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Effects of roughage inclusion and particle size on performance and rumination behavior of finishing beef steers[1]

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ABSTRACT: Roughage is typically mechanically processed to increase digestibility and improve handling and mixing characteristics in beef cattle finishing diets. Roughage is fed to promote ruminal health and decrease digestive upset, but inclusion in finishing diets is limited due to the cost per unit of energy. Rumination behavior may be a means to standardize roughage in beef cattle finishing diets, and increasing particle size of roughage may allow a decrease in roughage inclusion without sacrificing animal performance. Therefore, the objectives of this study were to quantify rumination time for a finishing beef animal and to evaluate the effects of corn stalk (CS) inclusion rate and particle size on rumination behavior, animal performance, and carcass characteristics. Fifty-one individually fed steers (385 ± 3.6 kg initial BW) were used in a randomized complete block design feeding study. Corn stalks were passed through a tub grinder equipped with a 7.62-cm screen once to generate long-grind CS (LG-CS) or twice to generate short-grind CS (SG-CS). Dietary treatments were based on steam-flaked corn and included, on a DM basis, 30% wet corn gluten feed (WCGF) with 5% SG-CS (5SG), 30% WCGF with 5% LG-CS (5LG), and 25% WCGF with 10% SG-CS (10SG). The Penn State Particle Separator was used to separate ingredients and treatment diets and to estimate physically effective NDF (peNDF). On d 70, each steer was fitted with a collar (HR Tag; SCR Dairy, Netanya, Isreal), which continuously measured rumination minutes via a sensory microphone. Long-grind CS contained more ($P < 0.01$) peNDF than SG-CS, and the 10SG diet contained more ($P = 0.03$) peNDF than the 5LG and 5SG diets. Dry matter intake was greatest ($P = 0.03$) for steers consuming 5LG and least for steers consuming 10SG, with cattle consuming 5SG being intermediate. Carcass-adjusted ADG and G:F were greatest ($P \leq 0.03$) for steers consuming 5LG and 5SG compared with steers consuming 10SG. Hot carcass weight tended ($P = 0.10$) to be greatest for steers consuming 5LG and least for steers consuming 10SG, with steers consuming 5SG being intermediate. Dressing percent was greater ($P = 0.01$) for steers consuming 5LG and 5SG than for steers consuming 10SG. A significant interaction ($P < 0.01$) occurred for rumination minutes × day. Rumination (min/day) were greatest ($P = 0.01$) for steers consuming 10SG followed by steers consuming 5LG and was lowest for steers consuming 5SG. Increasing particle size of roughage may be a means to decrease roughage inclusion rate while maintaining rumination and performance.

Key words: beef cattle, corn stalks, finishing diet, rumination

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INTRODUCTION

Fiber requirements and characteristics are not well defined for finishing cattle, especially in combination with fibrous byproducts such as distillers' grains and corn gluten feed. Benton et al. (2015) concluded performance was greater when feeding a low inclusion of corn stalks compared with a low inclusion of alfalfa or corn silage in finishing diets with 30% wet distillers' grains with solubles (**WDGS**). The data suggests

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that high-quality roughage may not be needed in finishing diets, whereas low-quality roughages may provide the appropriate stimulation for proper rumen function. Mertens (1997) proposed physically effective NDF (**peNDF**) as a means to classify different roughage sources. Physically effective NDF relates to the roughage's ability to stimulate rumination by considering particle size and NDF content (Mertens, 1997). Shain et al. (1999) noted that cattle consuming dry-rolled corn (**DRC**)-based finishing diets with wheat straw (5.6% DM basis) ruminated more than cattle consuming alfalfa (10% DM basis; 235 and 190 min/d, respectively). The greater rumination time suggests that NDF in wheat straw is more physically effective than NDF in alfalfa hay, even at lesser inclusion rates.

Fiber characteristics and rumination behavior has been more thoroughly researched in dairy cattle. Further research is needed to standardize rumination behavior and roughage characteristics (i.e., particle size and inclusion rate) for finishing cattle consuming steam-flaked corn (**SFC**). Physically effective NDF may be a means to standardize fiber and fiber requirements for feedlot diets (Mertens, 1997; Fox and Tedeschi, 2002). The hypothesis was that a longer particle size and lesser inclusion rate of a low-quality forage could replace a shorter particle size at a higher inclusion rate in SFC-based finishing diets. Therefore, the objectives of this study were to examine the effects of various inclusion rates and particle sizes of corn stalks on performance, carcass characteristics, and rumination behavior in finishing beef cattle.

MATERIALS AND METHODS

All procedures involving live animals were approved by the West Texas A&M – Cooperative Research, Education, and Extension Team University Animal Care and Use Committee (approval number 04-01-14).

Animals

Fifty-four crossbred steers (337 kg arrival BW) were received at the Texas A&M AgriLife Research/USDA-ARS Feedlot in Bushland, TX, on April 13, 2015. Steers were placed into 6 pens equipped with 9 Calan head gates (American Calan, Northwood, NH) per pen. Cattle were allowed ad libitum access to long stem hay and fresh water and allowed to rest for 24 h before processing. Steers were individually weighed (Trojan Livestock Handling Equipment, Weatherford, OK; Tru-Test Inc., Mineral Wells, TX; readability ± 0.45 kg; validated with 454 kg certified weights before each use), and a uniquely numbered ear tag was placed in the ear of each animal. Initial processing included vaccination for viral and clostridial disease (Bovi-Shield Gold 5 and Ultra-Choice 7; Zoetis Inc., Madison, NJ), long-acting growth implant (Revalor XS; 200 mg of tenbolone acetate plus 40 mg of estradiol; Merck Animal Health, Summit, NJ), treatment for internal and external parasites (Safeguard; Merck Animal Health), and Dectomax pour-on (Zoetis Inc.) and subcutaneous injection with tulathromycin (Draxxin; Zoetis Inc.). Weights were collected before feeding for that day and cattle were allowed ad libitum access to water. Following processing, steers were returned to the pens and offered a 40:60% roughage:concentrate grower diet and trained to use the individual head gates. At the beginning of the trial, 2 consecutive weights were collected and averaged to determine initial BW (n = 51; 385 ± 3.6 kg initial BW). Steers were stratified by initial BW and assigned into 2 weight blocks (3 pens per block). Within each block, steers were randomly assigned to pen, treatment, and head gate within pen (3 treatments per pen). Individual BW were collected before feeding at 35-d intervals, and 2-d consecutive weights were collected and averaged for final BW. One animal was removed due to sorting of roughage and another due to aggressive feeding behavior. On d 70 of the experiment, animals were administered an additional anthelmintic (Valbazen; Zoetis Inc.) and fitted with a collar (HR Tag; SCR Dairy, Netanya, Israel) that continuously measured rumination minutes via a sensory microphone that detected the passage of a feed bolus (Stangaferro et al., 2016). In addition, the collars also continuously measured activity, with activity defined as movement or no movement. One collar was removed due to a small sore on the neck of an animal; the data collected from that animal was removed from the data set.

Treatment and Experimental Design

To achieve different particle sizes of corn stalks (**CS**), CS were passed through a commercial tub grinder equipped with a 7.62-cm screen once (long-grind CS [**LG-CS**]) or twice (short-grind CS [**SG-CS**]). Particle size of individual ingredients and treatment diets were quantified using the Penn State Particle Separator (**PSPS**; Heinrichs, 2013). Three treatment diets were fed in a completely randomized block design. The treatment diets (Table 1) were SFC based and included, on a DM basis, 30% wet corn gluten feed (**WCGF**) with 5% SG-CS (**5SG**), 30% WCGF with 5% LG-CS (**5LG**), or 25% WCGF with 10% SG-CS (**10SG**). Corn stalks were replaced with WCGF in the 10SG diet instead of SFC, so that a portion of the fiber that was removed with the CS was replaced with fiber from WCGF.

Feed Management

Feed bunks were observed at approximately 0830 h each day to estimate orts and adjust daily feed calls. The bunks were managed such that ≤0.45 kg of dry orts remained in the bunk each day. Diets were mixed in a mixer wagon mounted on load cells (Roto-Mix IV 84-8; Roto-Mix, Dodge City, KS; Digi-Star LLC, Fort Atkinson, WI; readability ± 0.45 kg) and timed to allow 3 min of closed door mixing time to avoid pulverizing the diet and ingredients. Feed was then off-loaded into large plastic feed bins and weighed on a platform scale (Ohaus SD Series; Ohaus Corp., Parsippany, NJ) to the nearest 0.05 kg of the feed call and delivered to each individual bunk. Feeding began at 0900 h each day.

Sampling and Laboratory Analysis

Diet samples were collected from each bunk once a week and composited according to dietary treatment. Ingredient samples were collected weekly to determine DM content, composited by month, and sent to a commercial laboratory for nutrient analysis (Servi-Tech Laboratories, Amarillo, TX). Dry matter content of feed ingredients, diets, and orts was determined by drying in a forced-air oven at 55°C for 48 h (Despatch model LBB2-18-1; Despatch Industries, Minneapolis, MN). Samples of individual feed ingredients and mixed diets were separated using the PSPS as described by Kononoff et al. (2003). Percent peNDF was estimated by multiplying the percentage of sample larger than 4 mm in particle size (top 3 sieves) by the percent NDF (as a decimal) of the ingredient before separation. Mertens (1997) describes this method using a 1.18-mm sieve, based on the assumption that particles smaller than 1.18 mm can readily pass through the reticulo-omasal orifice without mastication and may be able to escape ruminal fermentation (Poppi and Norton, 1980). Since then, Yang et al. (2001) observed that particles >3.35 mm made up approximately 5% of duodenal digesta in Holstein cows. Hence, the PSPS used in this study contained 4-mm apertures in the third sieve. Steers were randomly selected (n = 9 per treatment) and a fecal sample was collected via rectal grab on d 1, 35, 70, 105, and 140. Fecal samples were analyzed for NDF and starch content by a commercial laboratory (Servi-Tech Laboratories).

Carcass Evaluation

When approximately 60% of the cattle within a BW block were visually apprised to have an external fat cover sufficient to grade USDA Choice, they were transported to a commercial abattoir (Tyson Fresh Meats, Amarillo, TX). Shipping occurred on d 148 for the heavy block and d 162 for the light block (average of 155 d on feed). Trained personnel from the West Texas A&M University Beef Carcass Research Center (Crayon, TX) collected HCW and liver abscess data on the day of slaughter, and USDA Quality and Yield Grade were determined after a 48-h chill. Carcass-adjusted final shrunk BW (**SBW**) was calculated from HCW divided by the average dressing percent (**DP**) across treatments (63.52%), and carcass-adjusted ADG was calculated from carcass-adjusted final SBW, initial BW, and days on feed, with carcass-adjusted G:F calculated as carcass-adjusted ADG divided by average DMI. Metabolizable energy, NEm, and NEg were calculated using methods described by Zinn and Shen (1998).

Table 1. Ingredient and nutrient composition of dietary treatments (DM basis, except DM)

	Dietary treatment[1]		
Item, % DM basis	5SG	5LG	10SG
Steam-flaked corn	54.45	54.35	55.90
Wet corn gluten feed	30.00	30.20	24.39
Short-grind corn stalks[2]	5.10	–	9.75
Long-grind corn stalks[2]	–	5.10	–
Supplement premix[3]	3.98	4.01	3.83
Urea	0.51	0.51	0.77
Limestone	2.41	2.26	1.83
Corn oil	3.55	3.58	3.53
Calculated nutrient values			
DM, %	78.38	78.88	80.14
CP, %	13.40	13.40	13.20
NDF, %	18.00	18.00	20.00
Ether extract, %	6.03	6.04	5.93
Ca, %	0.94	0.87	0.76
P, %	0.42	0.42	0.37
S, %	0.19	0.19	0.17
ME,[4] Mcal/kg	2.93	2.93	2.89
NEm,[4] Mcal/kg	2.23	2.23	2.16
NEg,[4] Mcal/kg	1.32	1.32	1.28

[1]5SG = 30% wet corn gluten feed with 5% short-grind corn stalks; 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks; 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks.

[2]Short-grind corn stalks were passed through a commercial tub grinder twice and long-grind corn stalks were passed through a commercial tub grinder once. The tub grinder was equipped with a 7.6-cm screen.

[3]Supplement was formulated to meet or exceed vitamin and mineral requirements established by the NRC (2000). Supplement provided 35.6 mg/kg of monensin and 7.9 mg/kg of tylosin (Elanco Animal Health, Greenfield, IN).

[4]Values for the experimental diets were calculated from NRC (2000) tabular degradable intake protein and NE values based on proximate analysis of ingredients.

Statistical Analysis

Analysis of variance for animal performance, fecal starch and NDF concentration, carcass characteristics, and rumination and activity data were performed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with animal as the experimental unit and weight

Table 2. Particle separation analysis and estimated physically effective NDF (peNDF) of feed ingredients

Item	Ingredient[1]				SEM	*P*-value
	SFC	WCGF	SG-CS	LG-CS		
No. of samples	16	16	16	16	–	–
NDF, % DM	8.40	33.80	70.76	73.00	–	–
	Retained/screen, %					
Sieve screen size, mm						
19.0	1.04[cf]	5.46[ce]	21.88[b]	30.60[a]	2.617	<0.01
8.0	75.25[a]	30.32[c]	33.38[bc]	38.76[b]	4.060	<0.01
4.0	13.26[b]	32.83[a]	16.12[b]	15.44[b]	2.067	<0.01
Particles less than 4 mm	10.45[b]	31.40[a]	28.62[a]	15.20[b]	3.332	<0.01
Particles greater than 4 mm	89.55[a]	68.60[b]	71.38[b]	84.80[a]	3.332	<0.01
Estimated peNDF,[2] % DM	7.52[d]	23.19[c]	50.51[b]	61.91[a]	1.895	<0.01

[a–c]Means within a row without a common superscript differ ($P \le 0.05$).

[d–f]Means within a row without a common superscript tend to differ ($P \le 0.10$).

[1]SFC = steam-flaked corn; WCGF = wet corn gluten feed; SG-CS = short-grind corn stalks (passed through a commercial tub grinder twice); LG-CS = long-grind corn stalks (passed through a commercial tub grinder once). The tub grinder was equipped with a 7.62-cm screen.

[2]Percent peNDF was estimated by multiplying the percentage of sample larger than 4 mm in particle size (top 3 sieves) by the percent NDF (as a decimal) of the ingredient before separation.

block considered a random effect. The model included effects of treatment, day, and treatment × day. When $P \le 0.10$, mean separation was performed using the LSMEANS statement with the PDIFF option in SAS. For rumination behavior, day was considered a repeated measure, with animal declared as the subject, and compound symmetry was selected as the covariance structure. Any observation that was outside 3 SD of the mean was considered an outlier and removed from the data set. The Kenward–Roger denominator degrees of freedom method was used when a data set contained missing observations. Analysis of variance for particle separation and estimated peNDF data were performed using the MIXED procedure of SAS. When $P \le 0.10$, mean separation was performed using the LSMEANS statement with the PDIFF option in SAS. For all analyses, effects were considered significant at a $P \le 0.05$ and tendencies were declared at $P \le 0.10$ to $P > 0.05$.

RESULTS AND DISCUSSION

Particle Separation

Particle separation results using the PSPS for individual feed ingredients are presented in Table 2. The proportion of particles that were larger than 19 mm was greatest ($P < 0.01$) for LG-CS followed by SG-CS, WCGF, and SFC. Wet corn gluten feed tended ($P = 0.10$) to contain more particles larger than 19 mm than SFC. Steam-flaked corn contained the greatest ($P < 0.01$) proportion of particles that were retained on the 8-mm sieve followed by LG-CS, SG-CS, and WCGF. Long-grind CS and SG-CS had similar ($P = 0.19$) proportions retained on the 8-mm sieve, whereas SG-CS and WGCF also had similar ($P = 0.45$) weights retained on the 8-mm sieve. Particles retained on the 4-mm sieve were greatest ($P < 0.01$) for WGCF compared with SG-CS, LG-CS, and SFC, with the latter 2 exhibiting similar values ($P > 0.17$). Wet corn gluten feed and SG-CS contained the greatest ($P < 0.01$) proportion of small particles (<4 mm) compared with LG-CS and SFC. Particles larger than 4 mm (sum of particles retained on the top 3 sieves of the PSPS) were greatest ($P < 0.01$) for SFC and LG-CS compared with SG-CS and WCGF. Estimated peNDF using particle separation was greatest ($P < 0.01$) for LG-CS followed by SG-CS, WCGF, and SFC. The estimated peNDF fits the experimental preconceived notion that the coarsest ingredients such as CS have a greater estimated peNDF than WCGF and SFC. Also, the fibrous ingredients (CS and WCGF) have a greater estimated peNDF value than SFC. Perhaps the most important difference is that the LG-CS have a greater estimated peNDF compared with the SG-CS, with both having similar nutrient content.

Results of particle separation data using the PSPS for the treatment diets are presented in Table 3. The 10SG diet contained the greatest ($P < 0.01$) proportion of particles larger than 19 mm followed by the 5LG and 5SG diets. No differences ($P = 0.13$) were observed for particles retained on the 8-mm sieve between the treatment diets. No differences ($P = 0.25$) were observed for particles smaller or larger than 4 mm between the treatment diets. Estimated peNDF was greater ($P < 0.01$) for the 10SG diet compared with the 5SG and 5LG diets (13.00, 11.40, and 11.29%, respectively). Taking into consideration the estimated peNDF of the ingredients and the fact that the diets were balanced to a similar nutrient composition, the authors attribute the peNDF differences of the treatment diets to CS inclusion rate rather than particle size. It seems that the differences

Table 3. Particle separation analysis and estimated physically effective NDF (peNDF) of treatment diets

Item	Dietary treatment[1] 5SG	5LG	10SG	SEM	*P*-value
No. of samples	21	21	21	–	–
NDF, % DM	18.00	18.00	20.00	–	–
	Retained/screen, %				
Sieve screen size, mm					
19.0	1.56[c]	2.47[b]	3.27[a]	0.386	<0.01
8.0	39.93	38.74	41.70	1.464	0.13
4.0	21.82[a]	21.52[a]	20.05[b]	0.562	0.01
Particles less than 4 mm	36.69	37.26	34.98	1.409	0.25
Particles greater than 4 mm	63.31	62.74	65.02	1.409	0.25
Estimated peNDF,[2] % DM	11.40[b]	11.29[b]	13.00[a]	0.260	<0.01

[a–c]Means within a row without a common superscript differ ($P \le 0.05$).

[1]5SG = 30% wet corn gluten feed with 5% short-grind corn stalks; 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks; 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks.

[2]Percent peNDF was estimated by multiplying the percentage of sample larger than 4 mm in particle size (top 3 sieves) by the percent NDF (as a decimal) of the ingredient before separation.

($P < 0.01$) in estimated peNDF between the LG-CS and SG-CS were not detectible between the 5LG and 5SG diets ($P = 0.69$) by the PSPS. Low inclusion rate of CS and potential mechanical pulverization of the larger particles during mixing could have further affected separation difference within treatment diets.

To maximize ADG, Mertens (2002) recommends a dietary peNDF value of 12 to 15%, and the peNDF values in the current study remained at the lower end of that range, whereas Fox and Tedeschi (2002) recommend that feedlot diets contain 7 to 10% peNDF. Values observed in this study lay between the recommendations of the 2, which further illustrates the need to refine the peNDF requirements of feedlot cattle.

Animal Performance

Treatment means for feedlot performance are presented in Table 4. No treatment × day ($P > 0.19$) interactions were observed for animal performance; therefore, only differences in treatment means will be discussed. No signs of sorting of the dietary treatments were evident for steers that remained on trial. No differences ($P = 0.52$) were observed for final SBW for steers consuming 5SG, 5LG, and 10SG. However, carcass-adjusted final SBW tended ($P = 0.10$) to be greatest for steers consuming 5LG and lowest for steers consuming 10SG, with steers consuming 5SG being intermediate. Results from Farran et al. (2006) would concur with the final BW observed in this study. Feeding 35% WCGF in DRC-based diets that contained 3.75 or 7.5% alfalfa hay (DM basis) had no effect on final BW (Farran et al., 2006). Benton et al. (2015) observed similar final BW for steers consuming 3 and 6% CS in DRC- and high-moisture corn-based-based diets with 30% WDGS. Kreikemeier et al. (1990) observed no differences in final BW of steers consuming 5 or 10% roughage (50:50 mixture of alfalfa hay and corn silage) in finishing diets with WDGS. In contrast, Parsons et al. (2007) evaluated 0, 4.5, and 9.2% alfalfa hay in SFC-based diets containing 40% WCGF and observed a linear increase in final BW and carcass-adjusted final BW as roughage inclusion rate increased.

Dry matter intake was greatest ($P = 0.03$) for steers consuming 5LG and least for cattle consuming 10SG, with cattle consuming 5SG intermediate (9.92, 9.73, and 9.54 kg/d, respectively). These results contrast with previous research where DMI increased as roughage inclusion rate increased (Farran et al., 2006; Parsons et al., 2007). Farran et al. (2006) observed a linear increase ($P < 0.01$) in DMI as alfalfa was increased from 0 to 7.5% of dietary DM. Parsons et al. (2007) also observed a linear increase ($P = 0.01$) in DMI as alfalfa hay was increased from 0 to 9% of dietary DM. Farran et al. (2006) replaced DRC with increasing levels of alfalfa, and Parsons et al. (2007) replaced SFC with alfalfa, whereas in the present study, CS replaced WCGF. Dietary energy is likely diluted to a greater extent when roughage replaces corn than when roughage replaces a fibrous byproduct. However, Benton et al. (2015) observed no differences ($P > 0.05$) in DMI for steers consuming 3 or 6% CS. Shain et al. (1999) observed no difference in DMI for steers consuming DRC-based diets with 5.2% wheat straw or 10% alfalfa. The similar intake response observed by Shain et al. (1999) may be due to roughage source and inclusion rate rather than inclusion rate alone. Overall, it is widely accepted that increasing roughage inclusion in finishing diets (up to the point of physical restriction) increases DMI (Kreikemeier et al., 1990; Galyean and Hubbert, 2014). The small sample size in this study may not have been able to capture this pattern

Table 4. Effect of corn stalk particle size and inclusion rate on finishing steer performance

Item	Dietary treatment[1]			SEM	*P*-value		
	5SG	5LG	10SG		Treatment	Day	Treatment × day
No. of steers	18	17	16	–	–	–	–
DOF[2]	155	155	155	–	–	–	–
Initial SBW,[3] kg	386	385	383	6.7	0.95	–	–
Final SBW,[3] kg	635	632	622	11.6	0.52	–	–
DMI, kg/d	9.73[ab]	9.92[a]	9.54[b]	0.14	0.03	0.46	0.97
ADG, kg/d	1.62	1.58	1.54	0.08	0.17	0.05	0.96
G:F, kg/kg	0.164[d]	0.160[e]	0.158[e]	0.003	0.10	<0.01	0.90
Carcass-adjusted performance[4]							
Final SBW, kg	631[ab]	639[a]	614[b]	11.8	0.10	–	–
ADG, kg/d	1.53[a]	1.54[a]	1.39[b]	0.062	0.03	–	–
G:F	0.156[a]	0.155[a]	0.142[b]	0.005	0.01	–	–

[a,b]Means within a row without a common superscript differ ($P \leq 0.05$).

[d,e]Means within a row without a common superscript tend to differ ($P \leq 0.10$).

[1]5SG = 30% wet corn gluten feed with 5% short-grind corn stalks; 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks; 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks.

[2]DOF = days on feed; Block 1 = 162 and Block 2 = 148.

[3]SBW = shrunk BW. A 4% shrink was applied to BW.

[4]Carcass-adjusted final SBW was calculated from HCW divided by the average dressing percent across treatments (63.52%) and carcass-adjusted ADG was calculated from carcass-adjusted final SBW, initial BW, and days on feed, with carcass-adjusted G:F calculated as carcass-adjusted ADG divided by average DMI.

of intake. In this study, DMI as a percent of SBW was 1.79, 1.83, and 1.78% (SEM = 0.025) for steers consuming 5SG, 5LG, and 10SG, respectively. Cattle consuming 5LG had a greater ($P \leq 0.05$) DMI as a percent of SBW than cattle consuming 5SG or 10SG, with no difference ($P = 0.55$) between cattle consuming 5SG and 10SG. Intake as a percent of SBW was statistically different in this study; however, the authors suspect there was no biological significance.

No differences ($P = 0.17$) in ADG were observed in this study. However, steers consuming 5SG and 5LG had a greater ($P < 0.01$) carcass-adjusted ADG than steers fed 10SG. This may be due to the dilution of energy as CS replaced WCGF in the 10SG diet. In contrast, Parsons et al. (2007) observed a linear increase in ADG and carcass-adjusted ADG as alfalfa hay was increased (0, 4.5, and 9.0%) in SFC-based diets. In contrast, May et al. (2011) reported no difference in ADG or carcass-adjusted ADG for steers consuming 7.5, 10, or 12.5% alfalfa hay in SFC-based diets containing 15 or 30% WDGS. In diets based on DRC, Farran et al. (2006) observed no differences in ADG for steers fed 3.75 or 7.5% alfalfa with 35% WCGF. Roughages are poor sources of energy compared with concentrates. Daily gain in cattle consuming higher levels of roughage is usually the product of increased DMI and subsequently increased NEg intake (Defoor et al., 2002). In this study, cattle consuming the less energy-dense diet (10SG) did not consume more DM than the steers consuming the 5% CS diets. Therefore, NEg intake was not increased compared with the steers fed 5% CS, and this was evident in carcass-adjusted ADG.

Gain efficiency tended ($P = 0.10$) to be greater for cattle consuming 5SG compared with cattle consuming 5LG or 10SG. Carcass-adjusted G:F was greater ($P = 0.01$) for steers consuming 5SG and 5LG diets compared with steers consuming the 10SG diet. In contrast, Parsons et al. (2007) observed no differences in G:F or carcass-adjusted G:F of cattle consuming 0, 4.5, or 9% alfalfa in diets containing 40% WCGF. May et al. (2011) reported a quadratic tendency for carcass-adjusted G:F when feeding approximately 8, 10.5, and 13% alfalfa hay in SFC-based diets with 15 or 30% WDGS (0.171, 0.163, and 0.167, respectively). Benton et al. (2015) reported no differences in G:F for steers consuming low or standard inclusions of alfalfa (4 and 8%, respectively), corn silage (6 and 12%, respectively), or CS (3 and 6%, respectively). Gain efficiencies reported in Parsons et al. (2007) and Benton et al. (2015) were likely not different due to intake being relative to gain for each roughage inclusion rate. In this study, cattle consuming 5SG consumed slightly less and gained slightly more than cattle consuming 5LG. Adjusting performance using a common DP tends to favor animals with the greatest DP and heaviest HCW. By using a lesser (compared with the actual) DP to calculate final SBW from HCW, the heaviest carcasses yield a greater carcass-adjusted final SBW compared with the live final SBW, which also increased carcass-adjusted G:F and ADG.

Energy values calculated from performance data using methods described by Zinn and Shen (1998) and fecal NDF and starch are presented in Table 5. No differences ($P \geq 0.49$) were observed for ME, NEm, or NEg values calculated from animal performance. Steers fed

Table 5. Effect of corn stalk particle size and inclusion rate on fecal NDF and starch concentrations and energy values calculated from animal performance

	Dietary treatment[1]				*P*-value[2]		
Item	5SG	5LG	10SG	SEM	Treatment	Day	Treatment × day
Fecal NDF, %	49.35[a]	47.36[b]	47.08[b]	0.779	0.03	<0.01	0.12
Fecal starch, %	0.87	1.01	1.23	0.130	0.15	0.04	0.19
Calculated energy values,[2] Mcal/kg of DM							
ME	3.04	3.01	2.99	0.045	0.50	–	–
NEm	2.07	2.04	2.02	0.038	0.50	–	–
NEg	1.40	1.38	1.36	0.033	0.49	–	–

[a,b]Means within a row without a common superscript differ ($P \leq 0.05$).

[1]5SG = 30% wet corn gluten feed with 5% short-grind corn stalks; 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks; 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks.

[2]Dietary NEm and NEg values were calculated as described by Zinn and Shen (1998).

5SG had a greater ($P = 0.03$) concentration of NDF in the feces compared with steers fed 5LG or 10SG. This could be due to the decreased ($P = 0.01$) rumination time (Fig. 1) observed for cattle consuming 5SG compared with cattle consuming 5LG and 10SG. Ruminal pH was not measured in this study; however, Church (1988) suggested that cattle that ruminate more often have greater salivary flow and ruminal buffering capacity. A higher ruminal pH would lead to increased digestion of fiber by cellulolytic bacteria (Church, 1988). Forage particle size and inclusion rate did not affect ($P = 0.15$) fecal starch concentration in this study. Across all treatments, estimated total tract digestibility of starch from fecal starch concentrations calculated using equations from Zinn et al. (2007) yielded a value of 99.5% for this study. These data are within the range reported by Zinn et al. (2007) and suggest the cattle efficiently utilized starch throughout the finishing period.

Carcass Characteristics

Carcass characteristics are presented in Table 6. Marbling score ($P = 0.65$), 12th-rib fat thickness ($P = 0.49$), LM area ($P = 0.65$), and KPH ($P = 0.99$) were similar across treatments. Hot carcass weight tended to be greater ($P = 0.10$) for steers fed 5LG compared with steers fed 10SG, with steers fed 5SG being intermediate. In contrast, Parsons et al. (2007) reported a linear increase in HCW as dietary roughage inclusion increased from 0 to 9% of dietary DM. Farran et al. (2006) also reported a linear increase in HCW as inclusion of roughage increased. In these 2 studies, DMI and ADG also increased as percent roughage in the diet increased. Overall, previous research demonstrated increased HCW from cattle consuming more roughage; however, this was not the case in the current study. Dressing percent was greater ($P = 0.01$) for the steers consuming 5% roughage, regardless of CS grind size, compared with cattle consuming the 10SG diet, which is likely due to increased gut fill of cattle fed the 10SG diet. May et al. (2011) and Quinn et al. (2011) reported no differences in DP when feeding various roughage concentrations and sources in SFC-based diets with 15 and 30% WDGS. Benton et al. (2015) also reported no differences in DP for steers fed various concentrations of alfalfa, CS, or corn silage in DRC- and high-moisture corn-based-based diets. In contrast, Parsons et al. (2007) reported a quadratic effect for DP of steers fed 0, 4.5, and 9% alfalfa, with the greatest DP observed for steers fed 4.5% alfalfa (62.78, 63.53, and 63.17%, respectively). These results concur with the results of the current study, that steers consuming approximately 5% roughage had the greatest DP. Decreasing roughage inclusion in finishing diets had no effect ($P = 0.76$) on percent normal or abscessed livers in this study. This may due to a small sample size for each treatment. A larger sample size may be more appropriate for liver abscess rate comparisons. Also, it is worthwhile to note that no digestive upset was observed in this study.

Rumination Behavior

Rumination × day minutes (d 70–148) are illustrated in Fig. 1, with a significant treatment × day interaction ($P < 0.01$) occurring. Treatment differences in rumination time did not occur until approximately d 112; however, no changes in diet composition or daily intake occurred at this time, so the response is difficult to explain. Steers consuming the 10SG diet ruminated the most (min/d) followed by steers consuming the 5LG diet, and steers consuming the 5SG diet ruminated the least ($P = 0.01$; 307, 289, and 245 min/d, respectively; Table 7). Excess roughage decreases dietary energy and limits gain, whereas too little roughage may increase the incidence of digestive upset and limit gain. Therefore, the appropriate roughage level is critical to achieve maximum gain. Currently, the appropriate roughage level and particle size is not known. In this study, daily gain was not different, so it is difficult

Table 6. Effect of corn stalk particle size and inclusion rate on carcass characteristics of finished beef steers

	Dietary treatment[1]				
Item	5SG	5LG	10SG	SEM	*P*-value
HCW, kg	401[de]	406[d]	390[e]	7.5	0.10
DP[2]	63.59[a]	64.32[a]	62.49[b]	0.586	0.01
Marbling score[3]	383	409	384	24.1	0.43
12th-rib fat, cm	1.34	1.28	1.15	0.159	0.49
LM area, cm^2	89.9	89.6	87.0	3.37	0.65
KPH, %	2.03	2.03	2.04	0.137	0.99
Calculated yield grade	3.11	3.11	3.02	0.247	0.92
Choice or greater, %	37.5	47.9	35.7	13.26	0.65
Select or less, %	62.5	52.1	64.3	13.26	0.65
Normal livers, %	94.4	88.9	92.9	7.39	0.76
Abscessed livers, %	5.6	11.1	7.1	7.39	0.76

[a,b]Means within a row without a common superscript differ ($P \leq 0.05$).

[d,e]Means within a row without a common superscript tend to differ ($P \leq 0.10$).

[1]5SG = 30% wet corn gluten feed with 5% short-grind corn stalks; 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks; 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks.

[2]DP = dressing percent: HCW/final shrunk BW.

[3]300 = Slight0; 400 = Small0.

to determine if rumination impacts performance. Perhaps in a larger pen-based study, where animals have a greater opportunity to overconsume feed, rumination time may impact performance. Dry matter intake was not different across day ($P = 0.46$; Table 4), whereas rumination time was different ($P < 0.01$) across day. Dry matter intake did not fluctuate from day to day as rumination time did; therefore, rumination time may not be completely dependent on daily intake but may be more dependent on meal patterns throughout the day. Retention time for slowly digesting roughage is likely longer than 24 h; therefore, intake level and patterns from previous days may affect rumination patterns for 1 single day. These data conflict with the estimated peNDF derived from the total diet particle separation analysis (Table 3). Estimated peNDF was greatest for the 10SG diet, which is confirmed by rumination time. However, there was no difference in peNDF between the 5LG and 5SG diets. According to rumination time, the 5LG diet showed characteristics of greater peNDF compared with the 5SG diet. Again, peNDF is defined as the portion of NDF that requires further mastication to allow passage out of the rumen (Mertens, 1997). These results suggest that further research is needed to compare measurement techniques to calculate peNDF in beef finishing diets (i.e., sieving vs. rumination behavior), but in this study, animal response (rumination time) appeared to be more sensitive to particle size than to sieving techniques. Beauchemin and Yang (2005) fed 3 different particle sizes of corn silage at approximately 42% dietary DM to 6 lactating Holstein cows to test the effects of feeding different amounts of peNDF (12.3, 11.1, and 10.1% peNDF). The cows were outfitted with a halter with a piezo disk (Edmund Scientific Co., Barrington, NJ) that measured jaw movements. As particle size (and peNDF) increased in the diet, daily rumination also increased. Shain et al. (1999) visually observed rumination behav-

Table 7. Effect of corn stalk particle size and inclusion rate on rumination time per kilogram of DM, NDF, and physically effective NDF (peNDF) consumed

	Dietary treatment[1]				*P*-value		
Item	5SG	5LG	10SG	SEM	Treatment	Day	Treatment × day
Rumination, min/d	245.44[c]	288.74[b]	307.16[a]	20.504	0.01	<0.01	<0.01
Rumination, min/kg							
DM	25.35[be]	29.31[ad]	30.45[a]	2.226	0.07	<0.01	<0.01
NDF	140.78	162.84	152.29	12.008	0.16	<0.01	<0.01
peNDF	222.28	259.62	234.29	18.902	0.11	<0.01	<0.01

[a–c]Treatment means within a row without a common superscript differ ($P \leq 0.05$).

[d,e]Treatment means within a row without a common superscript tend to differ ($P \leq 0.10$).

[1]5SG = 30% wet corn gluten feed with 5% short-grind corn stalks; 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks; 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks.

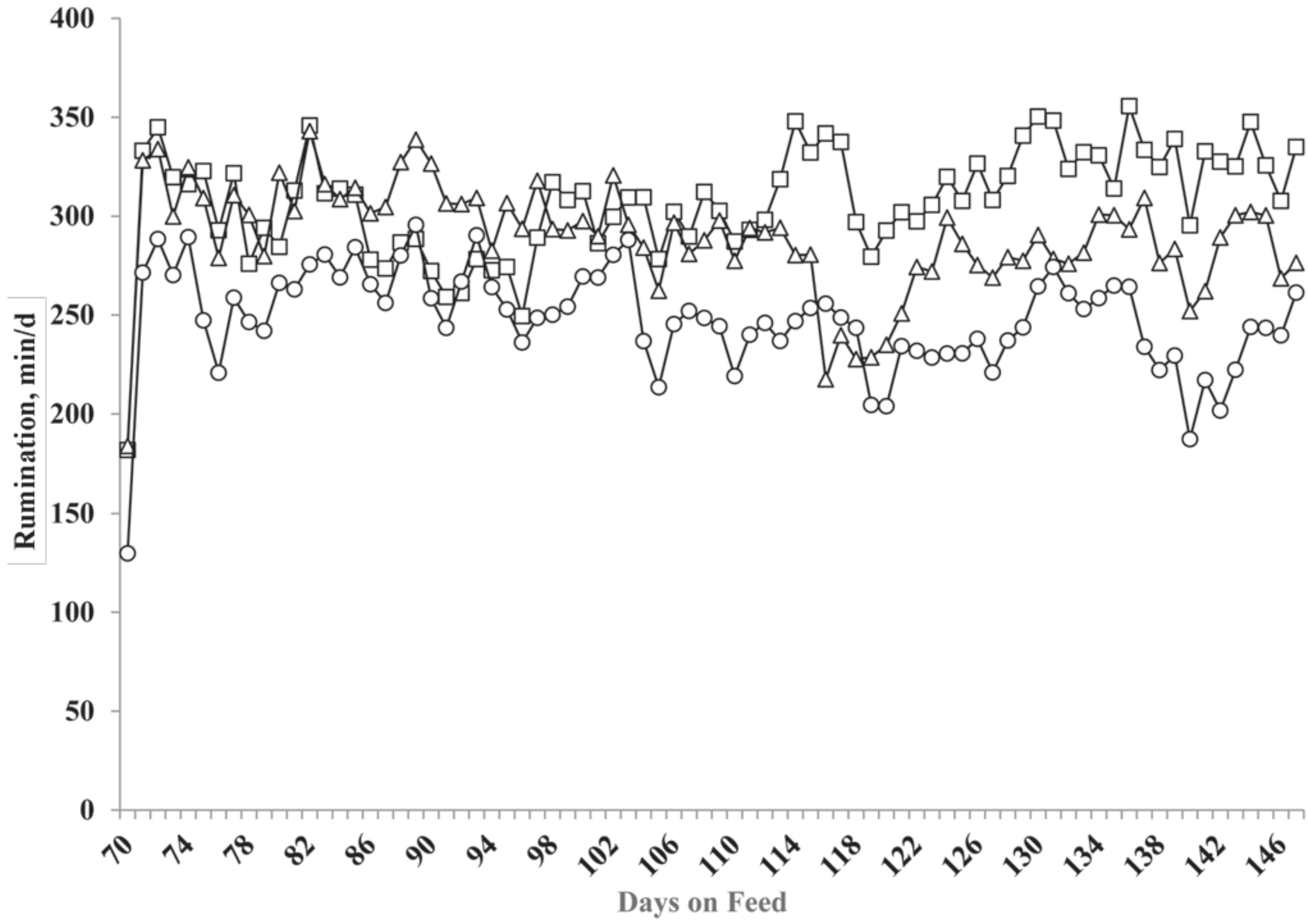

Figure 1. Effects of corn stalk particle size and inclusion rate on rumination behavior in finishing beef steers. 5SG = 30% wet corn gluten feed with 5% short-grind corn stalks (-○-); 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks (-Δ-); 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks (-□-). n = 17, n = 17, and n = 16 for 5SG, 5LG, and 10SG, respectively. Treatment × day ($P < 0.01$; SEM = 26.41).

ior of beef steers fed 10% alfalfa or 5% wheat straw and observed a greater rumination time for steers consuming wheat straw than for steers consuming alfalfa (235 and 190 min/d, respectively). At half the inclusion rate, wheat straw showed characteristics of containing more peNDF than did alfalfa. However, Shain et al. (1999) calculated peNDF by methods described by Mertens (1997) but did so only for individual roughage ingredients, not the mixed diets. Increasing particle size increased rumination time and, in theory, increased salivary flow to the rumen. Ruminal pH was not measured in this study. According to Owens et al. (1998), approximately half the bicarbonate that enters the rumen comes from saliva during eating and ruminating. Therefore, increasing rumination time should increase the buffering capacity of the rumen and may aid in controlling acidotic events in feedlot cattle.

Rumination minutes × hour within day are reported in Fig. 2. To reiterate, steers were fed at 0900 h. At 0200 h, rumination was greater (P = 0.01) for steers consuming 5LG and tended to be greater for steers consuming 10SG (P = 0.06) compared with steers consuming 5SG, with no difference (P = 0.48) between 5LG and 10SG (21.9, 21.0, and 18.6 min, respectively). At 0400 h, steers consuming 5LG ruminated more ($P < 0.01$) than steers consuming 5SG and tended to ruminate more (P = 0.08) than steers consuming 10SG, with no difference (P = 0.24) between 5SG and 10SG (24.9, 21.2, and 22.7 min, respectively). Rumination peaked at 0600 h, with steers consuming 5LG tending to ruminate more than steers consuming 10SG (P = 0.10) and more than steers consuming 5SG (P = 0.01), whereas rumination times of steers consuming 10SG and 5SG were not different (P = 0.22; 25.4, 23.4, and 21.9 min, respectively). Rumination time was least at 1000 h, with no differences ($P \geq 0.43$) between treatment diets. At 1600 h, steers consuming 10SG ruminated more (P = 0.01) than steers consuming 5SG, with steers consuming 5LG being intermediate (6.3, 3.2, and 4.4 min, respectively). No differences in rumination minutes were observed between 10SG and 5LG (P = 0.12) or between 5LG and 5SG (P = 0.31) at 1600 h. At 2200 h, steers consuming 10SG and 5LG ruminated a similar number of minutes (P = 0.81) and more ($P \leq$ 0.01) than steers consuming 5SG (18.2, 17.9, and 14.8 min, respectively). Rumination followed a similar pattern at 2400 h, with steers consuming 10SG and 5LG

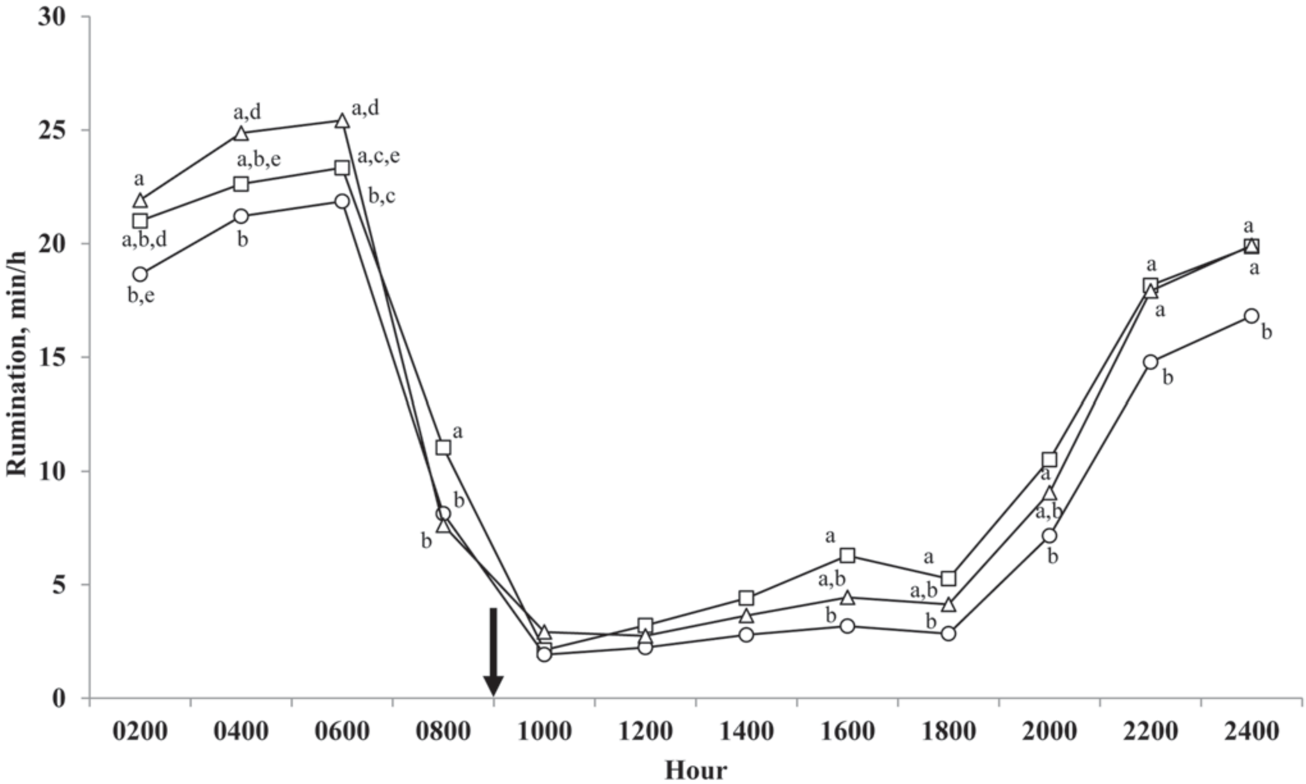

Figure 2. Effects of corn stalk particle size and inclusion rate on rumination behavior in finishing beef steers. 5SG = 30% wet corn gluten feed with 5% short-grind corn stalks (-○-); 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks (-Δ-); 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks (-□-). The arrow represents feeding at 0900 h. $n = 17$, $n = 17$, and $n = 16$ for 5SG, 5LG, and 10SG, respectively. Treatment × hour ($P < 0.01$; SEM = 1.25). [a–c]Within an hour, treatment means without a common superscript differ ($P \leq 0.05$); [d,e]within an hour, treatment means without a common superscript tend to differ ($P \leq 0.10$).

ruminating for a similar number of minutes ($P = 0.99$) and more ($P = 0.01$) than steers consuming 5SG (19.9, 19.9, and 16.8 min, respectively). It is unclear why rumination time was different throughout the day according to treatment; it may be that cattle consumed different amounts of feed throughout the day. In this study, feed consumption was not monitored throughout the day, so the rumination patterns are difficult to explain.

Activity minutes × hour within day are presented in Fig. 3. No treatment differences ($P = 0.44$) in activity were observed in this study. Rumination and activity data collected from the collars would suggest that cattle seem to ruminate during times of lesser activity, especially during the nighttime hours when they are most likely lying down.

A tendency ($P = 0.06$) was observed for rumination time per kilogram of DM, with steers consuming 10SG ruminating more than steers consuming 5SG ($P = 0.03$; Table 7). This can be explained by the greater rumination time and lesser DMI of the steers fed 10SG compared with steers consuming 5SG. Steers consuming 5LG ruminated for a similar amount ($P = 0.59$) of time per kilogram of DM as the steers fed 10SG but tended ($P = 0.07$) to ruminate more per kilogram of DM than steers fed 5SG. Rumination per kilogram of NDF was not different for steers consuming 5SG, 5LG, or 10SG. Also, Beauchemin and Yang (2005) observed no differences in rumination per kilogram of DM or NDF for dairy cows consuming multiple particles sizes of corn silage. There were no differences ($P = 0.11$) in rumination time per kilogram of peNDF in this study. In contrast, Beauchemin and Yang (2005) reported a linear decrease in rumination minutes per kilogram of peNDF as particle size increased; it is unclear why this response was observed. By dividing rumination time by kilogram of nutrient (DM, NDF, and peNDF) consumed, rumination time is not confounded by differences in intake among treatment diets. It is interesting to note that rumination minutes per kilogram of peNDF accounted for ≥75% of the total rumination minutes within a day.

Conclusions

Minimal research is available that compares roughage amount and particle size in beef cattle finishing diets. Different roughage sources and particle sizes need to be fed while monitoring rumination time to standardize the appropriate rumination behavior of finishing beef cattle. The authors speculate that

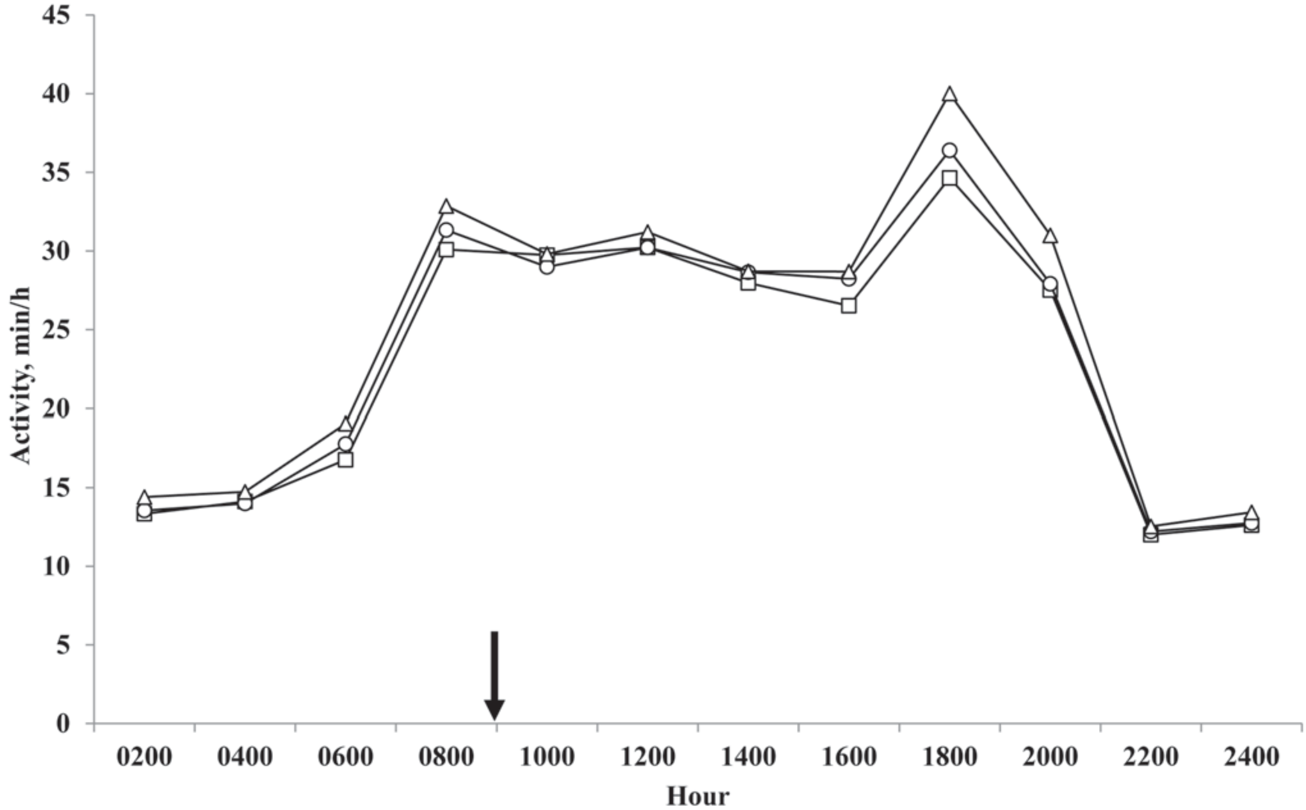

Figure 3. Effects of corn stalk particle size and inclusion rate on activity in finishing beef steers. 5SG = 30% wet corn gluten feed with 5% short-grind corn stalks (-○-); 5LG = 30% wet corn gluten feed with 5% long-grind corn stalks (-Δ-); 10SG = 25% wet corn gluten feed with 10% short-grind corn stalks (-□-). The arrow represents feeding at 0900 h. *n* = 17, *n* = 17, and *n* = 16 for 5SG, 5LG, and 10SG, respectively. Treatment × hour ($P = 0.12$; SEM = 1.69).

peNDF and NDF digestibility are inversely related. If an ingredient is highly digestible, it does not stimulate or require increased rumination compared with low-quality roughages. Therefore, higher-quality forages or smaller particle sizes at lesser inclusion rates may not stimulate optimal rumen function in finishing diets. However, there remains much to learn pertaining to adequate rumination for a feedlot animal. Results from this study suggest that increasing particle size of roughage may be a means to decrease roughage inclusion while maintaining rumination and performance. There may be limitations to increasing the particle size of roughage such as obtaining a consistent particle size, capability of the mill to handle a larger particle size, and the potential for cattle to sort roughage in the bunk. The ideal particle size of roughage in finishing diets is not well defined but, in theory, is one that promotes intake, generates rumination, maintains desirable performance, and prevents acidotic events. This also could be important in minimizing liver abscesses during the finishing period. Further research is needed to characterize fiber and validate measurement techniques, more specifically peNDF, and rumination characteristics that are most appropriate to maximize feedlot performance.

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