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Ruminant Nutrition

Impacts of including Sweet Bran and wet distillers grains with solubles alone or in combination in finishing cattle diets on physically effective fiber concentrations and rumen buffering characteristics of feedlot cattle

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ABSTRACT

This study evaluated the effects of Sweet Bran (SB) and wet distillers grains with solubles (WDGS) in the diet alone or in combination on physically effective neutral detergent fiber (peNDF), ruminal pH, and rumination behavior of finishing beef cattle. For this study, 455 steers (373 ± 15.5 kg) were allocated to 48 pens in a randomized complete block design. Treatments (n = 12 pens per treatment) were one of four steam-flaked corn-based diets containing no corn-milling products (CON), 20% WDGS (WDGS20), 20% SB (SB20), or 20% SB and 10% WDGS (COMBO). Within each pen, two steers were randomly selected to receive an indwelling ruminal pH bolus to quantify ruminal pH and a 3-axis accelerometer tag to measure rumination for the first 92 d of the study. Diet samples were collected weekly to determine particle size, neutral detergent fiber (NDF) concentration, and peNDF. Physically effective NDF was calculated using both the proportion of particles > 4.0 mm (peNDF$_{4.0}$) and the proportion of particles > 8.0 mm (peNDF$_{8.0}$). The percentage of particles > 4.0 mm was greatest ($P < 0.01$) for CON, intermediate for SB20, and least for WDGS20 and COMBO. Both NDF ($P < 0.01$) and peNDF$_{4.0}$ ($P < 0.01$) were greatest for COMBO, intermediate for WDGS20 and SB20, and least for CON. The percentage of particles > 8.0 was greatest ($P < 0.01$) for CON, intermediate for WDGS20 and SB20, and least for COMBO, but peNDF$_{8.0}$ did not differ ($P = 0.40$). A diet × day interaction ($P < 0.01$) was observed for daily rumination minutes per kg of DMI, NDF, peNDF$_{4.0}$, and peNDF$_{8.0}$. A diet × hour interaction ($P < 0.01$) was observed where CON cattle spent less time ruminating at 0800 and 1000 h in a 24 h period. Daily ruminal pH was greatest ($P < 0.01$) for COMBO, intermediate for SB20 and WDGS20, and least for CON. A diet × hour interaction ($P < 0.01$) was also observed for circadian ruminal pH, where pH was least for CON from 0800 to 1800 h. Relationships between peNDF, rumination behavior, and ruminal pH observed in this study suggest that SB and WDGS similarly enhance rumen buffering capacity when steam-flaked corn is replaced in the diet.

Key words: corn-milling products, cattle, feedlot, pH, physically effective fiber, rumination

Abbreviations: BW, body weight; CON, control treatment diet containing no corn-milling products;COMBO, combination treatment diet; DM, dry matter; DMI, dry matter intake; NDF, neutral detergent fiber; NEg, dietary net energy gain; NEm, dietary net energy maintenance; peNDF, physically effective neutral detergent fiber; peNDF$_{4.0}$, physically effective neutral detergent fiber > 4.0 mm; peNDF$_{8.0}$, physically effective neutral detergent fiber > 8.0 mm; PSPS, Penn State Particle Separator; SB, sweet bran; SB20, steam-flaked corn-based treatment diet containing 20% sweet bran; SD, standard deviation; WDGS, wet distillers grains with solubles; WDGS20, steam flaked corn-based treatment diet containing 20% wet distillers grains with solubles

INTRODUCTION

Sweet Bran (SB; Cargill, Blair, NE) and wet distillers grains with solubles (WDGS) are corn-milling products from sweetener and ethanol production and can be used as a cost-effective replacement for processed grains in feedlot cattle diets. Both SB and WDGS are low in starch and are categorized as fermentable, fibrous feed ingredients that have net energy values comparable to processed corn (Stock et al., 2000; Klopfenstein et al., 2008). Conversely, processed grains provide a greater proportion of energy as rapidly fermentable starch. When high concentrate diets containing large proportions of processed grains are fed to cattle, acidotic conditions may occur from the consistent microbial production of organic acids which weakens the integrity of the ruminal wall (Nagaraja, 2018), thus limiting absorptive capacity (Owens et al., 1998) and decreasing rumen motility (Bruce and Huber, 1973). Digestive disruption caused from acidosis can result in decreased dry matter intake (DMI) and performance of feedlot cattle (Brown et al., 2000). However, these alterations may be mitigated by increasing the roughage concentration of the diet (Galyean and Hubbert, 2014), reducing feeding variation (Schwartzkopf-Genswein et al., 2004), or increasing roughage particle size, saliva secretion, and rumination (Allen, 1997; Weiss et al., 2017).

Physically effective NDF (peNDF) combines measurements of particle size and neutral detergent fiber (NDF) concentration to predict rumination and the extent of mechanical stimulation provided by feed ingredients. Increasing the proportion of traditional roughage sources (i.e., alfalfa hay and corn stalks) within a diet increases peNDF and stimulates greater rumination (Mertens et al., 1997; Gentry et al., 2016) and production of saliva as a buffer (Allen, 1997). Previous research also suggests that fibrous corn-milling

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products provide a buffering effect and increase ruminal pH (Ham et al., 1994; Montgomery et al., 2004; Siverson et al., 2014) which reduces the incidence of acidosis, increases DMI and performance, and improves carcass characteristics in comparison to cattle fed no corn-milling products (Domby et al., 2014; Spowart et al., 2022). However, corn-milling products contain high concentrations of degradable fiber that are smaller in size compared to traditional roughage sources, which questions the contribution of these feedstuffs to overall peNDF. Furthermore, it is unclear if the buffering effect provided by replacing processed grains with corn-milling products is primarily influenced by reduced dietary starch or the physical characteristics of the fiber source and subsequent influence on rumination. We hypothesized that peNDF and ruminal pH of feedlot cattle would increase when corn-milling products such as SB and WDGS were used to replace a portion of the steam-flaked corn in the diet with minimal impacts on rumination behavior. The objective of this study was to quantify peNDF and rumen buffering characteristics of finishing steers consuming diets with SB and/or WDGS.

Animal Management and Treatments

All procedures involving the use of animals in this study were approved by the West Texas A&M University Institutional Animal Care and Use Committee (#2019.05.002). Crossbred steers [$n = 478$, average initial body weight (BW) = 234 ± 14.21 kg] were received at the West Texas A&M University Research Feedlot, fed a common growing diet (Table 1), and used in a 56-d receiving study to evaluate administration of different vaccination and metaphylaxis regimens at feedlot arrival (Munoz et al., 2020). After completion of the receiving study, steers that had previously received greater than two antimicrobial treatments were excluded from the pool of study candidates, and the remaining 455 steers were stratified into 12 BW blocks and allocated to 48 soil-surfaced pens (27.4 × 6.10 m) with 9 or 10 steers per pen in a randomized complete block design. Within each BW block, pens of cattle were randomly assigned to one of four dietary treatments consisting of steam-flaked corn-based diets with: no corn-milling products (CON); 20% WDGS (WDGS20); 20% SB (SB20); or a combination of 10% WDGS and 20% SB (COMBO) on a dry matter (DM) basis, resulting in a total

Table 1. Ingredient composition and nutrient analysis of finishing diets including no fibrous corn-milling products, wet distillers grains with solubles, and/or Sweet Bran

Item	REC[2]	Treatments[1]			
		CON	WDGS20	SB20	COMBO
Ingredient, % of DM					
Corn grain, flaked	28.5	76.6	63.9	62.6	53.2
Sweet Bran	42.0	—	—	20.0	20.0
Wet distillers with solubles	—	—	20.0	—	10.0
Corn stalks, ground	19.0	8.00	8.00	8.00	8.00
Cottonseed meal	—	6.00	—	—	—
Corn oil	—	2.45	1.08	2.45	1.78
Molasses blend[3]	7.00	2.50	2.50	2.50	2.50
Receiving supplement[4]	3.46	—	—	—	—
Finishing Supplement[5]	—	4.50	4.50	4.50	4.50
Nutrient composition, DM basis[6]					
Dry matter, %	70.8	82.9	63.2	74.9	66.3
Crude protein, %	15.0	13.5	15.9	13.6	15.1
RDP[7], %	9.47	7.90	7.68	8.57	8.26
RUP[7], %	5.53	5.59	8.22	5.03	6.84
Neutral detergent fiber, %	22.5	14.5	18.8	18.8	21.7
rNDF[8], %	13.8	5.81	5.81	5.81	5.81
Acid detergent fiber, %	17.4	8.20	9.80	9.30	10.70
Crude fat, %	3.30	5.30	5.30	5.50	5.50
Total starch, %	30.0	58.3	51.1	51.5	46.7
NEm, Mcal/kg[9]	1.94	2.15	2.18	2.17	2.16
NEg, Mcal/kg[9]	1.27	1.46	1.48	1.47	1.47

[1] CON, control, no corn milling products; WDGS20, 20% wet distillers grains with solubles; SB20, 20% Sweet Bran; COMBO, 20% sweet bran and 10% wet distillers grain with solubles.
[2] Receiving diet used during the transition period.
[3] 72 Brix Molasses Blend (Westway Feed Products LLC, Hereford, TX).
[4] Formulated to meet or exceed NASEM requirements (NASEM, 2016) and supplied 24 mg/kg monensin on a dry matter (DM) basis.
[5] Formulated to meet or exceed NASEM requirements (NASEM, 2016) and supplied 37 mg/kg monensin and 9 mg/kg tylosin on a DM basis.
[6] Analysis by Servi-Tech Laboratories (Hastings, NE).
[7] Ruminally degradable protein (RDP) and ruminally undegradable protein (RUP) calculated based on tabular values (NASEM, 2016).
[8] Roughage neutral detergent fiber (rNDF) calculated by multiplying the concentration of corn stalks in the diet by the NDF concentration of corn stalks (Servi-Tech Laboratories).
[9] Calculated based on tabular values (NASEM, 2016).

of 12 pen replicates per treatment. Treatments were designed to represent current industry practices for inclusion of corn-milling products in feedlot cattle diets when SB or WDGS were used either as the sole corn-milling product in the diet or in combination as described by Samuelson et al. (2016). To delineate the impacts of replacing a portion of the concentrate with corn-milling products, all diets were formulated to contain 8.0% corn stalks on a DM basis, which resulted in a similar (5.81% of DM) roughage NDF (rNDF) concentration. Diets were also formulated to supply similar concentrations of RDP and total fat, and 2.50% of DM of a commercially available molasses blend (72 Brix Molasses Blend, Westway Feed Products LLC, Hereford, TX) was used as a conditioning agent.

Cattle were transitioned from a common growing diet to their respective treatment diets from days 0 to 20 of the study using a two-ration blending system. Feed was mixed and delivered beginning at 0730 h using the delivery order: CON, WDGS20, SB20, and COMBO, and feed bunks were managed to allow little to no feed accumulation each morning. When feed refusals occurred in excess of 2.27 kg, orts were removed from the bunk, weighed, and analyzed for DM (100 °C for 24 h) to calculate daily DMI. Additional information on animal processing procedures, feed bunk management, and feed manufacturing and delivery as well as results for DMI, growth performance, and carcass characteristics are described in a companion paper by Spowart et al. (2022).

Two steers were randomly selected from each pen (n = 96) to receive both an indwelling ruminal pH bolus (Well Cow Limited, Roslin, UK) and a 3-axis accelerometer tag (SCR, Allflex Livestock Intelligence, Madison, WI) to quantify ruminal pH and rumination, respectively, for the first 92 d of the study. The ruminal pH data logging boluses were administered via intubation and were weighted to remain in the ventral portion of the rumen throughout the collection period.

Data Collection and Laboratory Analysis

Two fresh diet samples were collected weekly for analysis of NDF and to determine the particle size distribution of each diet using the Penn State Particle Separator (PSPS; Lammers et al., 1996; Heinrichs, 2013; Gentry et al., 2016) and calculate peNDF. Briefly, 400 g of each diet was shaken a total of 40 repetitions though four screens with varying diameters (19.0, 8.0, 4.0, and 1.18 mm). After shaking, the contents remaining on each tier were weighed and peNDF was calculated using two different methods. The peNDF of particles > 4.0 mm ($\text{peNDF}_{4.0}$) was calculated by multiplying the percentage of weight from the top 3 sieves (19.0, 8.0, and 4.0 mm) by the NDF concentration of the diet and expressed as a percentage, whereas peNDF of particles > 8.0 mm ($\text{peNDF}_{8.0}$) was calculated using only the percentage of weight from the top two sieves (19.0 and 8.0 mm). Both $\text{peNDF}_{4.0}$ and $\text{peNDF}_{8.0}$ have been reported previously (Yang and Beauchemin, 2006b; Gentry et al., 2016), but it is not clear which measurement is most appropriate for feedlot diets that contain low proportions of traditional roughage sources. Therefore, an additional objective of this study was to evaluate differences in peNDF calculation method and subsequent impacts on rumination minutes. The data collected for NDF, particle size, and peNDF included a total of 25 samples from each diet.

Rumination and ruminal pH were recorded from days 4 to 92. Data collection was initiated on day 4 following technology activation and a 48-h calibration period and terminated on day 92 so that each block was fully represented in the data set as harvest date differed by block. The average days on feed was 157 d (minimum = 93 d and maximum = 191 d). Rumination minutes were continuously recorded and averaged within 2 h time increments using the Data Flow II program (Allflex Livestock Intellegence). After collection, rumination data were managed according to methods previously described by Tomczak et al. (2019), where hourly rumination was summarized in 2-h intervals from 0000 to 2400 h and daily rumination was calculated as the sum of twelve 2-h time intervals within a day. Because the ruminal pH boluses did not remotely transmit data, cattle were removed from their pens to download data via a Bluetooth reader (Well Cow Ltd), which was then transmitted to an electronic database and accessed via the internet. Each week, a rotating schedule was used to download ruminal pH data where only individuals that were administered technology from three blocks were removed from the pens at one time (n = 24), which resulted in the data being downloaded from each animal once per month. To limit disruptions to feeding and behavior, the data downloads occurred before feeding each morning. Ruminal pH was electronically logged in 15-min intervals and averaged over 2-h intervals using Microsoft Excel 10 (Microsoft, Redmond, WA) to coincide with reporting of rumination data. Ruminal pH observations that exceeded ± 2 standard deviations of the mean were considered outliers and removed from the data set. This resulted in 15,480 of the 455,660 data points collected in this study (3.40%) being excluded from statistical analysis.

Statistical Analysis

Neutral detergent fiber concentrations, particle size distribution, and peNDF were analyzed using the MIXED procedures of SAS (SAS Inst. Inc, Cary, NC) where diet was included in the model and sample within diet was random. Ruminal pH and rumination were analyzed using the MIXED procedure of SAS with repeated measures. Effects of diet, day, hour, diet × day, and diet × hour were included in the model and pen within block was used as a random effect. Means were separated using the least significant difference test and pen was considered the experimental unit. The autoregressive covariance structure was used for each repeated variable. The Kenward–Roger denominator degrees of freedom adjustment was used when a data set contained missing variables. Treatment means were reported as least squares means ± standard error of the mean (SEM). Treatment differences were considered statistically significant when $P \leq 0.05$ and a tendency when $0.05 > P \leq 0.10$.

RESULTS AND DISCUSSION

Physically Effective NDF

Neutral detergent fiber (NDF) concentration was greatest ($P < 0.01$) for COMBO, intermediate for WDGS20 and SB20, and least for CON because of the greater inclusion rate of fibrous corn-milling products in the diet (Table 2). The proportion of particles captured on the 19.0-mm screen tended to be greater ($P = 0.10$) for SB20 than CON. The proportion of particles retained on the 8.0 mm screen were least ($P < 0.01$) for COMBO, intermediate for WDGS20 and SB20, and greatest for CON. In contrast, the proportion of particles retained on the 4.0-mm screen was greater ($P < 0.01$) for SB20, COMBO, and CON than WDGS20. The proportion of

Table 2. Particle separation and physically effective NDF (peNDF) analysis of diets formulated with no fibrous corn-milling products, wet distillers grain with solubles, and/or Sweet Bran

Item	Treatments[1]				SEM[2]	*P*-value
	CON	WDGS20	SB20	COMBO		
No. of samples	25	25	25	25	—	—
NDF, % of DM[3]	14.5^{c}	18.8^{b}	18.8^{b}	21.7^{a}	0.28	< 0.01
Sieve screen size, mm	Retained/screen, %					
19.0	0.408	0.554	0.687	0.546	0.08	0.10
8.0	41.2^{a}	32.9^{b}	34.5^{b}	29.0^{c}	1.39	<0.01
4.0	22.3^{a}	19.4^{b}	23.1^{a}	22.1^{a}	0.51	<0.01
1.18	19.0^{c}	25.5^{b}	26.3^{b}	30.8^{a}	0.52	<0.01
< 1.18	17.1^{bc}	21.7^{a}	15.5^{b}	17.7^{c}	0.66	<0.01
Particles > 4.0 mm	63.9	52.9	58.3	51.6	1.04	<0.01
$\text{peNDF}_{4.0}$[4]	9.22	9.93	11.0	11.2	0.23	<0.01
Particles > 8.0 mm	41.6^{a}	33.5^{b}	35.2^{b}	29.5^{c}	1.40	<0.01
$\text{peNDF}_{8.0}$[5]	5.98	6.29	6.60	6.40	0.26	0.40

[a–c] Means within a row with different superscript letters differ, $P < 0.05$.

[1] CON, control, no corn-milling products; WDGS20, 20% wet distillers grains with solubles; SB20, 20% Sweet Bran; COMBO, 20% Sweet Bran and 10% wet distillers grain with solubles.

[2] Standard error of the mean.

[3] Neutral detergent fiber (NDF) analyzed and calculated by Servi-Tech Laboratories (Hastings, NE) expressed on a dry matter (DM) basis.

[4] Physically effective neutral detergent fiber (peNDF) calculated by multiplying the percentage of weight (DM basis) from the top three sieves by the NDF content (DM basis) of the diet and expressed as a percentage (Gentry et al., 2016).

[5] peNDF calculated by multiplying the percentage of weight (DM basis) from the top two sieves by the NDF content (DM basis) of the diet and expressed as a percentage.

diet retained on the 1.18 mm screen was greatest ($P < 0.01$) for COMBO. The 1.18-mm screen was used as an additional measure to characterize the smaller particle size of the corn-milling products (Yang and Beauchemin, 2006a) used in this study and has not been extensively evaluated in previous research investigating particle size of cattle diets (Plaizier, 2004; Yang and Beauchemin, 2006b). The proportion of diet retained on the bottom pan (< 1.18 mm) was greater ($P < 0.01$) for WDGS20 than SB20, COMBO, and CON and greater for COMBO than SB20. These data suggest that SB and WDGS have a greater proportion of particles ≤ 4.0 mm in size compared to other ingredients used in the diet. Therefore, the percentage of particles that measured > 4.0 mm was greatest ($P < 0.01$) for CON, intermediate for SB20, and least for COMBO and WDGS20, with the proportion of particles measuring > 8.0 mm being greatest ($P < 0.01$) for CON, intermediate for WDGS20 and SB20, and least for COMBO.

The particle size of individual ingredients included in the diet was not determined in the current study, but it has been well documented the literature (Gentry et al., 2016; Jennings et al., 2020; Jennings et al., 2021; Lockard et al., 2021). Jennings et al. (2020) previously reported the particle size distribution of individual ingredients such as corn stalks, SB, and steam-flaked corn. Between these three ingredients, corn stalks comprised the majority of particles captured on the 19.0-mm screen (22.9% of retained particles for corn stalks vs. 1.4 and 0.0% for SB and steam-flaked corn, respectively). In contrast, the greatest proportion of both SB and steam-flaked corn particles were retained on the 8.0-mm screen (38.1% and 72.3% of retained particles for SB and steam-flaked corn, respectively). However, steam-flaked corn contained a greater proportion of particles > 4.0 mm (88.0%) compared to both SB (69.0%) and corn stalks (64.1%). More recently, Lockard et al. (2021) measured the particle size of individual feed ingredients commonly used in finishing cattle diets. The proportion of particles > 4.0 mm were reported as 83.0%, 80.0%, 75.3%, and 90.8% for steam-flaked corn, SB, corn stalks, and WDGS, respectively, with the majority of the WDGS particles being captured on the 8.0 (53.4% of retained particles) and 4.0 mm (28.7% of retained particles) screens. Cardoza (1985) identified that particles > 4.0 mm are important stimulators of ruminal contraction and rumination activity. However, although the proportion of particles > 4.0 mm for SB and WDGS reported by Jennings et al. (2020) and Lockard et al. (2021) were either similar or numerically greater than corn stalks, it is unlikely that corn-milling products stimulate rumination to the same extent as a traditional roughage sources such as corn stalks, particularly when corn stalks contain a greater proportion of particles larger than 19.0 mm and greater NDF (26.8%, 31.5%, and 70.8% for SB, WDGS, and corn stalks, respectively; NASEM, 2016). Furthermore, steam-flaked corn also contains a large portion of particles > 4.0 mm although it is not considered a fiber source and likely contributes minimally to rumination activity because of the high proportion of rapidly degradable starch and low NDF concentration. Therefore, additional measurements such as peNDF provide a unique opportunity to characterize the ingredients used in feedlot cattle diets because peNDF considers both the physical and chemical characteristics of feeds.

Physically effective NDF has historically been used to evaluate fibrous ingredients such as roughages; yet, there is limited research that discusses the interactions between fibrous corn-milling products and NDF concentration, particle size, peNDF, rumination, and ruminal pH. This is further complicated when evaluating feedlot diets that have characteristically low roughage concentrations. However, a growing body of research exists to characterize feedlot cattle diets using peNDF (Gentry et al, 2016; Weiss et al., 2017; Jennings et al, 2020) calculated by multiplying the proportion of particles > 4.0 mm by the dietary NDF concentration ($\text{peNDF}_{4.0}$). In the present study, $\text{peNDF}_{4.0}$ was greatest ($P < 0.01$) for COMBO and SB20 followed by WDGS20 and CON. Despite the larger proportion of particles > 4.0 mm, the CON diet had the lowest peNDF because it also contained the lowest NDF concentration. Because WDGS20 and SB20 had similar NDF concentrations, the 5.4% increase in the proportion of particles > 4.0 mm between WDGS20 and SB20 (52.9 vs. 58.3% for WDGS and SB) increased $\text{peNDF}_{4.0}$ by 1.1% (9.93% and 11.0% for WDGS and SB, respectively). In addition, WDGS20 and COMBO had the same proportion of particles > 4.0 mm. Therefore, the 2.9% greater NDF concentration (18.8% vs. 21.7% for WDGS and COMBO) increased $\text{peNDF}_{4.0}$ by 1.3% (9.93% vs. 11.2% for WDGS and COMBO, respectively). Furthermore, $\text{peNDF}_{4.0}$ did not differ between SB and COMBO when particle size decreased by 6.7% and NDF increased by 2.9%. Therefore, because the magnitude of change required to influence $\text{peNDF}_{4.0}$ was greater for NDF than particle size, this suggests that in the present study the NDF concentration had a stronger influence on $\text{peNDF}_{4.0}$. This is an important consideration for feedlot diets containing corn-milling products because although the particle size of these ingredients may not be as physically effective as traditional roughage sources, the greater NDF concentration increases $\text{peNDF}_{4.0}$ of the diet when fibrous corn-milling products are used to replace processed grains that contain greater proportions of dietary starch and less NDF. When the peNDF of each diet was calculated using the proportion of particles > 8.0 mm ($\text{peNDF}_{8.0}$), no difference ($P = 0.40$) was observed among CON, SB, WDGS, or COMBO. Because a large portion of SB and WDGS are captured on the 4.0-mm screen (Jennings et al., 2020; Lockard et al., 2021), using only the proportion of particles > 8.0 mm decreases the contribution of corn-milling products to peNDF. This concept is supported by a $\text{peNDF}_{8.0}$ concentration (5.98%, 6.29%, 6.60%, and 6.40% for CON, WDGS20, SB20, and COMBO, respectively) that is more similar to rNDF (5.81% on a DM basis) than $\text{peNDF}_{4.0}$ (9.22%, 9.93%, 11.0%, and 11.2% for CON, WDGS20, SB20, and COMBO, respectively). Therefore, additional information such as rumination behavior is needed to provide valuable insight into the interpretation of dietary peNDF, the utility of various methods used to calculate peNDF, and potential relationships with dietary corn-milling product inclusion.

Rumination

Daily rumination minutes for cattle consuming CON, WDGS20, SB20, and COMBO from days 4 to 92 are presented in Figure 1. A diet × day interaction ($P < 0.01$) was observed for daily rumination minutes. On day 17, cattle consuming SB20 had the greatest rumination minutes and COMBO was least. Similarly, on day 26, SB20 was greatest and the least rumination time was reported for COMBO and WDGS20. On days 42 and 47, rumination was greatest for SB20 and COMBO and least for CON. Daily rumination was greatest for COMBO and WDGS20 and least for CON on days 51 and 71. On days 52 and 59, rumination time was greatest for COMBO and least for CON. Cattle receiving COMBO, WDGS20, and SB20 had greater rumination than CON on day 66. These results indicate that when treatment differences occurred within day, the cattle consuming CON ruminated less than those receiving diets containing corn-milling products, particularly when differences occurred later in the feeding period. However, the main effect of diet was not statistically significant (effect of diet; $P = 0.39$), and overall rumination minutes (410, 436, 460, and 442 min for

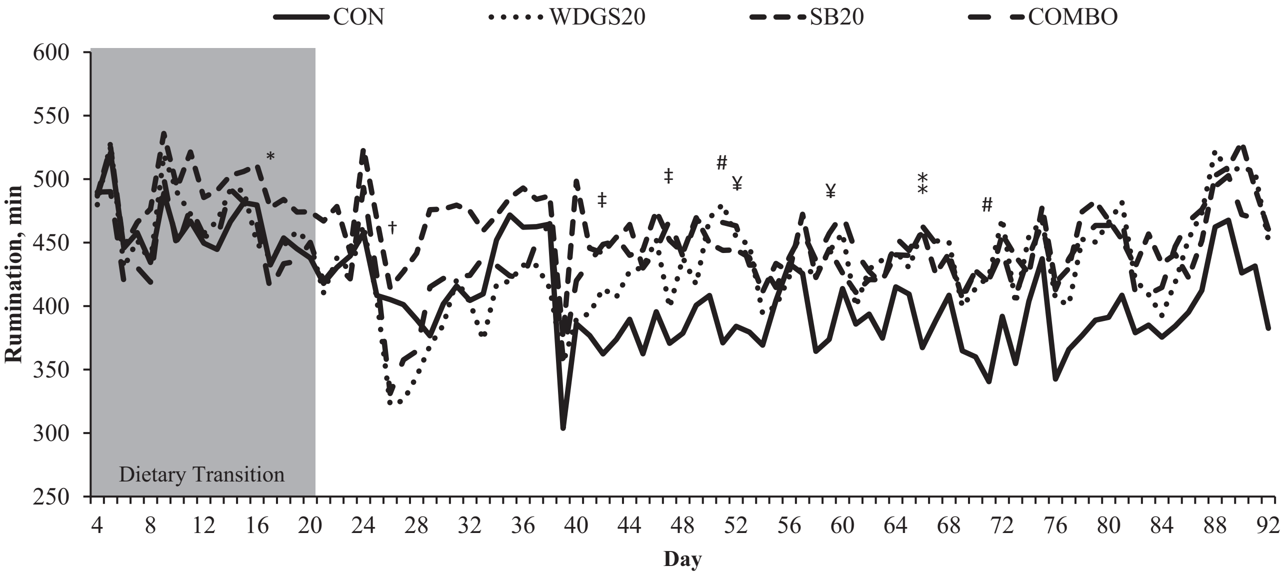

Figure 1. Daily rumination of finishing steers fed CON = control, no fibrous corn-milling products; WDGS20 = 20% wet distillers grains with solubles; SB20 = 20% Sweet Bran; COMBO = 20% sweet bran and 10% wet distillers grain with solubles. Two steers from each pen were randomly selected to receive a 3-axis accelerometer tag (Allflex Livestock Intelligence, Madison, WI) to quantify rumination minutes. The transition from the receiving diet to the finishing diet is indicated by the shaded area from days 0 to 20 of the feeding period. Effect of diet, $P = 0.39$; day, $P < 0.01$; diet × day, $P < 0.01$. Pooled standard error of the mean = 28.46 min. *SB20 vs. COMBO; †SB20 vs. WDGS20 and COMBO; ‡SB20 and COMBO vs. CON; #COMBO and WDGS20 vs. CON; ¥COMBO vs. CON; ‡COMBO, WDGS20, and SB20 vs. CON treatments differ within day, $P \leq 0.05$.

Table 3. Ruminal pH and rumination minutes in proportion to DM, NDF, and peNDF intake of finishing beef cattle consuming diets formulated with no fibrous corn-milling products, wet distillers grain with solubles, and/or Sweet Bran

Item	Treatment[1]					*P*-value		
	CON	WDGS20	SB20	COMBO	SEM[2]	Diet	Day	Diet × Day
Daily ruminal pH	5.47^{c}	5.63^{b}	5.69^{ab}	5.78^{a}	0.05	<0.01	<0.01	0.40
Rumination, min/d	410	436	460	442	20.41	0.39	<0.01	<0.01
Rumination, min/kg[3]								
Dry matter	46.8	45.5	48.4	46.8	2.24	0.81	<0.01	<0.01
NDF	312^{a}	238^{b}	253^{b}	215^{b}	12.15	<0.01	<0.01	<0.01
rNDF	750	728	775	752	36.87	0.82	<0.01	<0.01
peNDF$_{4.0}$	498^{a}	453^{ab}	440^{b}	418^{b}	21.58	0.04	<0.01	<0.01
peNDF$_{8.0}$	781	726	739	735	35.58	0.67	<0.01	<0.01

$^{a–c}$Means within a row with different superscript letters differ, $P < 0.05$.

[1] CON, control, no corn-milling products; WDGS20, 20% wet distillers grains with solubles; SB20, 20% Sweet Bran; COMBO, 20% sweet bran and 10% wet distillers grain with solubles.

[2] Standard error of the mean.

[3] Calculated by dividing daily rumination minutes by daily nutrient intake of dry matter (DM), neutral detergent fiber (NDF), roughage neutral detergent fiber (rNDF), physically effective fiber calculated using the proportion of particles > 4.0 mm (peNDF$_{4.0}$), and physically effective fiber calculated using the proportion of particles > 8.0 mm (peNDF$^{8.0}$)

CON, WDGS20, SB20, and COMBO, respectively; Table 3) were similar to that reported for feedlot cattle by Jennings et al. (2020).

Particle sizes > 4.0 mm stimulate rumination (Cardoza, 1985). However, even though the proportion of particles > 4.0 mm was greatest for CON, apart from days 17 and 26, this did not result in greater rumination minutes per day, as the increase in particle size can likely be attributed to a larger proportion of steam-flaked corn pieces with a larger diameter than either corn-milling product. These results also suggest that the source of corn-milling products could influence rumination to a small degree. For example, the greater particle size of SB vs. WDGS may explain the numerically greater rumination of cattle consuming SB20 and COMBO in comparison to WDGS20. In a companion study, Spowart et al. (2022) reported DMI was greater for cattle consuming diets containing grain-milling products than CON (9.10, 9.72, 9.76, and 9.64 kg for CON, WDGS20, SB20, and COMBO, respectively). Therefore, because rumination can be influenced by DMI (Welch and Smith, 1970; Bae et al., 1981), it is critical to evaluate rumination on a DMI equivalent basis to delineate potential biological responses in rumination minutes.

When evaluated as a function of DMI using the data reported by Spowart et al. (2022), a diet × day interaction (Figure 2; $P < 0.01$) was also observed for daily rumination per kg of DMI. On day 26, rumination per kg of DMI was least for WDGS20 and greatest for CON. On day 28, time spent ruminating per kg of DMI was greatest for SB20 and least for COMBO and WDGS20. On day 35, rumination per kg of DMI was least for COMBO and WDGS20 and greatest for CON, whereas rumination on day 36 was least for COMBO and greatest for CON. On day 40, daily rumination min per kg of DMI were greatest for SB20 and least for WDGS20 and COMBO. On day 47, time spent ruminating was greatest for COMBO and least for WDGS20. In the present study, cattle were transitioned from a common receiving diet that did not contain WDGS to diets containing either SB, WDGS, or both over the first 20 d of the feeding period. Replacing a portion of processed grains in the diet with WDGS has been shown to increase passage rate, which along with decreased particle size can be associated with less rumination (Welch et al., 1982; Firkins et al., 1985). Therefore, it is possible that the transient decrease in rumination of WDGS20 and COMBO from days 26 to 47 could have occurred during adaptation to differences in passage rate and/or particle size caused by adding WDGS to the diet. However, much of the disagreement between these daily rumination means appears to be because of random variation and is likely not biologically significant. Furthermore, no differences in rumination were observed after day 47.

When evaluating the overall effect of diet on rumination activity, daily rumination minutes per kg of DMI was not different among dietary treatments and were 48.8, 48.4, 46.8, and 45.5 for COMBO, SB20, CON, and WDGS20, respectively (effect of diet; $P = 0.81$). Although numerical differences in rumination per kg of DMI follow a similar pattern as overall daily rumination minutes, the magnitude of difference between treatments is lessened when DMI is considered. This supports the concept that the numerical difference in daily rumination minutes can at least be partly explained by differences in DMI between treatments and that rumination is likely not affected by the increased peNDF concentration supplied by replacing a portion of the processed grains in the diet with corn-milling products.

Previous research suggests that increasing the proportion of peNDF in the diet increases rumination time in both dairy and beef cattle (Beauchemin et al., 2003; Kononoff et al. 2003, Jennings et al., 2020). Traditionally, peNDF is defined as the fibrous proportion of a diet that stimulates rumen motility, rumination, and saliva production. However, fiber sources can vary in their ability to stimulate rumination and chewing activity because of differences in physical characteristics of the fiber source (Allen, 1997). Mertens et al. (1997) explained that non-forage fiber, such as corn-milling products, might not stimulate rumination to the same extent as traditional roughage sources because of their small particle size. Furthermore, Biricik et al. (2007) reported that replacing a proportion of corn silage with dry corn gluten feed decreased rumination time in dairy cows. Allen and Grant (2000) also observed decreased rumination in dairy cows when wet

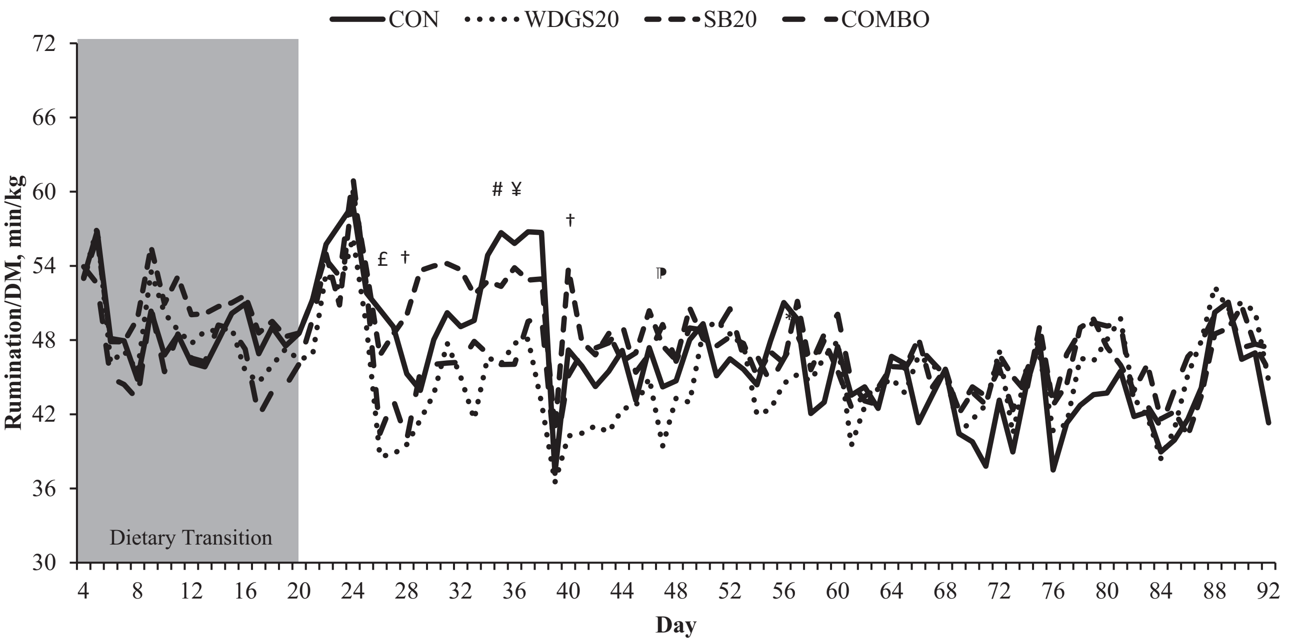

Figure 2. Daily rumination per kg of DM consumed by finishing steers fed CON = control, no fibrous corn-milling products; WDGS20 = 20% wet distillers grains with solubles; SB20 = 20% Sweet Bran; COMBO = 20% Sweet Bran and 10% wet distillers grain with solubles. Two steers from each pen were randomly selected to receive a 3-axis accelerometer tag (Allflex Livestock Intelligence, Madison, WI) to quantify rumination minutes. The transition from the receiving diet to the finishing diet is indicated by the shaded area from days 0 to 20 of the feeding period. Effect of diet, $P = 0.81$; day, $P < 0.01$; diet × day, $P < 0.01$. Pooled standard error of the mean = 3.12 min. †SB20 vs. WDGS20 and COMBO; #COMBO and WDGS20 vs. CON; ¥COMBO vs. CON; £WDGS20 vs. CON; ⁋COMBO vs. WDGS20 treatments differ within day, $P \le 0.05$. *.

corn gluten feed was used to replace a portion of alfalfa hay. However, limited information is available regarding how fibrous corn-milling products influence rumination compared to processed grains, and how this may be impacted by overall diet composition, particularly in feedlot cattle diets. In the present study, rumination per kg of DMI was similar among treatments despite greater peNDF$_{4.0}$ of the diets containing SB and/or WDGS. This suggests that peNDF$_{4.0}$ overestimates the physical contribution of corn-milling products and therefore may not be a useful measurement for feedlot cattle diets that have low roughage concentrations and contain high proportions of SB and WDGS.

In contrast, peNDF$_{8.0}$ was similar among diets. Excluding the proportion of particles between 4.0 and 8.0 mm from the peNDF calculation may help us to differentiate between fibrous products and traditional roughage sources, as these feedstuffs generally have a greater particle length than SB or WDGS and could provide a more realistic measurement of peNDF for feedlot cattle diets. For example, peNDF$_{8.0}$ is a way to primarily account for the NDF contributed by the roughage in the diet, while still allowing for a small contribution from corn-milling products, as the dietary rNDF (5.81% of DM) was only 97.2%, 92.4%, 88.0%, and 90.8% the value of peNDF$_{8.0}$ for CON, WDGS20, SB20, and COMBO. However, it may also be important to consider other factors such as dietary DM concentration, fiber concentration, and fiber source in addition to particle size when evaluating the viability of peNDF measurements. For instance, using the peNDF$_{8.0}$ for corn stalks (43.2%) reported by Lockard et al. (2021), the roughage peNDF (rpeNDF) supplied by the 8.0% of DM corn stalks can be estimated as 3.46%, which is 57.8%, 55.0%, 52.4%, and 54.1% the value of peNDF$_{8.0}$ for CON, WDGS20, SB20, and COMBO, and 59.6% of rNDF. Because rNDF, peNDF$_{8.0}$, and rpeNDF, did not differ among diets and agrees with the lack of treatment differences in overall rumination minutes and rumination minutes per kg of DMI, this suggests that perhaps any of these three variables can be used to evaluate the influence of diet on rumination minutes. However, additional research is needed to determine the accuracy of these methods as predictors of rumination and determine which may be most applicable in a production setting.

A diet × day interaction (Figure 3; $P < 0.01$) was detected for rumination minutes per kg of NDF intake where COMBO was less than CON on days 10, 12, 13, 14, and 16 to 19, 26, 31, 32, 34 to 37, 66, 71, 76, 77, 90, and 91. Similarly, WDGS20, SB20, and COMBO had less rumination minutes per kg of NDF than CON on days 20 to 25, 41 to 56, 58 to 65, 67 to 69, 74, 75, 77, 81, 82, 84, 85, and 87. On days 27, 33, and 38, rumination per kg of NDF was greatest for CON and least for WDGS20 and COMBO. In contrast, WDGS20 and COMBO had had less rumination per kg of NDF than SB20 and CON on days 28 to 30 and 40. On day 57, rumination was least for COMBO but increased as the concentration of corn-milling products in the diet was reduced from 30.0% to 0.0% of DM (CON). On days 15, 70, 73, 79, and 83, WDGS20 and COMBO had less rumination than CON. Cattle consuming SB20 and COMBO had less rumination time than CON on days 72, 80, and 86. Overall, steers consuming SB20, WDGS20, and COMBO ruminated less minutes per kg NDF intake in comparison to CON (effect of diet; $P < 0.01$). Although SB20, WDGS20, and COMBO contained greater proportions of NDF compared to CON, the NDF in CON was primarily provided by the corn stalks in the diet, whereas the NDF from SB20, WDGS20, and COMBO was provided by a combination of corn stalks and fibrous corn-milling products. Because corn stalks have a larger particle size and greater peNDF compared to fibrous corn-milling products such as SB (Gentry et al., 2016), this stimulated rumination to a greater extent when expressed per unit of dietary fiber intake. Alternatively, because low ruminal pH negatively impacts fibrolytic bacterial species (Kezar and Church, 1979), increased fermentability of the additional starch provided by CON may have impacted fiber degradation such that increased rumination was required to compensate for lower NDF digestion and reduce particle size to allow passage to the omasum (Fox and Tedeschi, 2002).

A diet × day interaction (Figure 4; $P < 0.01$) was also observed for rumination per kg of peNDF$_{4.0}$. Rumination time was less for SB20 and COMBO than CON on days 22, 24,

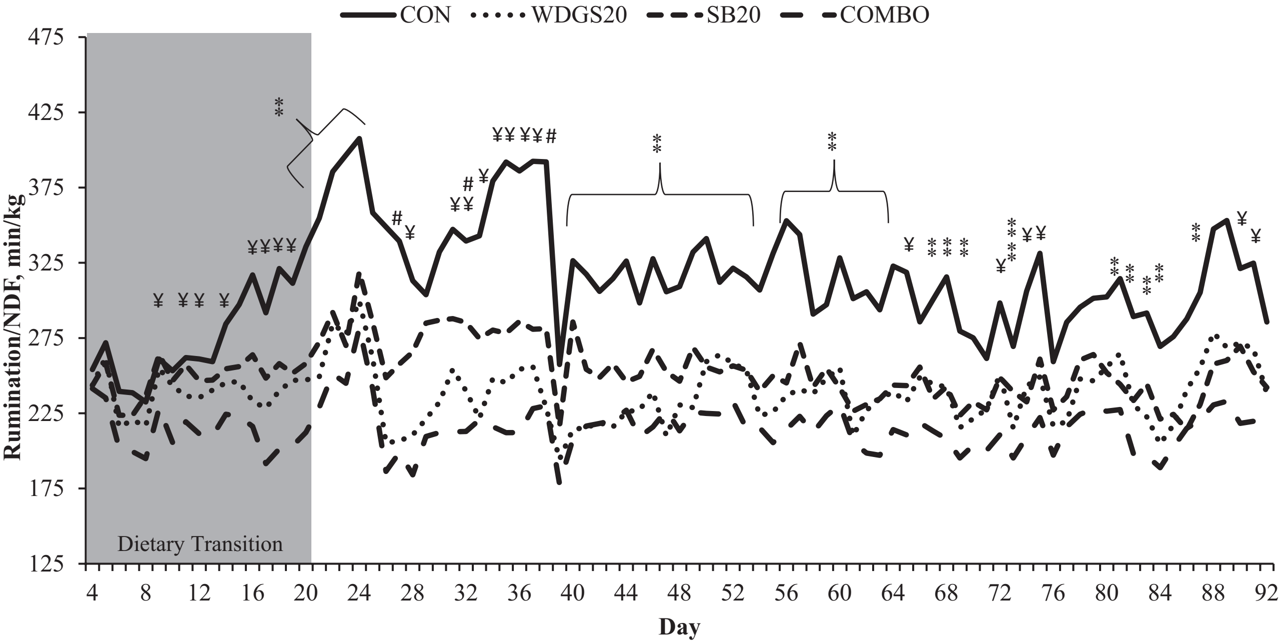

Figure 3. Daily rumination per kg of NDF intake of finishing steers fed CON = control, no fibrous corn-milling products; WDGS20 = 20% wet distillers grains with solubles; SB20 = 20% Sweet Bran; COMBO = 20% Sweet Bran and 10% wet distillers grain with solubles. Two steers from each pen were randomly selected to receive a 3-axis accelerometer tag (Allflex Livestock Intelligence, Madison, WI) to quantify rumination minutes. The transition from the receiving diet to the finishing diet is indicated by the shaded area from days 0 to 20 of the feeding period. Effect of diet, $P < 0.01$; day, $P < 0.01$; diet × day, $P < 0.01$. Pooled standard error of the mean = 17.92 min. #COMBO and WDGS20 vs. CON; ¥COMBO vs. CON; ‡COMBO, WDGS20, and SB20 vs. CON treatments differ within day, $P \leq 0.05$.

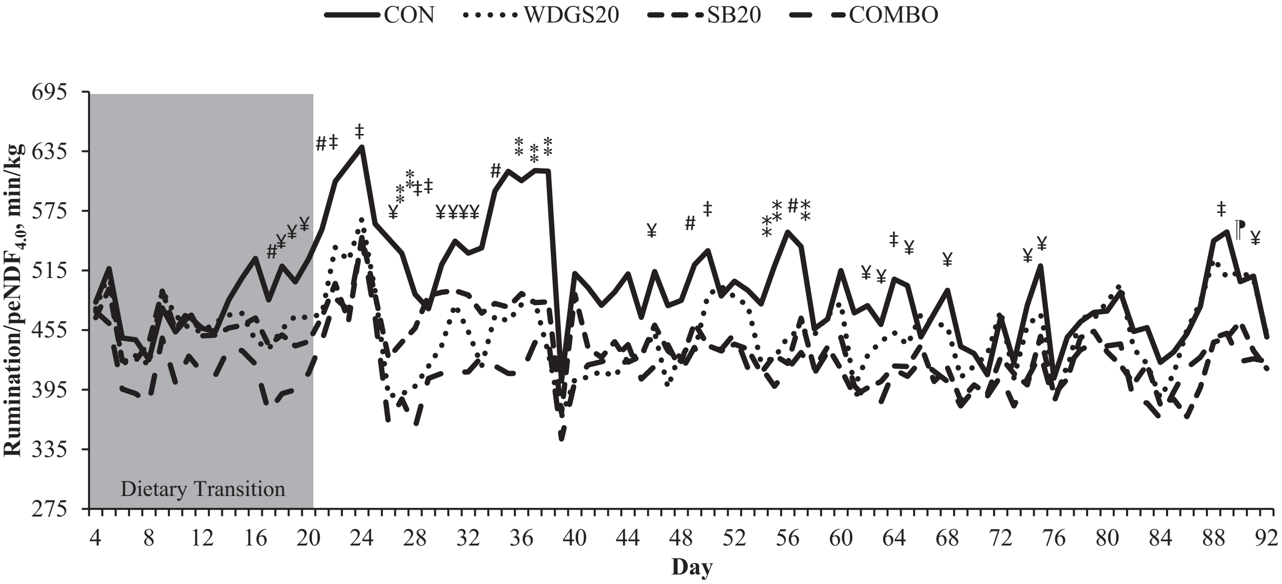

Figure 4. Daily rumination per kg of peNDF$_{4.0}$ intake of finishing steers fed CON = control, no fibrous corn-milling products; WDGS20 = 20% wet distillers grains with solubles; SB20 = 20% Sweet Bran; COMBO = 20% Sweet Bran and 10% wet distillers grain with solubles. Two steers from each pen were randomly selected to receive a 3-axis accelerometer tag (Allflex Livestock Intelligence, Madison, WI) to quantify rumination minutes. The transition from the receiving diet to the finishing diet is indicated by the shaded area from days 0 to 20 of the feeding period. Effect of diet, $P < 0.05$; day, $P < 0.01$; diet × day, $P < 0.01$. Pooled standard error of the mean = 30.26 min. ‡SB20 and COMBO vs. CON; #COMBO and WDGS20 vs. CON; ¥COMBO vs. CON; ‡COMBO, WDGS20, and SB20 vs. CON; £WDGS20 vs. CON treatments differ within day, $P \leq 0.05$.

50, 64, and 89. On days 17 to 19, 25, 30 to 32, 46, 62, 63, 65, 68, 75, 76, and 91, rumination per kg of peNDF$_{4.0}$ was less for COMBO than CON, and less for WDGS20 and COMBO than CON on days 16, 21, 33, 49, and 57. On days 28 and 29, rumination minutes per kg of peNDF$_{4.0}$ was less for COMBO and SB20 than CON, whereas rumination was greater for WDGS20, SB20, and COMBO than CON on days 26, 27, 35 to 38, 55, and 56. On day 90, WDGS20 ruminated the greatest per kg of peNDF$_{4.0}$, and COMBO was least. Daily rumination minutes per kg of peNDF$_{4.0}$ were 507, 458, 442, and 418 for CON, WDGS20, SB20, and COMBO (effect of diet; $P = 0.04$). There was also a diet × day interaction (Figure 5; $P < 0.01$) for rumination min per kg of peNDF$_{8.0}$. On days 26, 35, 37, and 38, rumination time was less for WDGS20, SB20, and COMBO than CON. Rumination minutes per kg of peNDF$_{8.0}$ was least for WDGS20 and COMBO and greatest for CON on days 27, 34, and 36, and least for WDGS and greatest for CON on day 47. Overall, average daily rumination minutes per kg of peNDF$_{8.0}$ were not statistically different (effect of diet; $P = 0.67$) among treatments, and were 781, 726, 739, and 735 for CON, WDGS20, SB20, and COMBO, respectively

Both rumination time per kg peNDF$_{4.0}$ and peNDF$_{8.0}$ were greater for CON for a portion of the study; however, this difference was more pronounced when rumination was evaluated per kg of peNDF$_{4.0}$. Similar to rumination per kg of NDF intake, because the peNDF in CON was provided primarily by the corn stalks in the diet as opposed to a combination of corn stalks and corn-milling products, this suggests that peNDF from forage-based ingredients stimulates rumination to a greater extent than SB, WDGS, or both. Although WDGS20, SB20, and COMBO contained a greater proportion of peNDF$_{4.0}$, this was primarily a function of greater NDF concentration and again implies that particle size is a more potent stimulus for rumination than the overall fiber concentration of the diet. Therefore, as noted previously, when using the PSPS to evaluate diets with high concentrations of fibrous corn-milling products, perhaps using only the top two tiers of the PSPS (particles > 8.0 mm) is more appropriate than peNDF$_{4.0}$, as it decreases the amount of fibrous products captured and the potential to overestimate their physical contribution to peNDF.

Because rNDF did not differ between diets, a diet × day interaction ($P < 0.01$) similar to rumination per kg of DMI was observed for rumination per kg of rNDF intake (data not shown). However, an interesting observation is that the rumination minutes per kg of rNDF intake (750, 728, 775, and 752 min for CON, WDGS, SB20, and COMBO, respectively) are similar to the values reported for rumination minutes per kg of peNDF$_{8.0}$. Furthermore, rumination minutes per kg of rNDF intake were numerically less than rumination min per peNDF$_{8.0}$ for CON, and numerically greater for WDGS20, SB20, and COMBO.

Circadian rumination minutes over the entire feeding period (day 0 to final) are presented in Figure 6. Hourly patterns in rumination (effect of hour; $P < 0.01$) are consistent with those reported by Tomczak et al. (2019) and likely influenced by changes in activity of cattle throughout the day. For example, Tomczak et al. (2019) explained that rumination is least when cattle are eating such as during and immediately after feeding (0600 to 1000 h) and during peak locomotion activity such as near dusk (1600 to 2000 h), which is also supported by Stricklin and Kautz-Scanavy (1984). In contrast, rumination is greatest during the night from 2000 to 0400 h. A diet × hour

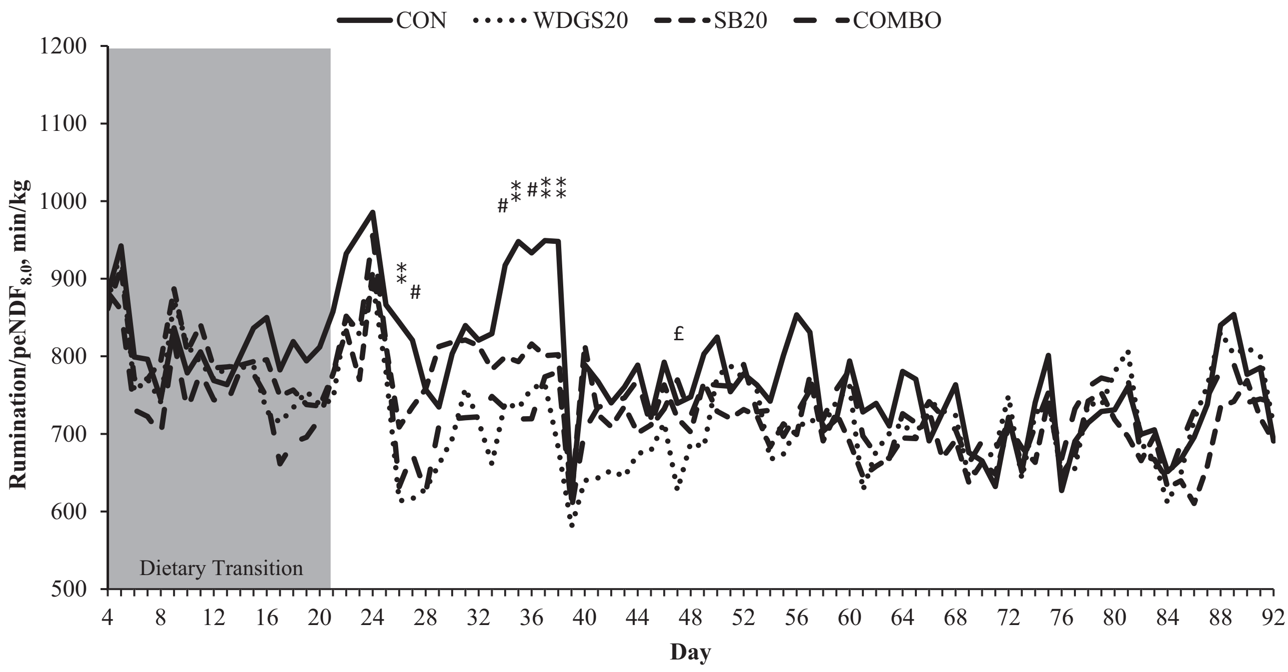

Figure 5. Daily rumination per kg of peNDF$_{8.0}$ intake of finishing steers fed CON = control, no fibrous corn-milling products; WDGS20 = 20% wet distillers grains with solubles; SB20 = 20% Sweet Bran; COMBO = 20% Sweet Bran and 10% wet distillers grain with solubles. Two steers from each pen were randomly selected to receive a 3-axis accelerometer tag (Allflex Livestock Intelligence, Madison, WI) to quantify rumination minutes. The transition from the receiving diet to the finishing diet is indicated by the shaded area from days 0 to 20 of the feeding period. Effect of diet, $P = 0.67$; day, $P < 0.01$; diet × day, $P < 0.01$. Pooled standard error of the mean = 49.58 min. #COMBO and WDGS20 vs. CON; ‡COMBO, WDGS20, and SB20 vs. CON treatments differ within day, $P \leq 0.05$.

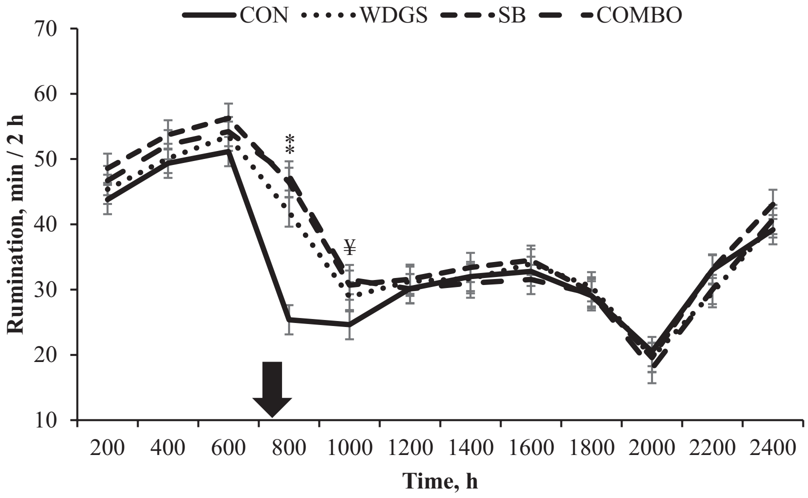

Figure 6. Overall (day 0 to final) circadian hourly rumination of finishing steers fed CON = control, no fibrous corn-milling products; WDGS20 = 20% wet distillers grains with solubles; SB20 = 20% Sweet Bran; COMBO = 20% Sweet Bran and 10% wet distillers grain with solubles. Steers were transitioned from a common receiving diet to their respective treatment diets from days 0 to 20 of the feeding period. Two steers from each pen were randomly selected to receive a 3-axis accelerometer tag (Allflex Livestock Intelligence, Madison, WI) to quantify rumination time and was continuously recorded and reported as the average of rumination time within a 2-h period. The arrow represents feeding beginning at 0730 h. Effect of diet, $P = 0.37$; hour, $P < 0.01$; diet × hour, $P < 0.01$. ¥COMBO vs. CON; ‡COMBO, WDGS20, and SB20 vs. CON treatments differ within day, $P \leq 0.05$.

interaction was observed for rumination, which was greater for SB20, WDGS20, and COMBO vs. CON at 0800 h, and greater for COMBO than CON at 1000 h. Feeding began each day at 0730 h and CON was the first diet delivered; therefore, it is possible that the lower rumination of CON from 0600 to 0800 h could have been impacted by time of feed delivery. Cattle are habitual and it is common to observe cattle moving towards and standing at the feed bunk immediately before feeding at the same time each day. If CON cattle had greater locomotion activity immediately before feeding, this could explain the lower rumination of CON, as it is likely that only cattle receiving CON were fed during the 2-h time interval from 0600 to 0800 h. However, the reduction in rumination minutes of CON continued from 0800 to 1000 h after other treatment diets were fed, indicating that CON cattle had less rumination minutes both immediately preceding and following feeding. Parsons et al. (2007) reported that cattle consuming a steam-flaked, corn-based diet have more aggressive feeding behavior in comparison to cattle consuming SB and will consume a larger meal during the first feeding event. Because rumination is inversely related to physical activity and eating (Tomczak et al., 2019), this may also suggest cattle are active and waiting at the bunk earlier in the day and therefore not ruminating, which could explain the reduced rumination of CON. However, as meal size and frequency were not measured in the current study, additional research is needed to determine if there is a relationship between eating behavior and rumination minutes of feedlot cattle consuming diets containing differing concentrations of corn-milling products.

Ruminal pH

Daily ruminal pH (Table 3) was greatest for COMBO (5.78), intermediate for WDGS20 (5.63), and least for CON (5.47), whereas SB20 (5.69) was greater than CON but not different from WDGS20 and COMBO (effect of diet; $P < 0.01$). Pitt et al. (1996) developed the equation $mean\ ruminal\ pH = 5.46 + 0.038 \times peNDF\ (\%\ DM)$ to predict ruminal pH based on dietary peNDF. Therefore, using the equation described by Pitt et al. (1996), the predicted mean ruminal pH of CON, WDGS20, SB20, and COMBO were 5.81, 5.84, 5.88, and 5.89 when calculated using $peNDF_{4.0}$ and 5.69, 5.70, 5.71, and 5.70 for $peNDF_{8.0}$. Because the pH values predicted from peNDF were more similar between treatments than observed pH, this suggests that the treatment differences between ruminal pH observed in the present study are not likely a result of differences in peNDF. Furthermore, minimal difference in rumination minutes per kg of DMI indicates that the greater pH of cattle consuming diets containing corn-milling products was not likely facilitated by additional buffering capacity from rumination.

The factors that influence ruminal pH are complicated and multifactorial, and the equations described by Pitt et al. (1996) do not account for differences in diet composition, feed management, eating behavior, fermentability, removal of fermentation end-products, and/or functionality of the rumen (NASEM, 2016). For example, decreasing the concentration of dietary starch has been shown to increase ruminal pH (Firkins et al., 1985; Krehbiel et al., 1995). Therefore, because the COMBO diet contained the lowest proportion of steam-flaked corn, this could explain the greater pH in COMBO because of less available starch and a greater rumen buffering capacity from the increased corn-milling product inclusion rate (30.0% total for COMBO). Montgomery et al. (2004) and Corrigan et al. (2009) also reported greater ruminal pH when a portion of the corn in the diet was replaced with SB and/or WDGS.

Overall (day 0 to final) hourly ruminal pH is presented in Figure 7. Hourly changes in ruminal pH throughout the day represent increases or decreases in the fermentation of substrates and mirror consumption patterns. Circadian ruminal pH increased (effect of hour; $P < 0.01$) from 2200 to 1000 h, which reflects a 0730 feeding time, then decreases from 1000 to 1400 h, as ruminal fermentation of nutrients increases after feeding and rumen microbes subsequently produce volatile fatty acids as a byproduct of nutrient metabolism (Hungate, 1966). There was a diet × hour effect

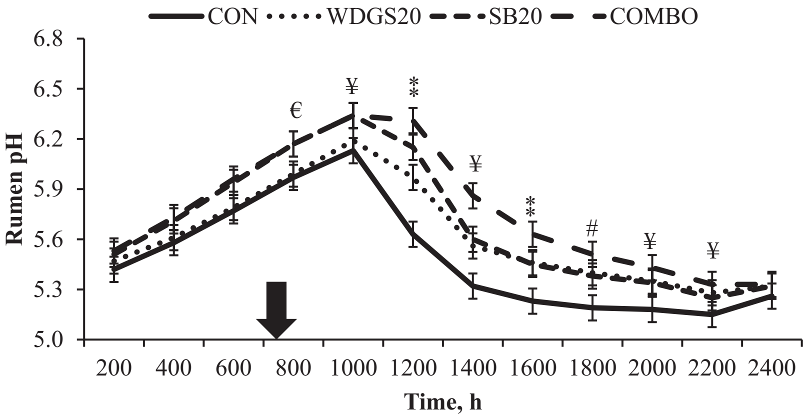

Figure 7. Overall (day 0 to final) circadian hourly ruminal pH of finishing steers fed CON = control, no fibrous corn-milling products; WDGS20 = 20% wet distillers grains with solubles; SB20 = 20% Sweet Bran; COMBO = 20% Sweet Bran and 10% wet distillers grain with solubles. Steers were transitioned from a common receiving diet to their respective treatment diets from days 0 to 20 of the feeding period. Two steers from each pen were randomly selected to receive both an indwelling ruminal pH bolus (Well Cow Limited, Roslin, UK) and ruminal pH data were automatically logged in 15-min time intervals and averaged across 2-h time increments. The arrow represents feeding beginning at 0730 h. Effect of diet, $P = 0.01$; hour, $P < 0.01$; diet × hour, $P < 0.01$. ¥COMBO vs. CON; #COMBO and WDGS20 vs. CON; ‡COMBO, WDGS20, and SB20 vs. CON; €WDGS and CON vs. COMBO treatments differ within day, $P \leq 0.05$.

($P = 0.01$) for circadian ruminal pH. Differences were detected starting at 0800 h such that ruminal pH for COMBO was greater than WDGS20 and CON. At 1000, 1400, and from 2000 to 2200 h, ruminal pH was greatest for COMBO and least for CON. At 1200 and 1600 h, ruminal pH was greater for COMBO, WDGS20, and SB20 than CON. At 1800 h, pH of COMBO and WDGS20 was greatest and CON was least. Collectively, these results suggest that after feeding ruminal pH is greatest for COMBO, followed by SB20 and WDGS20, and lowest for CON.

Although hourly differences in rumination minutes between treatments were most pronounced around feeding time each day, differences in hourly ruminal pH were most pronounced after feeding, when peak fermentation likely occurred. This further suggests that the pH modulation that occurred for diets containing corn-milling products was most likely facilitated by the greater proportion of fibrous ingredients and displacement of starch in the diet provided by COMBO, SB20, and WDGS20 than CON rather than additional buffering capacity from greater saliva production via increased rumination minutes. The CON diet included the greatest proportion of steam-flaked corn followed by WDGS20 and SB20, and COMBO. Therefore, the statistically greater ruminal pH observed in cattle consuming COMBO compared to SB20, WDGS20, and CON may be attributed to the overall greater corn-milling product concentration and a lower proportion of rapidly fermentable starch (Owens et al., 1998). Alternatively, changes in eating behavior of cattle consuming grain-milling products may have influenced circadian ruminal pH differently than CON.

CONCLUSIONS

Corn-milling products such as SB and WDGS contribute a significant amount of NDF and peNDF to the diet and may improve rumen health and cattle performance. Despite greater dietary peNDF, rumination per kg of DMI did not differ, but there was improvement in ruminal pH for diets containing fibrous corn-milling products with less starch and similar energy concentrations. Therefore, overall starch concentrations may influence ruminal pH to a greater extent than the physical characteristics of the diet. However, because corn-milling products are not traditional roughage sources, additional research is needed to further characterize these feed ingredients and determine the physical contribution of these products to rumen integrity and functionality. Our findings also suggest that peNDF comparisons among feedlot diets are problematic because low roughage concentrations combined with the potentially exaggerated contribution from corn-milling products may skew interpretations by overestimating peNDF. Furthermore, the methodology used to estimate peNDF in feedlot diets requires further exploration to determine the importance of particle size and better characterize the contribution to rumination activity and other ruminal buffering characteristics.

Acknowledgments

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Conflict of Interest Statement

None declared.

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