Standards for Grades of Carcass Beef*. Agric. Mark. Serv., USDA, Washington, DC.
- Vasconcelos, J. T., and M. L. Galyean. 2007. *Nutritional recommendations for feedlot consulting nutritionists: The 2007 Texas Tech University survey*. *J. Anim. Sci.* 85:2772–2781.
- Webster, W. W., S. F. Stinson, and W. H. Wong. 1971. Manual procedure for direct microassay of serum glucose by use of *o*-toluidine, and its adaptation to the 12/60 autoanalyzer. *Clin. Chem.* 17:1050–1054.
- White, T. W., and W. L. Reynolds. 1969. Various sources and levels of roughage in steer rations. *J. Anim. Sci.* 28:705–710.
- Xiong, Y., S. J. Bartle, and R. L. Preston. 1990. Improved enzymatic method to measure processing effects and starch availability in sorghum grain. *J. Anim. Sci.* 68:3861–3870.
- Xiong, Y., S. J. Bartle, and R. L. Preston. 1991. Density of steam-flaked sorghum grain, roughage level, and feeding regimen for feedlot steers. *J. Anim. Sci.* 69:1707–1718.
- Zinn, R. A. 1987. Influence of lasalocid and monensin plus tylosin on comparative feeding value of steam-flaked versus dry-rolled corn in diets for feedlot cattle. *J. Anim. Sci.* 65:256–266.
- Zinn, R. A. 1990. Influence of flake density on the comparative feeding value of steam-flaked corn for feedlot cattle. *J. Anim. Sci.* 68:767–775.
- Zinn, R. A., F. N. Owens, and R. A. Ware. 2002. Flaking corn: Processing mechanics, quality standards, and impacts on energy availability and performance of feedlot cattle. *J. Anim. Sci.* 80:1145–1156.

References

This article cites 33 articles, 31 of which you can access for free at:
<http://jas.fass.org/cgi/content/full/88/3/1135#BIBL>