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Effects of feedlot bunk management and bulk density of steam-flaked corn on growth performance, carcass characteristics, and liver score of finishing beef steers fed high-concentrate diets without by-products or tylosin phosphate

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ABSTRACT

Objective: Our objective was to evaluate effects of bunk management strategy and bulk density of steam-flaked corn (SFC) on growth performance, carcass characteristics, and incidence and severity of liver abscesses in finishing beef steers fed diets without tylosin phosphate.

Materials and Methods: Beef steers (n = 192; initial BW = 332 ± 8.1 kg) were used in a randomized complete block design comprised of 12 BW blocks and 12 pen replications per treatment. A 2 × 2 factorial arrangement of treatments was used: (1) slick-bunk management + 335 g/L SFC-based diets (SFC); (2) modified *ad libitum* bunk management + 335 g/L SFC; (3) slick-bunk management + 425 g/L SFC; (4) modified *ad libitum* bunk management + 425 g/L SFC.

Results and Discussion: Bunk management strategy did not affect growth performance, carcass characteristics, or liver abscess score ($P \geq 0.10$). The ADG of steers fed 425 g/L SFC was greater ($P = 0.05$) from d 35 to 105 than those fed 335 g/L SFC; however, overall ADG was not different ($P = 0.36$). The DMI of steers fed 425 g/L SFC was greater at each interim period ($P \leq 0.05$) and overall ($P \leq 0.01$) than those fed 335 g/L SFC. Gain-to-feed (G:F) of steers fed 425 g/L SFC tended ($P = 0.10$) to be lesser from d 0 to 35 but was not different overall ($P = 0.12$). Steers fed 425 g/L SFC tended to have greater backfat and calculated empty body fat percentage ($P \leq 0.07$) than those fed 335 g/L SFC and greater calculated YG ($P = 0.05$). Steers fed 425 g/L SFC had 43.5% fewer ($P = 0.04$) liver abscesses than those fed 335 g/L SFC, but liver abscess severity did not differ ($P \geq 0.12$).

Implications and Applications: Bunk management did not affect growth performance, carcass characteristics, or development of liver abscesses. Steers fed 425 g/L SFC-based diets had greater DMI and 43.5% fewer liver abscesses than those fed 335 g/L SFC-based diets with similar overall G:F, but carcasses were fatter. Greater bulk density of SFC may be a useful management strategy and a viable antimicrobial alternative to decrease liver abscesses.

Key words: beef cattle, bunk management, grain processing

INTRODUCTION

Bunk management and accurate feed delivery are the primary components to management of clinical and subclinical metabolic disorders (Pritchard and Bruns, 2003). Large daily DMI variation and irregular feeding behaviors are commonly implicated in diagnosis of metabolic disorders (Schwartzkopf-Genswein et al., 2003), a leading cause of feedlot mortality (USDA-NAHMS, 2011). Likewise, subclinical acidosis may induce rumenitis, leading to decreased G:F and formation of liver abscesses (Owens et al., 1998). Slick-bunk management is widely used in the feedlot industry to facilitate ease of bunk management, as it is believed to result in greater DMI throughout the feeding period and to reduce overconsumption leading to metabolic disorders (Galyean, 1996; Pritchard and Bruns, 2003).

In the United States, corn is the predominant cereal grain in feedlot diets (Galyean, 1996; Galyean and Gleghorn, 2001; Vasconcelos and Galyean, 2007; Samuelson et al., 2016). Zinn (1990) observed a linear increase in the extent of ruminal and total-tract starch digestion of

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steam-flaked corn (**SFC**) with an increased degree of processing by increasing roll pressure to produce lighter flake density. Although heat and pressure treatment improve starch availability of cereal grains and subsequent growth performance of cattle, the risk of developing metabolic disorders such as acidosis, rumenitis, and formation of liver abscesses are concomitantly increased (Owens et al., 1998). Cattle may develop liver abscesses during any production phase; however, prevalence and economic impact is greatest in the feedlot industry (Amachawadi and Nagaraja, 2016). Incidence of liver abscess at harvest for most feedlots is 12 to 32% and represents a major economic liability to the feeder, packer, and consumer (Nagaraja and Chengappa, 1998).

Bunk management and degree of corn processing affect DMI and growth performance of finishing beef cattle. Therefore, the study objective was to determine the effects of bunk management strategy and bulk density of SFC on growth performance, carcass characteristics, and liver abscess incidence in finishing beef cattle fed diets without tylosin phosphate.

MATERIALS AND METHODS

All live animal procedures were approved by the Texas Tech University Animal Care and Use committee before study initiation (ACUC #19094–11). The experiment was conducted from January 2020 to July 2020 at the Texas Tech University Burnett Center for Beef Cattle Research and Instruction, located 9.7 km east of New Deal, Texas.

Animals, Arrival Processing, and Management

Two-hundred four *Bos taurus* steers (arrival BW = 299 ± 26.2 kg) were sourced from a ranch in Southeast Colorado and transported approximately 8 h to the experimental location on December 12, 2019. Before arriving at the experimental location, the cattle had been weaned, castrated, and backgrounded for 30 d (details unknown). Steers rested overnight and were provided access to water and long-stem grass hay. The following morning, steers were individually weighed (Silencer hydraulic squeeze chute; Moly Manufacturing; Avery Weigh-Tronix load cells; readability ± 0.454 kg; scale calibrated with 454 kg of certified weights before use), affixed with an individually identifiable ear tag, administered an oral (Safeguard, Merck Animal Health) and transdermal (Dectomax, Zoetis) anthelmintic for treatment of internal and external parasites, and vaccinated against viral respiratory (Vista 5, Merck Animal Health), clostridial (Vision 8 with SPUR, Merck Animal Health), and *Mycoplasma bovis* (Myco-B One Dose, American Animal Health) pathogens. Steers were housed in soil-surfaced outdoor pens with partial shade during the 3-wk adaptation period and fed a 65% concentrate starter diet. Steers transitioned to the finishing diet using a 4-step process of 65, 70, 77, and 94% concentrate diets, where each interim diet was fed for 7 d. During this time, steers were moved from the soil-surfaced pens to acclimate to concrete-surfaced pens. On d 0, steers were consuming the final 94% concentrate diet. Day 0 was January 20, 2020. Throughout the study, the maximum observed temperature was 43.8°C, the minimum observed temperature was −10.5°C, and the average temperature was 18.2°C. Total precipitation was 223.8 mm and the average humidity was 45%.

Before the experiment began, steers were administered a time-release implant containing 200 mg of trenbolone acetate + 40 mg of estradiol 17β (Revalor-XS, Merck). Steers were housed in concrete-surfaced pens with partially slotted floors providing 15.95 m^2 of pen space and 60 cm of linear bunk space per animal (4 steers/pen). Each pen was equipped with automatic waterers, with float-action water supply, shared by adjacent pens. The cattle had no access to shade within the pens. On days when the temperature was exceeded 32°C, cattle were sprinkled with water once per hour until the temperature dropped below this threshold.

All steers were treated for lice using a transdermal insecticide on d 35 (Cyclence, Bayer Animal Health) and 105 (Dectomax, Zoetis). Implant retention was confirmed via ear palpation on d 35. All implants were retained, and abscess rate was 2.5%. Body weight was individually measured on d 0 (initial), 35, 105, and 140. The d-70 BW measures were not completed because of the pandemic restrictions on campus research activity. Final BW was collected on d 162 (6 blocks) or 190 (6 blocks). A 4% shrink was applied to all BW.

Treatment Application

The randomized complete block design consisted of 12 BW blocks and 12 pen replications per treatment with pen as the experimental unit for all dependent variables. Experimental treatments were randomly assigned to pen within block and arranged in a 2 × 2 factorial: (1) slick-bunk management + 335 g/L (26 lb/bu) SFC-based diet, or (2) modified *ad libitum* bunk management + 335 g/L (26 lb/bu) SFC-based diet, or (3) slick-bunk management + 425 g/L (33 lb/bu) SFC-based diet, or (4) modified *ad libitum* bunk management + 425 g/L (33 lb/bu) SFC-based diet.

Bunk Management

Bunks were monitored for residual feed at 0700 and 1600 h daily. Separate individuals executed each respective bunk management method. A bunk scoring system (Table 1) adapted and modified from Pritchard (1993) was used to indicate bunk conditions at both reading times. At 1600 h, a bunk score 2 was targeted for both treatments. For slick-bunk management, a bunk score 0 or 1/2 was targeted at 0700 h. For modified *ad libitum* management, a bunk score 1 or 1 1/2 was targeted at 0700 h. If the bunk was scored 2 or greater, the feed delivery was decreased equally to the visual estimate of residual feed. If the bunk was scored less than 1, the daily feed delivery was in-

Table 1. Bunk scoring system used throughout the experiment[1]

Item	Description
0	No feed remaining in bunk; slick 0730 h target for slick-bunk management
1/2	1 to 2% of previous day's feed remaining
1	Up to 5% of previous day's feed remaining 0730 h target for modified *ad libitum* bunk management
1 1/2	5% to 15% of previous day's feed remaining
2	15% to 50% of previous day's feed remaining
3	>50% of previous day's feed remaining, crown on feed is disturbed
4	Feed is virtually untouched, crown on feed is undisturbed

[1]Adapted and modified from Pritchard (1993).

creased 0.70 kg/animal as-fed to achieve some day-to-day residual feed carryover. For slick-bunk management at the 0700-h bunk read, the targeted bunk score of 0 or 1/2 was achieved 55% of the time, score of 1 for 21% of the time, score of 1 1/2 for 22% of the time, and score of 2 for 2% of the time. Likewise, the targeted bunk score of 1 or 1 1/2 at 0700 h for modified *ad libitum* management was achieved 59% of the time, and bunks were scored 0 for 19% of the time, 1/2 for 19% of the time, and 2 for 3% of the time.

Basal diet was the same regardless of bulk density treatment assignment, and only differed in the bulk density of SFC (Table 2). Diets were formulated to meet requirements for growing and finishing beef cattle (NASEM, 2016). All diets included 31.9 mg/kg DM monensin sodium (Rumensin 90, Elanco Animal Health). Steers were fed once daily beginning at 0800 h. Diets were mixed in a paddle-type mixer and conveyed to a tractor pulled mixer (Rotomix 84–8 wagon mixer; Rotomix; scale readability ± 0.45 kg). The diets were sampled 3 times each week throughout the study and composited by week. The weekly sample was divided by one-half and the first subsample was used to determine DM in a forced-air oven at 100°C for 24 h (The Grieve Corporation). The DM was used to calculate total DMI for each week. The second subsample was used for chemical analyses of CP, ADF, NDF, fat, starch, and ash content. On days when BW was collected, or when feed spoilage occurred, orts were collected, weighed, and dried in a forced-air oven as described previously. Data from measurement of orts were used to compute DMI.

Steam Flaking and Enzymatic Starch Availability Analysis

Whole corn grain was transported via auger to a vertical chest (2,268 kg capacity), where steam and a surfactant (Mycoflake, Kemin Industries) were applied at atmospheric pressure for approximately 30 min at 93°C, decreasing the DM content of the whole corn from 88.16% DM to 80.63% DM after the steam flaking process, adding (8.5% moisture). Whole corn then passed through a roller mill (46 × 61 cm) with roll tension set accordingly to produce either 335 g/L (26 lb/bu) or 425 g/L (33 lb/bu) flake bulk density, which was confirmed using a hand-type density tester (Seedburo Equipment Company). Steam-flaked

Table 2. Ingredient and nutrient composition of the experimental diets where bulk density of steam-flaked corn varied[1]

Item	Finishing diet
Ingredient, %	
Steam-flaked corn	78.95
Alfalfa hay	6.50
Cottonseed meal	4.25
Cane molasses	3.50
Yellow grease	2.50
Limestone	1.35
Urea	0.95
Supplement[2]	2.00
Analyzed nutrient composition[3]	
CP, %	12.25
NDF, %	11.75
ADF, %	7.20
Fat, %	4.95
Ca, %	0.46
P, %	0.26
NE_m,[4] Mcal/kg	2.11
NE_g,[4] Mcal/kg	1.45

[1]The average weekly DM of the 335 g/L-steam-flaked corn-based diet was 83.2% and DM of 425 g/L steam-flaked corn-based diet was 82.9%.

[2]Supplement supplied 5.99% potassium chloride, 44.40% CP, 3.82% sodium, 8.34 mg/kg cobalt carbonate, 395.00 mg/kg copper sulfate, 408.00 mg/kg iron sulfate, 764 mg/kg manganous oxide, 2.92 mg/kg selenium, and 2,490.00 mg/kg zinc sulfate on a DM basis.

[3]Analysis performed by ServiTech Laboratories (Amarillo, TX).

[4]Tabular values based on Beef Cattle Nutrient Requirements Model (NASEM, 2016).

corn of each bulk density was transported from the roller mill to individual, enclosed bulk bins via an air-lift system for storage. Steam-flaked corn was prepared 3 to 4 d per week for the duration of the study, and diets were mixed each morning as described previously. A sample of each bulk density was collected every 30 min during the steam flaking process directly beneath the roller mill. Samples, inclusive of flake and fines, were air-dried in a single, uniform layer for 24 h then frozen at −20°C for subsequent analysis of total and enzymatically available starch.

Total and enzymatically available starch (Table 3) analysis was conducted in duplicate according to Xiong et al. (1990) and modified to accommodate use of a biochemistry analyzer (2700D Select Biochemistry Analyzer, YSI Life Sciences). Samples were thawed and dried in a forced-air oven at 45°C for approximately 14 h, allowed to air-equilibrate, then ground in a Wiley mill (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co.) to pass a 1-mm screen before analysis. To determine total starch, 0.2 g of the ground sample was placed in a 50-mL digestion vial with 30 mL of acetate buffer solution (pH 4.50 ± 0.05), then placed in a 94°C reciprocating water bath for 75 min to gelatinize the starch. Following incubation, vials were cooled in an ice bath for 20 min then 1 mL of amyloglucosidase working solution [concentrated amyloglucosidase solution (ServiTech) diluted with acetate buffer solution to dispense 200 KU of enzyme per 1 mL of working solution] was added. Vials were then incubated at 40°C for 75 min in a reciprocating water bath, after which 4 mL of 10% (wt·vol^{-1}) zinc sulfate solution and 2 mL of 0.5 mol sodium hydroxide solution were added, and each vial was diluted to 50 mL with deionized water. Each suspension was gravity-filtered passing through Q5 filter paper (Fisher Scientific). Filtrate was analyzed for D-glucose. Samples for determination of available starch were prepared and analyzed in the same manner as those for total starch, excluding the initial gelatinization of starch. Powdered crystalline glucose (product A16828, Fisher Scientific) and purified corn starch (product S9679, Millipore-Sigma) were used as internal reference standards. Percentage total starch was 89.3 ± 1.82% for corn starch and 91.3 ± 2.35% for glucose.

Carcass Data

Steers were fed to equal back fat (similar degree of finish) by visual appraisal, then transported to a commercial abattoir for slaughter. The 12 blocks of steers were slaughtered on 2 dates (blocks 1 to 6 were slaughtered after 162 d on feed and blocks 6 to 12 were slaughtered after 191 d on feed). Within block, each treatment was represented one time to prevent confounding of treatment and slaughter date. Individual carcass measurements and liver scores were collected by plant personnel. Liver scores are described subsequently as normal = edible; A− = 1 to 2 small abscesses or inactive scars; A = 1 to 2 large abscesses, or multiple small abscesses; or A+ = multiple large abscesses (Brink et al., 1990; Brown and Lawrence, 2010). Quality and yield grades were determined by plant personnel using the E+V image analysis system described by Shackelford et al. (2003). The ADG and G:F were calculated on a BW and carcass-adjusted basis. Final BW was carcass-adjusted by dividing the hot carcass weight by the overall average DP (66.15%). Carcass-adjusted ADG was calculated by subtracting the initial BW from the carcass-adjusted final BW, then divided by days on feed. The G:F (live basis) was computed as the quotient of ADG divided by daily DMI. The carcass-adjusted G:F was calculated by dividing the carcass-adjusted ADG by the d 0 to final DMI. Dry matter intake/metabolic body size was calculated according to Kleiber (1961). Gain energy density was calculated as retained energy divided by 0 to final ADG. Performance-adjusted net energy for maintenance and gain were calculated using a quadratic formula (Zinn and Shen, 1998). Empty body fat was estimated from the equations of Guiroy et al. (2001) and adjusted final shrunk BW at 28% empty body fat was estimated using equations of Tylutki et al. (1994).

Statistical Analysis

Pen was the experimental unit for all dependent variables. Growth performance and continuous carcass variables were analyzed using PROC MIXED (SAS v9.4, SAS Institute Inc.). Bunk management strategy, bulk density of SFC, and the bunk management × bulk density interaction was included as a fixed effect, and block was included as a random effect. Categorical carcass data and liver score were analyzed as a binomial proportion using PROC GLIMMIX where bunk management strategy, bulk density of SFC, and the bunk management × bulk density interaction were fixed effects, and block was the random effect. Differences in LSM were determined using least significant difference. Treatment effects were considered statistically significant when $P \leq 0.05$, and tendencies were discussed when $0.05 < P \leq 0.10$.

Table 3. Analyzed total and enzymatically available starch of steam-flaked corn (SFC) processed to varying bulk densities on a DM basis[1]

Item	335 g/L	425 g/L
Total starch, %	74.8 ± 1.89	72.3 ± 2.19
Enzymatic starch availability, %	65.0 ± 4.18	36.5 ± 3.92
DM,[2] %	92.1 ± 0.66	91.5 ± 0.41

[1]Mean ± SD; n = 20 samples/mean for 335 g/L SFC and n = 19 samples/mean for 425 g/L SFC. Acceptable CV among duplicates was ≤3%.

[2]Dried in a forced-air oven at 45°C for 14 h.

RESULTS AND DISCUSSION

No significant interactions were observed ($P \geq 0.09$), thus main-effect LSM of bunk management and bulk density of SFC are reported throughout.

Feedlot Growth Performance

Bunk management strategy did not affect growth performance (Table 4; $P \geq 0.15$) except the standard deviation of ADG within pen, which was 25.6% greater among cattle under slick-bunk management from d 35 to 105 than those under modified *ad libitum* management ($P = 0.02$). Indeed, the magnitude of this variability was inconsequential as there were no further differences in growth performance attributed to bunk management strategy.

Fundamentally, bunk management manipulates cattle behavior and DMI to maximize growth performance while preventing metabolic disease including acidosis, rumenitis, and the formation of liver abscesses (Pritchard and Bruns, 2003). Slick-bunk management is a common practice in cattle feeding in the United States and is used to offer the amount of feed that matches maximal feed intake by the cattle, where the bunk is slick or empty just before the next feeding time. In slick-bunk management, carryover feed is minimized, so excessive starch is unavailable which discourages overeating that can lead to metabolic disorders. True *ad libitum* bunk management, albeit uncommon in commercial feedlots in the United States, is achieved when the animal has unrestricted access to feed in the bunk. Modified *ad libitum* bunk management used in the present study attempted to limit day-to-day feed carryover to ≤5% of feed delivered (bunk score 1 at 0730 h; Table 1) to prevent feed wastage and excessive overeating that can induce metabolic disorders. Average daily feed carryover in the present experiment was approximately 8% of the previous day's feed for modified *ad libitum*, although bunks were slick 38% of the time. In contrast, average daily feed carryover was 1% of the previous day's feed for slick-bunk management, although these bunks were slick most the time as discussed previously.

While the contribution of bunk management strategy to ADG variability is not well documented, the present study noted the SD of ADG to be greater in cattle under slick-bunk management from d 35 to 105, the period in which total ADG was greatest. The lack of differences in bunk management observed in this study is noteworthy. Many consulting nutritionists advise the use of slick-bunk management. The purported idea is that it yields maximum intake more successfully than methods that allow some degree of feed carryover because there is less inherent variation in feed delivered and DMI (Pritchard, 1993; Galyean, 1996). Rumen microbes function best when substrate availability and ruminal pH are consistent (Owens et al., 1995b; Russell, 2002). In the present experiment, both bunk management systems were intended to restrict the magnitude of day-to-day variation in feed delivery.

Other studies have also examined the effects of imposed variation in day-to-day feed delivery. Galyean et al. (1992) delivered steers either a constant daily feed allotment, or varied the amount of feed delivered by 10% daily or weekly. Although no differences in DMI were observed, the ADG of steers whose feed delivery varied daily was less than both those with constant feed delivery and those that varied weekly. Likewise, feed conversion (F:G) was poorest in cattle whose feed delivery varied daily (Galyean et al., 1992). Similarly, Cruz et al. (2016) conducted a 10-yr assessment of growth performance and feeding behavior of feedlot cattle with high or low daily DMI fluctuation calculated as DMI fluctuation (kg) ÷ previous day's DMI (kg) × 100. Cattle with low average daily DMI fluctuation (4.79%) had 4.1% greater ADG, 2.9% greater DMI, and 4.2% greater total BW gain than cohorts with high daily DMI fluctuation (6.74%; Cruz et al., 2016). Nonetheless, other studies have noted no differences in growth performance or digestive function in calf-fed Holsteins with 20% daily feed delivery variation (Zinn, 1994). In the present study, the effects of feed carryover through differing bunk management systems, but consistent day-to-day feed delivery were evaluated and no differences in feedlot growth performance were observed. Our results support the concept that consistent feed delivery is a component to maximizing production, but that feed carryover itself is perhaps less detrimental than believed.

Final BW was not different among cattle fed differing bulk densities of SFC ($P = 0.57$). The ADG of steers fed the 425 g/L SFC-based diet was 5.8% greater from d 35 to 105 ($P = 0.05$) than those fed the 335 g/L SFC-based diet but was not different from d 105 to final or from d 0 to final ($P \geq 0.36$). The standard deviation of ADG within pen did not differ ($P = 0.37$). At all interim periods, DMI of steers fed 425 g/L SFC-based diets was greater ($P \leq 0.05$) than those fed 335 g/L SFC-based diets and was 4.3% greater overall (d 0 to final; $P < 0.01$). Likewise, grams of DMI per kilogram of metabolic body size (Kleiber, 1961) was 4.1% greater in steers consuming 425 g/L SFC-based diets. Gain:feed of steers fed 425 g/L SFC-based diets tended ($P = 0.10$) to be 5.7% lesser from d 0 to 35 than those consuming 335 g/L SFC-based diets, but was not different from d 35 to 105, 105 to final, or 0 to final ($P \geq 0.12$). Gain energy density (**GED**) was not different ($P = 0.53$). On a carcass-adjusted basis, no differences in final BW, overall ADG, or G:F were observed ($P \geq 0.22$). As anticipated, both the performance-adjusted net energy (**paNE**) and the observed/expected NE was greater ($P < 0.01$) in 335 g/L SFC-based diets than 425 g/L SFC-based diets. This observation was validated by greater total starch and enzymatically available starch in 335 g/L SFC than 425 g/L SFC. The overall NE_g advantage in both diets of the present study compared with tabular values is likely a result of feeding both low-risk, single-source cattle, and the combination of high-quality mid-bloom alfalfa hay and added yellow grease in the diet.

Table 4. Main effects of bunk management and bulk density of steam-flaked corn on live and carcass-adjusted growth performance of finishing beef steers[1]

	Bunk management			Flake density			
Item	AL	S	*P*-value[2]	335 g/L	425 g/L	*P*-value[2]	SEM[3]
n, steers	93	95	—	93	95	—	—
n, pens	24	24	—	24	24	—	—
Live weight basis[4]							
Initial BW, kg	333	331	0.15	333	331	0.46	8.1
Final BW, kg	608	605	0.68	605	609	0.57	5.8
ADG, kg							
d 0 to 35	1.74	1.84	0.19	1.80	1.78	0.77	0.064
d 35 to 105	1.84	1.83	0.90	1.78	1.89	0.05	0.039
d 105 to final	1.19	1.15	0.33	1.18	1.16	0.62	0.034
d 0 to final[5]	1.56	1.56	0.93	1.54	1.58	0.36	0.028
SD of ADG, kg							
d 0 to 35	0.38	0.33	0.30	0.35	0.37	0.56	0.033
d 35 to 105	0.29	0.39	0.02	0.34	0.34	0.93	0.028
d 105 to final	0.27	0.26	0.95	0.25	0.28	0.37	0.030
d 0 to final	0.20	0.22	0.48	0.21	0.21	0.85	0.022
DMI, kg							
d 0 to 35	7.43	7.49	0.68	7.30	7.61	0.03	0.223
d 35 to 105	8.75	8.76	0.94	8.52	8.99	<0.01	0.160
d 105 to final	8.54	8.46	0.60	8.34	8.66	0.05	0.129
d 0 to final	8.41	8.39	0.87	8.21	8.58	<0.01	0.143
DMI/MBS,[6] g/kg	83.17	83.29	0.89	81.50	84.96	<0.01	0.866
Gain:feed							
d 0 to 35	0.234	0.246	0.16	0.247	0.233	0.10	0.0058
d 35 to 105	0.211	0.210	0.85	0.210	0.211	0.79	0.0049
d 105 to final	0.140	0.136	0.52	0.142	0.134	0.17	0.0041
d 0 to final	0.186	0.187	0.73	0.188	0.184	0.12	0.0026
GED,[7] Mcal/kg	7.08	7.06	0.76	7.05	7.10	0.53	0.058
Carcass-adjusted basis							
Final BW,[8] kg	610	606	0.67	604	612	0.38	6.38
ADG, kg	1.56	1.56	0.99	1.54	1.59	0.22	0.030
Gain:feed	0.186	0.187	0.87	0.187	0.185	0.58	0.0028
paNE,[9] Mcal/kg							
Maintenance	2.24	2.24	0.88	2.27	2.21	<0.01	0.016
Gain	1.55	1.55	0.88	1.58	1.53	<0.01	0.014
Tabular NE,[10] Mcal/kg							
Maintenance	2.11	2.11	—	2.11	2.11	—	—
Gain	1.45	1.45	—	1.45	1.45	—	—
Observed/expected NE[11]							
Maintenance	1.06	1.06	0.88	1.08	1.05	<0.01	0.008
Gain	1.07	1.07	0.88	1.09	1.05	<0.01	0.010

[1]Bunk management methods were modified *ad libitum* (AL; target up to 5% orts at 0730 h bunk read) or slick (S; target trace or slick at 0730 h bunk read). Bulk density of steam-flaked corn was 335 g/L (26 lb/bu) or 425 g/L (33 lb/bu). No interaction of bunk management × bulk density of steam-flaked corn was observed ($P \geq 0.24$).

[2]Observed significance level for main-effect comparison of bunk management or bulk density of steam-flaked corn.

[3]Pooled standard error of LSM (n = 24 pens/mean).

[4]Shrink (4%) was applied to all BW.

[5]Average days on feed was 177.

[6]Dry matter intake/metabolic body size (MBS), g/kg; MBS calculated according to Kleiber (1961).

[7]Gain energy density, Mcal/kg. Calculated as retained energy divided by d 0 to final ADG, kg.

[8]Calculated as hot carcass weight divided by overall DP (66.15%).

[9]pa = performance adjusted. Net energy for maintenance and gain were calculated using a quadratic formula (Zinn and Shen, 1998).

[10]Estimated using the Beef Cattle Nutrient Requirements Modeling software (NASEM, 2016).

[11]paNE/tabular NE.

Processing corn via steam flaking is critical in mitigating the cost of freight, specifically in the southern High Plains of the United States. Steam flaking improves rate and extent of starch digestion via a combination of moist heat and physical shear of starch granules, therefore creating greater surface area for microbial digestion (Zinn et al., 2002). In addition, heat applied to corn grain results in gelatinization, the irreversible swelling of starch granules, which improves starch solubility (Zinn et al., 2002). As corn is steam-flaked to a greater degree of processing, bulk density is lighter. In the present study, 335 g/L SFC had greater total starch and enzymatic starch availability than 425 g/L SFC. In comparison, Hales et al. (2010b) reported total starch of 72.9% and enzymatic starch availability of 67.3% in corn steam-flaked to 335 g/L (26 lb/bu), and total starch of 73.7% and enzymatic starch availability of 63.4% in corn steam-flaked to 386 g/L (30 lb/bu) using the same facilities as the present study. Likewise, Hales et al. (2010a) reported the total starch content of intact SFC to be 76.61%, and 74.23% in 335 g/L (26 lb/bu) or 386 g/L (30 lb/bu) flake, respectively.

Greater DMI in cattle fed 425 g/L SFC-based diets was anticipated because DMI decreases in response to greater dietary energy density (335 g/L) via chemostatic intake regulation and increased metabolic acid concentration (Krehbiel et al., 2006), as was observed when cattle were fed 335 g/L SFC in the present study. Likewise, Garrett and Johnson (1983) described concentration of ruminal acetate as the primary regulator of short-term DMI when dietary ME is above maintenance. In the present study, paNE and observed/expected NE of 425 g/L SFC diets was indeed lesser than that of 335 g/L SFC diets, supporting the observed increase in DMI when cattle eat to a constant energy. Generally, feedlot nutritionists prefer a medium bulk density (280 to 370 g/L; i.e., 23 to 29 lb/bu) over heavier bulk density counterparts to maximize the NE_g value of corn, and to avoid decreased DMI and digestive disfunction often observed in lighter bulk densities (Zinn, 1990; Owens et al., 1997; Swingle et al., 1999). Accordingly, steam flaking was the primary grain processing method in finishing diets in multiple consecutive feedlot nutritionist surveys (Galyean, 1996; Galyean and Gleghorn, 2001; Vasconcelos and Galyean, 2007; Samuelson et al., 2016). In the present study, final BW and overall ADG and G:F of cattle fed 425 g/L SFC-based diets did not differ from cattle fed 335 g/L diets. Likely, the magnitude of greater DMI in cattle fed 425 g/L SFC-based diets compensated for potential losses in NE_g value of SFC processed to a lesser degree. Specifically, the cattle fed 425 g/L SFC-based diets consumed 4.3% more DMI, yet the difference in paNE_g was 3.2% greater in cattle fed diets 335 g/L SFC-based diets.

Differing growth performance results have been observed in previous corn processing studies using the same facilities as the present study. Hales et al. (2010b) evaluated the effect of diets containing 335 g/L (26 lb/bu) or 386 g/L SFC (30 lb/bu) and 6% or 10% dietary roughage concentration. No differences were observed in ADG or DMI; however, overall G:F was lesser in cattle fed 386 g/L SFC. On a carcass-adjusted basis, G:F was not different (Hales et al., 2010b). Ponce et al. (2013) fed diets containing 25% wet corn gluten feed in combination with 283 g/L (22 lb/bu), 335 g/L (26 lb/bu), or 386 g/L (30 lb/bu) SFC and did not observe any differences in feedlot growth performance on both a live- and carcass-adjusted basis. Nonetheless, although not statistically significant, numerical trends were observed for overall DMI and carcass-adjusted ADG and G:F to increase with increasing bulk density (Ponce et al., 2013). Domby et al. (2014) fed 283 g/L or 360 g/L SFC (22 lb/bu or 28 lb/bu, respectively) in combination with differing dietary concentrations of wet corn gluten feed and roughage. No differences of bulk density were observed in ADG, DMI, or G:F on a live weight basis, but carcass-adjusted G:F was greater in cattle fed 360 g/L SFC (Domby et al., 2014). The ADG and G:F results of these studies generally support what was observed in the present study. Lack of differences in DMI reported by Ponce et al. (2013) and Domby et al. (2014) could be a difference in diet composition, as these studies included corn milling by-products, and the present study did not. Many other studies using SFC and steam-flaked sorghum have reported greater DMI with greater bulk density (Xiong et al., 1991; Reinhardt et al., 1997; Swingle et al., 1999; Theurer et al., 1999; Zinn et al., 2008).

Carcass Characteristics

No differences in hot carcass weight were observed for the main effects of bunk management ($P \geq 0.67$; Table 5). Additionally, continuous carcass variables were not affected by bunk management ($P \geq 0.34$). Old and Garrett (1987) reported that percentage water, fat, protein, and Mcal/kg of the empty body did not differ among cattle fed *ad libitum*, or 70% or 85% of *ad libitum* intake. When expressed as a percentage of gain, cattle fed 70% of *ad libitum* had more water, less fat, and more protein than those fed to *ad libitum* intake or 85% of *ad libitum* (Old and Garrett, 1987). In carcasses adjusted to an equivalent hot carcass weight, Preston et al. (1973) observed greater carcass adiposity in cattle fed *ad libitum* intake than those fed 80% of *ad libitum* by measure of marbling score, fat thickness, empty body fat percentage (**EBF**), and percentage KPH. Likewise, Delfino and Mathison (1991) reported hot carcass weight and DP to be greater with increasing feeding level (52, 64, or 70 g of DM/kg of $BW^{0.75}$). When the data of Preston et al. (1973), Old and Garrett (1987), and Delfino and Mathison (1991) were summarized in a meta-analysis by Owens et al. (1995a), carcass composition did not differ, which is in agreement with the main effect of bunk management in the present study. Additionally, compared with that of the present study, DMI was more restrictive in the studies of Preston et al. (1973), Old and Garrett (1987), and Delfino and Mathison (1991), which ranged from 85% of *ad libitum*

Table 5. Main effects of bunk management and bulk density of steam-flaked corn on carcass characteristics of finishing beef steers[1]

	Bunk management			Flake density			
Item	AL	S	*P*-value[2]	335 g/L	425 g/L	*P*-value[2]	SEM[3]
Hot carcass weight, kg	403	400	0.67	399	404	0.38	4.2
DP,[4] %	66.14	66.07	0.77	65.93	66.28	0.15	0.207
Marbling score[5]	507	515	0.65	502	520	0.29	13.3
Fat thickness, cm	1.66	1.68	0.76	1.59	1.75	0.07	0.065
Longissimus dorsi area, cm^2	94.88	93.59	0.34	94.98	93.49	0.27	1.053
Calculated YG	3.30	3.37	0.60	3.20	3.47	0.05	0.097
EBF,[6] %	31.10	31.32	0.69	30.67	31.76	0.06	0.428
AFBW,[7] kg	542	534	0.50	548	529	0.09	9.1

[1]Bunk management methods were modified *ad libitum* (AL; target up to 5% orts at 0730 h bunk read) or slick (S; target trace or slick at 0730 h bunk read). Bulk density of steam-flaked corn was 335 g/L (26 lb/bu) or 425 g/L (33 lb/bu). No interaction of bunk management × bulk density of steam-flaked corn was observed ($P \geq 0.33$).

[2]Observed significance level for main-effect comparison of bunk management or bulk density of steam-flaked corn.

[3]Pooled SE of LSM (n = 24 pens/mean).

[4]Calculated as hot carcass weight divided by final shrunk BW.

[5]Leading digit in marbling indicates score; 2 = trace, 3 = slight, 4 = small, 5 = modest, 6 = moderate, 7 = slightly abundant, 8 = moderately abundant, 9 = abundant. The following digits indicate degree of marbling within marbling score.

[6]Empty body fat, %. Estimated using equations of Guiroy et al. (2001).

[7]Adjusted final shrunk weight at 28% EBF estimated using equations of Tylutki et al. (1994).

DMI as the least restrictive and 70% of *ad libitum* DMI as the most restrictive. By comparison, slick-bunk management and other programmed feeding systems apply lesser DMI restrictions of 5 to 10% less than expected *ad libitum* DMI (Pritchard and Bruns, 2003), which further supports the lack of carcass differences between slick and modified *ad libitum* bunk management in the present study.

Hot carcass weight, DP, marbling score, and *Longissimus dorsi* area did not differ between steers fed 335 g/L SFC and 425 g/L SFC ($P \geq 0.15$). Fat thickness ($P = 0.07$) and calculated EBF ($P = 0.06$) tended to be greater in steers fed 425 g/L SFC-based diets. Similarly, the calculated YG of steers fed 425 g/L SFC-based diets was greater than those fed 335 g/L SFC-based diets. The final BW adjusted to 28% EBF tended to be 3.5% lesser in steers fed 425 g/L SFC ($P = 0.09$).

Percentage USDA Prime, Choice, or Select QG were not affected (Table 6; $P \geq 0.51$) by bunk management or bulk density of SFC. There was a tendency ($P = 0.10$) for steers on slick-bunk management to have greater percentage of YG 1 carcasses, but a biological reason for this tendency is unclear given that no other differences in carcass composition or live growth performance was observed. Cattle fed 425 g/L SFC-based diets had a lesser incidence of YG 3 carcasses ($P = 0.02$), and a greater incidence of YG 4 or 5 carcasses ($P < 0.01$).

Adipose is an energetically efficient tissue and accretes at approximately 1.6 times the rate of protein on a caloric basis, and on a wet-tissue basis, protein accretion requires fewer kilocalories than adipose accretion (1.2 vs. 8.3 kcal/g, respectively; Owens et al., 1995a). Therefore, taking into consideration the water stored within protein, lean tissue gain is 4 times more efficient than adipose tissue gain (Owens et al., 1995a). Nonetheless, adipose becomes a greater proportion of tissue gain with advanced maturity (Simpfendorfer, 1974; NASEM, 2016). Concomitantly, GED increases with advanced maturity, which leads to greater EBF% at harvest (Gentry et al., 2020). In the present study, cattle consuming 425 g/L SFC had greater carcass 12th rib fat thickness than 335 g/L SFC-fed cattle, had greater incidence of YG 4 and 5, and a tendency for greater calculated EBF% despite no differences observed in G:F or GED. Likewise, no difference in final BW were observed on both a live- and carcass-adjusted basis, but when final BW was adjusted to equivalent 28% EBF, steers fed 335 g/L SFC were heavier.

Greater carcass adiposity in cattle consuming the lesser processed SFC was likely a result of greater DMI and throughout the feeding period. Cattle fed the 425 g/L SFC-based diets consumed approximately 4.3% more Mcal of NE_g per animal daily than their counterparts fed 335 g/L SFC-fed cattle, which is consistent with a decreased net energy value for SFC processed to 425 g/L SFC. Greater carcass adiposity and lean yield in cattle consuming a lesser processed grain has been frequently, but not consistently reported by a variety of measurements, including greater hot carcass weight (Reinhardt et al., 1997; Swingle et al., 1999; Domby et al., 2014), DP (Reinhardt et al., 1997; Ponce et al., 2013; Domby et al., 2014), increase in percentage of Choice carcasses (Xiong et al., 1991; Hales et al., 2010b), greater LM area (Ponce et al., 2013), and greater fat thickness (Domby et al., 2014). These observations are likely caused by greater DMI throughout the feeding period (Xiong et al., 1991; Reinhardt et al., 1997; Swingle et al., 1999; Theurer et al., 1999), which is in agreement with the present study.

Liver abscess incidence and severity at slaughter were not affected by bunk management strategy ($P \geq 0.66$). Steers fed 425 g/L SFC-based diets had 43.51% fewer ($P = 0.04$) liver abscesses; however, no difference in liver abscess severity was observed ($P \geq 0.12$).

As free glucose is liberated from starch granules in the rumen, lactate-producing microbes, especially *Streptococcus bovis*, are provided a favorable environment for proliferation and lactic acidosis may develop as a result (Owens et al., 1998). *Streptococcus bovis* are lactate-producing, acid-tolerant ruminal bacteria with rapid doubling time in environments where readily fermentable carbohydrate is available, thus easily dominating the microbial environment and altering the ruminal ecology to a more acidic state (Russell, 2002). As the severity of lactic acidosis progresses, integrity of the rumen wall may become compromised, allowing rumen microbes to escape, enter hepatic circulation, and become sequestered in the liver. Consequently, a liver abscess is formed (Nagaraja and Chengappa, 1998). Liver abscesses have been known to be a detriment to growth performance and carcass value of beef cattle for several decades (Brown et al., 1975; Brink et al., 1990; Reinhardt and Hubbert, 2015). In a meta-analysis, Brink et al. (1990) reported cattle with severely abscessed livers had 8.2% less ADG, 6.2% less DMI, 8 kg less final BW, and 4.5% less hot carcass weight compared with cohorts with no liver abscess. Likewise, Brown and Lawrence (2010) reported hot carcass weight of cattle with A− or A+ livers to be less compared with cohorts with normal livers. In a survey of consulting feedlot nutritionists representing over 14 million cattle on feed annually (approximately 11.1%), Samuelson et al. (2016) reported medicated feed additives were used by 83.4% of nutritionist's clients to control liver abscesses. Of the compounds approved for this purpose, tylosin phosphate is considered most effective and therefore is the most widely used (Nagaraja et al., 1999).

In a national liver audit by Herrick (2018), 130,845 livers from 7 fed beef processing facilities were evaluated. Average liver abscess incidence was 20.3% overall (fed beef steers = 18.2%; fed beef heifers = 19.1%; fed Holsteins = 25.0%). Comparably, in the present study, liver abscess incidence in steers fed 425 g/L SFC-based diets without tylosin phosphate was 16.7%, a notable decrease compared with steers fed 335 g/L SFC-based diets (29.5%). Demonstrated in the present study, a lighter bulk density of SFC has greater enzymatic starch availability, which could serve as a predisposing factor for digestive dysfunction

Table 6. Main effects of bunk management and bulk density of steam-flaked corn on categorical carcass characteristics of finishing beef steers[1]

	Bunk management			Flake density			
Item	AL	S	*P*-value[2]	335 g/L	425 g/L	*P*-value[2]	SEM[3]
QG, %							
Prime	5.56	6.60	0.78	4.86	7.29	0.51	2.597
Choice	82.99	81.60	0.79	82.64	81.94	0.90	3.694
Select	11.46	11.81	0.93	12.50	10.76	0.68	3.605
YG, %							
1	7.29	13.54	0.10	10.76	10.07	0.85	3.126
2	28.47	19.10	0.13	24.31	23.26	0.87	4.309
3	46.53	42.71	0.55	52.08	37.15	0.02	6.071
4 or 5	17.71	24.65	0.19	12.85	29.51	<0.01	3.670
Liver score, %							
Abscessed	24.31	27.88	0.69	29.51	16.67	0.04	4.205
A[4]	19.10	16.67	0.66	22.22	13.54	0.12	3.820
A+[5]	5.21	5.21	1.00	7.29	3.13	0.25	2.532

[1]Bunk management methods were modified *ad libitum* (AL; target up to 5% orts at 0730 h bunk read) or slick (S; target trace or slick at 0730 h bunk read). Bulk density of steam-flaked corn was 335 g/L (26 lb/bu) or 425 g/L (33 lb/bu). No interaction of bunk management × bulk density of steam-flaked corn was observed ($P \geq 0.09$).

[2]Observed significance level for main-effect comparison of bunk management or bulk density of steam-flaked corn.

[3]Pooled SE of LSM (n = 24 pens/mean).

[4]A = 2 to 4 small active abscesses (<6 cm in diameter); minor abscesses.

[5]A+ = 1 or more large (>6 cm in diameter), active abscesses; severe abscesses.

and the development of liver abscesses, especially in diets with decreased NDF from roughage. As the beef industry continues to seek alternatives to antimicrobials, increasing bulk density of SFC from the industry average of 350 g/L (27 lb/bu; Samuelson et al., 2016) could be a management-based alternative to feeding tylosin phosphate; however, more research should be conducted in this area.

APPLICATIONS

Bunk management and bulk density of SFC are common feedlot management practices, and more research is needed involving these procedures with diets without tylosin phosphate. In the present study, bunk management did not affect measures of growth performance, carcass characteristics, or liver abscess score and severity. Compared with steers fed diets containing 335 g/L SFC, steers fed 425 g/L SFC-based diets had greater DMI, similar overall feed efficiency, and 43.5% fewer liver abscesses; however, the steers fed 425 g/L SFC-based diets were also fatter according to carcass-based measurements. Increasing bulk density of SFC, thereby decreasing degree of processing, could be a useful management strategy as the beef industry strives to decrease antimicrobial use, but additional research is needed.

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